ISSN 2229-5518

Effect of biochar application on Jew's Mallow growth and irrigation water use efficiency in Sudan

Gamareldawla H.D. Agbna[1]; Mohammed D.Y.Haroun; Njlaa Seddig; Farid Eltoum

[1] Department of Agricultural Engineering, College of Agricultural Studies, Sudan University of Science and Technology, Shambat, P.O. Box 71, Khartoum North, Sudan. (gmrcoo@yahoo.com)

Abstract

The application of biochar (charcoal or biomass-derived black carbon) to soil is proposed as a novel approach to improve soil fertility, improve soil water holding capacity and consequently water conservation, and to increase crop production. To assess these benefits, the experiment was carried out in a shelter at the college of Agricultural studies (shambat) Khartoum state, Sudan during 2019 autumn season. The aim of this study was to investigate the effect of two type of biochar (millet and peanut residues biochar) with three levels of biochar application (control (CK), 1% (T1), and 3% (T2) of w/w equivalent to 30 g and 90 g) on growth of Jew's mallow (*Corchorus Clitoris*) and irrigation water use efficiency (IWUE). The results showed that at 40 days from sowing, plant height, number of leaves, plant leaves area and plant fresh and dry weight values were significantly affected by the two type of biochar application, however, for both type, plant fresh weight (g) and number of leaves/plant were more affected under T2 treatment. On the other hand the biochar application did not significantly affect plant stem diameter. Furthermore, biochar increased the hydrological properties such as soil water content. In particular, T3 treatment recorded significant increases in both biochar type, which consequently enhanced plant growth parameters compared to the control (CK). Moreover, the biochar treatments (T1 and T2) improved IWUE in both biochar types.

Keywords: biochar, loamy sand, plant available water, cowpea biomass

1 .Introduction

Drought is among the most important factors limiting plant growth and agricultural production worldwide, especially in arid and semi-arid regions (Sun et al. 2013). In the near future, more severe episodes of drought with more erratic distribution of rain, along with rise in average and maximum temperatures are expected to occur as a result of climate change (IPCC, 2007) which will highly influence farming systems and agricultural production (World Bank, 2007).

Improving soil moisture holding capacity is among a few options available to enhance crop productivity under drought condition. Management strategies play an important role in the capability of soils to hold nutrients and water (Baronti et al. 2014). Recently, soil amending with biochar, a stable organic material created through pyrolysis of the plant materials, has been viewed as a sustainable and practical practice to improve soil properties and functions, including soil moisture holding capacity (Lehmann et al. 2011). Improved soil water holding capacity in response to the application of biochar have been reported in various conditions (Lehmann et al. 2011). Biochar potential to alter soil properties however is highly depended on the physical and chemical characteristics of the biochar including porosity and specific surface area, feedstock type and pyrolysis conditions, as well as rate and method of application (Baronti et al. 2014).

Biochar can be defined as carbonaceous matter burned with little to no exposure to oxygen. It is a form of black carbon, which is the umbrella term for carbon containing materials that have been thermally and chemically altered (Spokas et al.2014; Czimczik & Masiello 2007). This term encompasses a continuum of thermally altered materials, from slightly charred biomass to soot. While various forms of black carbon are found as a natural product of forest fires, biochar differs in that it is deliberately created and added to the environment for anthropogenic purposes. It has steadily gained popularity as a subject of scientific study because of its potential for long term carbon sequestration and ability to be beneficial as a soil amendment.

Biochar is highly porous, thus its application to soil is considered to improve a range of soil physical properties including total porosity, poresize distribution, soil density, soil moisture content, water holding capacity or plant available water content(PAWC), and infiltration or hydraulic conductivity (Atkinson et al. 2010; Major et al. 2009; Sohi et al. 2009b, 2010; Zwieten et al. 2012).

Several studies have been carried out throughout the world to identify the effects of incorporating organic matter into the soil, and the resulting advantages for its physical and hydraulic properties are well known (Castellini et al., 2014). In recent years there has been increased use of biochar as an addition to agricultural soils, since it is seen as potentially improving both crop productivity and soil quality (Vaccari et al., 2011; Baronti et al., 2014). It is an alternative that may be potentially integrated into sustainable agricultural systems, Actually, biochar can differentiate each other for several features: pyrolysis process (temperature and residence time), feedstock material and size (powder, granules, pellet). With regard to the size, biochar is typically distributed to soil in powdered or granular form to improveits incorporation and interaction with the soil matrix (Lehmann and Joseph, 2009; Novak et al., 2009). However, the incorporation into the soil may modify the physical and hydraulic properties of the porous medium, such as bulk density, water retention, hydraulic conductivity, porosity and penetration resistance. This is mainly due to both its highly porous structure and the exposed surface area (Lehmann and Joseph, 2009).

Most of the available studies focus on the biochemical effects of biochar on amended soil, including the nutrients that it makes available, as well as on its impact on CEC, pH, vegetative growth, crop yield, and its C sequestration potential (Atkinson et al., 2010; Mukherjee and Lal, 2013). The application of charcoal can increase the pH and decrease the Al saturation of acid soils, which often are major constraints for productive cropping in highly weathered soils of the humid tropics (Cochrane and Sanchez 1980; Mbagwu and Piccolo 1997).

Combined with the fact that soil wetting-and-drying cycles alter the level of soil saturation which can influence nutrients availability (*Nguyen* and *Marschner*, 2005) we expect biochar addition to have beneficial effects on nutrient cycles in soils. For example, pot experiments indicate that biochar reduces N leaching (*Lehmann* et al., 2007). *Steiner* (2007) reported a significantly higher N retention in charcoal-amended soil. Also higher contents of plant-available Ca and Mg in an infertile acidic tropical soil were detected where biochar was applied (*Major* et al., 2010a, b).

Most of the studies on biochar effects on plant growth focus on the analysis of total biomass production. However, for a better understanding of how plant growth can be affected, it is necessary to explore other parameters that are indicative of the physiological status of the plant.

Utilization of biochar and effluent can increase the soil concentration of plant available nutrients and water and enhance root growth environment (Yu et al. 2010; Kamman et al. 2011), ultimately improving crop productivity as a whole.

Jew's mallow is an important green vegetable of the Middle East, Egypt and Sudan as well as parts of tropical Africa. Jute is usually grown for the fibers, but the cultivar grown for vegetable use in short and branched (Yammaguchi 1983).

The crop is grown extensively throughout the Sudan, both under irrigated as a popular vegetable crop, and as a wild plant all over the rainfed areas of the country through the year except for the periods of low temperature in winter. The production in the Sudan is usually consumed locally.

Dried leaves are used in soups under the Arabic name "Molukhyia" The tender mucilaginous leaves are harvested and used as a cooked vegetable, in a similar manner to spinach greens. Harvested leaves may be dried and stored for significant periods (Tindall, 1983).

Jute mallow plays an important role in nutrition and household food security. The leaves contain an average of 15% dry matter, 4.8 g of protein, 259 mg of calcium, 4.5 mg of iron, 4.7 mg of vitamin A, 92 µg of folates, 1.5 mg of nicotinamide and 105 mg of ascorbic acid per 100 g of leaves.

1.2 Research Objectives

1.2.1General objective

The overall goal of this study to provide to a growing body of knowledge on biochar and its effects on the soil and plant. to determine the importance of the use of bio-char in soil to improve the physical properties of the soil and plant growth. It was used in this study the biochar produced from the remnants of millet and groundnut after drying and burning in isolation of oxygen and then mixed with the soil by a certain percentage was selected to know the effect of bio-char in improving the properties of soil and its impact on the growth of the crop.

1.2.2 Specific objective

*To Quantify the effects of biochar and effluent on crop growth, independently and concurrently.

*And to examine the quality of char, in terms of physical propertie of the soil.

2. Materials and methods

2.1 Experimental site

The study was carried out in a shelter at the experimental farm of the college of Agricultural studies (shambat), Sudan University of science and technology, Khartoum state, which lies between longitudes (32-32′E) latitude (15-40′N). The study was conducted during period of May –July 2019. Climate in the study site was a semi-desert with short rain period and sunshine hour ranging from 9-11 hour per day. The average temperature was 35 ^{0}C, the relatively humidity increase in the rainy season and reaches maximum in August 66% on someday.

2.2 Experiment design

In this experiment, two type of biochar were used (Millet and Peanut residues biochar). Jew's mallow seeds (*Corchorus Clitoris*) were sown on 23 May 2019, in each plastic pot (38 cm height and 20 cm width) containing 3 kg soil. Soil used in pots was taken from our experiment area, where the biochar was applied at the rate of 1% 30 g (T1) and 3% 90 g (T2) by weight for both type of biochar. Non-biochar pots served as control (CK). These rates were considered appropriate for the soil which was structurally poor and relatively deficient in nutrients and organic carbon. The soil was classified as a clay soil. Before filling into the pots, soil was mixed well and sieved by passing through 2 mm mesh. The pots were placed on a shelter under a randomized complete block design. Each treatment of biochar types were replicated three times and distributed randomly in order to minimize any effects from the differences between pots. Thus, each type of biochar treatment consisted of 9 pots and the experiment had a total of 18 pots.

2.3 Biochar production

All types of biochar used in this study were produced in the farm of the college of agricultural studies Sudan University of Science and technology. Biochar was produced at 350 - 500 °C pyrolysis temperature based on the recommendation of Lehmann (2007). The dry millet and peanut residues were packed into a container which was covered with a lid to generate biochar. It has been thought that pore size distribution in biochar particles is dependent on both raw materials and pyrolysis temperatures. The particle size of the biochar was about 5–8 mm in diameter after pyrolysis.

2.4 Measurements of growth parameters

Jew's mallow, was selected as the test crop. Jew's mallow seeds were sown in polyethylene bags (pot) on 23May2019 for the growing season. The plant pots were placed at spacing of 20 cm between rows and Colum. Random samples of three plants per plot were used for data collection. Plant growth parameters, (i.e., plant height, number of leaves, fresh plant and root weights (FPW and FRW), and dry plant and root weights (DPW and DRW)), from all nine pots were measured during the growing seasons. The plant growth period was divided into three stages, i.e., establishment (stage 1, 10 days), vegetative growth (stage 2, 15 days), and harvesting (stage 3, 15 days). Plant height was measured weekly, from the stem base to the top of the plant and the number of leaves were counted. The roots were separated from the soil after the harvesting, and FRW and DRW were measured. The fresh plant shoots were also collected at harvesting. The fresh plant shoot and FRW were then measured. The shoots and roots were placed in individual paper bags, and oven dried at 70 °C, until the dry weight remained constant. The plants were harvested six weeks after sowing by cutting the aboveground plants by hand just above the soil surface.

2.5 Irrigation management

At the start of the experiment, all pots were irrigated until drainage occurred to determine pot water holding capacity. After drainage to field capacity for three days, all pots displayed similar soil water content before sowing of the seeds of Jew's mallow. Pots were irrigated with tap water and the amount given was same (plants were irrigated with same amount of water throughout the experimental period). All the pots were irrigated every second to third day until the end of the experiment. The total amount of water applied (400 mm) to each treatment was calculated as the sum of water applied during the duration of the Jew's mallow growing period. The total numbers of days of irrigation during the growing periods were 16 days. The irrigation water use efficiency (IWUE) was calculated as the ratio of plant yield (fresh weight) to irrigation amount (Wang et al., 2009).

3. Results and discussions

The changes in soil water content (WC) in the 0–0.5 m soil layer during the growing season under the two biochar types and three biochar treatments are shown in Figure 1. Plots with biochar had higher WC values than those without biochar under all biochar types. The WC also increased as the amount of biochar increased. The greatest WC occurred under the treatment of biochar type (millet) and the highest biochar rate (Bm T2) while the smallest values occurred under the absence of biochar (Bg ck) (control). Moreover, the greatest WC amounts occurred in the higher biochar application rate of two type of biochar .

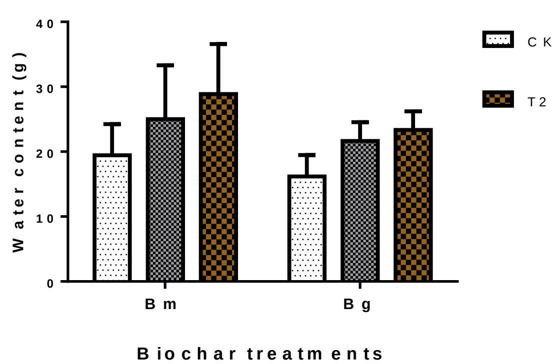

Fig1. Effect on soil water content of two type of biochar and their application rate (Ck,T1,T2 = 0 , 1%30g ,3%90g).

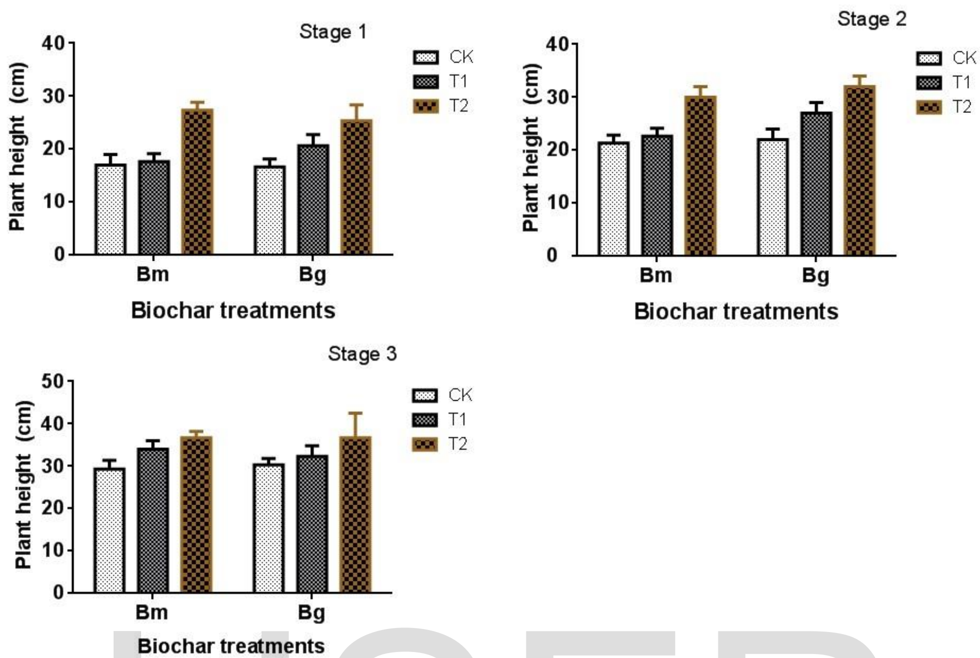

Figure 2 .Effect of biochar amendments (Ck, T1, and T2 = 0, 1% (30 g), and 3% (90g) w/w, respectively on plant height during growing seasons.

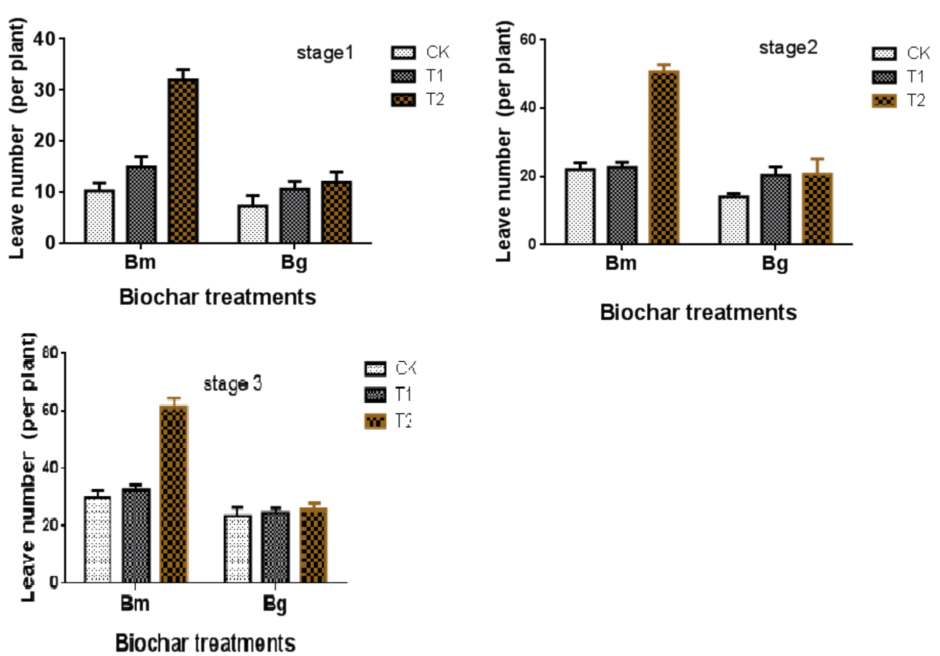

Figure3. Effect of biochar amendments (Ck, T1, and T2 = 0, 1% (30 g), and 3% (90g) w/w, respectively on number of leaves per plant during growing season.

The plant height and number of leaves serve as important indices that directly reflect the growth of the Jew's mallow plants. The changes in Jew's mallow height and the number of leaves at various growth stages under the biochar treatments are shown in Figure 2 and figure3. The plant height and number of leaves were significantly increased by increases in the amount of biochar application rate (P < 0.01). It is clear in that Figure 2 and figure3increasing biochar under increased plant height and the number of leaves at almost all of the growth stages. Moreover, the tallest plants with the greatest number of leaves, were obtained at the latest growth stage for Bm-T2 followed by Bm-T1 and Bm-ck.

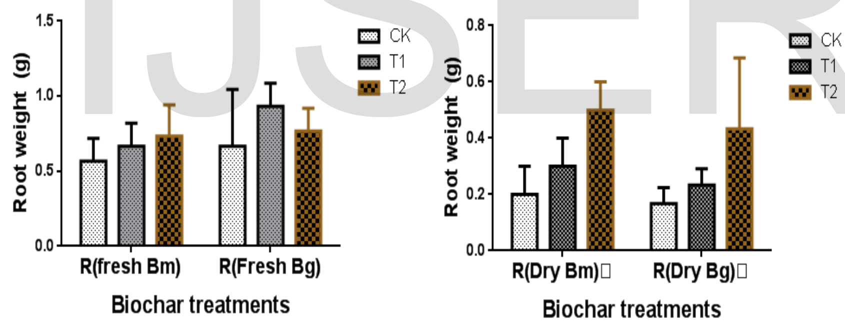

Figure4. Effect of biochar amendments (Ck, T1, and T2 = 0, 1% (30 g), and 3% (90g) w/w, respectively on total fresh root weight and total dry root weight (DPW)per plant during growing season.

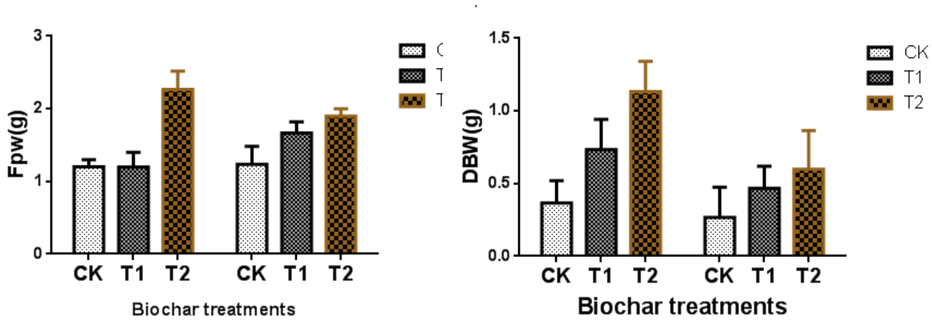

Figure5. Effect of biochar amendments (Ck, T1, and T2 = 0, 1% (30 g), and 3% (90g) w/w, respectively on total fresh weight and total dry vegetative weight (DPW)per plant during growing season.

The measured aboveground and root biomasses at harvest time aregiven in Figure 4. In general, the fresh plant weight (FPW) and dry plantweight (DPW) significantly increased with increasing biochar rate ($P < 0.05$). Similarly, the mean values of FPW and DPW were generally increased significantly with the increase in the amount of biochar rate ($P < 0.05$). The largest FPW and DPW values were produced by the Bm-T2 treatments (30g and 90g). The smallest FPW and DPW values were recorded for the Bg-Ck treatment (0). Increasing the amount of biochar from T1 to T2 increased the plant biomass. Adding biochar led to a significant increase ($P< 0.05$) in the fresh root weight . (FRW) in relation to the control (ck). Although, there were no significant differences in the FRW of Jew's mallow plants grown under either of the biochar types (Bm and Bg). The Bg-T1 treatment resulted in the largest FRW values (30g) followed by Bg-T2 (90g), and Bm-T2 (90g). The dry root weight (DRW) also increased significantly ($P < 0.05$) with an increasein biochar rate. Thus, higher biochar rates (T2 andT1) resulted in greater values of DRW under higher biochar levels (Bm and Bg) in the order: Bm-T2 (90g) >Bg –T2 (90g) >Bm-T1 (30g) for 2014. Biochar has been reported as playing a vital role in improving soil chemical and physical properties, facilitating crop growth, and increasing crop yields (Liu et al., 2014). Our study revealed that addition of biochar to a loam soil improved WC under both biochar treatments. This is in accordance with the findings of other studies (e.g., Andrenelli et al., 2016; Agbna et al., 2017). The reason that this occurs is that the biochar increases the porosity of the soil, which increases the potential to store water (Novak et al., 2009). Thus, biochar enhances the WC as well as improving other soil hydrological properties. Furthermore, biochar itself has a porous structure that can increase the absorption capacity.

Plant properties such as Jew's mallow plant height, number of leaves, fresh and dry weights of both above- and below-ground plant parts were all improved by biochar additions. Similar observations were made by Liu et al. (2014). The beneficial effects of biochar on plant growth are largely due to the nature of the biochar physical structure. The high micro porosity of biochar leads to a high specific surface area, which in turn increases the adsorptive capacity of the soil-biochar mixture (Cornelissen et al.,2004). The availability of organic matter and other nutrients can increase with biochar application, which is probably due to the creation of suitable environments in which micro organisms can dwell and propagate that provide them with various energy and nutrient sources (Steiner, 2007; Warnock et al., 2007).

4. Conclusion

This study investigated the effects of biochar on the growth of Jew's mallow in clay soil. The current study is strongly indicating the importance of the included organic resources in improving the productivity and quality of Jew's mallow crop. Our results support other studies that have found biochar application to increase plant growth. The results directly confirm the role of biochar in fertile the soil and building the organic carbon which may help in improving soil quality of the clay soils and increasing the water holding capacity and consequently increasing yield and productivity.

5- Recommendations

*Through this experiment, the plant was made using two type of biochar .We recommend the use of biochar for agriculture , in order to greatly improve the physical properties of the soil as well as to improve plant growth.

*From the comparisons made in this experiment, we noticed that the biochar produced from the leaves of the millet plant has a clear and effective effect on the vegetative total of the molasses, and the soil is more likely to retain water than the biochar produced from the bean.

Reference

Andrenelli, M., Maienza, A., Genesio, L., Miglietta, F., Pellegrini, S., Vaccari, F., Vignozzi, N., 2016. Field application of pelletized biochar: short term effect on the hydrological properties of a silty clay loam soil. Agric. Water Manage. 163, 190–196.

Atkinson CJ, Fitzgerald JD, Hipps NA (2010) Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant and Soil 337:1–18

Gamareldawla H.D. Agbna; Dongli She; Zhipeng Liu; Nazar A. Elshaikh; Guangcheng Shao; Timm Luis Carlos. Effects of deficit irrigation and biochar addition on the growth, yield, and quality of tomato. Scientia Horticulturae, 222 (2017) 90–101

Gamareldawla Agbna, Abubaker A, Amir B, Farid E, Mohamed H. Influence of Biochar Amendment on Soil Water Characteristics and Crop Growth Enhancement Under Salinity Stress. International Journal of Engineering Works Kambohwell Publishers Enterprise, 2017 (4) 49-54.

Baronti, S., F. P. Vaccari, F. Miglietta, C. Calzolari, E. Lugato, S. Orlandini, R. Pini, C. Zulian, and L. Genesio. 2014. Impact of biochar application on plant water relations in Vitis vinifera (L.). European Journal of Agronomy. 53, 38–44.

Cochrane TT, Sanchez PA (1980) Land resources, soil properties and their management in the Amazon region: a state of knowledge report. In: International Conference on Amazon Land Use and Agricultural Research, CIAT, Cali, Colombia

Cornelissen, G., Kukulska, Z., Kalaitzidis, S., Christanis, K., Gustafsson, Ö., 2004. Relations between environmental black carbon sorption and geochemical sorbent characteristics. Environ. Sci. Tech. 38, 3632–3640.

IPCC. 2007. Climate change 2007. Synthesis Report, IPCC, 2007. Technical Report, IPCC.

Jeffery S, Verheijen FGA, van der Velde M, Bastos AC (2011) A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agriculture, Ecosystems and Environment 144:175–187

Kookana RS, Sarmah AK, Van Zwieten L, Krull E, Singh B (2011) Biochar application to soil: agronomic and environmental benefits and unintended consequences. Advances in Agronomy 112: 103–143

Krull E (2011) Biochar. CSIRO fact sheet series, Australia Lehmann, J., M. C. Rillig, J. Thies, C. A. Masielloc, W. C. Hockadayd, and D. Crowley. 2011. Biochar effects on soil biota – a review. Soil Biology and Biochemistry, 43, 1812–1836.

Lehmann, J., Joseph, S., 2009. Biochar For Environmental Management: Science And Technology. Earthscan, London, UK

Lehmann J. 2007. Bio-energy in the black. Front Ecol Environ. 5:381 387.

Liu, Z., Chen, X., Jing, Y., Li, Q., Zhang, J., Huang, Q., 2014. Effects of biochar amendment on rapeseed and sweet potato yields and water stable aggregate in upland red soil. Catena 123, 45–51.

Mann CC. 2005. 1491: New revelations of the Americas before Columbus. New York (NY): Vintage and Anchor Book

Mas Yamaguchi 1983. World vegetables, Principles, production and nutritive values .pp 366. Department of vegetable crops. University of California at Davis, California. Ellis Harwood Limited, Publishers

Major, J., Lehmann, J., Rondon, M., Goodale, C., 2010. Fate of soil-applied black carbon: downward migration, leaching and soil respiration. Glob. Change Biol. 16, 1366–1379.

Mbagwu JSC, Piccolo A (1997) Effects of humic substances from oxidized coal on soil chemical properties and maize yield. In: Drozd J, Gonet SS, Senesi N, Weber J (eds) The role of humic substances in the ecosystems and in environmental protection. IHSS, Polish Society of Humic Substances, Wroclaw, Poland, pp 921–925

Mukherjee, A., Lal, R., 2013. Biochar impacts on soil physical properties and greenhouse gas emissions. Agronomy 3, 313–339.

Major J, Steiner C, Downie A, Lehmann J (2009) Chapter 15. Biochar effects on nutrient leaching. In: J Lehmann, S Joseph (eds) Biochar for environmental management: science and technology. Earthscan, London

Nguyen TH, Brown RA, Ball WP. 2004. An evaluation of thermal resistance as a measure of black carbon content in diesel soot, wood char, and sediment. Org Geochem. 35:217–234.

Novak, J.M., Lima, I., Xing, B., Gaskin, J.W., Steiner, C., Das, K.C., Ahmedna, M., Rehrah, D., Watts, D.W., Busscher, W.J., Schomberg, H., 2009. Characterization of designer biochar produced at different temperatures and their effects on a loamy sand. Ann. Environ. Sci. 2, 195–206.

Piccolo A, Pietramellara G, Mbagwu JSC (1997) Use of humic substances as soil conditioners to increase aggregate stability. Geoderma 75:267–277

Sun, X. P., H. L. Yan, X. Y. Kang, and F. W. Ma. 2013. Growth, gas exchange, and water-use efficiency response of two young apple cultivars to drought stress in two scion-one rootstock grafting system. Photosynthetica, 51(3), 404-410

Sohi SP, Lopez-Capel E, Krull E, Bol R (2009b) Biochar, climate change and soil: a review to guide future research. CSIRO Land and Water Science Report 05/09, 64 pp

Sohi SP, Krull E, Lopez-Capel E, Bol R, Donald LS (2010) Chapter 2—a review of biochar and its use and function in soil. Advances in Agronomy. Academic, New York

Steiner, C., 2007. Soil charcoal amendments maintain soil fertility and establish a carbon sink—research and prospects. Soil Eco. Rese. Dev. 1–6.

sSteiner C, Teixeira WG, Lehmann J, Nehls T, Macêdo JLV, Blum WEH, Zech W. 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant Soil. 291:275–290

Tindall, H.D. 1983. Vegetables in the tropics pp 392-397. Mac Milan press London.

World Bank (2007) Making the Most of Scarcity: Accountability for Better Water Management Results in the Middle East and North Africa. Available online at: http://siteresources.worldbank.org/INTMNAREGTOPWATRES/Resources/Making_the_Mo st_of_Scarcity.pdf

Warnock, D.D., Lehmann, J., Kuyper, T.W., Rillig, M.C., 2007. Mycorrhizal responses to biochar in soil–concepts and mechanisms. Plant Soil 300, 9–20.

Yu, Fang-Bo, Xi-Ping Luo, Cheng-Fang Song, Miao-Xian Zhang, and Sheng-Dao Shan. 2010. "Concentrated Biogas Slurry Enhanced Soil Fertility and Tomato Quality." *Acta Agriculturae Scandinavica, Section B - Plant Soil Science* 60 (3) (May): 262–268. doi:10.1080/09064710902893385.

Zwieten LV, Singh BP, Cox J (2012) Chapter four: biochar effects on soil properties. In: J Cox (ed) Biochar in horticulture: prospects for the use of biochar in Australian horticulture. Horticulture Australia, NSW Department of Primary Industries

Wang, Z., Liu, Z., Zhang, Z., Liu, X., 2009. Subsurface drip irrigation scheduling for cucumber (Cucumis sativus L.) grown in solar greenhouse based on 20 cm standard pan evaporation in Northeast China. Sci. Hortic. 123, 51–57.