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Biochar: usage, potential as alternative to chemical fertilizer and impact of biochar on soil –Microbial-Plant root interaction

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Abstract
Natural resource constraints in the country have severely hampered agricultural production, putting sustainable agriculture and food security in jeopardy. The farmer, through utilizing viable solutions, plays a critical role in ensuring that food needs of a growing human population are met, which has resulted in a greater reliance on chemical fertilizers for higher productivity. It enhances plant growth and energy, hence ensuring global food security; nevertheless, plants cultivated in this technique do not improve good plant characteristics such as root system, shoot system, nutritional features, and will not have enough time to grow and mature appropriately. Chemically generated plants will collect harmful compounds in the human body, which are extremely toxic. The adverse effects of chemical fertilizers will begin not only with their application on soil, but also with their manufacture, which will produce poisonous compounds or gases such as NH4, CO2, and CH4, among others, which will pollute the air. And when industrial pollutants are dumped into neighbouring water bodies without being cleansed, it pollutes the water it also contains the most alarming consequence of chemical waste accumulation in aquatic bodies, namely, water eutrophication. When used continuously in soil, it destroys soil health and quality, resulting in soil contamination. As a result, it is past time to recognize that this food production input is depleting our ecology and environment. As a result, continuing to use it without taking any remedial measures to minimize or judiciously use it will eventually deplete all natural resources and endanger all life on the planet. Only by adopting new agricultural technical techniques, such as transitioning from chemical intensive agriculture to organic inputs such as biochar, manure, and Nano fertilizers, can the negative effects of synthetic chemicals on human health and the environment be mitigated or eliminated. This would increase fertilizer application efficiency as well as use efficiency. Organic farming will help to maintain a healthy natural environment and ecology for current and future generations.

Keywords: chemical fertilizer, biochar, soil, microbial, plant interaction

1. Introduction
Most of Ethiopia economy system depends on, agricultural practices and this practice also highly dependent on natural resources for times. Agricultural production decreased as increased human population and other factors have degraded the natural resources in the country thus seriously threatening sustainable agriculture and food security [1, 2]. Soil nutrient depletion is an important concern, directly linked to food insecurity due to unsustainable intensified land use. The constrains including:- Mining of nutrients due to continuous cropping, abandoning of fallowing, reduced manure application, crop rotation, removal of crop residues to be used as fuel, inadequate replacement of nutrients, pollution from industrial production, lose through erosion and leaching coupled with low inherent fertility are among the major causes of soil fertility decline [3]. This is particularly evident in the intensively cultivated areas, traditionally called high-potential areas that are mainly concentrated in the highlands of Ethiopia. The most farmer using potential solutions and plays a key role in sustainable production meeting the food needs of a growing human population, which has led to an increasing dependence on the use of chemical fertilizers for increased productivity. Chemical fertilizers are industrially made substances which are composed of known quantities of nitrogen, phosphorus and potassium. However, the price of fertilizers is increasing from time to time becoming unaffordable to subsistent farmers. Not only expense but also some types of fertilizers such as Urea and DAP is a source of soil acidifying nature and aggravate acid cation losses and ultimately causes acidification of soils [4], causes air and ground water pollution as a result of eutrophication of water bodies [5].

According to Chun-Li *et al.* [6], though the practice of using chemical fertilizers and pesticides accelerates soil acidification, it also poses the risk of contaminating ground water and the atmosphere, problem crated in the export product in marketable. It also weakens the roots of plants thereby making them to be susceptible to unwanted diseases. In this regard, attempts have recently been made towards the production of nutrient rich high quality fertilizer biochar to ensure bio-safety.

The term organic fertilizer has most commonly referred to as the fertilizer which originated from plant and animal wastes and also includes therefore is recycled in the soil. They contain N, P, K and microelements in different rates depending to the source of the fertilizer. To increase the availability and uptake of mineral nutrients for plants [7]. It also include organic fertilizers (manure, etc.), which are rendered in an available form due to the interaction of micro-organisms or due to their association with plants [8]. Biochar has been identified as an alternative to chemical fertilizer to increase soil fertility and crop production in sustainable farming. These potential biological fertilizers would play the key role in productivity and sustainability of soil and also protect the environment as eco-friendly and cost effective inputs for the farmers [9]. Therefore, this review discusses to compare both biochar and chemical fertilizer in term of efficiency of amendments, cost effective, effect of soil health maintenance and to assessed soil-microbial-plant interaction.

2. Literature Reviews

2.1 Biochar

Biochar is a carbon-rich solid material and is intended to be added to soils as a means to sequester carbon (C) and maintain or improve soil functions. Interactions between biochar, soil, microbes, and plant roots are known to occur within a short period of time after application to the soil [10]. However, the extent, rates, and implications of these interactions are still far from being understood, and this knowledge is needed for an effective evaluation of the use of biochar as a soil amendment and tool for C sequestration. The studies [11] suggest that the types and rates of interactions (e.g. adsorption-desorption, precipitation-dissolution, redox reactions) that take place in the soil depend on the following factors:

1. Feedstock composition, in particular, the total percentage and species composition of the mineral fraction;
2. Pyrolysis process conditions;
3. Biochar particle size and delivery system; and
4. Soil properties and local environmental conditions.

2.2 Biochar as a means of carbon sequestration

One of the major potential benefits of biochar is an enrichment of soil fertility, carbon sequestration, and reduction of greenhouse gases (GHG) emission. Carbon sequestration is the capture and storage of carbon to prevent it from being released to the atmosphere. Some Studies suggest that biochar sequesters around 50% of the carbon available within the biomass feedstock being paralyzed, depending upon the feedstock type [12]. The remaining percentage of carbon is released during pyrolysis and may be captured for energy production [13]. Reported that large amounts of carbon may be sequestered in the soil for long time periods (hundreds to thousands of years at an estimate), but precise Estimates of carbon amounts sequestered as a result of biochar application are rare. According to Marris [14] suggests that a 250-hectare farm could sequester approximately 1,900 tons of CO_2 a year. One of the sources of greenhouse gases associated with the agriculture sector is a nitrous oxide (N_2O) and methane (CH_4). From this cropland soils and cropping lands are an important agricultural source of N_2O emissions and paddy fields, livestock manure, and enteric fermentation, are the leading sources of CH_4 emission. Some studies observed that during applied biochar to the soil, greenhouse gas emissions reduced significantly N_2O emissions. Such as carbon sequestration mechanisms affected by biochar, including:

- The stable carbon structure of biochar (aromatic carbon structure and crystal silicon Structure in silica-carbon complexes) [15, 16].
- The reaction of biochar with soil minerals, to forms a complex structure that protects Biochar from microbial degradation [17].
- biochar adsorption of soil organic matter (SOM), forming aggregates that protect the degradation of SOM [18].
- Protection of soil aggregates by fungal hyphae and the secreted glomalin [19].
- Modification of soil enzyme activities that control soil organic carbon decomposition [20]. These processes can reduce the CO2 emission from the decomposition of biochar and SOM. Emission of N_2O is 300 times stronger than CO_2 in terms of global warming potential, was reduced by 40 percent [21]. Laboratory studies suggest that N_2O emissions reduction from biochar-treated soil is dependent on soil moisture and soil aeration [22]. Greenhouse gas emission reductions may be 12% to 84% greater if biochar is land applied instead of combusted for energy purposes [23].

2.3 Physico-chemical properties of biochar

The impact of biochar as an amendment depends on its properties or attributes, biochar properties can be significantly influenced by feedstock source and pyrolysis condition (temperature, the rate of heating -slow *versus* fast pyrolysis), and time duration of charring. This certifications detailed characterization of biochar for their application to improve soil fertility and sequester carbon [24]. Between key properties are the large surface area (SA) and presence of micro pores [25] which contribute to the adsorptive properties of biochars and potentially alter soil's SA, pore size distribution (PSD), bulk density (BD), water holding capacity (WHC) and penetration resistance (PR). SA and the pore volume strong and direct relationship between as measured using N_2 adsorption.

In general, an abundance of small to medium-sized pores can enhance the SA of the material. Following the pore size classification used by the International Union of Pure and Applied Chemistry [26], understanding and determination of the relative abundance and stability of pores of different sizes (micropores: < 2 nm, mesopores: 2–50 nm and macro pores: > 50 nm) are keys to soil ecosystem functioning. According to Smernik and Skjemstad [27] observed that aromatic condensation in biochar increased with increasing pyrolysis temperature. Activated biochar contains the most highly condensed aromatic structures, but also showed the importance of feedstock and retention time on aromatic condensation. Further, manure-based biochar synthesized at low temperature may comprise a considerable proportion of aliphatic C and a low proportion of aromatic aryl C and thus can easily mineralized than wood-based biochars [28].

Suggested that low-temperature biochars were observed to have a less condensed C structure and are expected to have a greater reactivity in soil than higher temperature biochar and a better contribution to soil fertility. According to Jindo *et al.* [29] low-temperature pyrolysis formed high biochar yields; in contrast, high-temperature pyrolysis led to biochars with a high C content, large surface area, and high adsorption characteristics. Wan *et al.* [30] reported that pH, the content of carbonates, base cation and alkalinity of biochar increased with increase in pyrolysis temperature. The high pH of biochar has been attributed to hydrolysis of salts of Ca, Mg and K [31].

The results of study conducted by Singh and Cowie [32] suggested that, wood biochars had higher total C, lower ash content, lower total N, P, K, S, Ca, Mg, Al, Na, and Cu contents, and lower potential cation exchange capacity (CEC) and exchangeable cations than the manure-based biochars, and the leaf biochars were generally in-between. Increase in pyrolysis temperature increased the ash content, pH, and surface basicity and decreased surface acidity.

Wang *et al.* [33] found that for a given feedstock, increasing pyrolysis temperature from 500 °C to 700 °C increased the ash content, BET surface area, pH, total P and Ca contents and decreased the biochar yield, CEC, total acid and N. Increase in residence time from 4 to 8 or 16 hour, increased the surface area and ash content of biochar but decreased the biochar yield. FTIR analysis showed that more recalcitrant and aromatic structures were formed in the biochar at a higher temperature.

2.4 Biochar as a source of nutrient

Throughout pyrolysis, most of the Ca, Mg, K, P and plant micronutrients and half of N and S in biomass feedstock are isolated into biochar [34]. Nutrient composition and availability in biochar varied widely depending on the nature of feedstock and pyrolysis conditions [32].

Whereas the availability of nutrients from biochar is related to the type of bonds associated with the element involved [35]. Total P and K were increased significantly with the increase in pyrolysis temperature while total N followed the reverse trend [36]. Similarly, differences in pyrolysis temperature using the same feedstock (chicken manure) produced biochars with very different properties including, EC, pH and P and N concentrations [37]. Lehmann *et al.* [38] reported that most of the cations in the ash component of biochar were not bound by electrostatic forces but present as dissolved salts and thus act as a conditioner and fertilizer itself.

Hass *et al.* [39] evaluated the potential of chicken manure biochar as a nutrient source for acid Appalachian soil. The results revealed that increase in production temperature increased the availability of Cu, K, Mg, and Zn, while decreased that of Fe, Mn and S. Further increase in production temperature and activation reduced the availability of K, P, and S, while the availability of Cu and Zn was improved. Enders *et al.* [40] reported that biochar contains large amounts of carbon and macro or micro-nutrients depending on feedstock and pyrolysis temperature. As a result, biochar may directly supply plant-available nutrients once applied to the soil [41]. It is uncertain whether these soluble nutrients are released suddenly or over a time once added to the soil [42]. Available P, organic carbon, total nitrogen, soil pH, soil CEC, base saturation Ca and Mg were also found to be higher in coffee husk biochar than in that of corn cob biochar [43].

2.5 The advantage of biochar application on soil physical and chemical properties

The physical properties of biochar such as large surface area and presence of microspores contribute to the adsorptive properties of biochars and potentially alter soil surface area, pore size distribution, bulk density, water holding capacity and penetration resistance [44], increased soil organic matter, bioavailable nutrients and significantly enhance the microbial activities and thereby the soil aggregate formation and stability [45]. Glaser *et al.* [46] reported that the formation of complexes of biochar with minerals, as a result of interactions between oxidized carboxylic acid groups at the surface of biochar particles was responsible for the improved soil combined stability.

The unique properties of stable C rich biochar such as high surface area, a high charge per unit area, the occurrence of various surface functional groups and ash content positive effect on soil chemical properties. Application of biochar increased SOC, pH, EC, CEC and exchangeable bases [47] and decreased exchangeable acidity and exchangeable aluminum [30]. One consistent effect of biochar application was found to increase in soil pH which implied a liming value of biochar [48]. Collins [49] found nearly a unit increase in soil pH with biochar derived from herbaceous feedstock and 0.5 to 1 unit increase in the soil pH with biochar derived from woody sources. According to [50] credited the improvement of bean productivity due to an elevation of soil pH and another soil nutrient as a consequence of the use of biochar. The integration of biochar produced from crop straws increased the soil pH, exchangeable base cation, CEC, and base saturation and decreased exchangeable acidity, exchangeable Al and reactive Al. The resultant effects were dependent upon feedstock characteristics and pyrolysis temperature [30].

A study was taken up by [51] to know the effect of biochar incorporation on soil chemical properties of acidic soil. The study demonstrated the effectiveness of biochar in ameliorating acidity which increased the soil pH, EC, and CEC and decreased the exchangeable acidity. The liming potential of biochar can be attributed to their alkalinity, proton consumption capacity and base cation concentration. [43] reported that application of coffee husk residue biochar produced at 500°C and applied at the rate of 15 t h^{-1} significantly improved physicochemical properties of soil as compared to corn cob produced at the same temperature and the same application rate and his said that further field researches are needed to evaluate the interactive effects of biochar on physicochemical properties of acidic soil.

2.6 Environmental effect of chemical fertilizer

In order to attain more agricultural production per unit area, the world uses a significant number of chemicals such as fertilizers, insecticides, and herbicides. However, using more than the authorized amount of these chemicals and fertilizers causes various difficulties like environment pollution such as soil, water, air pollution, reduced input efficiency, decreased food quality, resistance development in different weeds, diseases, insects, soil degradation, micronutrient deficiency in soil, toxicity to different beneficial living organism present above and below the soil surface, less income from the production, etc. Despite these numerous issues, meeting the food demands of the world's rising population remains a struggle. As a result, there is a need to create nutrient-dense, chemical-free agricultural produce for human and animal use without depleting natural resources, which is why an emphasis on the production of food that is both high in quality and quantity should be placed.

Fertilizer use is undoubtedly beneficial to plants in terms of providing deficient nutrients; however, it also has several other advantages, such as being a less expensive source of nutrient, having a higher nutrient content and solubility, resulting in immediate availability, and requiring less fertilizer, making it more acceptable than organic fertilizer. There is abundance of evidence that inorganic fertilizers can improve the yield of crop significantly [52]. Fertilizers raise soil fertility so that the yield of crops is independent and no longer are limited by the deficient amounts of plant nutrients [53]. Despite these benefits, fertilizer has several negative effects on the environment because of its growing consumption and lowering nutrient use efficiency. Therefore, the major challenge in intensive agricultural production systems is to combine intensive cultivation with high nutrient use efficiency.

Soil nutrient level gets decreased over time when crop plants get harvested, and these nutrients get replenished either through natural decomposition process or by adding fertilizers. Hence fertilizer is an essential component of modern agriculture.

But though chemical fertilizers are the major cause of sufficient crop production for the world population, their overuse is bringing serious challenges to the present and future generations like polluted air, water, and soil, the degraded lands, depleted soils and increased emissions of greenhouse gases. These synthetic fertilizers are not only becoming hazardous for our environment but also to humans, animals and to the microbial life forms too. It's high time that everyone understands the ill effects of using excess chemical fertilizers and take initiatives for reducing the use of chemical fertilizer and pesticides substituting it with other organic amendments like organic manures which not only provides essential nutrients to the plants but also maintains the soil health for the subsequent crops. There are so many other technologies developing like slow or controlled released fertilizers, prilled or granulated fertilizer, nitrification inhibitors, Nano-fertilizer etc., all these are the promising options we can use to overcome these serious challenges and can save our environment as well as the ecosystem. Let us now learn about the different hazards occurring due to excessive use of chemical fertilizers used for enhancing the crop production.

Table 1: Summary of effects of chemical fertilizer on the environment as shows.

	Type of fertilizer	Pollutant	Mechanism	Effect on humans	Examples	
1	Nitrogen Source of fertilizer	air	Through oxidation using soil bacteria provides (NO)x	distraction of O_3 to expose on living things by ultraviolet radiation	(NO)x	[54]
2	Nitrogen Source of fertilizer	water	Through leaching from the root zone after application of fertilizer	Gastric cancer, blue baby syndrome etc.	Nitrate	[55]
3	Nitrogen and Phosphors source of fertilizer	soil	Through release of H^{+1} ion in to the soil becomes soil acidity and residual of heavy metals during manufacturing phosphors respectively	Reduction of nutrient availability of for plant and Accumulation of food grains	Urea, DAP, triple super phosphate	[56]

2.7 Interactions between biochar and Soil-microbes habitat for plant nutrients

Biochar can participate in soil processes such as organic matter decomposition as it takes part in the direct extracellular electron transfer (DEET) between soil organic matter (or soil minerals) and microbial cells, as well as in the direct interspecific electron transfer between microbial cells (DIET) [57]. The identification and quantification of the reactive components of biochar particles that are responsible for the electron transfer between the biochar and soil microbes are essential to investigate biochar-involved elemental cycling. The electron transfer between biochar particles and soil minerals, organic matter, pollutant molecules, and microbial cells, as well as in response of the microbial community to the reactive components of the biochar, is an emerging research field that seeks to further clarify the effects of biochar on soil biogeochemical processes. Plant physiologists at times view soil as simply a source of nutrients to plants it is really a complex ecosystem hosting bacteria, fungi, and animals [58]. Plants exhibit a diverse array of interactions with these soil-dwelling organisms, which span the full range of ecological possibilities (competitive, exploitative, neutral, commensal, and mutualistic). At this time, in response to the requirement of more sustainable agricultural production and in order to hold global warming, there are attempts to restore Terra Preta (ancient soils amended with black carbon) by including biochar to soils as means of increasing soil fertility and carbon sequestration [59]. Biochar addition to soil not only soil nutrition amendment but also it has a great impact on plant development and root colonization by microorganisms (e.g. mycorrhizal fungi) and nematodes [60]. Interactions between biochar, soil, microbes, and plant roots were known to occur within a short period after application to the soil [10]. According to this authors Dissolution, hydrolysis, carbonation, and decarbonation, hydration, and redox reactions are the major process affecting biochar weathering in the soil, as well as interactions with soil biota. The rates of these reactions occur depending on the nature of the reactions, type of biochar, and climatic conditions. Biochar can influence physical and chemical properties as well as beneficial soil microorganisms like bacteria, fungi, and invertebrates, both in field and laboratory conditions [60]. Biochar has also been shown to enhance nutrient availability over longer time scales by enhancing nitrogen (N) mineralization or nitrification [61] as a result of enhanced microbial growth and activity [62] and by reducing soil nutrient losses due to its high ion exchange capacity [63]. Numerous recent studies have shown that the positive effects of biochar on soil fertility can result in enhanced plant growth, thereby having an indirect positive effect on net ecosystem C uptake and Biochar, as a soil amendment, can increase microbial biomass [64], stimulate soil microbial activity and change microbial community in soil [65].

3. Conclusion

Fertilizer application is critical in today's agricultural crop production system since it replenishes soil nutrient levels while also promoting crop development and output. However, in order to reduce the many types of dangers that occur as a result of excessive fertilizer usage, judicious and sustainable fertilizer use should be undertaken. To do so, adequate soil testing and analysis should be performed first, followed by fertilizer application.

As a result, integrated usage of various types of nutrient supplements, such as chemical fertilizer, organic manures, bio fertilizers, and other slow or controlled released fertilizers, should be employed to assure both enhanced and sustainable agricultural production and environmental protection. Improved nutrient utilization efficient fertilizers, particularly nitrogen, should be adopted by employing biochar, organic manures, and controlled-release or slow-release fertilizers to avoid pollution concerns caused by chemical fertilizers. Improved nutrient utilization efficient fertilizers, particularly nitrogen, should be adopted by employing organic manures, controlled-release or slow-release fertilizers to avoid the pollution dangers associated with chemical fertilizers. Current resources should be modified in favor of resource sustainability while concurrently increasing productivity.

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