Review

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Review

An Overview of Climate Change Impacts on Agriculture and Their Mitigation Strategies

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Abstract: In recent days, the adverse effect of climate change on soil properties in the agriculture sector is a dreadful reality worldwide. Climate change-induced abiotic stresses such as salinity, drought and temperature fluctuations are devastating the crops' physiological responses, productivity and overall yield which is ultimately posing a serious threat to global food security and agroecosystems. The applications of chemical fertilizers and pesticides contribute towards further deterioration and rapid change in climate. Therefore, more careful, eco-friendly and sustainable strategies are required to mitigate the impact of climate-induced damage on agriculture sector. This paper reviews the recently reported damaging impacts of abiotic stresses on various crops along with two emerging mitigation strategies; biochar and biostimulants, in light of recent studies for combating the worsening impact of deteriorated environment and climate change on crops physiological responses, yields, soil properties, and environment. Here we highlighted the impact of climate change on agriculture and soil properties along with recently emerging mitigation strategies applying biochar and biostimulants, towards protecting the soil, agriculture and environment.

Keywords: climate change; mitigation strategies; crops; biochar; biostimulants; soil

1. Introduction

Climate change refers to a long-term and significant change in the measure of climate such as rainfall, temperature, wind or snow pattern[1]. Global warming and greenhouse gas (GHG) emissions are considered major factors, responsible for adversely accelerating the degree of climate change[2]. Due to continuously increasing anthropogenic activities, the global average temperature increased by 0.9°C since 19th century and it is expected to be further increased to 1.5 °C by 2050[3]. Manifolds and continuous increases in GHG emissions are highly affecting the terrestrial, freshwater and marine ecosystems by causing substantial and irreversible losses[4]. These GHGs block the transmission of infrared radiations that tries to escape from the atmosphere and thus trapped heat as in the 'greenhouse'[5]. The major GHG sources include burning fossil fuels, use of nitrogen fertilizers, soil management, flooded rice fields, land conversions, burning biomass, livestock production and manure management[6]. Climate change is projected to have significant impacts on agriculture through direct and indirect effects on crops, soils, livestock and pests[7]. Though, climate change is a slow process involving relatively small changes in temperature and precipitation over long periods of time, nevertheless these slow changes in climate influence the various soil processes particularly those related to soil fertility. The effects of climate change on soils are expected mainly through alteration in soil moisture conditions and increase in soil temperature and CO_2 levels as a consequence[8]. Global climate change is projected to have variable effects on soil processes and properties important for restoring soil fertility and productivity[9]. The major effect of climate change is expected through elevation in CO_2 and increase in temperature and salinity[10].

Crop production is vulnerable to climate variability, and climate change-associated increases in temperature, increases in CO_2, and changing patterns of rainfall may lead to a considerable decline in crop production[3]. Changes in temperature, moisture, wet-drying and freeze-thawing cycles, etc. can lead to alterations in the growth and physiology of soil microorganisms[11]. Climate-induced changes in environmental parameters can indeed influence both the structure and function of soil

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microbial communities, and modify, for instance, the level of interaction among microorganisms required for the degradation of organic pollutants in soil, soil organic carbon stocks, soil properties such as pH, Cation exchange capacity (CEC), Water Holding Capacity (WEC), nutrients stock[12–14]. Also, extreme weather events such as droughts, extreme heat waves, and heavy rainfall leading to floods have increased in past decades increased the leaching, soil erosion and runoff at alarming rates. Enhancing crop production to meet rising demands owing to the increasing population, against the background of the threats of climate change, is a challenging task. Therefore, we require more attention towards adaptation and mitigation research. From past few decades, the agriculture technologies have been successful in eradicating huger from many parts of the world but by the virtue of chemical means and usage, which raised more concern for environment, health and future agriculture[15]. During recent high input farming systems and technologies, chemical fertilizers (consisting of N, P or K) are applied excessively to provide the plant nutrient requirement for increasing the agriculture productivity worldwide[16]. The use of chemical fertilizers caused more harm than good in long term prospective. Therefore, modern agriculture sector needs more clean and green strategies for improving crop productivity and mitigation of climate change impact, simultaneously.

Various terms and strategies came forth to counter the use of agrochemicals and provide assistance in improving agriculture such as biochar, biostimulants and bio fertilizers[17–19]. Recent advances in research have provided evidence of these strategies for having potential to improve soil properties, crop yield and offsetting the GHG emissions at significant levels. All of these strategies work on minimizing the adverse effects of climate change and act as replacement to agrochemicals. These strategies further drawn attention towards naturally occurring products to substitute the need and use of synthetic products [20–22].

In this review, we provide an evaluation based on what is recently known, of the potential of various biological tools such as biochar and biostimulants, as a green strategy to counter the impact of climate change on atmosphere and agriculture.

2. Impact of climate change on agriculture and soil properties

In agriculture sector, the fluctuations in climate such as global rainfall, continuous rise of carbon dioxide and average temperature led towards increase in frequency of extreme events that cause flood and drought disasters by posing a serious threat to global crops and serial productivity[23,24] (Figure 1). The variation in temperature and rainfall has direct effect on growth and maturity time of crops due to which the crops are adversely subjected to various biotic and abiotic stresses[25]. According to a recent study, these biotic and abiotic stresses are responsible for losses of 30-50% agricultural productivity worldwide[26]. In addition to loss of productivity climate change is also a threat towards a significant expand in the range of pests and pathogens that could lead to the increase frequency and severity of plant diseases[27–29].

With increase in human population and industrialization the frequency and consequences of global warming are expected to rise, which will not be confined to any particular region but ultimately will be distributed to the global ecosystems[30]. These dangerous impacts of climate change on crop yields may compromise and risk the food security worldwide[31,32]. Hence food insecurity and climate change are also considered as two major challenges of 21st century[33].

In addition to having direct effect on plants, climate change is also adversely affecting the soil systems. Fluctuations in carbon dioxide concentration in atmosphere, rate, pattern and precipitation amounts, increasing temperature are modifying the soil plant system by influencing the rate of decomposition and soil organic carbon level[34,35]. The soil structure, fertility, microbial population and processes directly depends upon available organic carbon in soil[34,35].

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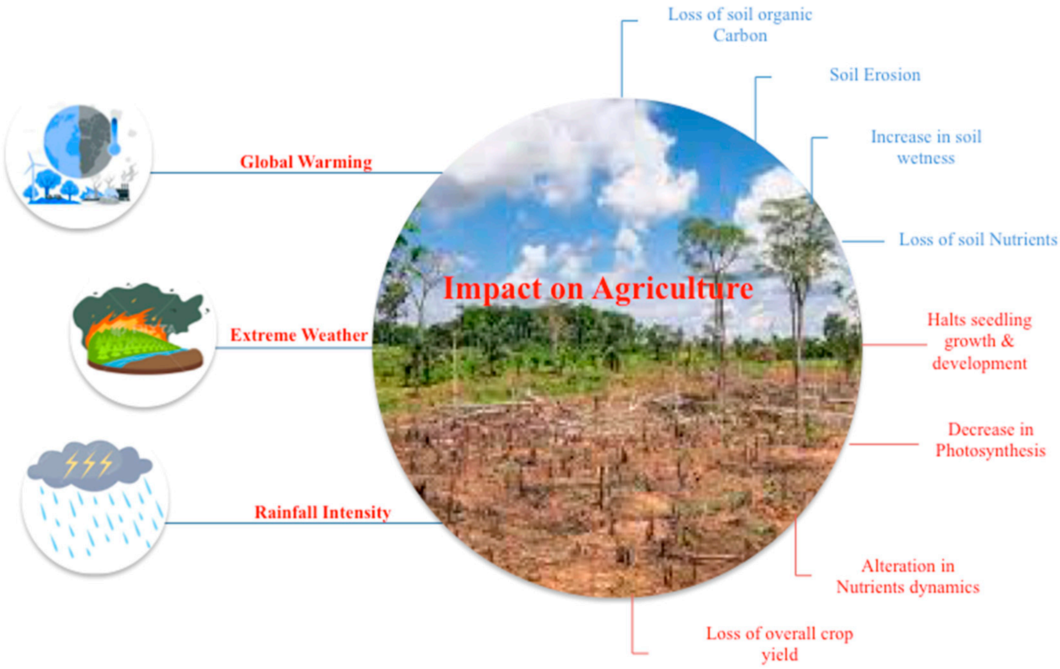

Figure 1. Impact of climate-induced environmental extremes on agriculture, soil and crops.

Recent studies have shown that the combinatorial effect of temperature and moisture determine the transformation process of minerals into soil compounds[36]. Fluctuation and precipitation frequencies and seasonal temperature also affects the hydro physical properties of soil by changing soil water regime. The soil physical properties such as mechanical composition or texture, structure including shape and stability, bulk density and porosity, size distribution of pores, all of them significantly affect the hydrological properties (hydraulic conductivity and water retention etc.) of soil. All these properties collectively contribute towards air, water and heat management of soil. These physical properties greatly influence the chemical and biological processes of soil, ultimately having a great impact on soil fertility and crops yield (Figure 2).

To find out the degree of influence of climate change on physical properties of soil is quite a complex process. The most common and significant direct impact of climate on disturbing the soil structure are destructive capability of rain drops, filtering water and surface runoff and extreme events of rain[38]. Whereas the indirect effects are resulted by the fluctuations in vegetation patterns, biological properties of soil such sensitivity of termites, earthworms and soil microbiome to these climatic changes[39]. Soil texture, bulk density and organic matter content directly depends on climate condition[40]. Recent studies have shown that increased level of carbon dioxide in atmosphere greatly reduces the soil organic matter by increasing the soil microbial activity. Hence it results in more carbon turnover to atmosphere by accelerating the positive feedback in global carbon cycle as a rise in global temperature[40]. In addition, the loss of organic matter due to soil microbial activity and soil erosion results in increase in soil bulk density which in turn increases the soil compaction. The soil bulk density and compaction inhibit the growth of plant roots and collectively result in poor crop yield[41].

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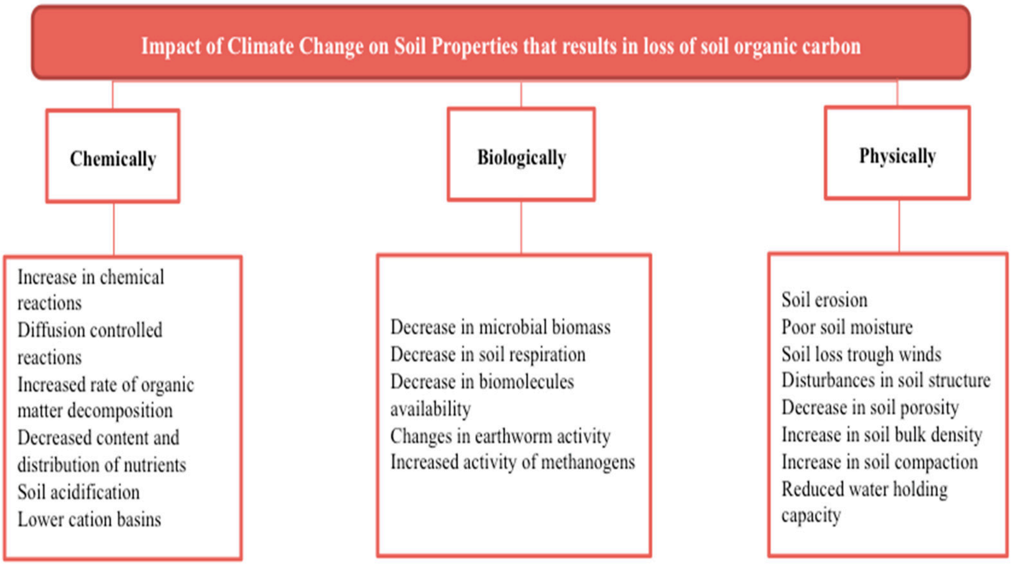

Figure 2. Climate extremes associated deterioration of soil by various mechanisms [42].

Extreme climate events also affect the soil chemical properties such as pH, content and distribution of soluble salts, nutrients, carbonates, cation exchange capacity and value of base saturation[43]. By increasing precipitation and rate of weathering, the phenomena lead to accelerate leaching and results in soil acidification. Acidic pH of soil facilitates the mobility of toxic heavy metals leaving the soil depleted with basic cations[44]. Recent studies revealed that soil from more arid and warmer sites possess lower level of organic carbon, nitrogen and phosphorous in soil. Soil organic matter is one of the most important factors for measuring the efficiency of soil. Biological decomposition aids up the soil organic matter and the rate of decomposition by microorganisms increases with increase in temperature[45]. However, the increase is not a continuous process and after certain limits further rises in temperature result in changes in microbial physiology by reducing carbon usage efficiency. Changes in temperature, moisture, wet-drying and freeze-thawing cycles, etc. can lead to alterations in the growth and physiology of soil microorganisms Climate-induced changes in environmental parameters can indeed influence both the structure and function of soil microbial communities, and modify, for instance, the level of interaction among microorganisms required for the degradation of organic pollutants in soil.

3. Crops physiochemical responses to various climate change parameters

Crops growth and yield depends upon several important factors such as atmospheric temperature and CO2 levels, precipitation amounts and patterns, associated salinity and accumulation of toxins in soil[35]. With increase in global temperature, significant changes in several hydrological parameters have been reported such as evapotranspiration, runoff, ground water and soil moisture[46]. Most of crops have quite a narrow range of survival over high temperatures (40-45 °C)[47]. It is well known established fact that enzymes depend upon optimum temperature to work and failure of only a single critical enzyme system can halt the growth of crops or organism[48]. High temperatures or heat stress is found associated with various physiochemical mechanisms of crops such as cellular injury, membrane lipids peroxidation and oxidative stress[47]. Moreover, the optimum temperature levels are different for different crops. For instance, the higher temperature (> 35 °C) damages the rice crops, sorghum pistils and pearl millet[49]. Similarly, the loss of wheat productivity has been observed at high temperatures (table 1). The exposure of crops to higher temperatures during different stages of development results differently[50,51]. Recent studies reported that the rice crop encounters heat stress during stage of grain development affects the crop the most. The heat stress during anthesis has been observed to inhibit pollen shed and decline in number of grains. The heat stress during reproductive stages leads to the significant losses of crop

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yield as pollen and pistils are susceptible to high temperatures [52]. Crops possess various mechanisms to resist and minimize the losses of flowering such as increase in rate of transpiration to set cooling environment around plants[53]. However, at high temperatures the plants prefers to use more energy for the maintenance and respiration, which results in compromise upon their growth[54].

According to one estimate, with every 1°C rise in temperature, the yield of crops can significantly reduce by 5-10% in future[55]. Higher temperatures compel plants to complete their growth cycle in less time. This leaves plants with less time to reproduce and ultimately results in considerable loss in yield[56]. It is also observed that higher temperature range cause declines in rice yields and reproduction in beans by increasing respiration at night[57].

Increase in salinity is also a major threat to crops yield and it is reported to increase in coastal agriculture lands by increase in sea levels during consecutive years. The water moves from soil towards plant roots by osmosis and this process depends upon salt levels in the soil and plants[58]. The higher soil salt levels may derive water back from plant roots towards soil and can cause reduced productivity or even death of crop plant. Salinity also affects the uptake of nitrogen by plant roots, growth and plants reproduction[59]. The higher temperatures and lower precipitations increase the rate of evapotranspiration in crops, which in turn results in salts accumulation on soil surface. In this way the underground water used for irrigation appears brackish and high in soluble salts content such as Na+ and Cl-, with lesser amounts of Ca2+, K+ and NO-3[60]. The hyper-ion salt stress causes oxidative damage and metabolic impairment in crops. The higher Cl- levels also affect the electrical conductivity. For some crops the levels beyond 2dsm-1 limits the growth and yield[61]. Moreover, the higher salinity temperatures have been observed to affect the physiological responses of crops in several ways such as by inhibiting photosynthesis, stomata closure, reducing water content, and osmotic potential, triggering nutrient imbalance and osmolyte changes (supplementary Table S1).

With increase in industrialization, urbanization, mining and use of agrochemicals, the natural sources such as water and soil are consistently getting polluted with loads of heavy metals such as nickel, copper, cadmium, lead, cobalt and chromium[62]. These heavy metals are a serious threat to agroecosystems with potential toxic effect on crop plants. The risk of contamination of soil and proportion of metals that causes toxicity in soil determines the active effect on the environment[63]. Climate change affects the bioavailability and mobility of heavy metal in soils. A higher average temperature increases the mobilization process and disturbs the environmental natural balance[64]. Climate change also leads to the acidification of soil and heavy metals toxicity worsens the acidification effect as heavy metals further decrease the photosynthesis and various physiological processes in crop plants[65].

Nickel is reported to have direct impact on seeds germination of various crop plants by affecting their enzyme activity of amylase, protease and ribonuclease. By this it significantly affects the digestion and transport of foods resources such as carbohydrates and proteins in seeds during germination[66]. Nickel toxicity have also been reported for affecting various physiochemical processes by reducing plants height, length of roots, biomass and chlorophyll content, and leakage of electrolytes[67]. In few crops, the nickel toxicity has been reported to have an impact on chlorophyll content and accumulation of various cations such as K+, Na+, and Ca2+[68]. Lead toxicity has been observed to significantly affect the various morphological and physiological processes of crops such as halting germination, development of seedlings, elongation of roots, transpiration, growth, chlorophyll, proteins and water content of plant, impaired nutrient uptake and inducing stomata closure. Lead polluted soils are reported with inhibited seedling growth with alterations in possible mechanisms such as increase in peroxidation of lipids, superoxide dismutase, and glutathione ascorbate cycle activation[69].

Copper toxicity has been reported to affect the seedlings in sunflower crops by inducing the generation of reactive oxygen species and lowering the activity of catalase. Another study reported that the copper toxicity halts the germination of seeds by down regulation of α-amylase activity and affects the uptake of water, transport of food resources and overall metabolism[70]. Cadmium and cobalt also affect the seed germination process by causing delays in germination. Cadmium toxicity

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is found associated with impaired transport of food resources and membrane damage. It is also reported to strongly affect the germination percent, growth of embryo, and biomass distribution. Chromium toxicity results in reduced growth of crops, lower chlorophyll, proteins, proline content and higher metal uptake[71].

4. Climate change mitigation strategies for improved agriculture

4.1. Biochar

Biochar is a solid black stable carbon material mainly composed of carbon, minerals, volatile matter and moisture[72]. From thousands of years, the pyrolysis of biomass into biofuels and biochar presents potential capability to sequester loads of CO_2 from atmosphere as well as to amend soils in earth layers[73]. Biochar, a porous solid material resulted from biomass carbonization at no oxygen and low temperature (400℃), is considered as a significant tool in mitigation of climate change because of its role in reducing GHG emissions from soil and sequestration of carbon in more stable form of carbon material[74]. The biochar properties highly depend upon pyrolysis temperature, the biochar produced at high pyrolytic temperatures such as more than 500℃, has been reported to improve porosity and bulk density to a significant extent. The biochar produced at lower than 500℃ pyrolytic temperature has been reported to have higher impact on the fungal and bacterial diversity of soil. Especially in coarse textured soil, it is reported to effect bacterial diversity where as in fine textured soils, it affects fungal diversity more. [75]

Several recent studies have been reported for a role of biochar in improving the efficiency of fertilizer use and thus reducing the economic and environmental burden of manufacturing given requirements of fertilizers[76–78]. The biochar based efficient use of fertilizer can avoid the manufacturing fraction of fertilizers and associated GHG emissions[79]. The biochar based fertilizers can increase crop productivity significantly and further increases the crop productivity in soils which are not responsive to common fertilizers (Figure 3A) [80].

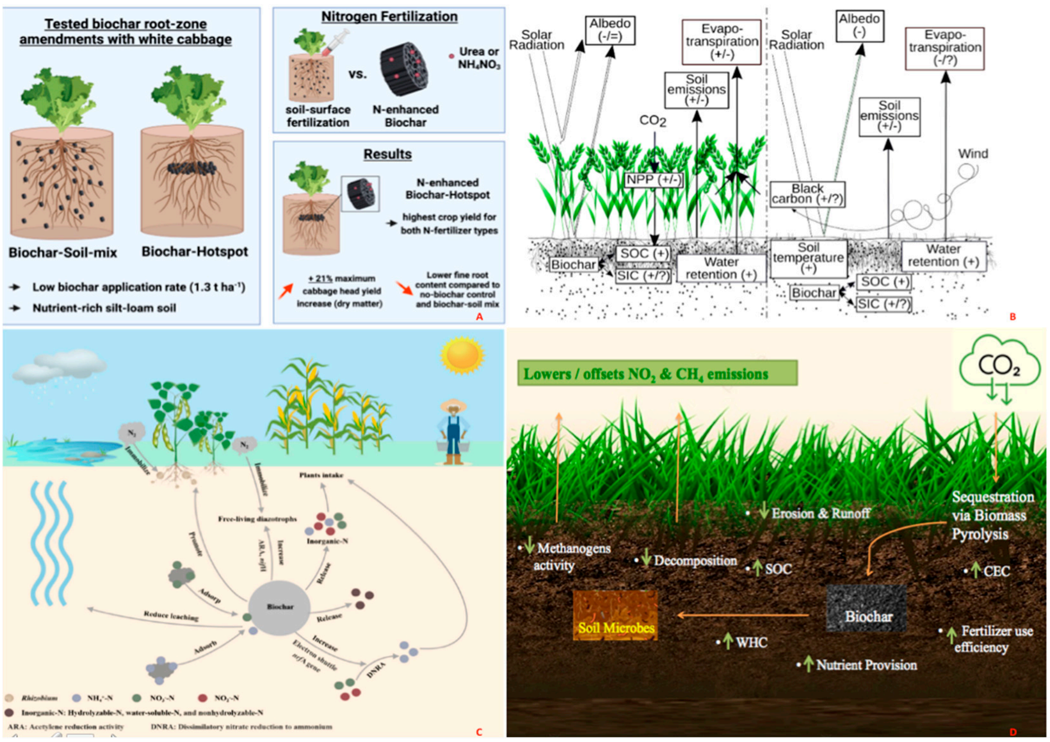

Figure 3. Potential role of biochar in soil amendments and crops productivity by various mechanisms; 3A: increase in crop productivity by biochar induced root zone amendment of crop, 3B: biochar effect on climate under cultivated field by inducing positive effect on increasing soil organic carbon, soil inorganic carbon, water retention and decreasing emissions and evapotranspiration, 3C: Mechanism

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of biochar associated improvement of soil nitrogen, 3D: Overall role of biochar in improving soil properties and crop productivity.

Biochar has gigantic ability to sequester CO_2 while preventing release of carbon back in atmosphere after its decomposition (Figure 3B)[81]. With this practice, about 2.5 gigatons of CO_2 can be sequestered annually[82]. The slower decomposition of biochar in comparison to biomass stems its potential to mitigate climate change impact as it lowers the rates of returning photo-synthetically fixed carbon back into the atmosphere[83]. The difference in the rates of decomposition of biochar and raw biomass critically determines the net carbon stock available in soil that evolved over time[83]. Biochar presents larger soil carbon stocks with prolonged lifetime in comparison to raw biomass[84]. The embedded carbon of biochar in this case is considered as a redistribution of carbon from biomass sources, with the ability to persistently derive larger carbon sequestration and influence on net GHG balances[85].

Biochar is composed of mixture of compounds with varying decaying kinetics in soil and over the time, the decay rates of biochar slow down[86]. Also the microorganisms cannot digest biochar completely, therefore, the biochar-based amendments of soil are considered as a source of permanent agent for carbon sequestration in soil[87]. Depending on the physico-chemical properties of biochar, it can offer a sustainable way towards suitable feedstock for circular economy paradigm. The application of biochar as enrichment of soil can offset CO2 emission of land by 12% annually. Moreover, along with preforming critical role in improving soil health and crop productivity, it has ability to minimize 1/8 of CO2 annual emissions [82]. This mitigation strategy could possibly reverse the net global warming and can significantly aid in carbon negative technology development for sustainable human civilization future.

Biochar turnovers the rate of native soil organic matter by significantly varying the stocks of non-pyrogenic soil carbon[88]. The ways by which biochar can impact the soil organic matter includes reduction in the amounts of detritus in soil in comparison to adding biomass to soil directly[61], increase in the yields of plants biomass [89], by altering the rates of stabilization, humification and soil organic matter[90]. Biochar is also reported to have an impact on improvement of the crops yield by nutrient provision, alteration in pH of soil, enhancing cation exchange capacity (CEC) of soil, improving efficiency of fertilizer use and enhancing the water holding capacity in drainage of clayey or sandy soils (Figure 3) (Supplementary Table S2). The biochar application has also been reported for improving the microbes mediated chemical reactions and enzymatic activity of soil (Figure 3C) [91]. The soil applications of biochar also have the potential to minimize soil runoff and erosion. A systematic meta-analysis revealed the mitigation of soil erosion by 16% and runoff by 25% upon biochar-based soil amendment. This effect was found stronger in tropical zones over subtropical [92].

Moreover, the biochar also plays an important role in mitigation of climate change impact by several other secondary mechanisms such as it plays role in reduction of nitrous oxides and methane emissions in soil. Pyrolysis of biomass to biochar can avoid processes such as decomposition and combustion of biomass, which actually contributes to the emission of NOx and methane in atmosphere. According to a recent study, the applications of biochar could lower the emissions by 50-80% in an acid savanna oxisol and by 70-80% in slightly acidic to neutral soil. Another study estimated the annual soil nitrous oxide emissions avoided by applications of biochar as by the reduction factor RN of 25%. A study from China being a huge GHG emitter revealed the potential of biochar to offset the total CH4 and N2O emissions from China's crop land by pyrolysis of waste to biochar[93]. The biochar application in fusion with dicyandiamide has been reported to reduce the cumulative N2O emissions by 69-70% and CO2 emissions by 30-43%. The reduction in emissions was found associated with damage to bacterial network complexity [94]. Similarly few studies reported for the reduced methane emissions for soil by application of biochar[79]. However, further research input is required to estimate the associated reduced fraction of nitrous oxide or methane emissions in various soil conditions.

In summary, biochar has high potential to mitigate the climate change impact on soil, agriculture and ultimately on crops yield. However, there is further need to careful policy making, designs,

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protocols, project monitoring and advice for agriculture extensions to maximize the output and to avoid any negative outcomes associated with poor irrigation practices and implications.

4.2. Biostimulants

More recently, biostimulants are reported as one among various significant and potential mitigation strategies in assisting plants to develop resistance against several environmental abiotic stresses resulted by rapidly changing climatic conditions[95]. Various recent studies have shown the tremendous potential of biostimulants in agriculture by providing aid to plants against climate change–induced stresses such as salinity, drought, temperature etc. [96]. Biostimulants are microbes, organic compounds or amalgamation of these two that could help in regulation of plant growth and certain behaviors by alteration in molecular, biochemical, physiological and anatomical levels[97]. Biostimulants can act as a promising mitigation strategy in recent crop production scenario as they are reported to function through various modes of action due to their diverse nature and the varying composition of these bioactive compounds[98]. Biostimulants could be broadly categorized into various classes such as botanical extracts including seaweed/ algae extracts, amino acids, protein hydrolysates, vitamins, antioxidants, cell–free microbial products, anti–transpiration agents, chitin, fulvic and humic acid along with their derivatives [99,100]. The application of biostimulants in very small amount could be potential enough to induce resistance against stresses and this quality of biostimulants makes this class different from fertilizers and manures application to soil. Studies have also revealed their ability towards the maintenance of the ecological balance in agro-ecosystems by reducing the use of chemical fertilizers, pesticides and heavy metals in agricultural practices[101]. Based upon the immense potential of biostimulants, the European Commission has planned to substitute the 30% of chemical fertilizers with organic–based inputs by the end of 2050[95]. Along with the tremendous ability of augmentation in the levels of production, biostimulants have also been reported for its role in reducing the greenhouse gases emission by decreasing the fertilizer consumption in agriculture sector[102]. A recent study reported that extract of seaweed can significantly reduce the release of greenhouse gas by supplementing synthetic fertilizer input in sugarcane cultivation and observed a potential offset of 260 kg CO2 equivalent/Mg cane production/ha by 5% foliar application of seaweed extract[103]. Biostimulants–induced responses differs among the plant species from the morphological modifications to the gene expression, their mode of application and phyto–hormone responses[104]. The Table 1 highlighted the recent studies, which demonstrated the extraordinary potential of biostimulants for mitigation of the adverse abiotic stresses such as salinity, drought, and heat or cold stress induced by change in climatic conditions without compromising crop quality, productivity and production.

Table 1. Role of biostimulants in mitigation of climate change impact and improving crops yield.

Sr. No	Biostimulant	Crop	Effect of treatment on crop	Ref.
1	*Trichoderma album* and *Bacillus megaterium*	Onion	Overall better yield, enhanced levels of potassium by 105.7%, Proline by 34%, calcium by 37% and total free amino acids by 144% after treatment with *T. album* Pretreatment with *T. album* and *B. megaterium* both, enhanced total carbohydrates, antioxidants, activity of superoxide dismutase, catalase, ascorbate peroxidase, glutathione-S-transferase, ascorbic acid, and flavonoids	[105]
2	Silicate Compound and antagonistic bacteria *Bacillus sp.*	Banana	Treatment resulted in enhanced physiological growth performance of bananas, significantly resisted against *Fusarium* wil disease in bananas that results by pathogenic causative agent *Fusarium*	[106]

			cubense, the incidence of *Fusarium* wilt decreased by 56.25%	
3	Natural organic matter based Biostimulant	Tomatoes	Plants resisted drought stress and resulted in enhanced growth of plant roots (36%), and shoots (27%)	[107]
		Avocados	Plants developed drought and salt resistance resulting in 45% increase in yield	
4	*Ascophyllum nodosum*	Watermelon	In response to salt stress, the treatment of plants with Biostimulant provoked a positive phenotypic response	[108]
5	Menadione sodium bisulfite encapsulated chitosan nanoparticles	Tomatoes	Treatment of plants with Biostimulant increased the tolerance against drought stress and delay the need for retreatment by 1 week	[109]
6	*Ascophyllum nodosum* and zeolite	Spinach	Combined use of Biostimulant resulted in significant improvement in water storage capacity of plants	[110]
7	*Yucca schidigera* extracts	Broccoli	Treatment of plants with Biostimulant resulted in strong effect of plants against drought and salt stress, also promoted germination and early vigor	[111]
8	*Chondrus crispus* extracts	Tomatoes	Treatment resulted in drought tolerance in plants along with enhanced shoot height and biomass	[112]
9	*Ascophyllum nodosum*	Tomatoes	Plants developed drought resistance by 40% in comparison to control	[113]
10	Mixture of *Ruinex, Penergetic, Azofix*	Wheat	Humus content increased, Nitrogen and carbon content of soil increased, results over three years show that biostmilants resulted in promotion of mobile humic substance and mobile humic acid release better.	[114]
11	*Pseudomonas fluorescens, Stenotrophomonas rhizopus, Agrobacterium rubi*	Strawberry	Treatment resulted in seven-fold increase in plant growth and fruit production, also plants developed resistance against angular leaf spot disease caused by *Xanthomonas fragariae*	[115]
12	Amino acids	Savory	Treatment resulted in enhanced dry matter yield, essential oil content, carvacrol, gamma-terpinene, alpha-terpinene, *p*-cymene	[116]

Concluding Remarks

The uncertain climate scenario negatively impacts agriculture and is a serious cause of concern for global food security. The mitigation strategies to offset the climate-induced deleterious impact on agricultural productivity, such as biochar and biostimulants have potential to significantly minimize the unfavorable impact without compromising environmental sustainability. Further planning and application of these mitigation strategies in an interdisciplinary approach can save future of agroecosystem and can be used as biological tools to overcome the unpredicted climate change impact on agriculture.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

Author Contributions: Conceptualization, A.R. and F.B.; validation, A.R.; resources, A.R. and F.B.; writing—original draft preparation, F.B.; review and editing, A.R.; visualization, F.B.; supervision, A.R.; project administration, A.R.; funding acquisition, A.R. All authors have read and agreed to the published version of the manuscript.

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