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Role of Biochar: In agriculture sector its implication and perspective

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Abstract

Modern agriculture is leading mining of nutrients and reduction in soil organic matter levels through repetitive harvesting of crops. Declining fertility status of soil is now becoming primary concern for growing of the crops. This decline of the soil continues until management practices are improved, additional nutrients are applied, rotation with nitrogen fixing crops is practiced, or until a fallow period occurs allowing a gradual recovery of the soil through natural ecological development. Soil health is the foundation of a vigorous and sustainable food system. Plants obtain their nutrition from organic matter and minerals present in soils. As the land is cultivated, the agricultural process disturbs the natural soil systems including nutrient cycling and the release and uptake of nutrients. As the natural stores of the most important nutrients for plant growth decline in the soil, growth rates of crops are inhibited. The most widespread solution to this depletion is the application of soil amendments in the form of fertilizers containing the three major nutrients: nitrogen, phosphorus, and potassium. Among these nutrients, nitrogen is considered the most limiting for plant growth. Nitrogen builds protein structures, hormones, chlorophyll, vitamins, and enzymes, and promotes stem and leaf growth. Biochar may be added to soils with the intention to improve the soil health, improve soil fertility, and sequester carbon. However, the variable application rates, uncertain feedstock effects, and initial soil state provide a wide range of cost for marginally improved yield from biochar additions, which is often economically impracticable. The need for further research on optimizing biochar application to improve crop yields.

Keywords: Biochar; Soil health; Soil fertility; Nutrients; Carbon

Introduction

India has to produce 300 Mt of food grains by 2020 to feed growing population. The net cultivated land (142.5 M ha) is limited and pressure for production of food grains is increasing, therefore, maintenance of soil fertility is a prime issue for farmers. To achieve the above food demand, 45 million tonnes nutrients are required in which 35 Mt is estimated to be supplied by chemical fertilizer and remaining by organic sources Anonymous (2012-13). The present day agriculture is facing a problem of continuous decline in soil nutrients reserve and decrease in organic matter content of soil. This may be due to intensive cropping system coupled with limited application of FYM, green manure, vermicompost and crop residue in the field (Jatav *et al*., 2016) [15]. This intensification of agricultural production on a global scale is necessary in order to secure the food supply for an increasing world population. As a result, fallow periods are often reduced in shifting cultivation in the humid tropics leading to irreversible soil degradation and increased destruction of remaining natural forests due to cultivation of new areas after slash and burn (Vosti *et al*. 2001) [32]. Natural organic biomass burning creates black carbon which forms a considerable proportion of the soil's organic carbon. Due to black carbon's aromatic structure it is recalcitrant and has the potential for long term carbon sequestration in soil. Soils with in the Amazon basin contain numerous sites where the '*dark earth of the Indians'* (Terra preta de Indio, or Amazonian Dark Earths (ADE)) exist and are composed of variable quantities of highly stable organic black carbon waste ('biochar') Utomo (2010) [29]. The apparent high agronomic fertility of these sites, relative to tropical soils in general, has attracted interest. Biochar can be produced by 'baking' organic matter under low oxygen (Pyrolysis). The quantities of key mineral elements within these biochar can be directly related to the levels of these components in the feedstock prior to burning (Lehmann 2006) [20]. Their incorporation in soils influences soil structure, texture, porosity, particle size distribution and density. The molecular structure of biochar shows a high degree of chemical and microbial stability.

A key physical feature of most biochar is their highly porous structure and large surface area. This structure can provide refugia for beneficial soil micro-organisms such as mycorrhizae and bacteria, and influences the binding of important nutritive cations and anions. This binding can enhance the availability of macro-nutrients such as N and P. Other biochar soil changes include alkalization of soil pH and increases in electrical conductivity (EC) and cation exchange capacity (CEC). Ammonium leaching has been shown to be reduced, along with N_2O soil emissions. There may also be reductions in soil mechanical impedance. Terra preta soils contain a higher number of 'operational taxonomic units' and have highly distinctive microbial communities relative to neighboring soils Zwieten *et al*., 2007 [30]. The potential importance of biochar soil incorporation on mycorrhizal fungi has also been noted with biochar providing a physical niche devoid of fungal grazers. Improvements in soil field capacity have been recorded upon biochar additions.

Biochar and effect on soil properties

In general biochar is charcoal produced from plant matter and stored in the soil as a means of removing carbon dioxide from the atmosphere. Rice Husk Biochar used as experimental material. In many place it is considered as a waste material coming form gasifire plant which uses rice husk as fuel. Farmer established rice mills as small scale industries. They burn rice husk under controlled supply of oxygen and obtained smokes are used to mix diesel to get smoke diesel aerosol. Therefore, the fuel efficiency of diesel engine is increased. The remaining incomplete dark black material of rice husk is known as rice husk biochar (RHB). The RHB which was used as research experiment material is shown in figure-1(Jatav *et al*., 2016) [15]. SEM micrographs and associated EDS spectra for mineral phases in poplar wood biochar is in shown in Figure-3. The global production of biochar (black carbon) has been estimated to be between 50 and 270 Tg yr^{-1}, with as much as 80 % of this remaining as residues in the soil (Jha *et al*., 2010) [16]. Total of 9.5 billion tonnes of carbon could potentially be stored in soils by the year 2100 using a wide variety of biochar application programmes (Lehmann, 2007) [21]. Evidence shows that bioavailability and plant uptake of key nutrients increases in response to biochar application, particularly when in the presence of added nutrients. Depending on the quantity of biochar added to soil significant improvements in plant productivity have been achieved, but these reports derive predominantly from studies in the tropics (Lehmann *et al*., 2006) [20]. As yet there is limited critical analysis of possible agricultural impacts of biochar application in temperate regions, nor on the likelihood of utilising such soils as long-term sites for carbon. Systematic potential component of biochar for sustainable management in agriculture is shown in figure-2

Physical Properties

Biochar itself is a porous material thus it can adsorbed and retain huge amount of water. Dugan *et al*. (2010) [9] also reported that the maize stover biochar and saw dust biochar increased the water holding capacity of loamy sand in Ghana when it was applied @ 5, 10 and 15 ton ha.$^{-1}$ WHC increased due to the fact that small pores in biochar retain moisture and there are largely absent in coarse texture soils (Downie *et al.*, 2009) [8]. The increased moisture retention depends on higher porosity of biochar. Soils amendment with biochar is more in effective improving WHC in sandy soils than in loamy and clay soils by improved water holding capacity (Glaser *et al*., 2002) [12]. Pietikainen *et al* (2000) [24] reported that two biochars, one prepared from humus and one from wood, had a higher water-holding capacity (WHC) (2.9 mL g^{-1} dry matter) than activated carbon (1.5mL g^{-1} dry matter). Smaller pores will attract and retain capillary soil water much longer than larger pores (larger than 10µm to20µm) in both the biochar and the soil. During thermal conversion, the mineral and carbon skeleton formed retains the rudimentary porosity and structure of the original material. Microscopy analysis prove the presence of aligned honeycomb-like groups of pores on the order of 10µm in diameter, most likely the carbonaceous skeleton from the biological capillary structure of the raw material (Laine *et al*,1991) [18]. BET surface areas of olive kernel biochars increased with increasing mass loss (burn off) Zabaniotou *et al* (2008) [34], regardless of the activation temperature. Micropores (<2nm in diameter) are responsible for adsorption and high surface area the total pore volume of the biochar will be divided into micro pores (pores of internal diameter less than 2 nm), meso pores (pores of internal width between 2nm and 50nm) and macro pores (pores of internal width greater than 50nm) (Rouquerol *et al*, 1999) [19, 25].

Physicochemical Properties

Soil application of biochar resulted in significant increase in soil pH. Van Zweiten *et al.* (2010) [31] suggested that biochar derived from poultry litter facilitates liming in soil resulting in rise of pH of acidic or neutral soils. Hoshi (2001) [13] in his experiment suggested that the 20 per cent increase in height and 40 per cent increase in volume of tea trees were partly due to the ability of the biochar to maintain the pH of the soil. Such ability is related to the liming value of the biochar. Van Zwieten *et al.,* 2007 [30] reported a nearly 30 to 40 per cent increase in wheat height when biochar produced from paper mill sludge was applied at a rate of 10 t ha^{-1} to an acidic soil but not to a neutral soil.

Chemical Properties

Organic Carbon: The increase in soil organic carbon with application of biochar might have resulted from recalcitrant nature of carbon found in biochar which is largely resistant to decomposition (Lehmann *et al.* 2003) [22]. Utomo (2010) [29] also reported that soil carbon increased significantly over control. Sukartono *et al.* (2011) [27] also reported that biochar application increased soil organic carbon content. Available N, P and K: Applying biochar to forest soils along with natural or synthetic fertilizers has been found to increase the bioavailability and plant uptake of phosphorus (P), alkaline metals and some trace metals (Glaser *et al*, 2002; Lehmann *et al*, 2003; Steiner *et al*, 2008) [12, 22, 26], but the mechanisms for these increases are still a matter of speculation. Lehmann *et al* (2003) [22] demonstrated the ability of biochar to retain applied fertilizer against leaching with resulting increase in fertilizer-use efficiency. In the manufacture of the N-enriched biochar, Day *et al* (2004) [6] suggested that biochar produced at a lower temperature of 400 °C to 500 °C is more effective in adsorbing ammonia than that produced at higher temperatures (700 °C to 1000°).

Biological activity

Ameloot *et al*. (2013) [1] showed that the type of biochar alone has a significant effect on soil enzymatic activity. The quoted authors proved that poultry litter biochar produced at 400 C and amended to soil @ 20 t/ha caused a significant increase in the activity of dehydrogenases. Biochar has positive effect on mycorrhizal association when applied to soil (Warnock *et al*., 2007) [33]. Steiner *et al*. (2007) evaluated the increase in microbial biomass when biochar is applied to soil and its efficacy as measure of CO_2 released per microbial biomass carbon in soil as well as increase in basal respiration. Biochar does not contribute directly for microbial population in soil. Hence higher porosity of biochar creates favourable environment for microbes to make habitat in soil (Thies and Rillig, 2009) [28]. Researchers have suggested that biochar benefits microbial communities by providing suitable habitats for microorganisms that protect them from predation (Pietikainen *et al.,* 2000) [24]. Microbial cells typically range in size from 0.5µm to 5µm, and consist predominantly of bacteria, fungi, actinomycetes and lichens (Lal, 2006) [19]. Algae are 2µm to 20µm (Lal, 2006) [19]. The macro pores present in biochars serve as habitat for microorganisms. The loss of volatile and condensable compounds from biochars and the concomitant relative increase in the organized phase formed by graphite-like crystallites leads to the increase in solid density (or true density) of the round 1.5 g cm-3 to 1.7g cm-3 (Jankowska *et al*, 1991) [14].

Biochar prospects and essential research

The global potential of biochar (non-fuel use charcoal) reaches far beyond *slash and char*. Inspired by the recreation of *Terra Preta*, most biochar research was restricted to the humid tropics. More information is needed on the agronomic potential of charcoal, the potential to use alternative biomass sources (crop residues) and production of by-products to evaluate the opportunities for adopting a biochar system on a global scale. Biochar as soil amendment needs to be studied in different climate and soil types. Today, crop residue biomass represents a considerable problem as well as new challenges and opportunities. A system converting biomass into energy (hydrogen-rich gas) and producing charcoal as a by-product might offer an opportunity to address these problems. Charcoal can be produced by incomplete combustion from any biomass, and it is a by-product of the Pyrolysis technology used for biofuel and ammonia production (Day, *et al*., 2005) [7]. The acknowledgement of biochar as carbon sink would facilitate C-trading mechanisms. Although most scientists agree that the half-life of charcoal is in the range of centuries or millennia, a better knowledge of the charcoal's durability in different ecosystems is important to achieve this goal. An access to the C trade market holds out the prospect to reduce or eliminate the deforestation of primary forest, because using intact primary forest would reduce the farmer's C credits. Fearnside (1997) [10] estimated the above-ground biomass of unlogged forests to be 434 Mg ha^{-1}, about half of which is C. This C is lost if burned in a slash-and-burn scenario and lost at a high percentage if used for charcoal production. The C trade could provide an incentive to cease further deforestation; instead reforestation and recuperation of degraded land for fuel and food crops would gain magnitude. As tropical forests account for between 20 and 25% of the world terrestrial C reservoir (Bernoux, *et al*., 2001) [4], this consequently reduces emissions from tropical forest conversion, which is estimated to contribute globally as much as 25 % of the net CO2 emissions. Today most biomass gasification systems tend to suppress the creation of residuals, like total organic carbon (TOC) and ashes. C-emission trading options and a better knowledge of charcoal as soil additive would add value to these residues. Further, this would facilitate the use of alternative biomass, those which are currently avoided due to their higher TOC residuals. The tarry vapors constitute a significant loss of carbon during carbonization (Antal and Gronli, 2003) [3], although representing another valuable product. Despite a lack of research, 4 Christoph Steiner these condensed vapors are used for agricultural purposes mainly in Asia and Brazil (GERAIS, 1985; Glass, 2001) [11]. Japanese researchers attempt to produce charcoal with a specific pore size distribution to favor desired microorganisms (Okimori pers. communication). Pore structure, surface area, and adsorption properties are strongly influenced by the peak temperature during charcoal production (Antal and Gronli, 2003) [3]. Increasing porosity is achieved with increasing temperature but the functional groups are gradually lost. In this context, it is also important to discern the mechanisms of nutrient retention (mainly N) due to charcoal applications. The charcoal's low biodegradability (Kuhlbusch and Crutzen, 1995), low nutrient content (Antal and Gronli, 2003) [3], and high porosity and specific surface area (Braida, *et al*., 2003) [5] makes charcoal a rather exceptional SOM constituent. *Terra Preta* research has shown that oxidation on the edges of the aromatic backbone and adsorption of other organic matter to charcoal is responsible for the increased CEC, though the relative importance of these two processes remains unclear (Liang, *et al*., 2006) [23].

Conclusion

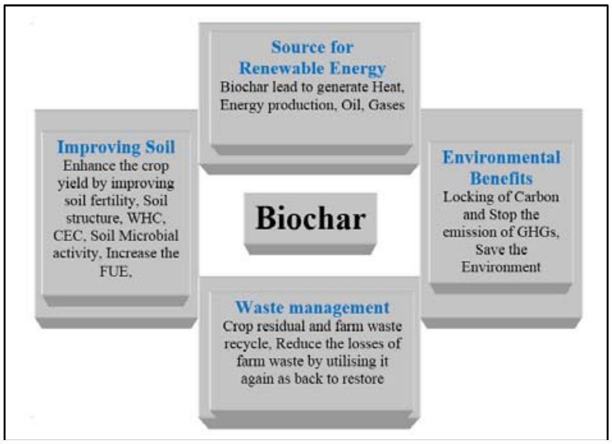
Energy from crop residues could lower fossil energy consumption and CO_2-emissions, and become a completely new income source for farmers and rural regions. The biochar byproduct of this process could serve to recycle nutrients, improve soils and sequester carbon. A review by Johannes Lehmann (2006) [20] and the article "*Black is the new green*" emphasize the potential of biochar on a global scale. A global analysis by Lehmann, *et al*. (2006) [20] revealed that up to 12% of the total anthropogenic C emissions by land use change (0.21 Pg C) can be off-set annually in soil, if slash and burn is replaced by slash and char. Agricultural and forestry wastes add a conservatively estimated 0.16 Pg C yr^{-1}. If the demand for renewable fuels by the year 2100 was met through pyrolysis, bio-char sequestration could exceed current emissions from fossil fuels (5.4 Pg C yr^{-1}). The described mixture of driving forces and technologies has the potential to use residual waste carbon-rich residues to reshape agriculture, balance carbon and address nutrient depletion.

Table 1: Physico- chemical characteristics of Rice husk biochar

Properties	**Biochar**
Colour	2.5 YR 2.5/0 (Black)
Bulk density (Mg m^{-3})	0.40
Porosity	72%
Particle density (Mg m^{-3})	1.40
Available WHC (Using keens box)	218%
pH (H_2O) 1:2.5	9.5
pH (0.01M $CaCl_2$) 1:2.5	9.4
pH (0.01M $CaCl_2$) 1:5	9.3
EC (dSm^{-1})	2.56
Organic carbon (%)	4.80
Ca & Mg (mg kg $^{-1)}$	0.21
Na (mg kg $^{-1}$)	0.35
Total N (%)	0.10
Total P (%)	0.15
Total K (%)	0.20
DTPA Extractable Metal (mgkg^{1})	
Ni	Not Detected
Cr	Not Detected
Pb	Not Detected
Cd	Not Detected

Source: Jatav *et al*., 2016 [15]

Fig 1: Experimental material Rice husk Biochar (Jatav *et al*., 2016) [15]



Source for Renewable Energy
Biochar lead to generate Heat, Energy production, Oil, Gases

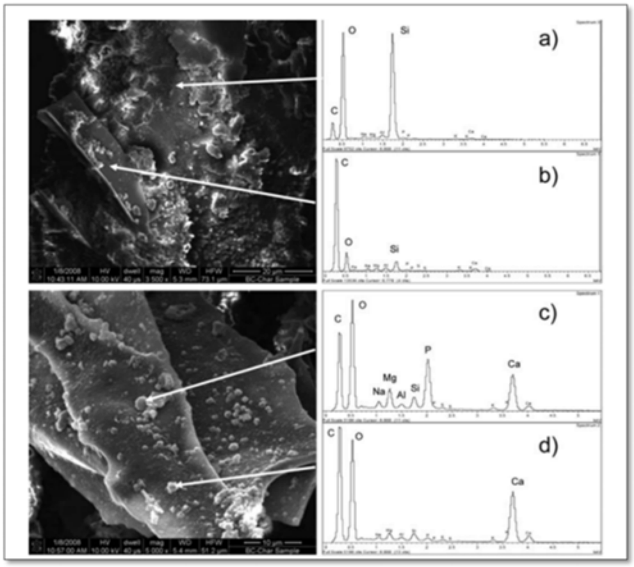
Improving Soil
Enhance the crop yield by improving soil fertility, Soil structure, WHC, CEC, Soil Microbial activity, Increase the FUE,

Biochar

Environmental Benefits
Locking of Carbon and Stop the emission of GHGs, Save the Environment

Waste management
Crop residual and farm waste recycle, Reduce the losses of farm waste by utilising it again as back to restore

Fig 2: Systematic potential component of biochar for sustainable management in agriculture



Source: micrographs taken at the Environmental Molecular Sciences Laboratory, Richland, W.A.

Fig 3: SEM micrographs and associated EDS spectra for mineral phases in poplar wood biochar from a combustion facility: probable minerals include (a) amorphous $SiO2$; (b) trace dehydroxylated silicates (mostly char); (c) $Ca_{10} (PO_4)6(OH)_2$, $CaHPO_4$; and (d) CaO, $CaCO_3$

References

1. Ameloote NR, Graber FGA. Verheijen, Deneve S. Interactions between biochar stability and soil organisms: review and research needs. Eur. J Soil Sci. 2013; 64:379-390. doi: 10.1111/ejss.12064.
2. Anonymous Agriculture statistics at a glance. Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi, 2012-13.
3. Antal MJ, Gronli M. The Art, Science, and Technology of Charcoal Production. *Ind. Eng. Chem. Res*., 2003; 42:1619-1640 doi**:** 10.1021/ie0207919.
4. Bernoux M, Graca PMA, Cerri CC, Fearnside PM, Feigl BJ, Piccolo MC. In The biogeochemistry of the Amazon Basin; McClain, M. E.; Victoria, R. L. and Richey, J E., Ed. Oxford University Press: New York, 2001, 165-184.
5. Braida WJ, Pignatello JJ, Lu YF, Ravikovitch PI, Naimark AV, Xing BS. Sorption hysteresis of benzene in biochar particles. Environmental Science & Technology, 2003; 37(2):409-417.
6. Day D, Evans RJ, Lee JW, Reicosky D. ‘Valuable and stable co-product from fossil fuel exhaust scrubbing’, *Prepr. Paper* - American Chemical Society Div. Fuel Chemistry. 2004; 49:352-355.
7. Day D, Evans RJ, Lee JW, Reicosky D. Energy. 2005; 30:2558-2579.
8. Downie A, Crosky A, Munroe P. Physical Properties of Biochar (Chapter 2), in: J. Lehmann and S. Joseph (Eds.), Biochar for Environmental Management: Science and Technology. 2009.
9. Dugan E, Anne Verhoef, Steve Robinson A, Saran Sohi. Biochar from sawdust, maize stover and charcoal: Impact on water holding capacities (WHC) of three soils from Ghan. (2010) 19th World Congress of Soil Science, Soil Solutions for a Changing World.1 - Brisbane, Australia. Published on DVD. 2010, 9-12.
10. Fearnside PM. Greenhouse gases from deforestation in Brazilian Amazonia: Net committed emissions. Clim. Change. 1997; 35:321-360.
11. Gerais fCTDM. Sti/cit, Brasilia, Documentos 1985; 23:18.
12. Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - A review. *Biol. Fert. Soils,* 2002; 35:104-120.
13. Hoshi T. Growth promotion of tea trees by putting bamboo charcoal in soil, in Proceedings of 2001 International Conference on Ocha (Tea) Culture and Science, Tokyo, Japan, 2001, 147-150.
14. Jankowska H, Swiatkowski A, Choma J. Active Carbon (Chichester, West Sussex: Ellis Horwood), 1991.
15. Jatav HS, Singh SK, Singh YV, Paul A, Kumar V, Singh P *et al*. Effect of Biochar on Yield and Heavy Metals Uptake in Rice Grown on Soil Amended with Sewage Sludge J Pure Appl. Microbio. 2016; 10(2):1367-1377.
16. Jha Pramod B, Lakaria AK, BL, Subba Rao. A. Biochar in agriculture - prospects and related Implications. Current Science. 2010; 99:1218-1225.
17. Kuhlbusch TAJ, Crutzen PJ. Toward a global estimate of black carbon in residues of vegetation fires representing a sink of atmospheric CO_2 and a source of O_2. *Global Biogeochem. Cy*. 1995; 9:491-501.
18. Laine J, Simoni S, Calles R. Preparation of activated carbon from coconut shell in a small scale concurrent flow rotary kiln, Chem. Eng. Commun. 1991; 99:15-23
19. Lal R. Encyclopedia of Soil Science, CRC Press, Boca Raton, FL Rouquerol, F., Rouquerol, I. and Sing, K. *Adsorption by Powders and Porous Solids*, Academic Press, London, UK, 1999, 2006.
20. Lehmann J. A handful of carbon. Nature. 2006; 447:143-144.

21. Lehmann J. Bioenergy in the black. Frontiers in Ecology and Environment. 2007; 5:38-387.
22. Lehmann J, da Silva JP, Steiner C, Nehls T, Zech W, Glaser B. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: Fertiliser, manure and charcoal amendments, *Plant and Soils*, 2003; 249:343-357.
23. Liang B, Lehmann J, Solomon D, Grossman J, O Neill B, Skjemstad JO *et al*. Black Carbon Increases Cation Exchange Capacity in Soils. *Soil Sci. Soc. Am. J.*, 2006; 70:1719-1730.
24. Pietikainen J, Kiikkila O, Fritze H. Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus', *Oikos*. 2000; 89:231-242.
25. Rouquerol F, Rouquerol J, Sing K. Adsorption by powders and porous solids. Principles, methodology and application, Published Academic Press, ISBN 0-12-598920- 2, London, 1999.
26. Steiner C, Das KC, Garcia M, Forster B, Zech W. 'Charcoal and smoke extract stimulate the soil microbial community in a highly weathered xanthic Ferralsol', *Pedobiologia*, 2008; 51:359-366.
27. Sukartono, Utomo WH, Kusuma Z, Nugroho WH. Soil Fertility Status, Nutrient Uptake, and Maize (*Zea mays* L.) Yield Following Biochar and Cattle Manure Application on Sandy Soils of Lombok, Indonesia. J of Trop. Agri. 2011; 49:47-52.
28. Thies JE, Rillig MC. Characteristics of Biochar-Biological Properties (Chapter 6), in: J. Lehmann and S. Joseph (Eds.), Biochar for Environmental Management: Science and Technology, *Earthscan*, London, UK, 2009, 85.
29. Utomo WH. Rice husk biochar for rice based cropping system in acid soil. The characteristics of rice husk biochar and its influence on the properties of acid sulphate soils and rice growth in West Kalimantan, Indonesia. J of Agri. Sci. 2010; 2(1).
30. Van Zwieten L, Kimber S, Downie A, Chan KY, Cowie A, Wainberg R *et al*. Papermill char: Benefits to soil health and plant production', in Proceedings of the Conference of the International Agrichar Initiative. 30 April-2 May 2007, Terrigal, NSW, Australia, 2007.
31. Van Zwieten L, Kimber S, Morris S, Chan KY, Downie A, Rust J *et al*. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant and Soil. 2010; 327:235-246.
32. Vosti SA, Carpentier CL, Witcover J, Valentim JF. Intensified small-scale livestock systems in the western Brazilian Amazon. In: Angelsen A, Kaimowith D (eds) Agricultural technologies and tropical deforestation. CABI, Wallingford, UK. 2001, 113-133.
33. Warnock DD, Lehmann J, Kuyper TW, Rillig MC. Mycorrhizal responses to biochar in soil - concepts and mechanisms. Plant and Soil. 2007; 300:9-20.
34. Zabaniotou A, Stavropoulos G, Skoulou V. Activated carbon from olive kernels in a two-stage process: Industrial improvement', *Bioresource Technology*, 2008; 99:320-326.