Potential Use of Biochar-Based Fertilizer in Fruit Orchards

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Agricultural production, hunger, poverty, and sustainability possess a strong linkage, the incidence of poverty tends to be higher in agricultural and rural populations than elsewhere. The majority of the world's impoverished farmers reside in rural areas. Compared to metropolitan regions, these areas have higher rates of child malnutrition and hunger. Furthermore, the higher the proportion of the rural population that earns its living solely from subsistence farming (without the benefit of pro-poor technologies and market access); the greater the incidence of malnutrition. As a result, improvements in agricultural productivity targeted at small-scale farmers will mostly help the rural poor. One of the essential inputs needed to increase agricultural output and farmers' income in India is fertilizer. A fertilizer is deemed efficient when it produces a higher yield with the least amount of application. But, in practice, it is difficult to estimate fertilizer use efficiency as it depends on a number of parameters, including losses due to leaching, volatilization, denitrification, immobilization by chemical precipitation, nutrient interaction in soil, fertilizer characteristics, etc.

With regard to the overall amount of fertilizer consumed, South Asian countries are the major consumers. India comes in first place among SAARC (South Asian Association for Regional Cooperation) countries and second overall in the world in fertilizer consumption.

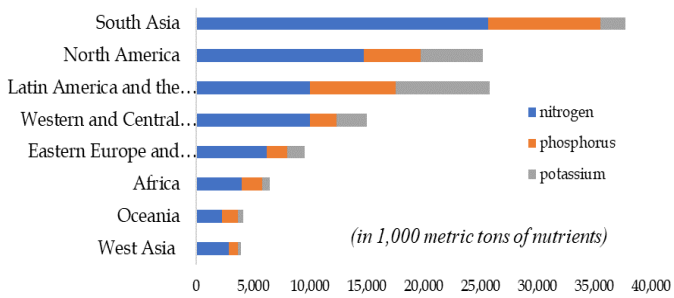

Fig. 1: Global fertilizer utilization by region and nutrient in 2022

Source: Statista, 2024

The maintenance of agricultural productivity is seriously threatened by the non-judicious use of chemical fertilizers, as these degrade the soil and environment even though they initially increase yields. Runoff from farms causes contamination in the water, which gives rise to algal blooms and leads to the early eutrophication of water resources. Inadequate nutrient management and a reduction in organic matter affect soil significantly, which ultimately causes a reduction in productivity. Over-reliance on chemical fertilizers can damage soil health by interfering with the soil's natural nutrient recycling, reducing microbial activity, and changing the pH of the soil. Over time, this can lead to soil compaction and decreased fertility. Further supporting the need for more sustainable nutrient management techniques are the financial strain on farmers and possible health hazards to workers and consumers.

Challenges in nutrient management in fruit orchards

The quality and quantity of land and water resources, as well as how these are managed for fruit production, exert an enormous effect on the orchard's performance. India's population is growing at an accelerating rate; hence, the main challenge facing fruit growers today is maintaining or boosting yields to keep up with the growing demand for processed or fresh fruits. Fruit output can differ greatly depending on how available resources are used. Due to a lack of proper knowledge about the crop, soil properties, and fertiliser nature, improper use of chemical fertilizers is quite common. Improper uses are impairing the soil fertility and ultimately leading to soil acidification, which directly and indirectly affects yield and fruit quality, as well as increasing the susceptibility of fruit crops to pests and diseases.

Mitigating these issues and guaranteeing a robust and fruitful horticultural system require balancing chemical fertilizers use with organic substitutes and implementing integrated measures. Biochar offers a sustainable and efficient supplement to nutrient sources, with implications for biodiversity, environmental conservation, human health, and economic sustainability. The carbonisation of farm residues is the key objective of biochar applications in agriculture. Waste products from fruit production systems, such as pruned wood, weeds, fruit peel, and

other organic wastes, present interesting bio-resources for conversion into valuable soil enriching compounds.

Biochar: Biochar's early origins can be traced back to 2000 years ago in the Amazon Basin's American Indian communities. An ancient indigenous civilization developed highly productive soils known as Terra preta, which means "the black soils of the Indians." Biochar is highly enriched with carbon formed by the thermal breakdown of organic biomass under anaerobic conditions applied to soil, which improves soil fertility, water retention, and carbon sequestration. The primary constituents of biochar are, carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulphur (S). Its primary functions are to store soil nutrients and trap carbon from the atmosphere. It is highly porous in nature as it contains macropores as well as micropores, which increase the surface area, and this porous structure provides an excellent habitat for microorganisms (such as bacteria, actinomycetes, and arbuscular mycorrhizal fungi) where they can colonize, grow, and reproduce. The activity of several enzymes, like urease, increases in biochar-rich soils. Being highly stable in nature, it has the capacity to store carbon for a longer period of time.

Biochar-based Fertilizers: Biochar-based fertilizers (BCFs) refer to biochar that is enriched with essential plant nutrients like nitrogen, phosphorus, potassium, etc. It improves soil health, sequesters carbon, and increases productivity as well, which ultimately leads to sustainable agriculture. There are various forms and compositions of BCFs. All BCFs are slow-release and increase the availability of nutrients for a longer period of time. These are prepared by the thermal decomposition of organic wastes. The porous structure, lowers the bulk density and compaction of the soil. The slow release of nutrients by the BCF's reduces leaching losses, nutrient run-off losses, volatilization etc. BCF's possess higher fertilizer use efficiency than any other conventional fertilizers. These fertilizers buffer the soil pH as they contain organic and inorganic bases, which ultimately solve the problem of soil acidity because the alkaline cations present in BCF's get converted into hydroxides, carbonates, and oxides.

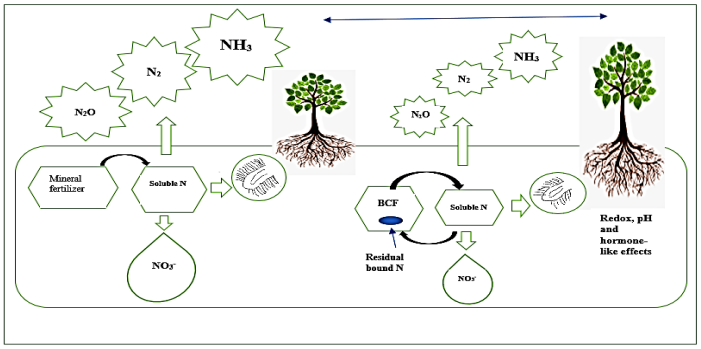

Fig. 2: N cycle of Biochar-based Fertilizer and mineral fertilizer

Based on: Rasse *et al.*, 2022

Types of Biochar-based Fertilizer

BCF's choice of biochar-based fertilizer depends upon crop requirements, soil type, climatic conditions, etc. The major types of BCFs are described as follows:

1. Biochar Blended with Organic Fertilizers: Biochar blended with organic fertilizers such as vermicompost, farmyard manure, cow urine, etc. comes under this category. Such types of BCF are rich in organic matter and can enhance soil fertility, nutrient retention, and promote microbial activity in the soil.

2. Nutrient-Enriched Biochar: Nutrient-enriched biochar is infused or coated with additional nutrients (macro or micronutrients) to supplement the fertilizer properties and slowly release the nutrients, thus increasing their availability in the soil.

3. Biochar Coated with Nutrients: Applying a layer of necessary nutrients to the external surface of biochar particles is known as "biochar coated with nutrients." This coating allows for this controlled release of nutrients into the soil, improving nutrient availability for plants while also enhancing soil structure and microbial activity.

4. Biochar with Microbial Inoculants: Biochar with microbial inoculants refers to biochar that has been combined with beneficial microorganisms, such as mycorrhizal fungi, nitrogen-fixing bacteria, or plant growth-promoting rhizobacteria (PGPR), such as *Bacillus subtilis*. These fertilizers enhance soil biodiversity, improve nutrient cycling, and promote plant growth and resilience by fostering symbiotic relationships between plants and soil microbes.

5. Biochar Mixed with Commercial Fertilizer: Biochar mixed with commercial fertilizer either as a carrier or as an additive, falls under this category. These BCFs lead to increased fertilizer use efficiency. In this type, the nutrient solution is prepared by dissolving commercial fertilizer with distilled water, and then adding biochar to it.

6. Commercial Fertilizers with Biochar Coating: Commercial fertilizers with biochar coatings are conventional fertilizers that have been coated or blended with biochar particles. The biochar coatings enhance the fertilizer properties by improving nutrient retention and reducing nutrient losses through leaching or volatilization.

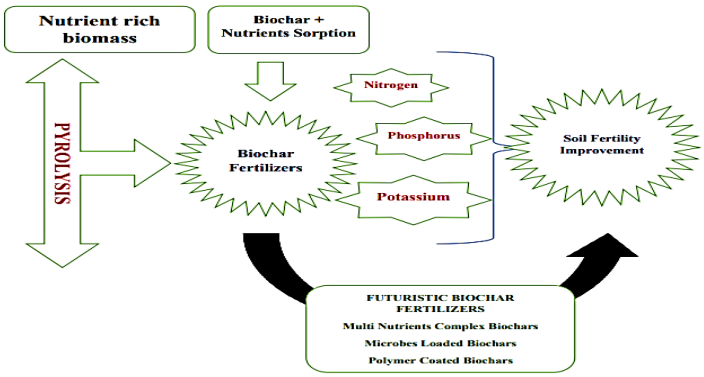

Fig. 3: Biochar Enriched with Nutrients: A Route to Sustainable Farming

Based on: Karim *et al.*, 2022

Effect on Plant Growth and Productivity

The application of biochar-based fertilizers shows a positive result in improving soil health, which ultimately results in better crop performance as compared to conventional fertilizer applications. These fertilizers improve plant performance under stressful conditions (like salinity stress, drought stress, etc.). Application of nutrient-enriched biochar helps to decrease the reactive oxygen species level and improve the soil water holding capacity, which results in better water uptake by plants. BCF's application also increases the concentration of secondary metabolites like terpenoids, carotenoids, polyphenols, etc. Long-term application of these fertilizers increases the bacterial abundance in the soil. These fertilizers increase fruit yield (weight, fruit size, fruit number) and improve fruit quality (soluble protein, total acid, soluble solids, etc.). In a study on grapes, Wei *et al.* (2020) reported that the BCF treated soil significantly increased the grape yield in terms of grape weight, length, and width by 7.6%, 3.8%, and 3.8%, respectively, compared to the untreated control. Additionally, an increase of 28.6%, 1.0%, 10.8%, and 15.8% was observed, respectively, in soluble proteins, soluble solids, firmness, and total acid content of the fruits in grapes grown on BCF treated soil.

BCFs: the way forward

Biochar-based fertilizers (BCFs), provide an environmentally friendly option for sustainable agriculture. Their slow-release property results in better fertilizer use efficiency. The BCFs are a better alternative to conventional fertilizers as they not only increase the productivity of fruit orchards but also improve fruit quality, soil health, and reduce metal toxicity. Every fruit crop will respond differently to the BCF application as they have different growing habits, but in order to maximize production, it is necessary to optimize the timing and dosage of BCFs. However, to understand its specific effects on different fruit varieties, soil types, and climatic conditions, more research and development needed to be done on the usage of BCFs.

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