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Biochar: A Soil Enhancer and Carbon Sequestration Tool

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SUMMARY

Biochar is a finely grained solid substance obtained from the carbonisation of any kind of biomass. Biochar is a carbon-rich substance that is prepared by heating the biomass at high temperatures (400-700℃) in full or partial absence of oxygen. It can be used as a soil amendment and/or conditioner which, when added to soil, improves the physical, chemical, biological as well as nutritive properties of soil. However, it is not a fertiliser or any source of plant nutrients thus it should not be used as an alternative to fertilisers. Still, the biochar used in soil is considered fertile as it mobilises the nutrients present in the soil. Simply, biochar is a kind of finely grained black coloured charcoal made up of plant parts. The use of ashes and coal in traditional agriculture has been prevalent since the ancient period. However, the importance of biochar in improving soil quality is being understood nowadays. Also, biochar is found in soils where vegetation is being burnt and in areas where slash and burn for agriculture and livelihood had been practised. Biochar is generally produced from the pyrolysis of any kind of waste biomass like rice husk, plant parts, branches, woods, sawdust, bones, sugarcane bi-product, fallen tree leaves, weeds, straw, grasses etc. Biochar is a product that has multiple uses in many sectors. But, mainly, biochar is produced as a soil amendment to improve the quality and productivity of the soil.

INTRODUCTION

The term *biochar* is relatively new in Nepalese agriculture. While biochar originated as a method for carbon sequestration and reducing greenhouse gas emissions, its significance for agriculture was recognised later. Over the years, many research programs have been conducted to explore the importance and utility of biochar in agriculture. Biochar is a finely grained, solid substance produced by the carbonization of various types of biomass. Carbon (C), one of the most abundant chemical elements on Earth, plays a crucial role in nutrient cycling and the functioning of soil ecosystems. Soil carbon is the largest component of the terrestrial pool in the global carbon cycle. Plants capture carbon from the atmosphere through photosynthesis, converting solar energy into carbon-rich biomass (also known as organic matter). When this biomass dies, it is decomposed by soil organisms that consume the carbon-rich material, releasing most of it back into the atmosphere as carbon dioxide. However, a small portion of the carbon is transformed into more stable forms within the organisms. The carbon is released back into the soil upon the death and decomposition of these organisms. Biochar is produced by heating biomass at high temperatures (400–700°C) in the absence or limited presence of oxygen, a process known as pyrolysis. This results in a carbon-rich, stable organic compound. Alternatively, biochar can be created using a process called hydrothermal carbonization, which involves heating biomass in hot compressed water (Kambo & Dutta, 2015). Biochar is typically made from a variety of waste biomass, such as rice husks, plant parts, branches, sawdust, bones, sugarcane by-products, fallen tree leaves, weeds, straw, and grasses, with about one-third of the material used for its production being biomass (Vista et al., 2016), the yield of biochar is much smaller than the raw material used. This makes the scientific application of biochar crucial—not only to maximize its benefits but also to ensure its economic viability and contribute to soil improvement. Therefore, applying the appropriate amount of biochar is essential to avoid wastage and achieve the best results.

While biochar is not a new concept in modern agricultural practices in Nepal, its use dates back to ancient agricultural traditions. The practice of applying ashes and coal to improve soil fertility has been common for centuries. However, the significance of biochar in enhancing soil quality is now becoming more widely recognized. Biochar's primary function is as a soil amendment that improves soil structure, increases biodiversity, and enhances the retention of water and nutrients, making them more available to plants. Additionally, biochar's ability to hold carbon makes it a promising tool for carbon sequestration, helping to mitigate climate change. Combining biochar with nutrient amendments, such as farmyard manure (FYM) and other fertilizers, has shown synergistic effects, boosting plant productivity beyond what is achievable with either biochar or fertilizers alone.

Many countries are already utilizing biochar in combination with organic and inorganic fertilizers to improve soil health and agricultural productivity. Biochar is alkaline, with a high carbon content and a low nitrogen content (less than 0.2 mg kg^{-1}), resulting in a C/N ratio of approximately 38.2. Its ability to retain and slowly release nutrients, improve soil texture, and sequester carbon, makes it a highly valuable resource for sustainable agriculture and environmental management.

Impact of Biochar on Soil Type and Nutrient Status

The effect of biochar on soil nutrient status is influenced by both the characteristics of the soil and the properties of the biochar used. Research has shown that biochars can vary significantly in their properties, particularly in terms of nutrient content. These variations highlight the importance of selecting the appropriate biochar for specific soil types to achieve optimal results. Based on these research findings, it is recommended to prepare and apply biochar as a strategy for enhancing soil fertility and productivity. Additionally, it is suggested that farmers be trained on the preparation and application of biochar. This capacity-building initiative would empower farmers to produce their own biochar, ensuring greater sustainability and cost-effectiveness in soil management practices. Biochar should not be used as a direct fertilizer. Instead, it should be applied as a catalyst and blended with other fertilizers and manures to help mobilize nutrients in the soil more effectively. Farmers should avoid excessive application of biochar. The recommended dosage is 30 tons per hectare. Even a lower dose of biochar can have beneficial effects compared to no application at all. Over use of biochar can lead to issues such as soil alkalinity and nutrient immobilization, making these nutrients unavailable to plants. This can hinder the optimal utilization of biochar and other resources.

Effect of Various Doses of Biochar on Changes in Soil Properties

S.No	Soil Property	Change
1.	Soil pH	Biochar increases soil pH, improving soil reaction. It can be used to remediate soil acidity in most acidic soils, providing a partial amelioration of soil acidity.
2.	Total Nitrogen	The total nitrogen content in the soil decreases during the first 2-3 weeks after biochar application
3.	Exchangeable Ammonium	The application of biochar leads to a decrease in the exchangeable ammonium levels in the soil.
4.	Available Phosphorus	Biochar application has no significant effect on the dynamics of phosphorus availability in the soil (Quilliam et al., 2012).
5.	Available Potassium	The addition of biochar increases the available potassium content, with higher doses leading to greater increases in potassium levels.
6.	Earthworms and Biota	Biochar can have a negative impact on soil biota, particularly earthworms. High doses of biochar, especially that produced from poultry manure, resulted in 100% mortality of *Eisenia fetida* (Liesch et al., 2010).

Reasons for Biochar Use

S.No	Reason	Uses
1.	Reducing Requirements for Other Inputs	Biochar can reduce the need for conventional fertilizers and other agricultural inputs by enhancing soil fertility and nutrient retention. This objective focuses on minimizing input costs, but does not require concerns over biochar's carbon sequestration potential.
2.	Sequestering Carbon	Biochar can play a role in mitigating climate change by sequestering carbon in the soil, reducing atmospheric greenhouse gas concentrations. Users who prioritize carbon sequestration will consider the long-term benefits and risks related to biochar's carbon retention ability. For these users, risks associated with long-term carbon storage and environmental impacts are significant.
3.	Increasing Crop Yields	Biochar can help address specific soil constraints (e.g., poor soil structure, acidity, or compaction), thereby boosting crop productivity. If used to improve soil quality, biochar helps optimize conditions for plant growth by improving aeration, water retention, and nutrient availability
4.	Improving	Biochar may improve the quality of crops by enhancing nutrient uptake, which can

	Crop Quality	lead to better protein content or other desired traits. For example, biochar's effects on soil pH and nutrient availability can help improve crop performance, especially where soils are deficient in essential nutrients.
5.	Soil Remediation	Biochar is increasingly being used to remediate contaminated soils, such as those affected by heavy metals or organic pollutants. It can help to adsorb contaminants and reduce their bioavailability, which in turn improves soil health and ecosystem function.
6.	**Enhancing Soil Properties**	Biochar can improve the physical properties of soil, such as reducing bulk density and improving soil structure. This is especially useful for improving transport efficiency of soil, making it easier to handle or even improving soil aesthetics by giving it a darker, richer color.

Carbon Sequestration Potential

There is limited research on the long-term carbon sequestration potential of organic amendments, except for manures and biosolids. A recent review suggests that approximately 45% of the carbon applied in compost is retained in the soil over 20 years, with the percentage dropping to 10% over 100 years. The actual sequestration value is influenced by the quantity and frequency of amendments applied, as well as climate and soil conditions. Despite the limited research, the review indicates that compost can help mitigate greenhouse gas emissions by reducing emissions, capturing atmospheric carbon, and preventing further emissions. The production of carbon-rich amendments like biochar typically involves harvesting carbon sources from one area, processing them into amendments, and applying them to another area. This redistribution of carbon can lead to a loss of soil organic carbon in the first area. Therefore, life cycle assessments are increasingly being used to evaluate the net benefit of carbon-rich amendments, considering their full environmental impact.

Potential Risks Associated with Biochar Products

Biochar offers a variety of benefits, but it is essential for early adopters to be aware of potential risks associated with its production and application. These risks need to be carefully managed to avoid negative impacts on the environment, health, safety, and finances (productivity).The risks associated with biochar can be broken down into several stages throughout its life cycle, each of which must be carefully considered: Risk factors include:

Biomass Sourced for Feedstock		
1.	Contamination	Biomass may contain harmful chemicals or heavy metals (e.g., from polluted sites) that could be released during pyrolysis and subsequently impact soil, plants, or human health.
2.	Sustainability	Over-harvesting biomass (e.g., deforestation) can negatively affect the environment and biodiversity.
3.	Greenhouse Gas Emissions	If the biomass is not sourced sustainably, it may contribute to increased carbon emissions, undermining the potential carbon sequestration benefits of biochar.
Production System		
1.	Emissions	During the pyrolysis process, gases such as carbon monoxide, volatile organic compounds (VOCs), and particulate matter may be released, potentially contributing to air pollution if not properly controlled
2.	Energy Use	Some biochar production methods require significant energy inputs. If non-renewable energy sources are used, the process may contribute to greenhouse gas emissions rather than reducing them.
3.	Safety Risks	The high temperatures required for pyrolysis present fire and burn hazards. Inadequate safety measures can lead to accidents.
Quality of Biochar Product		
1.	Inconsistent Properties	The quality of biochar can vary greatly, leading to unpredictable effects on soil. For example, biochar with a high pH may exacerbate soil alkalinity, negatively impacting plant growth in acid-loving crops.
2.	Toxicity	Poorly produced biochar or biochar derived from contaminated feedstocks may release toxic compounds, including heavy metals or polycyclic

		aromatic hydrocarbons (PAHs), which could harm plants, soil organisms, or humans
Application Method of Biochar		
1.	Over-application	Applying too much biochar can alter soil pH and nutrient availability, leading to negative effects on plant health and productivity. Excessive biochar may also cause nutrient lock-up, making some nutrients unavailable to plants.
2.	Improper Mixing	If biochar is not evenly incorporated into the soil, it may lead to localized changes in soil properties, causing uneven plant growth.
3.	Soil Disruption	Incorrect application methods may disrupt soil structure or lead to the biochar being washed away by rain.
Impact of Biochar Once Applied		
1.	Soil Alkalinity	Biochar is often alkaline, and when applied in high amounts, it can increase soil pH, which may not be desirable for certain crops, particularly those that thrive in acidic soils.
2.	Nutrient Imbalance	Biochar's influence on nutrient cycling can be complex. It may affect nutrient retention and availability, potentially leading to imbalances in the soil that can harm crops if not managed properly.
3.	Impact on Soil Organisms	High doses of biochar could harm beneficial soil microorganisms and fauna, such as earthworms, particularly if it is produced from certain feedstocks like poultry manure.
Long-Term Fate of Biochar Once Applied		
1.	Carbon Sequestration	While biochar can sequester carbon in the soil for extended periods, its long-term sequestration potential can vary depending on the soil type and environmental conditions. Improper application or low-quality biochar may reduce its effectiveness in capturing and storing carbon.
2.	Leaching of Contaminants	Over time, biochar may release heavy metals or other contaminants into the soil, especially if it was produced from contaminated feedstocks. This could have long-term negative effects on soil health and the environment
Risks to Productivity and Financial Viability		
1.	Decreased Soil Productivity	There is a possibility that biochar may not result in the expected productivity increases, or it could even decrease production capacity, particularly if its application is not well-targeted. The cost of biochar production and application must be justified by the benefits it provides to soil and crop yields
2.	Soil Constraints	To reduce the risk of ineffective use, it is essential to target biochar applications towards specific soil constraints that affect crop growth. For example, if a soil suffers from waterlogging and biochar is proven to improve the hydrology of heavy soils, the application could enhance productivity. However, if there is no existing constraint, biochar application may not provide any tangible benefits. Furthermore, other soil amendments that address the same constraint should be considered to determine the most cost-effective solution.
3.	Pesticide Efficacy	Biochar can sometimes reduce the effectiveness of certain pesticides and herbicides. This occurs because biochar can bind to the active ingredients in these chemicals, rendering them less available and thus reducing their effectiveness. This is an important consideration for growers using biochar in conjunction with chemical pest control strategies
4.	Water Repellence	If biochar becomes dry, it can become hydrophobic, meaning it repels water. Dry biochar may float on water, which could pose a risk to soil hydrology if it is applied as a thick blanket. In such cases, it could prevent water from reaching the root zone of plants. However, once biochar absorbs water into its pores, it typically sinks and improves water retention in the soil, helping to maintain moisture for longer periods.

5.	Toxic Effects	If the biochar contains contaminants that negatively affect seed germination or plant growth.
6.	Unfavourable Soil Characteristics	Biochar can alter soil pH, and if it makes the soil too alkaline, it could harm plant growth.
7.	Exacerbation of Existing Problems	In some cases, biochar may worsen existing issues in the soil rather than addressing them
8.	Water Repellence	As mentioned, dry biochar could prevent water from reaching plants' roots.
9.	Chemical treatments	Reduced Effectiveness of Herbicides/Pesticides

CONCLUSION

While biochar can offer a wide range of benefits, it is essential to carefully manage the associated risks. By understanding the various stages of biochar production and application, early adopters can take appropriate action to minimize negative impacts on the environment, health, safety, and finances. Identifying specific goals and applying biochar with the correct methods can help ensure positive outcomes while avoiding potential risks.

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