Biochar Utilization

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Contributor: Carlos Rodriguez Franco, Deborah S. Page-Dumroese, Derek Pierson, Timothy Nicosia

Carbon (C) in gaseous form is a component of several greenhouse gases emitted during the combustion of fossil fuels. C movement between the atmosphere, land (biosphere and lithosphere), and ocean (hydrosphere) alters the total amount in each pool. Human activities accelerate C movement into the atmosphere, causing increases in temperature.

Keywords: carbon ; climate change ; sequestration

1. Introduction

Carbon (C) is one of the most common elements in the universe and on Earth, is the fourth most abundant element by mass, and is the basic building block of humans, animals, plants, and soils [1]. Carbon abundance in organic compounds and polymers makes it the chemical foundation of all life. There are one million organic compounds containing only C and hydrogen (H). When a C atom combines with two oxygen (O) atoms, it forms carbon dioxide (CO_2), one of the greenhouse gases (GHGs) causing warming on Earth and influencing climate change [2]. Carbon dioxide is one of the anthropogenic GHG emissions responsible for increased temperatures that influence climate change on Earth [3].

There is widespread recognition of climate change and its impacts on humans, plants, and animals. Increasing temperatures are linked to extreme environmental disturbances all over the world, such as extreme droughts, hurricanes, snowstorms, and intense precipitation, among others. These disturbances cause environmental imbalances in forest ecosystems affecting their health, vigor, and productivity. Forest consequences are manifested as widespread or prolonged insect and disease attacks, high tree mortality, and increases in extreme wildland fires, with further negative effects on the soil, ecosystem services (e.g., erosion and water storage), and rural communities. Further, changes in precipitation patterns may decrease soil organic C (SOC) pools, structural integrity, and nutrient cycles, with adverse impacts on biomass productivity, biodiversity, and the environment [4].

The International Paris Agreement (2015) seeks to limit the increase in average global temperature to 2 °C, with efforts to limit the increase to 1.5 °C. Controlling and mitigating CO_2 emissions are a priority for sustainability and global economic development, but also for sustainable natural resources. Forests and soils provide climate forcing feedback [5] that helps move C from atmospheric to terrestrial pools. However, there is a societal lack of awareness about the importance of C, its role in climate change, and the need to decrease atmospheric C. Although awareness about the impacts of climate change on urban populations is increasing, there are many people who do not fully understand the impacts caused by increased temperatures. Notwithstanding these misunderstandings, leaders representing a majority of countries have recognized the urgency of taking action to limit global temperature increases. This is the goal of the agreement signed by 196 countries at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. However, to limit global warming to 1.5 °C, GHG emissions must reach their highest value before 2025 and begin to decline by 43% until 2030 [6].

2. Biochar from Low-Value Woody Residues

Large amounts of charcoal remain in soils today as relics from indigenous burning or past wildfires. It is estimated that the total C storage of charcoal in soil is as high as 250 Mg C ha^{-1} m^{-1} compared to typical values of 100 Mg C ha^{-1} m^{-1} in Amazonian soils derived from similar parent material [7]. Globally, up to 12% of anthropogenic C emissions (0.21 Pg C) can be offset annually in soil if slash-and-burn agriculture is replaced by slash-and-char methods, and it is estimated that by 2100, this change from burning to charring could increase C sequestration to between 5.5 and 9.5 Pg C yr^{-1} [8]. Further, adding biochar to soils can result in global CO_2 removal, with the potential to remove 6.23 ± 0.24% of total GHG emissions in the 155 countries studied over a 100-year timeframe (base year 2020) [9]. The authors also pointed out that biochar could remove more than 10% of national emissions in 28 countries.

Biochar applications to forest soils are a rapid method to increase soil C and mitigate atmospheric GHGs, particularly CO_2. This, combined with sustainable harvesting, is a path toward for climate-smart forest operations. In addition to biochar increasing C sequestration when combined with sustainable biomass production, this can be a C-negative opportunity and therefore used to actively remove CO_2 from the atmosphere, with potentially major implications to mitigate climate change [10][11][12][13][14]. Biochar is a C-rich material formed through thermal decomposition of biomass at high temperature (<700 °C) under reduced oxygen conditions [9][15][16]. When producing biochar from organic materials, the proportion of the amount of biomass transformed into carbon as total solid carbon in biochar varies from approximately

5% when using gasification technologies to approximately 35% when using slow pyrolysis technologies [17]. When added to the soil, biochar remains relatively stable for an extended period of time [18] when determined by the oxygen O/C ratio. When the O/C is lower than 0.2, then the biochar half-life is approximately 1000 years [19]. Biochar longevity is a result of a large proportion of condensed aromatic C [20].

Biochar is particularly well suited for improving degraded soils and improving ecosystem services. However, knowledge of biochar and soil properties is critical for developing application rates that affect plant productivity [21]. Biochar can improve soil physical, chemical, and biological properties while also reducing soil GHG emissions and subsequently stabilizing C pools [10][22][23].

Biochar also has potential applications in waste management, renewable energy, C sequestration, GHG emission reduction, and soil and water remediation, but its best use in forestry is in the potential for enhancing soil health and C sequestration. Place-based biochar production and its use on local degraded soils is one strategy that, when combined with various silvicultural treatments, can restore a variety of ecosystem services, in addition to building the soil C stock [11]. Biochar can improve water quality, bind heavy metals, decrease toxic chemical concentrations, and improve soil health to establish sustainable plant cover that results in less soil erosion, leaching, or other unintended, negative environmental impacts [12]. In addition to applying untreated biochar to degraded soils, there has been efforts made to design biochar tailored for specific environmental hazards. For example, to increase the adsorption capacity of biochar, a bimetal-doped biochar was created as an absorbent to better remove Hg from contaminated substrates [13].

During all forest harvest operations, there is a large volume of non-merchantable woody residues that are generally left in a pile and burned. Burning these piles also creates smoke, releases CO_2 into the atmosphere, can cause long-term damage to the soil, and can effectively eliminate forest vegetation production in that area. However, the production of biochar from the non-merchantable woody residues can occur at a variety of scales that range from small-scale conservation burns to fixed bioenergy facilities. Other C sequestration opportunities for both merchantable and non-merchantable woody biomass include combining bioenergy production with C capture and sequestration, which can lead to net negative emissions as the C stored in photosynthesizing biomass is sequestered rather than released into the atmosphere [24].

In summary, depending on the method used to create biochar, technologies exist to generate heat, create negative C emissions, and sequester C. Biological C sequestration can be achieved through changes in forest practices such as afforestation, the application of biochar to soil, and the combination of biochar and bioenergy production with C capture and storage, where biochar has a moderate potential for delivering negative emissions which are estimated to be about 0.7 Gt of C_e per year [25]. In addition to the potential soil benefits of biochar, other co-products of combustions, such as bio-oil and biogas, can provide climate change mitigation benefits.

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