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Priyanka Rani
1. IAS, BHU, Varanasi, Uttar Pradesh, India
2. Veer Kunwar Singh College of Agriculture, Dumraon, Buxar Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

Harshita Nayar
IAS, BHU, Varanasi, Uttar Pradesh, India

Sumit Rai
GB Pant National Institute of Himalayan Environment & Sustainable Development, Kosi-Katarmal, Almora, Uttarakhand, India

Saroj Kumar Prasad
IAS, BHU, Varanasi, Uttar Pradesh, India

Rajesh Kumar Singh
IAS, BHU, Varanasi, Uttar Pradesh, India

Correspondence
Priyanka Rani
1. IAS, BHU, Varanasi, Uttar Pradesh, India
2. Veer Kunwar Singh College of Agriculture, Dumraon, Buxar Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India

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Biochar: Moisture stress mitigation

Priyanka Rani, Harshita Nayar, Sumit Rai, Saroj Kumar Prasad and Rajesh Kumar Singh

Abstract
Biochar is used as soil amendment and soil conditioner that can be used for enhancing soil water storage which may increase soil fertility and sustain crop production. The main objective of this review is to emphasise the potential effects of biochar in alleviating soil moisture stress or drought condition and future prospect of the role of biochar under drought. Moisture stress negatively affect soil fertility and plant growth. Application of biochar, carbonised biomass developed from combustion (between 300 and 1000^{0}c) of biomass under limited oxygen supply, ameliorates the negative effects of drought on plants. The biochar application increased the plant growth, biomass, and yield under drought and also increased photosynthesis, nutrient uptake, and modified gas exchange characteristics in moisture stressed plants. Under drought stress, biochar increased the water holding capacity of soil, increasing plant water status, decreased Na + uptake, and increased K+ uptake by plants, regulation of stomatal conductance and phytohormones thus improved the physical, chemical and biological properties of soil. Therefore, Biochar when utilized correctly, can be an important agricultural tool used to increase nutrients and organic resources in moisture stressed or depleted soils. This is because the lumps of biochar are full of holes (Honey comb like) and crevices that help serve as habitats for soil microorganisms.

Keywords: Biochar, soil amendment, soil conditioner, soil fertility, soil productivity

1. Introduction
Unprecedented growth in urban population and enhanced anthropogenic interventions have resulted global environmental change including land degradation, loss of biodiversity, alteration in hydrology and climate patterns which surely have serious negative consequences for world food security, particularly affecting the more vulnerable socio-economic sectors (Ericksen *et al.* 2009; Lal 2010) [29, 51]. Indian population, which increased from 683 million in 1981 to 1,210 million in 2010, is estimated to reach 1,412 million in 2025 and 1,475 million in 2030. To feed the projected population of 1.48 billion by 2030, India needs to produce 350 million tonnes (mt) of food grains. The expanded food needs of future must be met through intensive agriculture without any expansion in the arable land. India's arable land area of 159.7 million hectares (394.6 million acres) is the second largest in the world, after the United States. Its gross irrigated crop area of 82.6 million hectares (215.6 million acres) is the largest in the world. Rainfall data over the past century indicates that there has been a severe drought every eight to nine years. India faced 22 major droughts between 1871 and 2002. The drought of 1987 was perhaps the worst drought of the last century, with an overall rainfall deficit of 19 per cent. It affected nearly 60 per cent of the crop area and more than 85 million people were severely affected. During the year 2017-18, as per information available till date, Chhattisgarh Madhya Pradesh and Rajasthan had declared drought. Indian agriculture mainly dependent on rainfall, and low rainfall in the arid to semiarid region creates periods of drought resulting in crop moisture stress (Grulke, 2010) [36]. Due to these natural calamities, increasing population and decreasing arable land, feeding this increasing population is putting pressure on existing natural resources. Agricultural crops are frequently exposed to abiotic stresses such as drought, salinity and heavy metal stress (Osakabe *et al*. 2014; Parihar *et al*. 2015; Rizwan *et al*. 2016a) [69, 70, 75]. Among these abiotic stresses, drought is most critical threats to agricultural production. Drought stress is negatively affect the plant production all over the world, especially in arid and semi-arid regions, and is expected to increase with climate

Changes such as increasing of global temperature and increasing soil drought (EEA, 2011) [28]. Soil drought restricts plant growth and biomass production, particularly in arid and semi-arid regions (Asrar *et al*., 2012) [9]. Drought stress is responsible for the reduction of growth and yield of plants (Wang *et al*. 2014a, b; Bodner *et al*. 2015) [87, 88, 14]. In the recent past, drought has severely affected terrestrial agriculture. For example, Xia *et al*. (2015) [92] reported that drought stress increased Cd uptake in peanuts when peanuts are grown in Cd contaminated calcareous soil. Drought also cause oxidative stress in plants through the production of reactive oxygen species (ROS) (De Carvalho 2008; Abbasi *et al*. 2015) [21, 2]. Drought has disastrous effects on chickpea production worldwide (Ahmad *et al*., 2014; Fang and Xiong, 2015; Dikilitas *et al*., 2016; Alwhibi *et al*., 2017; Dubey *et al*., 2018) [30, 23, 26]. Drought reduces leaf water contents, nutrient uptake, photosynthesis, growth, and yield of plants (Gupta and Huang 2014; Noman *et al*. 2015; Siddiqui *et al*. 2015) [37, 62, 79].

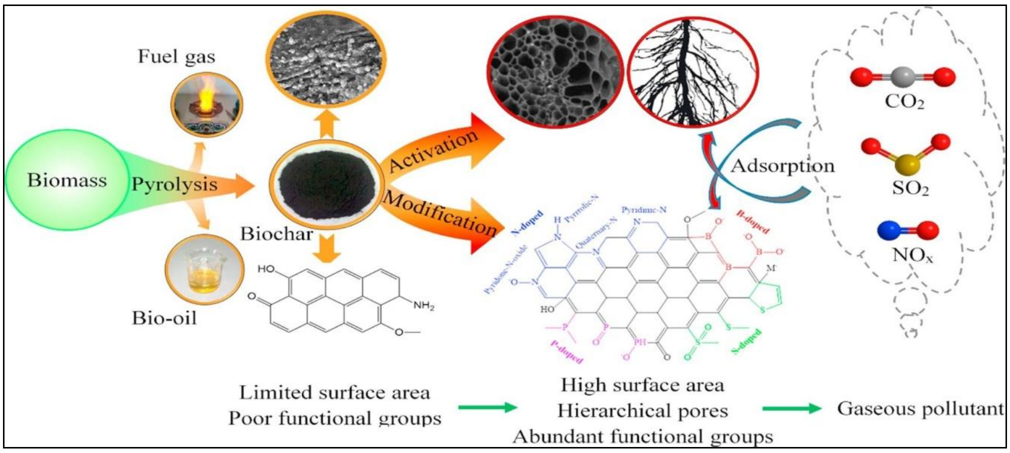
In India, every year about 435.98 mt tons of agro-residues are produced, out of which 313.62 mt are surplus. These residues are either partially utilized or un-utilized due to various constraints (Murali *et al.*, 2010) [61]. Conversion of these agro-residues into biochar is best way to crop residue management as well as it is one of the best Solution that has been proposed to mitigate soil moisture stress when it is applied as a soil amendment or soil to soils. Biochar, also called black gold for agriculture, is being used increasingly in agriculture with an intention to mitigate drought and climate change by sequestering carbon (C), improving soil properties and functions and enhancing crop yield (Lehmann, 2007; Sohi *et al*.,2010) [52, 78]. Biochar is the product obtained from pyrolysis of any organic material that is, heating to high temperatures (300 to 1000^{0}c) in the absence of oxygen. Biochar is a porous, carbon rich (80%) compound which is highly resistant to decay. Its structure (hexagonal honey comb like) enables it to store both water and nutrient elements, and, for this reason, it is being considered as a defense against drought (Novak *et al*., 2009a; Major *et al*., 2010; Ippolito *et al*., in press) [63]. Biochar increase crop productivity "through an improved water holding capacity (whc) of the soil, along with improved crop nutrient availability, especially in sandy soils (Jeffery *et al*., 2011; Tryon, 1948) [43, 83].

Applications of biochar enhance soil fertility, carbon sequestration, bio-energy production, and immobilization of organic and inorganic pollutants (Fiaz *et al*. 2014; Ok *et al*. 2011, 2015; Rajapaksha *et al*. 2016. Rizwan *et al*. 2016b; Abbas *et al*. 2017a) [32, 67, 71, 74, 1]. biochar application increased plant growth and biomass and nutrient uptake under drought and salt stress (e.g., Akhtar *et al*. 2014,2015a; Haider *et al*. 2015; Kim *et al*. 2016) [4-5, 38, 48]. Biochar also improved soil physicochemical properties including soil pH, cation exchange capacity (CEC), soil structure, water holding capacity (WHC), and surface area under abiotic stresses (Chaganti and Crohn 2015; Hammer *et al*. 2015; Andrenelli *et al*. 2016; Bamminger *et al*. 2016; Lim *et al*. 2016) [17, 39, 7, 10, 56]. Biochar application also reduced sodium ion (Na+) uptake and increased potassium (K+) uptake under salt stress (Wu *et al*.2014; Drake *et al*. 2016; Usman *et al*. 2016) [91, 25, 85].

1.1 What is biochar

Biochar is a fine-grained, carbon-rich, highly porous product remaining after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperatures (~350–600°C) in an environment with little or no oxygen (Amonette and Joseph, 2009) [6].

It is a C rich black coloured material produced by burning of any organic compound through pyrolysis process. It is very recalcitrant in nature (Cheng *et al*., 2008) [20] due to high degree of aromatic city. When considering a potential feedstock for biochar production, biomass availability and moisture content must be considered to ensure continual operation of the processing plant, with minimal energy input requirements. Pyrolysis of these types of wastes may produce both energy and a biochar product with relatively high levels of plant nutrients. Biochar is not a pure carbon (C) as it includes ash, hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S) (Duku *et al*. 2011; Lehmann and Joseph 2015) [27, 55]. The residence time of biochar in soil is reported in the ranges of 100–1000 s years. The properties of biochar vary greatly with different sources of feedstock and with different production temperature.



Source: Yin gquan Chen *et al*.2017)

Fig 1: Flow chart of Biochar production

1.2 Potential benefits of Biochar

Appropriate application of biochar in soil improves soil physical, chemical, biological, microbiological properties. Hence improves soil fertility, its productivity, soil health and quality of soil on sustainable basis.

- It darken the colour of soil. Zhang *et al*. (2013) [97], soil reflectance can also be decreased by biochar amendment due to the darkening of soil color, as well as the increase in SOC content.

- It Regulate soil temperature.
- Lowers the soil bulk density in light textured soil but slightly increases in heavy textured soil. Andrenelli *et al*. (2016) [7], who showed that soil amended with pelletized biochar had a bulk density ∼10% lower than that of control soil. it also improves soil water-retention properties, with such improvement possibly correlated with both the inherent retention capacity of the biochar and a more functional arrangement of soil aggregates/particles in the presence of biochar pellets (Andrenelli *et al*., 2016) [7]
- Biochar improve water infiltration rate, soil moisture retention, increasing agricultural resilience and provides support to intensive sustainable agriculture which helps to cut pressure for new forest clearances and enhances biodiversity conservation benefits. By improving moisture retention, it may also reduce the demand for irrigation and make cropping more secure.
- Biochar reduces soil acidity / raises pH (Rodriguez *et al.*, 2009), reduces aluminium toxicity and increases cation exchange capacity.
- It offers a more environment-friendly way to sequester C into the soil by storing recalcitrant form of C in soil. It not only improves good and problematic nutrient-poor soils, but also enhances plant growth which in turn raises and sustains crop yield. Pot experiment in alluvial soil with rice husk biochar @ 5 and 10 t ha^{-1}increases 11 and 17% higher dry matter respectively, over control (Rani *et al.*,2013) [72]
- With the application of Appropriate dose of biochar to soil, It enhances soil nutrient affinity i.e. retention of plant nutrients, mainly in the case of N retention on permeable soils under rainy conditions. Biochar @5kg/ha with sludge increase nitrogen content of rice plants, ranged between 0.747 to 2.053 %, (Rani *et al*, 2015) [73].
- Biochar helps to reduce GHG emissions associated with agricultural development. Application of manure or compost to the soil may stimulate the release of GHGs and also may have a limited residence time in soil. Pyrolysis destroys microorganisms and some veterinary pharmaceuticals. It has also been reported by many researchers worldwide to suppress CH4 and N2O emission from cultivated soil, thereby reducing global warming. Biochar can reduce N_2O and NO emissions, transformed from $NO_3^-$and NH_4^+ by denitrifying and nitrifying bacteria, respectively (Van Zwieten *et al*., 2009; Spokas *et al*., 2010) [86, 81].
- Biochar may play role in bioremediation by binding agrochemicals and help reduce phosphate and nitrate and agrochemicals pollution of streams and groundwater, thus helping resolve major problems hindering sustained and improved agriculture.
- It also reduces plant uptake of pesticides from contaminated soils (Yu *et al.*, 2009) [94-95].
- It can support biofuel production, reduce its C footprint and even enable it to move toward being C neutral.
- Soil microbial biomass improved with the use of biochar and supports other beneficial organisms like earthworms, helps in nitrogen fixation, phosphate mobilization and solubilization by increasing arbuscular mycorrhizal fungi in soil.
- It provides opportunities for poor to benefit from C offset market and also reduces dependency of farmers on input suppliers like different agrochemicals.
- Biochar may be a useful input to counter harmful compounds like heavy metals, dioxins and polycyclic aromatic hydrocarbons (PAHs) present in sewage or refuse inputs (peri-urban / urban agriculture).

Table 1: Effect of biochar on different soil properties (Srinivasarao *et al.* 2013) [82].

some selected soil properties	Findings	Reference
Cation exchange capacity	50% increase	Glaser *et al.*, 2002 [35]
Fertilizer use efficiency	10-30% increase	Gaunt and Cowie, 2009 [34]
Liming agent	1 unit pH increase	Lehman and Rondon, 2006 [53]
Crop productivity	20-120% increase	do
Biological nitrogen fixation	50-72% increase	do
Soil moisture retention	Up to 18% increase	Tryon, 1948 [83]
Mycorrhizal fungi	40% increase	Warnock *et al.*, 2007 [89]
Bulk density	Soil dependent	Laird, 2008 [49]
Methane emission	100% decrease	Rondon *et al.*, 2005 [77]
Nitrous oxide emissions	50% decrease	Yanai *et al.*, 2007 [93]

Table 2: Impact of biochar on water holding capacity (Mukherjee and Lal, 2013)

Soil type	Biochar type	Study type (Scale)	Rate of biochar application% (g g-1)	Water holding capacity (g cm-3)	References
Residue sand	Municipal green waste 450^{0}c	laboratory	0	0.11	Jones *et al*. (2010) [44]
			2.6	0.16	
			5.2	0.20	
Norfolk loamy sand ap	Pecan shells 700^{0}c	laboratory	0	0.64	Busscher *et al*. (2010) [16]
			0.5	0.59	
			1.0	0.60	
			2.0	0.66	
Sandy loam	Ponderosa pine (Pinus ponderosa) 450^{0}c	laboratory	0	11.9	Briggs *et al*. (2012) [15]
			0.5	12.4	
			1.0	13.0	
			5.0	18.8	

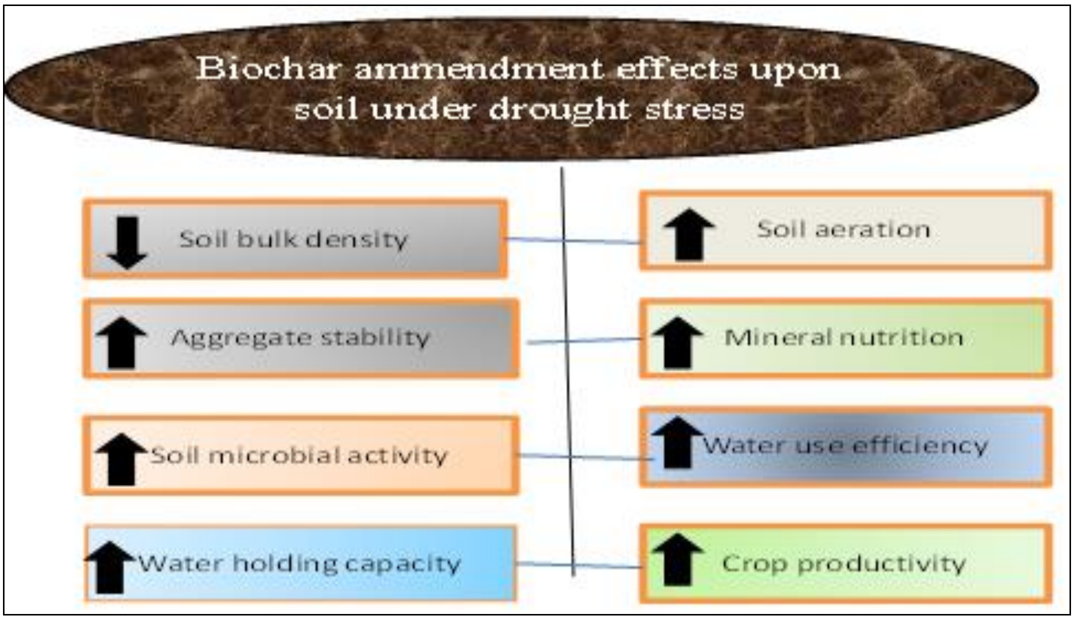


Fig 2: Possible effects of biochar in soil moisture stress

1.3 Biochar as a water stress mitigating tool

1.3.1 Biochar and moisture stress: Application of biochar to soil has been considered as a win-win approach in soil C sequestration and influences soil hydraulic parameters and water retention (Glaser *et al.*, 2002; Kameyama *et al.*, 2011) [35, 46]. Increasing soil organic matter (SOM) content improves soil moisture retention and crop water availability, which is a key factor in determining agricultural productivity (Bates *et al.*, 2008) [11]. Under dry condition, where the quantity and quality of water is extremely variable, this could be an effective method for storing soil moisture. Biochar in soil contributes to better water storage through modifying the pore size distribution associated with improving aggregate stability (Downie *et al.*, 2009) [24] and by water storage in pores (Downie *et al.*, 2009; Chen *et al.*, 2010; Shackley and Sohi, 2010) [24, 18, 78]. There is no second opinion on enhancement of water holding capacity and plant available moisture in sandy soils due to biochar additions, however there is no guarantee that it will increase the available water in loam and clay soils (Srinivasrao *et al.*, 2013b). Glaser *et al.* (2002) [35] studied the effect of increasing rate of biochar application on different soil and found improved water retention only in sandy soil (table: 3). It is because of its high surface area and porous nature which increases the micro pore distribution as well as water holding capacity of sandy soil. But, in loamy soils, there was no change; and in clayey soil, the available soil moisture declined with increasing rate of charcoal additions, probably due to increased percolation and infiltration rate of the soil. Therefore, maximum benefit of biochar application can be realized in sandy areas where leaching loss is more pronounced.

Table 3: Effect of biomass derived char on percentage of available moisture in soil on a volume basis (Glaser *et al.* (2002) [35]

Soil	0% biochar	15% biochar	30% biochar	45% biochar
Sandy	6.7	7.1	7.5	7.9
Loam	10.6	10.6	10.6	10.6
clay	17.8	16.6	15.4	14.2

1.4 Effect of biochar on moisture stress condition

Recently, umpteen researchers have been found that addition of biochar has very much potential in improving water holding capacity (table: 4). It implicit that soil amended biochar could retain more water from rainfall, which should increase crop production in non-irrigated dryland regions (Jeffery *et al.*, 2011) [43], and reduce the frequency and amount of irrigating water needed to grow crops in irrigated regions. Keshavaraz afshar *et al.* (2016) studied the effect of biochar application on drought stress condition and noticed slight improvement in soil water holding capacity. Similarly, Basso *et al.* (2013) observed addition of biochar increases water holding capacity in sandy loam soil and might increase the water availability for crop use. They used hard wood fast pyrolysis biochar and found increase in gravity-drained water content 23% relative to the control. Through the addition of poultry litter biochar, relative water content (RWC) increased both in well watered and water stressed condition (Mannan *et al.*, 2016). Increase in RWC was 3.83, 5.25 and 3.51% in well watered condition and 4.35, 6.81 and 4.92% in water stress condition by addition of biochar 25, 50 and 100 t ha^{-1}, respectively. Incorporation of biochar also increased the overall accumulation of osmotic active substances such as K^+ in the plant tissues, possibly due to its large cation content, leading to an improved plant water uptake which ultimately increased leaf water content (Gaskin *et al.*, 2012).

Depth and method of biochar application in soil are essential factors which determine the potential of moisture conservation. Till date, two types of biochar application have been studied: uniform top mixing and deep banding (Basso *et al.*, 2013). Blackwell *et al.* (2010) [13] evaluated banded application of biochar on dryland wheat (*Triticum spp.*) production in Western and South Australia and found that banding biochar can reduce fertilizer and irrigation requirements without affecting yields.

Bulk density is an important soil characteristic affecting water infiltration (Ueckert *et al.*, 1978) [84], and recent research has found application of biochar reduces soil bulk density (Oguntunde *et al.*, 2008; Laird *et al.*, 2010a) [65, 50]. Decreasing soil bulk density has a positive effect on soil as it enhances soil porosity and soil aeration, root and microbial respiration.

Table 4: Effect of biochar application on soil water holding capacity.

Type of biochar	% increase in soil water retention	References
Switch grass biochar	15.9	Novak *et al.* (2009a) [63]
Hardwood slow pyrolyse biochar	15	Laird *et al.* (2010a) [50]
Biochar (pellet)	20	Bartocci *et al.* (2017)
Coffee husk or rice husk biochar	26-33	Duong *et al.* (2017)
Yellow pine biochar	Doubled of initial value (16%)	Yu *et al.* (2013) [94]

1.5 Biochar mitigating drought

Among all the abiotic stresses, drought causes catastrophic damages particularly to crops. Drought stress is commonly characterized by uncertainty in monsoon, reduced water holding capacity of soil, diminished leaf water potential and loss of turgor and stomatal closure, reduced cell enlargement and growth (Mannan *et al.,* 2016) [59]. Drought significantly affects plant growth, nutrient and water uptake, photosynthesis, assimilate partitioning and ultimately on crop yield and quality (farooq *et al.,* 2009b) [31]. In severe cases water stress checks photosynthesis, disturbance of metabolism and finally the death of plant (Jaleel *et al.,* 2008) [42]. Moisture stress also inhibits cell elongation more as compared to cell division. Besides, the negative impact of drought on soil health is lack of nutrient uptake by crops, since water is the major medium of nutrient mobilization and translocation in soil as well as plants as a result of water uptake. Reduced nutrient and water uptake ultimately results in loss in crop yield and quality produce. In dryland, WUE ranges from 0.25 to 1.5 kg m^{-3}, whereas in irrigated areas it ranges from 0.5 to 1.7 kg m^{-3}, depending on the crop (Howell, 2001; Deng *et al.,* 2006) [40, 22]. Thus, water use efficiency not only in dry land but also in irrigated land need to be considerably increased in order to meet the growing demand of food and fuel (Oki and Kanae, 2006) [68].

Basically, biochar is a carbon- enriched product obtained by heating organic biomass, such as wood, manure or leaves in a sealed container with little or absence of oxygen rather than burning it (Lehmann *et al,* 2009; Wayne, 2012) [6, 90]. It is produced under thermal decomposition position these organic material in the presence of reduced concentration of oxygen at a temperature above 700 ºC (Lehmann and Joseph, 2009) [6]. Hexagonal microscopic structure of biochar is one of the primary deciding factors in its soil conditioning properties; the surface area of the pre-charred source material can be increased several thousand folds. The value of surface area increases from 10 m^2 g^{-1} to 100-500 m^2 g^{-1}, affected by types of feedstock and pyrolysis temperature (Chen *et al.,* 2017) [19]. This increase in surface area is the outcome of pyrolysis of the organic materials through which volatiles are driven off and highly concentrated carbon chains compounds left out. These chains can transform to different organizational patterns to develop some new porosities based on the production temperature, with increased temperatures leading to increased organization (Beslee and Marmiroli, 2011). It is believed that surface of biochar is formed or attached with carboxylate or other ionizable functional groups and on oxidation it enhances the cation exchange capacity (CEC) of biochar with time, once it is mixed with soil (Cheng *et al.,* 2006, 2008; Liang *et al.,* 2006) [20]. Hypothetically, increased water holding capacity over time in soil amended with biochar is the result of chemical changes occurring on the biochar compounds. Therefore, CEC can be considered as the indirect measure of the extent of oxidation and water retention capacity of biochar amended soil (Basso *et al.,* 2013).

Biochar contains high amount of carbon (up to 80% depending on pyrolysis conditions (Antal and Gronli, 2003) [8] and nature of feed stock; it generally has a high pH, low bulk density, and may be concentrated in nutrients from the original plant residues (Laird *et al.,* 2010a) [50]. It can be recommended as a potential soil amendment and may be used both to store C due in part to recalcitrant C, and to improve soil aeration, water-holding, and nutrient-retention properties (Joseph *et al.,* 2010). Addition to this, incorporation of biochar is observed to increase the microbial activities and thus, results in faster decomposition of native organic carbon content (Wardle *et al.,* 2008). Since, organic amendments generally increase water holding capacity, biochar amended soil has a high capacity to retain water due to presence of large amounts of small pores in biochar (Major *et al.,* 2009). If it enhanced water retention capacity of soil, then it would be very beneficial for crop production under drought or dryland condition.

2. Conclusion

Use of biochar as soil amendment to agricultural land to mitigate moisture stress and sustained agricultural productivity is not a new phenomenon. A number of benefits have been identified within the literatures. Biochar that has upgraded extensively is promoted to improve a range of soil properties such as soil pH, cation exchange capacity and soil water holding capacity, and can be derived from a wide range of forest residue, sewage sludge, organic and agricultural wastes biomass feedstock, at different pyrolysis condition. Biochar defined by its useful application to soil, is expected to enhance an advantage from enduring chemical and physical and biological properties. For large surface area and porosity of biochar, they can raise the capacity of water holding of soil and the absorption of nutrients with a view to decrease loss and an augment soil structure, Studies reported above showed that biochar application increased the plant growth and biomass under moisture stress condition. Biochar soil usage increased the photosynthesis, nutrient uptake, and modified gas exchange characteristics in plants. The biochar-mediated enhancement in drought tolerance of plants is mainly associated with a reduction of Na+ uptake and increases K+ uptake in plants, which regulate osmoregulation properties stomatal conductance. It improves accumulation of minerals, and phyto hormone. Overall, this review could contribute to a better understanding of the biochar-potential tool to mitigate soil moisture stress. So biochar might progress fertility of soil and raise crop yields in future if it is applied to soil with a suitable application rates.

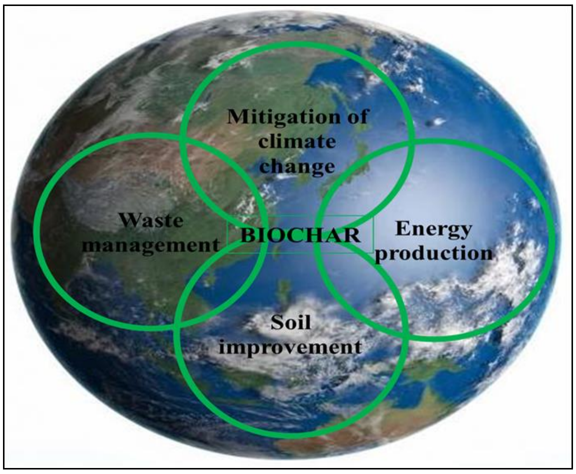


Fig 3: Social, environmental and financial benefits of biochar.

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