**APPLICATION TECHNIQUES OF BIOCHAR IN AGRICULTURAL LAND**

**Enriching Biochar through Nutrient Infusion or Addition of Biofertilizers**

Biochar improves soil fertility by improving its physical, chemical, and biological structure. However, its nutrient content is inherently low. Typically, the levels of nitrogen (N), phosphorus (P), and potassium (K) in biochar are less than 1%, significantly lower than the minimum nutrient requirement for fertilizers, which must contain at least 5% nutrients. Thus, while biochar can support soil fertility, it cannot replace fertilizers that are essential to meet the nutritional demands of plants directly.

To enhance the benefits of biochar, adding nutrients plants require to the biochar is essential. This process, known as enrichment, aims to improve biochar's ability to store and provide essential nutrients, promoting healthier plant growth. Enrichment can be achieved by mixing biochar with organic fertilizers, chemical fertilizers, or biofertilizers such as decomposing microbes and nitrogen-fixing bacteria. Once enriched, biochar absorbs and retains water and serves as a nutrient source for plants. Enriched biochar helps to improve soil fertility, increase nutrient availability, and restore poor or degraded soils. This enrichment process also supports sustainable and environmentally friendly agricultural practices.

Biochar enrichment has been implemented in various ways globally to enhance soil fertility. Farmers in Brazil mix biochar with manure and compost to improve acidic tropical soils, significantly increasing maize and soybean yields. In India, biochar is enriched with biofertilizers such as phosphate-solubilizing microbes to enhance arid soils, which has proven effective in boosting the productivity of legume crops. In Japan, biochar is soaked in nitrogen fertilizer solutions before application, significantly improving rice yields in paddy fields. Meanwhile, in sub-Saharan Africa, biochar is combined with plant ash and agricultural waste to rehabilitate marginal soils, leading to better growth and higher sorghum and millet yields. These approaches demonstrate that biochar enrichment can be tailored to the specific needs of soils and crops in different regions, supporting more productive and sustainable agriculture.

**Biochar Application Guidelines: Dosage, Timing, and Application Techniques**

The dosage of biochar application on agricultural land depends on soil conditions, the kind of crops being grown, and its intended purpose. The recommended dosage ranges from 5 to 20 tons of biochar per hectare to achieve significant results. Degraded or poor soils require a higher dosage, around 15 to 20 tons per hectare. A dosage of 5 to 10 tons per hectare is sufficient for sufficiently fertile soils to enhance fertilizer use efficiency and support soil microorganism diversity. In addition to soil conditions, the dosage of biochar application also depends on the cultivated crop type. Vegetable or food crops require more nutrients and thus need higher doses, while forest or woody plants require lower doses.

The right timing for biochar application depends on the type of crop and the farming system used. Biochar should be applied before the planting season begins for food crops such as rice, corn, or sorghum. It is mixed into the soil during land preparation, allowing the nutrients to integrate with the soil and support plant growth from the start of the planting season. For horticultural crops like vegetables or fruits, biochar can be applied either before or during the planting process. Gradual application of biochar throughout the growing season can also be done to support sustainable plant growth.

For perennial crops such as coffee, oil palm, or cacao, the best time to apply biochar is during land preparation or the initial planting stage when the seedlings are planted. At this stage, biochar can be mixed with the soil around the planting hole or added to the seedling growth medium to improve soil structure, water retention, and nutrient availability. Biochar can be applied around the base of the plants (root zone) before the rainy season begins in plantations that are already producing. It allows the biochar to absorb rainwater and improve the soil more effectively. Applying biochar after pruning for land with declining fertility is also very beneficial to enhance soil regeneration. This approach supports the sustainable productivity of plantations by gradually improving soil quality.

The application techniques for biochar in agricultural land are diverse and can be tailored to the crop type and the farming system. One commonly used technique is mixing biochar with soil during land preparation. Biochar can be evenly spread over the soil surface and then incorporated by plowing or loosening the soil with a hoe, allowing it to integrate into the soil layers where plant roots grow. In irrigated farming systems, biochar can be applied by mixing it into planting holes or irrigation furrows before water is channeled. This method ensures that biochar is placed directly in the plant root zone, making it more effective in supporting plant growth. Biochar can be mixed directly into the growing medium for horticultural crops using raised beds or polybags. On plantations with perennial crops such as coffee, oil palm, or cacao, biochar is applied around the active root zone (under the plant canopy). Biochar is mixed with soil or fertilizer and placed in small holes or trenches made around the plant's stem. After filling these holes with biochar, they are covered with soil to prevent the biochar from being washed away by surface runoff.

**Effectiveness of Biochar Compared to Other Soil Amendments**

Soil amendments are materials used to improve soil quality, making it more fertile and supporting plant growth. These amendments improve soil structure, enhance water retention capacity, and balance nutrients within the soil. Using soil amendments is particularly important on degraded or infertile land due to erosion, excessive chemical use, or drought. Soil amendments can be organic or inorganic. Common organic amendments include manure, compost, and biochar. Dolomite lime is the most commonly used inorganic amendment in agricultural land, which helps neutralize soil acidity. By using soil amendments, farmers can improve land productivity sustainably while maintaining soil health for the long term.

Compared to other organic soil amendments, biochar has several advantages, including its ability to persist in the soil for a long time, its micro-porous structure that can absorb and retain water and nutrients more effectively, and its provision of living spaces for soil microorganisms. Biochar is a chemically stable material due to its pyrolysis production process, resulting in a carbon structure resistant to microbial decomposition. Unlike organic materials such as compost or manure, which decompose within months to years, biochar can remain intact for hundreds of years, maintaining soil structure in the long term. Pores in biochar allow it to function like a sponge, absorbing and storing large amounts of water, air, and nutrients. While organic amendments like compost or manure also improve soil structure, they tend to be denser and have fewer pores than biochar. The pores in biochar provide an ideal habitat for soil microorganisms, which play a crucial role in nutrient cycling and soil health. Additionally, these pores help reduce nutrient leaching by rainfall, ensuring that nutrients remain available to plants for longer periods.

Compared to dolomitic lime, biochar also offers several advantages. Dolomitic lime is typically used to reduce soil acidity, but its benefits are temporary and limited to pH adjustment. In contrast, biochar helps neutralize acidic soils, improves soil structure, enhances water retention, and provides a habitat for beneficial soil microorganisms. Additionally, biochar can retain nutrients for longer periods, ensuring that plants have a steady supply of nutrients. Unlike dolomitic lime, biochar also helps store carbon, which is beneficial for mitigating the effects of climate change. With its broader and more lasting benefits, biochar is a better choice for comprehensive soil improvement.

**Future Prospects of Biochar in Sustainable Agriculture**

Sustainable agriculture focuses on maintaining soil fertility so crop yields remain high and farming activities can continue in the long term. In sustainable farming, soil fertility is preserved through practices such as crop rotation, the use of organic fertilizers, and simple technologies like biochar or bio-based fertilizers. These practices help keep the soil fertile, prevent degradation, combat erosion, and reduce excessive use of chemical inputs. With fertile soil, farmers can achieve stable harvests each season while protecting the environment. Such agricultural practices are crucial to ensure that, in the future, farmers can continue to farm optimally, even when faced with challenges like climate change or the growing demand for food.

Biochar is one of the promising simple technologies for sustainable agriculture. It offers numerous benefits for soil health, crop yield improvement, and environmental preservation. Currently, many agricultural lands worldwide have experienced degradation due to various factors such as unsustainable farming practices, soil erosion, excessive chemical use, and climate change. These lands have lost their fertility, leading to a significant decrease in agricultural productivity. In Asia, excessive chemical fertilizer use has resulted in hardening and infertility of the soil. In Africa, soil erosion caused by heavy rains and strong winds has damaged the fertile topsoil. In South America, deforestation for agricultural purposes has led to degraded, barren lands that are no longer productive. These conditions directly affect the livelihoods of farmers who rely on the land for sustenance while also threatening global food security. Efforts to restore degraded lands are crucial to ensure the sustainability of agriculture and meet the ever-growing food demands of the future.