Biochar: A Sustainable Approach for Food Waste Management to Reduce Water Stress and Enhance Plant Growth

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Abstract

Application of biochar in agriculture is getting popular as it can improve soil water retention, fertility, plant growth, and crop yield. Present work focuses on the biochar preparation by pyrolysis from mixture of vegetable and fruit wastes (cauliflower, cabbage, banana peels, corn leaves and corn cobs) representative of mixed preparation or plate waste. Biochar produced at 400 °C was found most appropriate based on its properties after the characterization and it was used as soil amendment to see its effect on the plant growth and water retention capacity of the amended soil. Pot experiments were conducted at laboratory-scale having 0%, 2% and 6% biochar mixed with sand. Each pot was sowed with seeds of chickpeas (*Cicer arietinum L.*) over sixty days. In both the cases (2 and 6%) application of biochar resulted in 73 mL and 118 mL reduction in evapotranspiration in comparison to the control (0% biochar). The lower fraction (2%) of biochar achieved optimum plant growth with maximum seedlings germination, leaves number, flowers number and chickpea fruiting at the completion of the test, while 6% gave slightly better plant height and reductions in irrigation requirements. Both biochar loadings increase the nutrient content of the shoot and root biomass, particularly in relation to K and NO_3^- This study demonstrates 2% biochar application is an effective to increase chickpea yield and to reduce water stress. It signifies that the food waste valorization in the form of biochar could be a positive step influence towards agricultural sustainability and water-food nexus approach.

Keywords: Pyrolysis; Biochar; Soil fertility; Water retention; Agriculture practice; Water-food nexus

1. Introduction

Food security is an ever-pressing issue due to increasing population, deteriorated soil quality and increasing water stress around the world. According to the Food and Agriculture Organization (FAO) of the United Nations, approximately 1.3 billion tonnes of food is wasted every year [1], in which fruit and vegetable losses in industrialized countries account more than 32% before reaching the point of sale. Scialabba et al. [2] reported that out of 950 million tons (MT) of vegetable production, 500 MT of waste is generated worldwide. While supply chain management and waste minimization are critical to sustainable food supply, it is also important to find alternative ways to process rejected products and leftovers from food processing plants [3]. Biochar is an emerging product to increase soil fertility and plant growth in different agricultural soil types [4]. It has advantages over compost in that it provides long term carbon sequestration and soil remediation as well as being easier to store and transport. Biochar produced from feedstock containing lignocellulosic compounds has an expected half-life of 100 to 1000 years, which is approximately 10-1000 times greater than the lifetime of soil organic matter [5]. Thus, biochar addition to soil could provide a potential sink for soil organic carbon.

Vegetable and fruit wastes have 7 to 44% cellulose, 4 to 34% hemicellulose and 15 to 69% lignin [6], which are beneficial for high quality biochar production. Vegetable and fruit wastes can be easily collected from farms and processing factories, but are also commonly produced as mixed waste in restaurant and canteen kitchens. Among various vegetable and fruit wastes; cauliflower, cabbage, banana, and corn are commonly grown vegetables and are consumed worldwide. Around 30–50% of waste is produced from cabbage and cauliflower stems and leaves from farm to plate [7]. These two wastes contain 11-15% cellulose, 2.6-3% hemicellulose, and 2.5-3.2% lignin by weight [8]. 118 million tonnes of banana peel waste is generated annually from tropical and subtropical regions and contains around 41% cellulose, 10% hemicellulose and 9% lignin [9, 10]. In the United States of America (USA) it is estimated 250 million tons of corn waste is produced from the processing of 345 million tons of corn [11]. The corn wastes contain 29% of cellulose, 32% of hemicellulose and 29% of lignin [12].

Chickpea (*Cicer arietinum L.*) is cultivated on large-scale in these arid and semiarid environments. About 90% of the world's chickpea is grown under rainfed conditions where the crop grows and matures on a progressively depleting soil moisture profile and experiences terminal drought, a condition in which grain yield of chickpea is low [13]. Average chickpea yield remains low in major producing countries due to the inadequate water supply and soil water retention. Biochar has been commonly reported to increase soil water retention capacity in various types of soils common to arid and semiarid environments prone to drought, and in areas with limited irrigation capabilities [4].

Our study aims to determine the potential impact of biochar derived from cellulose-rich mixed vegetable-fruit waste feedstock using a model mixed food waste comprising major vegetable/fruit waste sources; namely cauliflower, cabbage, banana and corn for agriculture practice. Specifically, we evaluate the effect of mixed vegetable waste biochar on chickpeas that can enhance the water retention capacity, plant growth and yield as a means to enhance the production of this subsistence crop within some of the most populated and water stressed regions of the world.

2. Materials and Method

2.1. Biochar application

A detailed feedstock preparation, biochar production and characterization was reported by Pradhan et al. [14]. The biochar produced at 400 °C was selected for pot tests based upon it having the maximum CEC of 53.2 cmolc.kg^{-1}, relatively low pH of 8.0 and low ECE of 379.6 $\mu\text{S.cm}^{-1}$ [14] out of other three temperatures tested (300, 400 and 600 °C). Similar properties of biochar from previous studies have been found most effective for plant growth [15]. The improved soil CEC that results from application of biochar with a high CEC reflects a higher nutrient retention capability and reduced nutrient loss by leaching, which is a beneficial for soil microbial activity, especially for microbes living in soils with low organic matter content [16]. Different functional groups and the surface morphology of biochar were analyzed by Fourier transform infrared (FT-IR) spectroscopy and scanning electron microscope (SEM), respectively, as described in our previous published work [14].

2.2. Soil characteristics

Regional soil was collected from the university campus and characterized for the sand, silt and clay content by following the standard procedure reported by Whiting et al. [17]. The optimal biochar produced at 400 °C was mixed with soil at three different fractions of 0% (no biochar), 2%, and 6% (w/w). The grain size distribution was determined by oven drying and sieving according to ASTM standard D422-63 [18]. The granularity of the sands was analyzed based upon d_{10} (10% of particles are finer than this size), d_{30} (30% of particles are finer than this size) and d_{60} (60% of particles are finer than this size). The degree and uniformity of particle size grading was calculated by using Eq. 1 and Eq. 2.

$$C_u = \frac{d_{60}}{d_{10}} \qquad (1)$$

$$C_c = \frac{d_{30}2}{d_{60} \times d_{10}} \qquad (2)$$

C_u= Coefficient of uniformity; C_c= Coefficient of curvature

The porosity, moisture content, and bulk density of soil at three different fractions were measured by following the procedure reported by Peterson [19].

2.3. Pot test with chickpea

The soil with a particle size less than 1 mm diameter was used for the pot tests. Unplanted and planted pot tests were conducted using plastic pots of 9 cm diameter. In each pot 400 g of soil was packed to a depth of 5.5 cm. 20 chickpea

(Cicer arietinum L.) seeds were sown per pot and each pot condition was run in triplicate. Pot tests were conducted outdoors at the Hamad Bin Khalifa University campus, Qatar located at 25.3157° N and 51.4341° E under a green mesh shade cloth to prevent exposure from the intense sun in Qatar. Temperatures during the test averaged 35 ± 5 °C during the day time and approximately 25 ± 5 °C in the night. The temperature was measured from a weather station situated just outside the green shade area.

A water balance was conducted on the pots to determine the quantity of water drained, retained and evapotranspired on a daily basis by measuring the weight of the pots after drainage of the irrigation event and again 24 h after water application just prior to the subsequent irrigation. This enabled the determination of water drainage, evapotranspiration, and water retention. The total water mass balance in unplanted and planted pots was determined according to Eq. 3 to 6.

$$TWL = WLE + WD \qquad (3)$$

$$\mathrm{WR} = \mathrm{TWS} - \mathrm{WD} - \mathrm{WLE} \qquad (4)$$

$$WD = m_{i,post} + m_{i,WS} - m_{i-1,pre} \qquad (5)$$

$$WLE = m_{i,post} - m_{i,pre} \qquad (6)$$

TWL: Total water loss (mL); WLE: Water loss by evaporation (mL); WD: Water drained (mL); WR: Water retained (mL); TWS: Total water supply (mL); $m_{i,post}$: Mass of the pot after watering and once immediate drainage has ceased (g); $m_{i,WS}$: Mass of water supplied during irrigation (g); $m_{i-1,pre}$: Mass of pot just prior to the current irrigation event (g); $m_{i,pre}$: Mass of the pot just prior to the upcoming irrigation event (g).

Seeds germination, germination period, plant height, number of leaves, and number of flowers were measured daily for a period of 60 days. At the end of the experiment on day 61 the plants were harvested from each pot. The roots and shoots were separated and dried by a thermo scientific oven at 70 °C for 48 h. After drying the weights were measured to determine root and shoot biomass mass [20].

2.4. Nutrient test for plant biomass and biochar amended soil

The oven dried shoot and root biomass were crushed separately by a mortar and pestle to a finer size for microwave digestion. 500 mg of shoot and root biomass were used for the digestion whereas 100 mg of soil biochar samples were used for digestion. The sample was digested with 8 mL concentrated nitric acid (HNO_3) and 2 mL of hydrogen peroxide (H_2O_2) using a microwave digester (Ethos UP, Milestone). The temperature was set at 200 °C with a ramp rate of 13 °C.min^{-1} under a pressure of 90 bar and a residence time of 45 min. After digestion the samples were removed and kept outside to cool down. Then 10 mL of concentrated hydrochloric acid (HCl) was added and left overnight for complete digestion of any residue left. After digestion the samples were diluted with deionized water and filtered through a 0.22 µm filter paper. The minerals content was measured by inductively coupled plasma optical emission spectroscopy (ICP-OES) using an Agilent 5110 ICP-OES that enables synchronous radial and axial measurement. The concentration of ammonia (NH_4^+), nitrate (NO_3^-), orthophosphate (PO_4^{3-}) and sulfate (SO_4^{2-}) was measured by a segmented flow analyzer (Sans+, Skalar) using the manufacturers chemistry methods while SO_4-S and NO_3-N were measured by ion chromatography (940 Professional IC Vario, Metrohm).

2.5. Statistical analysis

The statistical significance of changes in plant growth and water retention capacity at different biochar application rates were determined using variance (ANOVA) with a Fishers lowest significant difference test (LSD) at p = 0.05. The significance of variation for the three different conditions over the incubation period was analyzed using a one way, linear model in the Statistical Package for the Social Sciences (SPSS) package.

3. Results and Discussion

3.1. Biochar characteristics

The biochar used had the highest CEC and a relatively low pH of the biochars produced at differing temperatures. The high CEC of biochar at 400 °C is due to the presence of various charged functional groups which are shown in the FTIR spectra (Fig. 1). Oxygen (O) containing functional groups like alcohol, carbonyl, and carboxylate are generally believed to contribute to biochar CEC because they may carry a negative charge and can serve in sorption of cations (Fig. 2a).

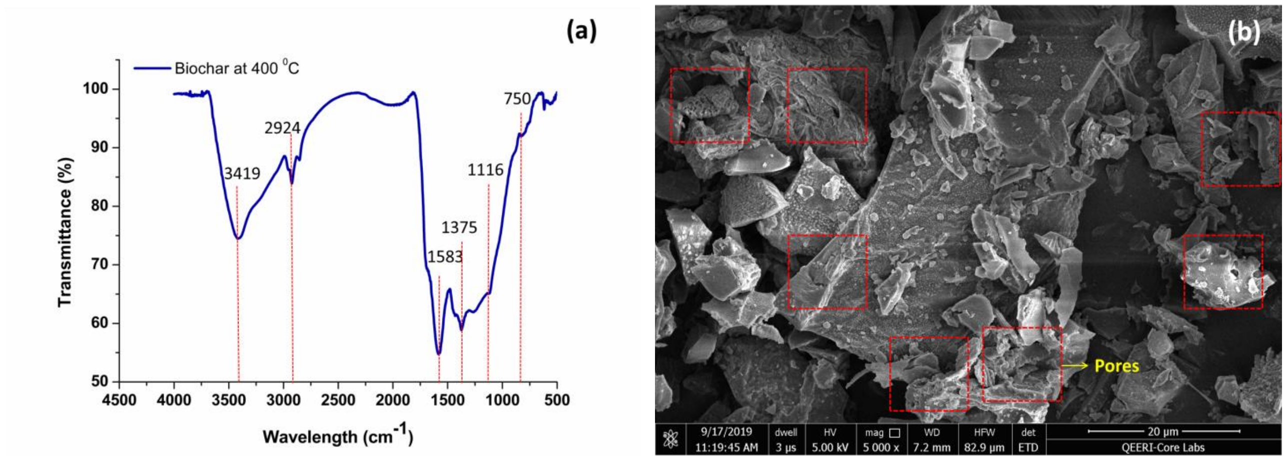

Fig. 3 (a) The FT-IR spectrum and (b) surface structure by SEM analysis of biochar produced at 400 °C. *3419: C-H stretching (alkane); 2924: C-H stretching (alkane); 1583: C=C stretching (cyclic alkene); 1375: C-O stretching, S=O stretching (aromatic ester, sulfate); 1116: C-O stretching (secondary alcohol); 750: C-H bending (monosubstituted),*

Gámiz et al. [16] reported biochar produced at low temperatures generally has a variety of surface functional groups compared to high-temperature biochars, the latter which more closely resemble aromatic graphitic carbon. SEM imaging showed small macropores present in the surface of the biochar produced at 400 °C (Fig. 4b). These pores could reduce water flux past the biochar particles and retain more water in sand-biochar mixtures [21].

3.2. Biochar impacts on soil mixture characteristics

Characteristics of the soil and amended soil are shown in Table 1. The sand had a high ECE and low CEC, TC and N. The addition of a small quantity of biochar (2, 6%) had notable changes in the properties of the soil mixture, resulting in a beneficial increase of soil CEC, N, and C than the control condition. A mild increase in soil pH and BET surface area was also observed, along with a beneficial reduction in soil ECE. The soil used is a well graded loamy sandy soil. The application of 2% and 6% biochar reduced bulk density by approximately 4% and increased porosity by around 5% compared to the control condition. The improvement in soil physicochemical properties by biochar application is due to the one particular size of biochar, lower ECE, higher CEC, presence of nutrients, as well as high carbon and nitrogen content [22]. An improvement of soil chemical and physical properties due to 2% and 6% biochar addition illustrate that biochar could be a good amendment in agriculture practice to improve soil fertility.

Table 1: Variation in soil properties by the application of different fraction of biochar

Different properties	0% (control)	2%	6%
Structure	Sandy loam	-	-
Sand (%)	73.6	-	-
Silt (%)	15.7	-	-
Clay (%)	16.2	-	-
d_{10}:d_{30}:d_{60} (mm)	0.07: 0.15:0.34	-	-
C_u: C_c	5.15:1.1	-	-
Porosity (%)	49.3±1.0	53.36±1.43	54.26±1.45
Bulk density (g.cm^{-3})	1.54±0.02	1.48±0.03	1.47±0.01
pH	7.24±0.12	7.35±0.02	7.47±0.05
ECE (µS.cm^{-1})	3583±144	2161±93	1849±86
TC (%)	1.32±0.04	13.6±0.7	16.3±0.9
TN (%)	0.42±0.02	1.40±0.05	1.53±0.07
BET surface area (m^2.g^{-1})	0.72	1.76	1.84

CEC ($cmol_c.kg^{-1}$)	10.20±0.62	21.07±1.80	27.26±3.64
K ($mg.kg^{-1}$)	25.45±0.84	84.70±2.12	97.5±8.80
Mn ($mg.kg^{-1}$)	0.23±0.05	3.5±0.4	4.0±0.3
Ni ($mg.kg^{-1}$)	5.23±0.06	5.15±0.05	5.18±0.04
Zn ($mg.kg^{-1}$)	14.53±0.52	25.24±0.47	25.87±0.61
NH_4^+ ($mg.kg^{-1}$)	227.3±7.1	410.7±15	444.0±3.2
NO_3^- ($mg.kg^{-1}$)	655.3±8.0	1870.7±7.5	2051.0±8.2
PO_4^{3-} ($mg.kg^{-1}$)	138.7±5.5	675.3±6.1	604.7±7.5
SO_4^{2-} ($mg.kg^{-1}$)	196.7±5.7	389.3±5.0	415.0±8.0

ECE: electrical conductivity; CEC: cation exchange capacity; TC: total carbon; FC: fixed carbon; TN: nitrogen; K: potassium; Mn: manganese; Ni: nickel; Zn: zinc

3.3. Biochar impact on chickpeas growth

The growth of chickpeas in biochar amended soil was faster in comparison to the control and even early on showed a slightly greater number of germinated plants (Fig. 2a). A maximum of 60, 92 and 87% seed germination was recorded in the control, 2% biochar and 6% biochar, respectively, after a time span of 30 days. The differences between the control and 2% and 6% biochar were statistically significant (p = 0.0001). Due to the limited watering conditions applied to all test conditions and the high rate of evapotranspiration, the control plants started to deteriorate after day 30 and started to die after 40 days due to water stress. A loss of plants was also noted around the same period for the 2 and 6% biochar conditions. This loss was greater in the 6% biochar which originally had a much higher germination rate. However, the two biochar conditions both had approximately 60% of seeds germinated and surviving at the end of the test (day 60).

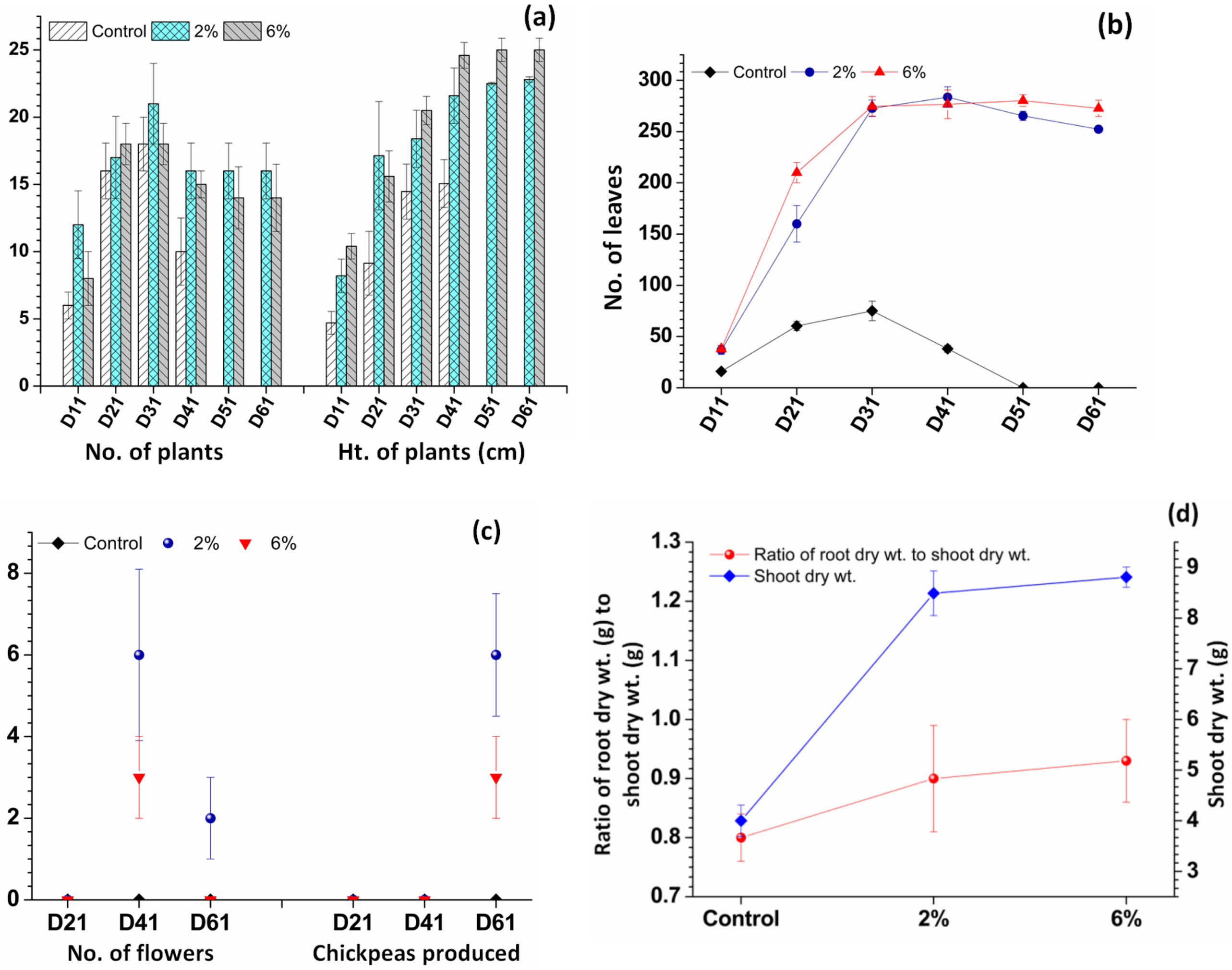

Fig. 2 Biochar effect on (a) seeds germinated and height of plant, (b) number of leaves, (c) number of flowers and chickpeas produced and (d) the shoot and root biomass. *D: day; No.: number; Ht.: height; wt.: weight; error bars represent ±standard deviation of three pots.*

In control conditions the maximum plant height of 15±2.3 cm was achieved after forty days (Fig. 2a). The 2% biochar conditions had a height of 23±2.3 cm at the same time and the 6% biochar loading a 25 cm±1.8 height. Both control and 6% biochar showed a statistical difference to the intermediate 2% biochar height ($p = 0.001$ and $p = 0.02$ respectively). From day 41 to 61 the change in chickpea height was relatively stable in 2% and 6% biochar soil amendments with a plant height of 23 and 25 cm, respectively, with no statistical difference ($p = 0.59$). Yadav et al. [23] reported in their study that neutral soil amended with lower (0.25%) fraction of biochar prepared using Napier grass (*Pennisetum purpureum*) could achieve 19% of chickpea germination and 50% increase in plant height in comparison to their control after a twenty day period. In the present study, 2% application of vegetable waste biochar increased seed germination by 60% and plant height by 43% in comparison to the control after forty days, which suggests that biochar derived from vegetable waste is an excellent soil amendment material for chickpeas cultivation.

A large difference was noticed in the average number of leaves produced per plant among all three conditions (Fig. 2b). In the control condition, the maximum average number of leaves per plant was 75±9.5 after 30 days. For soil having 2% biochar the average leaves per plant at the same time of the experiment was 273±8.1and was significantly different to the control ($p = 0.0001$), while the 6% biochar treatment was similar ($p = 0.96$). However, the maximum number of leaves for 2% biochar (284±10) was achieved after 40 days while for 6% biochar it was achieved at 50 days (280±5.7). After 60 days the 2% biochar condition showed an 11% reduction in leaves from its maximum value, while the 6% biochar condition was relatively stable.

With respect to flowers and chickpeas, the control showed no production of either during the entire experimental period, while soil having 6% biochar developed 4±1.5 flowers by the 50th day and 3±1 chickpeas at the 60th day (Fig. 2c). The 2% biochar condition had the maximum flower and chickpea production, reaching 6±2.1 flowers after day 40 days and 6±1.5 chickpeas after day 60. At the end of the pot test, flowering was noticed in 2% biochar, while no flowering was observed in 6% biochar. These results suggest that a relatively lower application of biochar (2%) in soil is efficient for chickpea cultivation.

The 2 and 6% biochar application in soil showed differences in the growth performance of the shoot and root biomass compared with the control (Fig. 2d). The maximum root biomass of 8.8±0.2 g was recorded in case of 6% biochar whereas the maximum shoot biomass of 8.2±0.6 g was recorded in the case of 2% biochar. The 2% biochar application increased the root biomass by 137% and shoot biomass by 93% in comparison to the control. For the 6% biochar condition the increase was 143% for shoot biomass and 81% for root biomass in comparison to control ($p = 0.005$). No significant difference was noticed for biomass quantity between the 2% and 6% biochar conditions ($p = 0.33$). Sg et al. [24] applied 2% poultry litter biochar in Pinedene and Griffin soils and found similar improvements in chickpea shoot and root biomass with an increase of 80% compared to the control. An increasing rate of root to shoot biomass ratio in 2% and 6% biochar compared to control could reduce transpiration and increase nutrient uptake [25, 26]. Root to shoot ratio of harvested biomass is an indication of plant response to growing conditions, where root development is promoted with nutrient and water availability [27].

3.4. Biochar impact on water retention capacity

Drought stress negatively affects the plant growth and yield. However, it was found that biochar application significantly mitigates the detrimental effects of water stress (Fig. 3) and improves plant growth. The water loss via drainage and evapotranspiration were monitored for the unplanted and planted pots for all three soil conditions over the experiment and are shown in Fig. 3. The 2% biochar condition significantly improved the water retention capacity of soil compared to the control ($p = 0.0001$) in the unplanted pot condition (Fig. 3a). A further small but not statistically significant increase in water retention was observed in the 6% biochar condition compared to the 2% biochar condition ($p = 0.396$). This indicates that a higher fraction of biochar addition to the loamy sand can improve the soil structure to hold more water but that 2% is sufficient to realize most of the available improvement possible [28]. After sixty days of water application it was observed that around 15% of water loss could be prevented by the addition of 2 and 6% biochar in comparison to control. In total by the end of the experiment the control retained 55 ±9.07 mL of water out of a total of 3115 mL of water supplied. The addition of 2% biochar to the soil increased soil water retention to 77±10 mL. A small increase of 12±3 mL of water retention was observed in 6% biochar in comparison to 2% biochar ($p=0.009$). Most positive effects of biochar application to the soil are improved of water retention capacity due to the coarse or medium-textured soils, because of changes in soil porosity and uniformity [29].

Along with good plant growth; 55±4 mL of water was retained in control conditions after 30 days, while 76 ±5 mL of water was retained in soil containing 2% biochar (significant difference, $p = 0.02$). In the control 230±9 mL and 1362±17 mL of water was lost to drainage and evapotranspiration, respectively, while in 2% biochar 200±5 mL and 1354±22 mL of water was lost by drainage and evapotranspiration out of a total water supply of 1810 mL. Similar water loss in was observed in 6% biochar with a drainage of 183±3 mL and evapotranspiration of 1359±22 mL. Although evapotranspiration was similar among the three conditions ($p = 0.61$), it should be noted that higher plant growth was observed in the 2% and 6% biochar treatment (Fig. 3b).For the application of 2% and 6% biochar an additional 30 mL and 47 mL of water drainage was prevented ($p = 0.001$) which can provide significant benefits in rain-irrigated agriculture.

This study demonstrates that biochar derived from mixed vegetable wastes at 400 °C by pyrolysis is a suitable amendment for sandy soils as it increases soil porosity. . Furthermore, the fine particle size (75 µm) of biochar could be able to help to fill the pore spaces of a sandy loam soil matrix, contributing to the increased water holding capacity. Therefore, the water retention capacity of biochar amended soil was increased (Table 1).

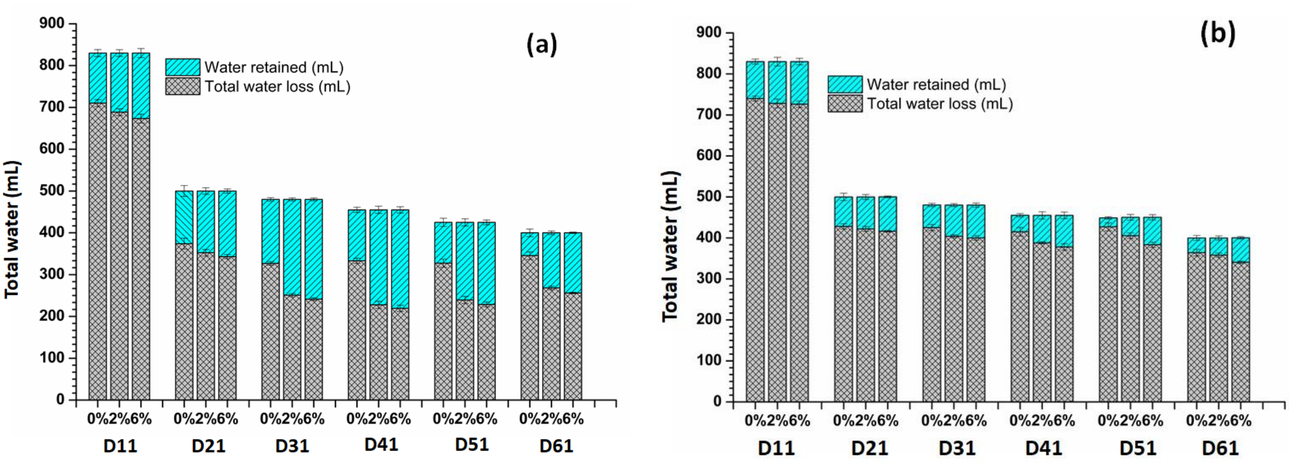

Fig. 3: Biochar effect on water retention capacity of soil in (a) unplanted and (b) planted pot. *Error bars represent ±standard deviation of three pots.*

3.5. Nutrients content by Plant shoots and roots

A significant enhancement in chickpeas shoot and root nutrient contents was noticed in 2% and 6% biochar pot compared to the control condition ($p = 0.03$). Fig. 4 shows the minerals and nutrients content by root and shoot biomass. In 2% and 6% biochar application, potassium (K) accumulation in the shoot biomass was higher than in the root biomass, whereas manganese (Mn) and nickel (Ni) were more in the root biomass and zinc (Zn) was similar (Fig. 4a). In the biochar treatments K was much higher in both the shoot and root biomass than the control, while for Zn the biochar shoots were also much higher than the control and for Mn biochar treatments were much higher in the roots. K and Zn are good sources for plants to increase metabolic processes like photosynthesis and chlorophyll biosynthesis and explain or correlate well with the reduced growth in the control [30]. The only measure where the control had higher concentrations than both biochar treatments was for Ni in the shoot. Higher Ni concentrations are known to retard branch and leaves development, as well as result in abnormal flower shape [31]. Increasing rate of nutrients content in shoot than root by biochar application also reflected the increase of biomass in shoot than root (Fig. 2d).

Addition of 2% and 6% biochar to the soil increases NH_4^+, NO_3^-, PO_4^{3-} and SO_4^{2-} content in shoot biomass by more than 85% compared to the control ($p = 0.0001$). For the root biomass biochar addition increased NO_3^-, PO_4^{3-} and SO_4^{2-} by more than 70%, while NH_4^+ was increased by 36% compared with the control ($p = 0.0001$) (Fig. 4b). NO_3^- concentration in root and shoot biomass showed a slight maximum in 6% biochar ($p = 0.0001$), whereas other nutrients in 2% and 6% biochar showed minimal variation ($p = 0.25$). Most plants grow best if they accumulate both NO_3^- and NH_4^+ and generally experience an increased crop yield, which was noticed in 2% and 6% biochar [32]. However, unfavorably high concentrations of NH_4^+ in the root may lead to damage of the plant, possibly explaining why uptake of this nutrient did not increase to the same degree as others in the biochar treatments. The extremely high uptake of K, Mn and NO_3^- relative to control may be related to the high mobility of these ions in wet soil, as it is expected biochar loaded soil will reduce the leaching of these elements to lower soil levels or groundwater/drainage). The much higher levels of NO_3^- in the shoot than root is a common trait among plants, as the petiole is the plant organ with the greatest accumulation of NO_3^- [33]. Many factors affect its accumulation including nitrogen availability, temperature, light and water availability. While greater water availability in the soil has been shown to lower nitrate accumulation [34], this is likely due to reduced transpiration pressure required to abstract water from the soil. In the case of biochar addition the matric-head and soil-water curve is modified and may therefore affect the nitrate accumulation in a similar manner to reduced soil water content.

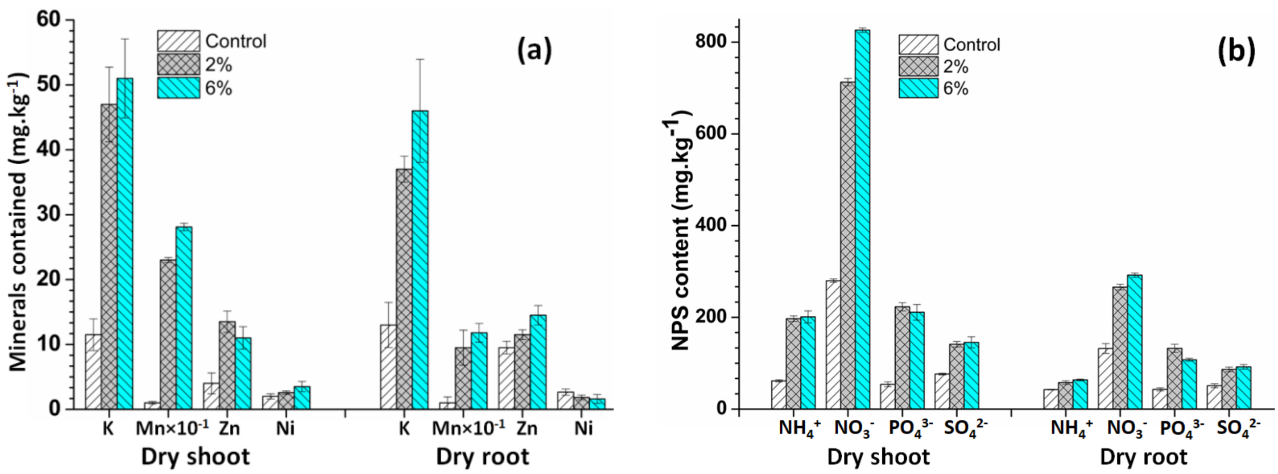

Fig.4 (a) Minerals content (b) NPS content by dry shoot and root biomass. *N: nitrogen; P: phosphorous; S: sulphur*

2% biochar application showed a slightly higher PO_4^{3-} concentration in shoot and root biomass than 6% biochar. Phosphorus content in plants increases the flower formation and improvement of crop production [35], which was observed in 2% biochar planted pots (Fig. 2c). Soil water content and phosphorus (P) availability interactions have been shown to have a significant effect on the shoot and root biomass. Lower water availability limits the diffusion of P, making P limitations more severe than under conditions with available water [27], such as with biochar addition. Root biomass contained maximum NH_4^+ and SO_4^{2-} while optimum $NO_3^-$and PO_4^{3-} was observed in shoot biomass. There is an insignificant variation of $NH_4^+$and SO_4^{2-} in 2% and 6% biochar (p = 0.43). The biochar addition to the soil increases the accumulation efficiency of the plant to extract $NH_4^+$and SO_4^2 from the soil. Moreover, a lower biochar application rate effectively increases the accumulation of minerals and NH_4^+, NO_3^-, PO_4^{3-} and SO_4^{2-} by plant root and shoot.

3.6. Nutrients retained in soil after plant harvest

Fig. 5 represents the nutrients retained in the soil mixture after harvesting the plants. Higher retention of K and Ni was noticed in control conditions than 2% and 6% biochar, whereas a slight increase of Mn and Zn retention was detected in 2% and 6% biochar than control. After the utilization of K, Mn, Ni and Zn by plant and considering that retained by the soil, a loss of 0.95, 0.198, 0.95 and 0.32 mg.kg^{-1} of K, Mn, Ni and Zn was lost in the control condition out of total mineral contained by soil (Table 1). Whereas, for 2% and 6% biochar application the lost minerals were reduced by approximately 72% and 90% minerals, respectively, compare to the control. This is most likely due to the reduction in water loss by drainage under biochar application compared to the control, as well as improved adsorption ability of biochar due to its high surface area, porosity and surface charge. After the consumption of NH_4^+, NO_3^-, PO_4^{3-} and SO_4^{2-} by plant and considering NH_4^+, NO_3^-, PO_4^{3-} and SO_4^{2-} retained by the soil, a loss of 30, 42, 11 and 20 mg.kg^{-1} of NH_4^+, NO_3^-, PO_4^{3-} and SO_4^{2-} was lost in the control condition by leaching (Fig. 5b). In comparison, 12.4, 9.3, 5.8, 6.0 mg.kg^{-1} and 9.5, 5.2, 4.0, 3.2 mg.kg^{-1} of NH_4^+, NO_3^-, PO_4^{3-} and SO_4^{2-} was lost in 2% and 6% biochar respectively by leaching due to the reduction of water by drainage, showing similar behavior to the metals. For the macronutrients the amount of NH_4^+, NO_3^-, PO_4^{3-} and SO_4^{2-} retained in the soil was considerably more apparent in 2% and 6% biochar treatments compared to the control, when comparing these to the retention of metals. This may be due to their greater solubility and mobility via drainage. NPS retention in 2% and 6% biochar had slight variation, which suggested 2% biochar application is suitable for enhancing plant growth, water retention, and nutrient retention in agriculture practice.

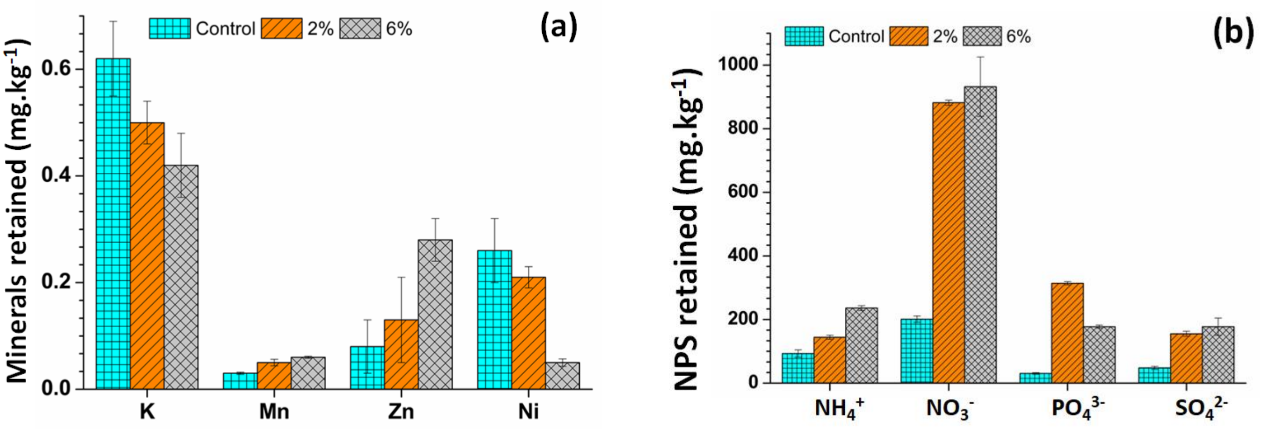

Fig. 5 (a) Minerals retained (b) NPS retained in biochar amended soil after harvesting the plants. *N: nitrogen; P: phosphorous; S: sulphur*

3.7. Validation with reported studies

Sg et al. [24] conducted a study where they applied poultry litter and acacia derived biochar to two sandy loam soils for chickpea growth at application rates of 0.5, 1 and 2%. In their study biochar application increased the pH of the acidic soils by around 1-2 pH units to a pH that was still slightly acidic. Poultry litter biochar, another more cellulose rich (28%) feedstock, increased the CEC more than lignin rich acacia biochar in all soil types. It also resulted in better chickpea growth in all three soils tested, particularly the two finer more acidic soils and better nutrient uptake by the plants. In general, similar observations were seen from our study. However, Sg et al., did not that their highest application rate of 2% led to a deterioration in the chickpea growth in the most sandy soil, which they associated with increased retention of NO_3^- in the soil. In another study Lusiba et al. [36] applied 0, 5, 10 and 20 t ha^{-1} biochar to two types of sandy loam soil by applying extra phosphorus fertilizer 90 kg ha^{-1}. The lowest rate of biochar application (5 t ha^{-1}) in two types of soil significantly increased chickpeas plant biomass, grain yield and water moisture content than higher rates of biochar application. However, biochar application had no effect on yield components in the loamy sand soil, but increased the plant biomass. Therefore, growth and yield of chickpea varied in biochar application produced from different feed stocks, soil type and seasons. From the current study with sandy loam soil, little difference was observed between the biochar loading rates used.

4. Conclusion

The properties of biochar produced from pyrolysis of vegetable and fruit wastes showed that it is an efficient soil amendment agent for sandy loam soils to increase soil fertility, plant growth and water retention capacity. The study demonstrates production of biochar from mixed vegetable and fruit wastes is an effective route for recycling food waste to reduce the burden of municipal solid waste management. The application of vegetable waste biochar as a soil amender/conditioner for the chickpea growth showed a positive effect for plant growth in terms of height; leaf, flower and, chickpea production; and biomass generation. Biochar application is also efficient to bind and accumulate nutrients by the plant root and help to develop shoot growth. Importantly, for arid agriculture and natural rain-fed chickpea cultivation, the application of biochar had significant reductions in the water requirements associated with evapotranspiration and improving the water holding ability of the soil. The entire investigation revealed that the properties of the produced biochar are in line with the requirements necessary to establish it as a suitable soil amendment agent for sustainable agriculture.

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