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Applications of Biochar Derived from Biomass Pyrolysis in Agriculture

Mini Review

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Author Details

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Abstract

Biochar is a carbon-rich substance that is produced through the process of pyrolysis of biomass. The process of adding biochar to the soil is becoming popular in the practice of modern farming. Biochar improves the physical properties of the soil as well as the water retention capacity of the soil. Moreover, it is a major source of vital inorganic compounds such as calcium (Ca), potassium (K), and phosphorus (P). These compounds are vital in the fertility and nutritional value of plants. Biochar is also a major tool in the process of carbon sequestration that aims to reduce the adverse effects on the environment. The effectiveness of biochar is dependent upon the process of pyrolysis, the type of biochar, and the soil type.

Keywords: Biochar, Pyrolysis, biomass, soil amendment, Agriculture.

Graphical Abstract

(Figure 1)

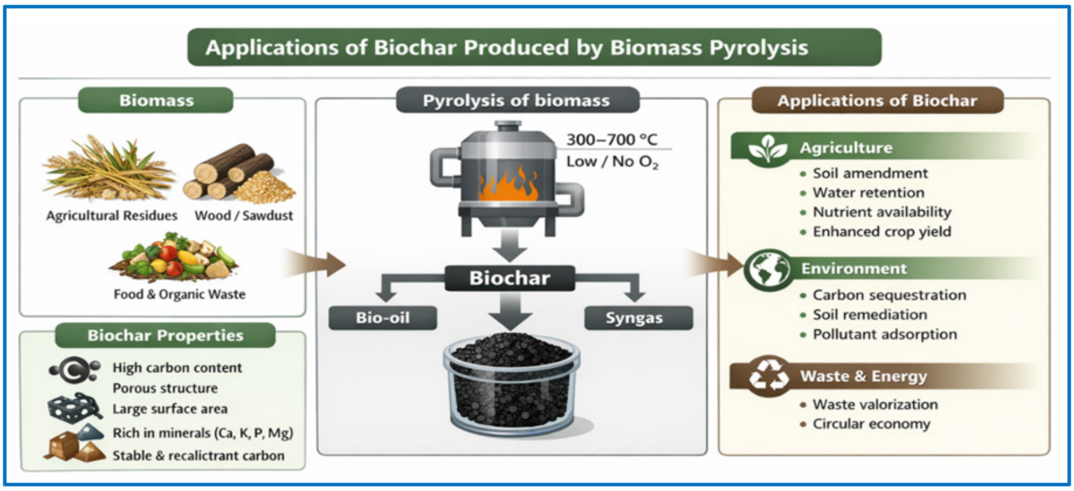

Figure 1: Graphical Abstract.

Introduction

The degradation of agricultural soils, the decline in their fertility, and the increase in environmental constraints linked to climate change are now major challenges for global agriculture [1]. The intensification of farming practices and the prolonged use of chemical inputs have contributed to the depletion of soil organic matter, affecting soil structure, water retention capacity, and biological functioning [2]. In this context, identifying sustainable and effective soil amendments is essential to ensuring agricultural productivity while limiting environmental impacts.

Biochar, a carbonaceous material obtained by pyrolysis of biomass in an oxygen-poor atmosphere, is increasingly being studied as an agricultural soil amendment [3]. Thanks to its porous structure, high chemical stability, and ability to interact with soil nutrients and microorganisms, biochar can improve the physical and chemical properties of soils while promoting the availability of nutrients for plants [4,5]. Furthermore, the production of biochar from agricultural and forestry residues is part of a circular economy approach and the valorisation of organic waste [6].

Beyond its agronomic effects, biochar is of particular interest for long-term carbon sequestration, potentially contributing to the reduction of greenhouse gas emissions [7]. However, the effectiveness of biochar depends heavily on the biomass used, the pyrolysis conditions, and the characteristics of the soil [8,9]. This mini review aims to summarize recent advances in the production, properties, and agricultural applications of biochar, while discussing its limitations and prospects for sustainable agriculture.

Production and Characteristics of Biochar Produced by Biomass Pyrolysis

Biochar production is based on pyrolysis, a process of heating biomass in the absence (or near absence) of oxygen [10]. Key parameters include temperature, residence time, and the type of biomass used [9]. In general, slow pyrolysis between 400°C and 600°C is considered optimal for producing biochar with favorable properties for soils, including a high specific surface area and porous structure [9,11].

The types of biomasses used to produce biochar are very varied: agricultural residues (rice straw, corn, wheat), forestry waste, animal manure, or urban residues [12]. Each raw material influences the final composition of biochar, particularly its nutrient content, such as calcium (Ca), potassium (K), phosphorus (P), and magnesium (Mg) [13,14].

The composition of inorganic elements depends heavily on the initial biomass: for example, biochar's derived from animal manure tend to contain more essential nutrients (NPK), while those derived from forest residues may have a high stable carbon content [15].

Applications of Biochar in Agriculture

Effects of Biochar on soil properties

The application of biochar modifies soil structure by increasing its porosity and reducing its bulk density, which improves aeration and water retention. This improvement is particularly evident in sandy soils or soils poor in organic matter, where biochar can significantly increase water retention capacity [2]. Another important effect is the change in pH and cation exchange capacity (CEC). Many biochars have a higher pH than the original soil, which can reduce the acidity of acidic soils and improve the availability of certain nutrients. However, excessive applications can sometimes raise the pH beyond optimal levels for certain crops [16].

The interaction between biochar and soil nutrients is also critical. Biochar can increase nutrient retention, reduce nutrient leaching and increase nutrient availability to plants [13]. According to a global meta-analysis, biochar improves levels of organic carbon, total nitrogen (TN), and other soil quality parameters, which is associated with better agronomic performance [17].

Biochar and plant nutrition

Biochar can play a direct role in plant nutrition by influencing the availability of macro- and micronutrients. For example, biochar's rich in phosphorus or potassium can help supply these essential elements, especially in deficient soils. In addition, by increasing nutrient retention and CEC, biochar helps reduce losses through leaching [18].

Impact on crop growth and yield

Various studies and meta-analyses indicate that applying biochar improves crop yields in many contexts. For example, a comprehensive analysis showed that biochar is particularly effective in low-fertility soils, increasing the yield of many crops (corn, vegetables) by improving soil properties and plant nutrition [19]. However, the effect of biochar on plant growth varies depending on soil type, biochar type, and climatic conditions. In some situations, less obvious or variable results have been reported, highlighting the importance of choosing the right biochar (feedstock and pyrolysis conditions) for each specific agronomic context [7,19].

The Role of biochar in Agricultural Sustainability

One of the major benefits of biochar is its potential for carbon sequestration in soils. Unlike organic matter, which decomposes quickly, the carbon in biochar is very stable and can persist for centuries, thereby helping to reduce the amount of CO_2 in the atmosphere [20]. Some estimates indicate that biochar can store carbon for hundreds to over a thousand years [3]. In addition to carbon sequestration, the application of biochar also influences greenhouse gas (GHG) emissions from soils. Recent studies show that, in the long term, biochar can reduce emissions of methane (CH_4) and nitrous oxide (N_2O), two powerful greenhouse gases linked to fertilization and soil processes [17].

The integration of biochar into agricultural systems is also part of a circular economy approach, as it makes use of agricultural residues and other organic waste to produce a useful soil amendment, thereby reducing external inputs while improving the sustainability of cropping systems.

Limitations, Constraints, and Future Prospects

Despite its many potential benefits, the use of biochar in agriculture presents significant constraints. On the one hand, agronomic effects vary depending on soil types, crops, and the biochar used. It is therefore crucial to adapt biochar choices to local conditions. On the other hand, economic and technical constraints still hinder the widespread adoption of biochar. Large-scale production requires specialized equipment and rigorous pyrolysis management to ensure consistent product quality. In addition, initial costs can be high for small farmers without financial support or incentives.

Looking ahead, further research is needed on optimizing production conditions, long-term assessment of crop effects, and the development of integrated strategies combining biochar and fertilization.

Conclusion

Biochar produced by pyrolysis is a promising strategy for enhancing agricultural sustainability. Its unique properties, such as soil improvement, increased water and nutrient retention, and support for plant growth, make it a relevant amendment in many agronomic contexts. Furthermore, its potential role in carbon sequestration and reducing

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greenhouse gas emissions reinforces its appeal for sustainable agricultural systems. Nevertheless, further research is needed to optimize its use in a variety of conditions.

Conflicts of Interest

The author declares no conflicts of interest.

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