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PROSPECTS FOR SUSTAINABLE SOIL CARBON STORAGE AND CLIMATE CHANGE MITIGATION USING BIOCHAR

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Abstract: Biochar plays an important role in climate change mitigation by promoting long-term soil carbon storage and potentially reducing greenhouse gas emissions. Its relatively stable carbon compounds contribute to increasing soil carbon stocks. In addition, biochar can improve soil water retention, nutrient availability, and biological activity. Its effectiveness depends on feedstock type, pyrolysis temperature, and soil characteristics. Therefore, biochar represents a promising approach to enhancing carbon sequestration, reducing soil degradation, and promoting sustainable agriculture.

Keywords: Biochar, soil carbon storage, carbon sequestration, climate change mitigation, pyrolysis, greenhouse gas emissions, soil fertility, sustainable agriculture.

Annotatsiya: Biochar tuproqda uglerodni uzoq muddat saqlash va iqlim o‘zgarishini yumshatishda muhim ahamiyatga ega bo‘lgan uglerodga boy material hisoblanadi. U organik biomassani kislorod cheklangan sharoitda piroliz qilish orqali olinadi. Biochar tarkibidagi nisbatan barqaror uglerod birikmalari tuproqdagi uglerod zaxiralarini oshirishga yordam beradi. Shuningdek, u tuproqning suvni ushlab turish qobiliyati, oziq moddalar mavjudligi va biologik faolligini yaxshilashi mumkin. Biocharning samaradorligi xomashyo turi, piroliz harorati hamda tuproq-iqlim sharoitlariga bog‘liq. Shu sababli biochar uglerod sekvestratsiyasini kuchaytirish, tuproq degradatsiyasini kamaytirish va barqaror qishloq xo‘jaligini rivojlantirishning istiqbolli vositasi hisoblanadi.

Kalit so‘zlar: biochar, tuproq uglerodi, uglerod sekvestratsiyasi, iqlim o‘zgarishini yumshatish, piroliz, issiqxona gazlari emissiyasi, tuproq unumdorligi, barqaror qishloq xo‘jaligi.

Аннотация: Биоуголь (biochar) представляет собой богатый углеродом материал, который играет важную роль в долгосрочном накоплении углерода в почве и смягчении последствий изменения климата. Он производится путём пиролиза органической биомассы в условиях ограниченного доступа кислорода. Относительно стабильные углеродные соединения биоугля способствуют увеличению запасов углерода в почве. Кроме того, его применение может улучшать водоудерживающую способность почвы, доступность питательных веществ и биологическую активность. Эффективность биоугля зависит от вида исходного сырья, температуры пиролиза и почвенно-климатических условий. Таким образом, биоуголь является перспективным средством повышения секвестрации углерода, снижения деградации почв и развития устойчивого сельского хозяйства.

Ключевые слова: биоуголь, почвенный углерод, секвестрация углерода, смягчение изменения климата, пиролиз, выбросы парниковых газов, плодородие почвы, устойчивое сельское хозяйство.

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Introduction

According to the latest Intergovernmental Panel on Climate Change (IPCC) assessment report, human activities have caused a considerable increase in greenhouse gases (GHG) emissions to the atmosphere with the carbon dioxide (CO_2) concentration reaching up to 422 ppm in 2024. It is predicted that the concentration of CO_2 in the atmosphere will reach to 600–700 ppm by the end of this century, if no concrete actions are taken to reduce their emissions at the global level [1]. Thus, in recent years, significant efforts have been made worldwide to develop novel strategies to reduce GHG emissions/carbon footprints to combat global warming, control climate change and protect the planet. In recent years, biomass-derived carbon materials (e.g., biochar) are receiving much attention as they can provide a nature-based green solution to enhance the carbon sequestration capacity of soil and thus the mitigation of climate change.

Materials and Methods

This study was based on a literature review of the role of biochar in soil carbon sequestration and climate change mitigation. Scientific publications addressing biochar production from plant biomass, carbon stability, soil organic carbon (SOC) interactions, and greenhouse gas emissions were analyzed. Particular attention was given to the effects of feedstock type, carbon-to-nitrogen (C/N) ratio, and pyrolysis conditions on biochar properties and its potential for long-term carbon storage. The selected studies were compared to identify the mechanisms through which biochar may influence soil carbon dynamics and CO_2 emissions. The analysis was based on previously published findings, and no new laboratory or field experiments were conducted [1,2].

Results

The literature analysis showed that biochar application can increase soil carbon sequestration by an average of 61% (95% confidence interval: 36–90%) [1]. Biochar can also improve soil porosity, water retention, and nutrient availability [3]. Its carbon stability depends on feedstock type, pyrolysis temperature, and soil conditions [4]. However, its effects on greenhouse gas emissions vary depending on environmental conditions. Overall, biochar is a promising approach to long-term soil carbon storage and sustainable agriculture.

Discussion

Biochar can enhance soil carbon sequestration by influencing microbial activity and nutrient cycling. It may promote beneficial bacteria such as *Bacillus* and *Pseudomonas*, which contribute to nutrient availability and organic matter transformation. Nitrogen-fixing bacteria, including *Rhizobium* and *Azotobacter*, may also respond positively to biochar application under suitable soil conditions. However, these effects depend on biochar properties, soil pH, moisture, and application rate. Therefore, biochar selection should consider both carbon stability and its effects on soil microbial communities to support sustainable agriculture and climate change mitigation.

Overall, the interplay between soil, climate and biochar characteristics drives its weathering and weathering dynamics. Soil pH, mineralogy, redox potential, microbial activity, and organic matter content collectively control biochar stability and functionality in soil systems which are in the meantime driven by climate conditions. As a result, a comprehensive understanding of these processes and their interaction would facilitate optimized biochar applications for sustainable soil management [4]. In addition to increasing the amount of organic carbon in the soil, BC amendments alter the soil's porosity, cation exchange capacity, and redox potential. On the contrary, research has demonstrated that the introduction of BC can enhance both soil biochemistry and plant physiology in the presence of abiotic stressors. The longevity of BC's effects on soil quality and its role in carbon sequestration also make it a strategic tool for environmental applications. It assists in creating a long-lasting positive impact on soil health and has the potential to store carbon for thousands of years, contributing to climate change mitigation efforts [5].

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