

**EFFECTS OF BIOCHAR AMENDMENT ON
SOIL RESPIRATION**

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ABSTRACT

The objectives of this study were to quantify the effects of biochar amendment on soil respiration rate and to investigate the relationship between soil temperature, moisture content and pH on soil respiration. Five rice husk biochar treatments (0, 1, 5, 10 and 20 t ha⁻¹) were applied on soil plots in a completely randomized design (CRD) at the experimental field of the School of Sustainable Agriculture, Universiti Malaysia Sabah (6°02' N, 116°07' E). Each treatment was replicated three times resulting in 15 sample plots, each measuring 1 m² in size. Soil respiration data were collected using an LI-8100 Automated Soil CO₂ Flux System (LI-Cor Inc., Lincoln, NE, USA). Soil temperature and soil moisture data were measured with a soil thermometer and soil moisture meter (SM100) respectively. Data was recorded once a week in the morning (6.00 a.m.-8.00 a.m.) and evening section (5.00 p.m.-7.00 p.m.). The soil respiration for the 1 t ha⁻¹ and 5 t ha⁻¹ biochar treatments were significantly different in this study. The maximum rate of soil respiration produced from 5 t ha⁻¹ of biochar amendment was approximately 9.45 t CO₂ ha⁻¹ yr⁻¹. Soil temperature was positively correlated with soil respiration. Increased soil temperature enhanced the soil respiration especially above 30°C. The soil moisture showed an inverse relationship with soil respiration. Rainfall event and distribution affected the results of soil temperature and moisture and hence soil respiration. Higher rainfall increased the soil moisture content but also reduced soil respiration significantly. The 1 t ha⁻¹ biochar treatment increased the soil pH but the higher biochar treatments (10 and 20 t ha⁻¹) significantly increased soil acidity. In conclusion, the 5 t ha⁻¹ biochar amendment was effective in increasing soil respiration and influenced soil properties such as soil pH and moisture which will affect agriculture activities of farmers.

KESAN PERUBAHAN BIOCHAR KE ATAS RESPIRASI TANAH

ABSTRAK

Objektif kajian ini ialah untuk menguji kesan penambahan dan perubahan biochar ke atas kadar respirasi tanah serta mengkaji hubungan antara suhu tanah, kelembapan tanah dan pH tanah dalam respirasi tanah. Lima jenis rawatan biochar (0, 1, 5, 10 and 20 t ha⁻¹) telah ditambah dalam plot tanah secara susunan menggunakan rekabentuk rawak lengkap di Makmal Ladang Sekolah Pertanian Lestari, Universiti Malaysia Sabah (6° 02' U, 116° 07' T). Setiap rawatan diulang dengan tiga replikasi dan setiap plot tanah bersaiz 1 m². Kadar respirasi tanah diukur dengan menggunakan *LI-8100 Automated Soil CO₂ Flux System (LI-Cor Inc., Lincoln, NE, USA)*. Manakala suhu tanah and kelembapan tanah masing-masing diukur dengan menggunakan thermometer tanah serta meter kelembapan tanah SM100. Data diambilkan sekali dalam seminggu pada waktu pagi (6.00a.m.) dan waktu petang (5.00p.m.). Keputusan analisis menunjukkan bahawa 1 t ha⁻¹ dan 5 t ha⁻¹ biochar memapar perbezaan signifikan dalam respirasi tanah. Suhu tanah didapati berkorelasi positif dengan respirasi tanah dimana semakin meningkat suhu tanah, semakin tinggi kadar respirasi tanah. Namun, kelembapan tanah menunjukkan korelasi berkadar songsang kepada respirasi tanah. Penambahan biochar dengan kuantiti 1 t ha⁻¹ dapat meningkatkan nilai pH tanah tetapi kajian juga membuktikan bahawa peningkatan kuantiti biochar (10 dan 20 t ha⁻¹) meningkatkan keasidan tanah secara signifikan. Peningkatan kuantiti biochar menyebabkan penambahan asid yang dihasilkan daripada mikroorganisma di dalam tanah. Secara ringkas, penambahan biochar sebanyak 5 t ha⁻¹ dapat meningkatkan kadar respirasi tanah dan memperbaiki ciri-ciri tanah yang berpotensi untuk menggalakkan aktiviti pertanian untuk petani.

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LIST OF ABBREVIATIONS

AMF	Arbuscular mycorrhizal fungi
ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
GHG	Green house gas
SOM	Soil Organic Matter
TCA	Tricarboxylic acid

CHAPTER 1

INTRODUCTION

1.1 Introduction

Global climate changes, such as global warming, have many negative effects on the environment and human health. It also has an influence on agricultural crop production. These climate changes not only reduce crop productivity, but also affect soil properties. Soil is the major supporting system for human life and welfare. Soil has been referred to as "Earth's Living Skin" (Dent *et al.*, 2005) which indicates the importance of soil. Soil provides anchorage to plant roots, holds water and stores nutrients. Soil also provides a home and active sites for microorganisms. Soils are complex and dynamic ecosystems with communities of organisms. Like all ecosystems they have a food web that may include bacteria, fungi, algae, protists, insects, worms, plant roots and burrowing animals. Soils also carry out essential ecosystem functions like water storage and filtration and, perhaps most importantly, decomposition.

Soil is the main source of atmospheric carbon. Carbon is an essential part of all organic molecules and as constituents of the atmosphere, carbon compounds such as carbon dioxide (CO₂) and methane (CH₄) substantially influence the global climate (Molles, 2005). Man intervenes in the earth's carbon cycle in two main ways that add CO₂ to the atmosphere. This includes clearing trees and other plants that absorb CO₂ through photosynthesis and adding large amounts of CO₂ by burning fossil fuels and woods (Miller, 2004). These activities cause large imbalances between carbon release to the atmosphere and carbon uptake by other ecosystem components that leads to an increase in the CO₂, equivalent to a rate of 4.1×10^9 tons per year (IPCC, 2007). Thus, the application of biochar to soil has attracted a lot of researches in the last few years



and its application has shown to not only contribute to carbon storage but also improves soil fertility (Glaser *et al.*, 2001; Marris, 2006).

Biochar is defined as charcoal for which, owing to its inherent properties, scientific consensus exists that application to soil at a specific site is expected to sustainably sequester carbon and concurrently improve soil functions. It is produced by pyrolysis of biomass and for biosequestration or carbon storage. Biochar can be described as a "soil conditioner" which is derived and manufactured by many types of biomass feedstock such as wood, crop residues and manures. Previous researches on biochar application showed that biochar resulted in both positive and negative effects on soil. Biochar amendment positively enhances and improves soil fertility by increasing the population of microbes in soil but excessive application may limit the uptake of certain nutrient elements (Gaskin *et al.*, 2010).

Biochar is one type of organic material which can enhance the number of soil microbes and increase the rate of soil respiration. Soil respiration is an ecosystem process that releases CO₂ from soil via root respiration or organic matter decomposition by soil microbes. Soil respiration is also intimately associated with nutrient processes such as mineralization (Luo and Zhou, 2006). The increase in soil respiration rate directly affects the soil decomposition process and enhances organic matter decay which improves the fertility of the soil. In agricultural production, crop residues could constitute a sustainable source for black carbon production, which could then be used to improve soil quality.

1.2 Justification

Today, many issues such as global warming, climate change, low soil fertility and water shortage are challenges faced by all farmers in producing high crop yields. Biochar application to soil is one approach to fulfill the farmer's needs in crop production. From previous research on biochar application to soil, it is proven that it benefits the fertility of the soil and maintains soil moisture content. In addition, biochar application can increase the microbial activity occurring in the soil by increasing the rate of soil respiration. The high metabolism or activities of soil microbes will improve the soil fertility as well as maximize the soil used for crop cultivation. Furthermore, the potential for terrestrial carbon cycle management in the soil pool is the main reason for

the current research interest in biochar. Research on biochar will provide evidence for carbon equivalent savings which takes into account the benefits to land users and upstream food processors.

Biochar is a carbon negative substance which encourages the decaying or decomposition process and captures the CO₂ in a virtually permanent carbon stock preventing its re-release into the atmosphere. Can biochar reduce the release of CO₂ into the atmosphere and retain it inside soil or enhance soil respiration by activating the organic matter decomposition by microbes? This study will investigate whether biochar is really carbon negative as claimed bearing in mind that it can increase soil respiration.

Furthermore, not many researches have been done on rice husk biochar amendment and soil respiration. Most of the research on soil respiration and biochar application has been done in Western countries with cool climates. There is no research on biochar application effects on soil respiration in Malaysia.

This study will provide some information on the effects of biochar amendment on soil respiration. In addition, this study will also provide information on the effects of soil temperature on soil respiration after biochar application.

1.3 Research Objectives

The objectives of this study were:

- i. To quantify the effect of rice husk biochar amendment on soil respiration.
- ii. To determine the relationship between soil temperature and soil respiration.
- iii. To evaluate the effect of rice husk biochar amendment on soil moisture content and soil pH.

1.4 Hypotheses

- H_0 : Rice husk biochar amendment significantly affects soil respiration, temperature, moisture content and pH.
- H_a : Rice husk biochar amendment does not significantly affect soil respiration, temperature, moisture content and pH.

CHAPTER 2

LITERATURE REVIEW

2.1 Greenhouse Effect and Global Warming

Global warming has become an environmental issue in these recent years. The main cause of global warming is the increasing levels of carbon dioxide, methane and other greenhouse gases that retain heat in the atmosphere. According to Johansen, (2008) the rate of carbon dioxide increased on average about 3.1% per year between 2000 and 2004. Consequently, our earth's atmospheric CO₂ is out of balance. Carbon dioxide is not the only gas emitted from soil with the potential to influence the climate. The annual fluxes of CO₂ from the atmosphere to land or from land to the atmosphere are at the order of 60 Pg C year⁻¹ (IPPC WGI, 2007). Atmospheric carbon increased at a rate of 3.2 ± 0.1 Pg C year⁻¹ with the oceans absorbing 2.3 ± 0.8 Pg C year⁻¹ with an estimated terrestrial sink of 2.3 ± 1.3 Pg C year⁻¹ (Schimel *et al.*, 2001; IPPC WGI, 2007). This occurrence may cause the current land carbon sink to switch to a land carbon source. Soil carbon pools are smaller now than they were before human intervention.

Burning fossil fuels combines oxygen with carbon, which creates an abundance of CO₂. Excess CO₂ causes the greenhouse effect, trapping the sun's heat. Other gases, like methane and nitrous oxide, exacerbate the greenhouse effect. Methane is six times more abundant in the atmosphere than N₂O (1.8 ppm compared to 0.3 ppm for methane), and has an annual flux approximately 50 times higher. Aside from industrial emissions, including natural gas exploitation and distribution (accounting for about 20%), methane emanates primarily from the soil of natural habitats and thus, uniquely for the main greenhouse gases, increasing rates of emission have begun to stabilize (Sohi *et al.*, 2009).



Carbon dioxide (CO₂), methane (CH₄) and nitrous oxides (NO_x) are important drivers of the anthropogenic greenhouse effect (Lehmann *et al.*, 2006). Methane (CH₄) production also occurs as a part of the carbon cycle. Therefore, there has been increasing interest in low temperature pyrolysis of organic materials to produce a charcoal product termed biochar. It has been postulated that biochar is an inert substance that could be a beneficial soil amendment in increasing soil quality and a permanent mechanism for carbon (C) sequestration to reduce CO₂ enrichment of the atmosphere from anthropogenic activities. An experiment had shown that addition of 2% w/w of biochar could reduce the emission of CH₄ (Rondon *et al.*, 2004).

The longevity of biochar in the soil is an important element when comparing pyrolysis bioenergy and biochar production with conventional bioenergy strategies, in mitigating climate change. The application of biochar aims to reduce greenhouse gas (GHG) emissions especially the emission of nitrous oxide. It can decrease 50% to 80% of GHG from cropland (Sohi *et al.*, 2009). Therefore, biochar has the ability to suppress methane emissions in the atmosphere.

2.2 Soil Carbon Cycling

The Carbon cycle is a complex interaction of the biogeochemical and other processes by which carbon is exchanged between the earth's atmosphere, soil as well as the ocean. Recently there has been increased interest in the carbon cycle because of man's awareness of how atmospheric levels of carbon dioxide (CO₂) affect global climate change. The global carbon cycle consists of the geochemical reservoirs that store carbon on the earth and the pathways that transport carbon between them (Peng *et al.*, 2008).

Soil contains a huge and dynamic carbon pool that is a critical regulator of the global carbon budget (Johnston *et al.*, 2004). From the earth's terrestrial C, soil stores 4.5 times the amount of C contained in vegetation (Lal, 2004). There are various forms of soil carbon that are received, stored and emitted through the carbon cycle. Soil carbon may be very stable and stay in the soil for thousands of years or it may be broken down in just a few hours. Soil carbon stores are far greater than the atmosphere and plants combined. The two main processes that impact the soil carbon cycling are soil respiration and also soil sequestration.

Soil carbon sequestration is the process of transferring or moving of carbon dioxide from the atmosphere into the soil. The infiltration of CO₂ may be through crop residues, fertilizers or other organic solids application. The process of transferring or sequestering carbon helps off-set emissions from fossil fuel combustion or other carbon release activities. Biochar reverses the fossil fuel deposition of CO₂ in the atmosphere by removing carbon from the active cycle and sequestering it in the inactive carbon cycle. This carbon sequestration results in advantages and increases the soil quality for crop production or long term agronomic benefit. Soil carbon sequestration also decreases soil disturbance incidents such as forest practices or soil tilling activities. Carbon sequestration also improves the soil structure and enhances soil activities. The major soil activity is soil microbial activity which can decompose and activate the plant root microbial mechanisms (Sohi *et al.*, 2009).

Furthermore, the estimated amount of organic C stored in world soils is about 1100 to 1600 Pg, more than twice the C in living vegetation which is 560 Pg and also in the atmosphere (750 Pg) (Sundquist, 1993). Approximately 10% - 20% of the carbon in plant residue forms the SOM, sometimes called humus. Some of the carbon incorporated into SOM can persist in soils for hundreds or even thousands of years (Kimble *et al.*, 2007). Conversion of biomass C to biochar C leads to sequestration of about 50% of initial C compared to the low amounts retained after burning about 3% and biological decomposition which is less than 10-20% after 5 years. Therefore, biochar yields more stable soil carbon than burning or direct biomass application on land (Lehmann *et al.*, 2006).

The transformation of organic matter into black carbon greatly reduces its degradability and creates a long-term carbon sink. Due to its low degradability, black carbon is almost ubiquitous in terrestrial soils (Knoblauch *et al.*, 2010). Biochar removes the circulating CO₂ from the atmosphere and sinks the carbon in a permanent soil carbon pool, making it a carbon negative process. Thus, interest has been increasing in using biochar as a soil amendment to sequester carbon to improve soil quality and also reduce the potential negative impacts of bioenergy production (Laird, 2008; Lehmann, 2007).

2.3 Biochar Properties

Biochar is an organic material produced via the pyrolysis of C-based feedstocks (biomass) and is best described as a 'soil conditioner' (Lehmann and Joseph, 2008; Verheijen *et al.*, 2010). Despite many different materials having been proposed as biomass feedstock for biochar (including wood, crop residues and manures), the suitability of each feedstock for such an application is dependent on a number of chemical, physical, environmental, as well as economic and logistical factors. There are many types of biochar products such as grass biochar, woodchips, wood pellets, poultry litter, bonemeal and some are unknown feedstock. The most common biochar products are derived from rice husk, sugarcane, maize blade, cereal husk and others. Biochar can be produced from a wide range of organic feedstocks under different pyrolysis conditions and at a range of scales. Many different materials have been proposed as biomass feedstocks for biochar. When biochar is created from biomass, approximately 50% of the carbon that the plants absorb as CO₂ from the atmosphere is "fixed" in the charcoal (Verheijen *et al.*, 2010).

Biochar, the third combustible product produced in pyrolysis, is the solid charred and carbon-rich residue (Sohi *et al.*, 2009). Biochar production is a combustion process that may be curtailed at a point where any desired ratio in these products has been achieved. Biochar comprises part of a continuum of materials described as 'black carbon' (Schmidt *et al.*, 2001). The most important source for black carbon in soils is vegetation fire, which combusts most of the organic matter into volatile components between 0.1% and 3.4% of the initial biomass as black carbon or biochar (Kuhlbusch and Crutzen, 1996; Czimczik *et al.*, 2003; Fearnside *et al.*, 2007).

Pyrolysis has a requirement for initial energy, in the same way as in straight combustion where some heat in the flame is used to initiate combustion of new feedstock. However, the relative requirements must be carefully compared, together with any difference between pyrolysis and alternative bioenergy technologies in the energy requirement of feedstock transportation and drying (Sohi *et al.*, 2009). The biomass pyrolysis processes are a well-established technology for biofuels and biochar production. The commercial exploitation of biochar by-products as a soil amendment is still in its infancy. In Japan, which has the largest market for such products, approximately 15000 t yr⁻¹ is traded annually for soil use (Okimori *et al.*, 2003).

Usually biochar products are gasified for extraction of residual energy, or used in production of high value products such as activated carbon (Demirbas *et al.*, 2006). Using pyrolysis to turn sustainably produced biomass into a recalcitrant substance that is decomposed at a much slower rate, constitutes both a tool for carbon sequestration and avoiding emission. Conversion of biomass to biochar fundamentally alters the transformation dynamics with respect to C sequestration. Upon charring approximately 50% of the C contained in the biomass is immediately released, leaving a stable biochar residue (Figure 2.1). It is argued that sequestration of carbon in biochar allows for a much longer storage time compared with other terrestrial sequestration strategies, such as afforestation (Schulze *et al.*, 2000).

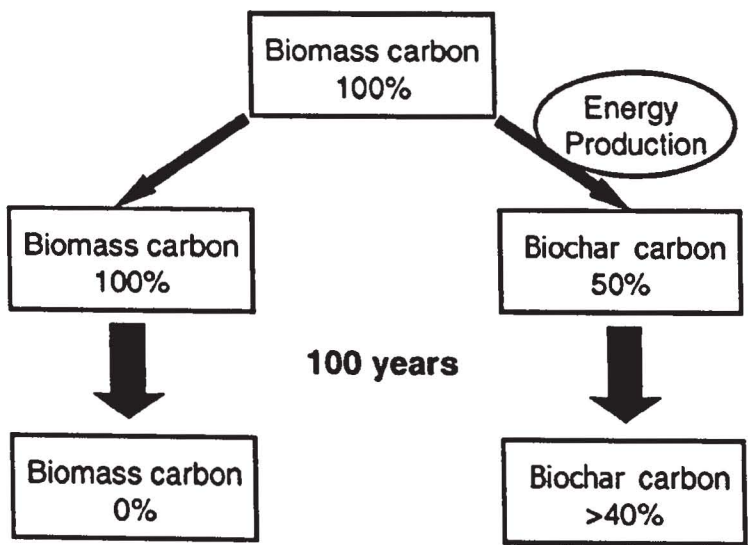


Figure 2.1 Carbon remaining after biomass and biochar decomposition
Source: Lehmann *et al.*, 2006

2.4 Effects of Biochar on Soil Properties

Biochar is a highly stable carbon compound created when biomass is heated to temperatures between 350 °C and 600 °C in the absence of oxygen (Whitman and Lehmann, 2009). The application of biochar into soil not only improves the soil properties, it can also directly raise crop productivity and increase the economic value in agriculture. Biochar is a type of SOM which is used as a critical component of the terrestrial biosphere that facilitates the production and growth of agriculture crops and other biota. Increased carbon stocks in the soil increases soil fertility, workability, water holding capacity and reduces erosion risk (Figure 2.2). Meanwhile, it can reduce

the vulnerability of managed soils to future global warming (Smith, 2008). Biochar application has been widely used in plant nurseries and contour rows of steep land used for vegetables or grain crops.

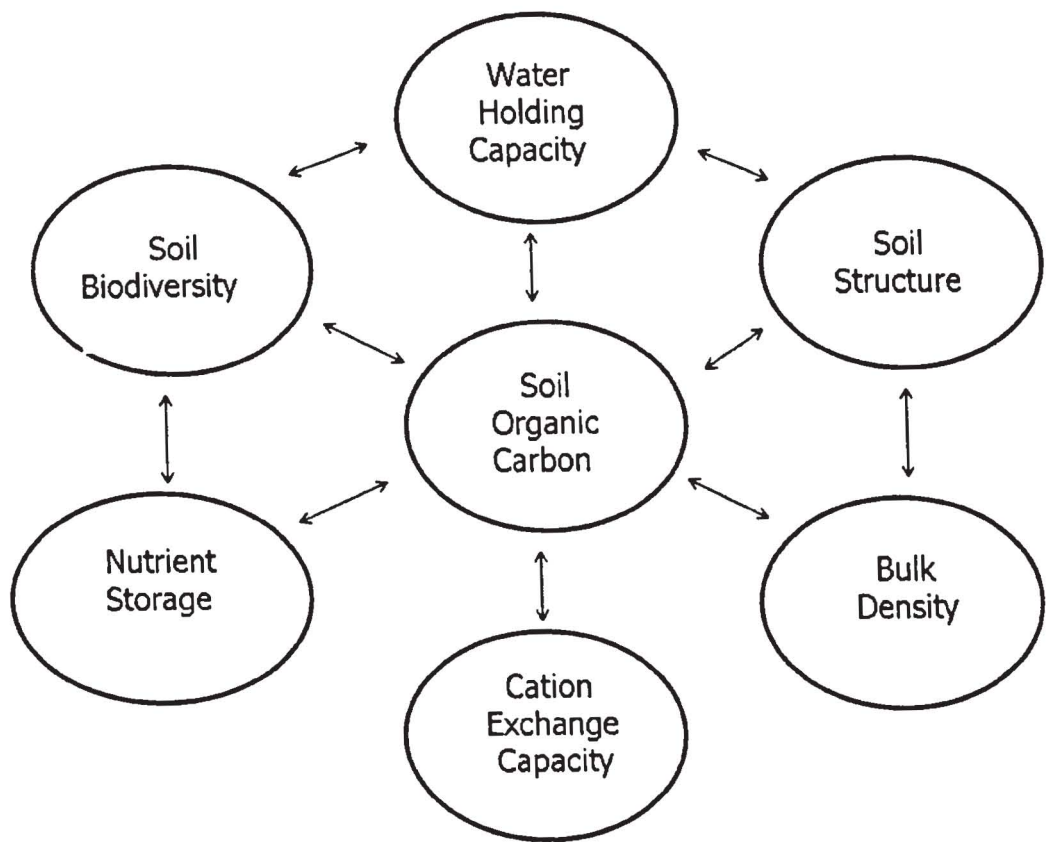


Figure 2.2 Illustration of the relationships between soil organic carbon and other soil functions

Source: Kimble *et al.*, 2007

2.4.1 Soil Nutrient Fertility

The application of biochar to degraded agricultural soils in the USA is considered beneficial for simultaneously improving soil fertility while sequestering C as a means of reducing anthropogenic emissions of CO₂ to the atmosphere (Laird, 2008). Biochar amendments enhance soil fertility by adding a highly stable form which contributes CEC and adsorbs both nutrients and less stable biogenic humic materials. Biochar addition increases the fertility status and pH of soils because the biochar contains inorganic components (e.g., Ca, K, Mg, P, etc.) that act as liming agents and supply plant available nutrients (Glaser *et al.*, 2001; Glaser *et al.*, 2002; Chan *et al.*, 2007b; Novak *et al.*, 2009).

When creating biochar, 50% of the original carbon in the biomass is captured and stored in the char. Human experimentation thousands of years ago revealed that biochar is a great soil amendment, increasing the productivity of most soils. High rates of biochar addition in the tropical environment have been associated with increased plant uptake of P, K, Ca, Zn and Cu (Lehmann and Rondon, 2006). In contrast to mainstream chemical fertilizer, biochar also contains bioavailable elements such as selenium that could be essential for enhancing crop growth. The application of biochar might not result in greater yields in the short term; but it is possible to achieve predictability in yield through lower susceptibility during flood or drought (Sohi *et al.*, 2009).

Biochar from herbaceous and woody feedstock sources are found to have a carbon content of 60.5%-66.7% and 74.5%-80% respectively (Galinato and Yoder, 2010). These figures show that for every ton of biochar applied to the soil, 0.61 to 0.80 ton of carbon (equivalent to 2.2-2.93 tons of CO₂) can be sequestered (Collins, 2008). This fertilizer effect could be explained by a stimulation of soil microorganisms that consequently lead to an increased recycling of nutrients trapped in biomass residues. Any fertilizer effect of these biochars will be the biggest direct benefit after biochar addition to the soils and the carbon storage functions will gain importance in the longer term (Steinbeiss *et al.*, 2009).

From reported application rates in studies of fertility and crop growth, positive effects of biochar applied ranged from 10 to 100 Mg ha⁻¹ for low or moderate nutrient feedstock in tropical and subtropical soil (Chan *et al.*, 2007a; Steiner *et al.*, 2007; Novak *et al.*, 2009 ; Gaskin *et al.*, 2010). It has also been observed in several studies that biochar addition to soils improved soil fertility and thus increased crop yields on agricultural lands (Marris, 2006; Chan *et al.*, 2007a, 2007b).

2.4.2 Soil Microbial Activity

Recent studies suggest that biochar may, under certain circumstances, have a positive effect on the occurrence of mycorrhizal fungi populations and their association with plant root systems. Since mycorrhizal fungi are critical and ubiquitous components of terrestrial ecosystems that can have dramatic beneficial effects on plant productivity, there is significant interest in the effect of biochar on these special soil fungi.

Tryon (1948), Matsubara *et al.* (2002), DeLuca *et al.* (2006), and Gundale and DeLuca (2006) demonstrated that biochar additions can change soil nutrient availability by affecting soil physico-chemical properties. Increases in soil nutrient availability may result in enhanced host plant performance and elevated tissue nutrient concentrations in addition to higher colonization rates of the host plant roots by arbuscular mycorrhizal fungi (Ishii and Kadoya, 1994). Biochar can also increase the ability of arbuscular mycorrhizal fungi (AMF) to assist their host in resisting infection by plant pathogens (Matsubara *et al.* 2002).

Soil microbial diversity and population size, as well as population composition and activity, may be affected by the amount and type of biochar present or added to the soil. On the other hand, microorganisms are able to change the amount and properties of biochar in soil (Lehmann and Rondon, 2006). Both effects will have significant influence on nutrient cycles and nutrient availability to plants. Pietikainen *et al.* (2005) found greater bacterial growth rate in layers of charcoal than in the underlying organic horizon in a temperate forest soil. A higher retention of microorganisms in biochar soils may be responsible for greater activity and diversity due to a high surface area as well as surface hydrophobicity of both the microorganisms and biochar.

Mycorrhizal fungi are an important but often overlooked aspect of soil plant production and soil formation. Mycorrhizal fungi establish mutualistic relationships with the plants. Most often this relationship is symbiotic in which both the plant and fungi benefit from one another. However it can also be parasitic with the fungi benefiting to the detriment of the plant where extremely low levels of phosphorus or other nutrients are available. The interaction is such that the plant provides energy rich carbohydrates made from photosynthesis to the fungi which the fungi could not otherwise obtain. In exchange the fungi shoot form a web of hyphae that extend the reach of the plant's roots and funnel water and nutrients from the soil to the plant. The nutrients delivered to the plants are typically phosphorus (P), copper (Cu), and zinc (Zn), the most important being the phosphorus (Lard, 2008).

The extent of this relationship is vast with approximately 90% of all terrestrial land plants having associations with mycorrhizal fungi and 66% of terrestrial land plants having associations with the most common soil fungi which are AMF. From the

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