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Improving Soil Productivity Through Charred Biomass Amendment to Soil

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Abstract: Soil-fertility management is crucial for maintaining or increasing the yield. Application of charred biomass to soil seems to be a positive impact on soil fertility and crop growth. We investigated the effect of charred biomass (CB) addition on selected soil properties and yield of beet root (*Beta vulgaris*) through laboratory incubation and green house studies. Treatments were T_0 (control), T_1 (CB), T_2 (NPK fertilizer) and T_3 (Combination). Complete randomized design was used with three replicates for incubation experiment and four replicates for pot trial. Results of incubation experiment with different treatments indicated that pH of soil significantly increased in T_1 (CB) and decreased in T_2 (NPK fertilizer). EC was significantly increased in NPK fertilizer followed by T_3 (Combination). Available N was significantly higher in T_2 (NPK fertilizer) followed by T_3 (Combination) and T_1 (CB). Available P, Available K, Cation exchange capacity and microbial biomass carbon were significantly increased in T_1 (CB) compared with other treatments. Results of pot experiment showed that leaching loss was lowest in CB treated pots. The yield of beet root was increased by 156.36%, 60.41% and 126.43% in T_1 (CB), T_2 (NPK fertilizer) and T_3 (Combination) respectively compared to control. Results therefore indicate that addition of charred biomass has potential to increase the yield of beet root through improving soil properties and reducing leaching losses of both nitrate and ammonium.

Key words: Charred biomass · Available nutrients · Microbial biomass · Cation exchange capacity · Yield

INTRODUCTION

Due the decline in soil productivity as a result of continuous cultivation, Crop yields continue to decline on farmers fields and there is a huge gap between potential crop yields and actual crop yields. In the context of agriculture, as demand for food increases, current agricultural lands are over-fertilized in the attempt to raise soil productivity, while the expansion of the agricultural frontier signifies more pasture lands and forests converted into new cultivation areas, soon to be over-fertilized. A higher-than-optimal application to soil leads to loss of reactive nitrogen into the environment, causing pollution to soil, water and land. Due to intensive cultivation of annual crops in Jaffna peninsula, the nitrate-nitrogen levels exceeds WHO recommended levels [1]. To achieve food sufficiency, there is the urgent need to address the soil infertility problem. The use of organic sources to improve soil fertility also had limited success due to the bulkiness of the organic inputs, slow rate of action and low availability as they have alternative uses like for fuel, for livestock feeding, building materials etc. The Integrated Soil Fertility Management (ISFM) which combines the application of inorganic fertilizers and organic fertilizers for crop production has been proposed by Vanlauwe *et al*. [2]. However, the quality of organic inputs in terms of N, lignin and polyphenols has been suggested to influence the decomposition of organic inputs [3]. High quality materials are expected to decompose rapidly to release plant nutrients to synchronize with crop demands. Low quality materials on the other hand are expected to first immobilize soil nutrients and then subsequently release it gradually for crop demand. The decomposition of organic sources release gases green house gases like CO_2, methane, N_2O. Global concerns for climate change thus necessitate the search for agricultural management practices that can be used to achieve food security and at the same time contribute to adaptation and mitigation of climate change. Biochar, a product obtained from pyrolysis of woody materials may provide such a management practice [4]. Applied as a soil enhancer, the highly organic carbon-

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intensive biochar improves the structure, water retention capacity, fertility and carbon sequestration of degraded soils. The enhanced nutrient retention capacity of the soil reduces the total fertilizer requirements and also the environmental damage associated with fertilizers, including N_2O emissions, fertilizer runoff into surface waters and nitrogen leaching into groundwater. Further and most importantly, biochar locks up rapidly decomposing carbon in plant biomass in a much more durable form, with most of it remaining in the soil for orders of magnitudes longer than any other organic amendments. This means that biochar offers a long-term sink for the purposes of reducing carbon dioxide emissions from the atmosphere, making chance to turn bioenergy into a carbon-negative industry [5]. The use of biochar could allow the total soil organic carbon (SOC) sequestered in soils to be several magnitudes larger than is naturally possible. Again, it is relatively simple to verify for national carbon accounting and is more resistant to climate than the conventional SOC [6]. Carbon trading that include agricultural soil sequestration will enable farmers to trade their sequestered biochar soil applications and facilitate the expansion of a range of new technologies that improve farm productivity, energy security, with potential for large positive environmental outcomes.

On this background experiments were conducted with the following objectives:

- Study the effect of charred biomass application alone and in combination with inorganic fertilizers on selected properties of soil of kondavil belonging to Inuvil series of Jaffna peninsula.
- Study the effect charred biomass application alone and in combination inorganic fertilizers on yield of Beet root crop in Inuvil series.

MATERIALS AND METHODS

Soil Sampling: For this study, soil samples were collected from Kondavil area belonging to Inuvil series in Jaffna peninsula. Table 1 shows some selected physical and chemical properties of the soils. The top 0 - 15 cm was sampled and all plant debris was removed. The samples were air-dried and sieved through a 2 mm mesh size.

Charred Biomass Production: The charred biomass used in the study was obtained from bakery. It was produced from fire wood under “kiln”. The chemical compositions of the charred biomass were: Organic C, 6.48%; Total Nitrogen 2.1%; Available nitrogen, 17.1 mg/kg; Total $P_2 0_5$, 412.82 mg/kg; K_2O, 11750.68 mg/kg. The char was ground and applied to soil.

Table 1: selected properties of soil used for study

Characters	
Texture	Sandy loam
Sand (%)	76.86
Silt (%)	7.71
Clay (%)	15.43
pH (1:5 / soil: water)	7.4
EC (dS/m)	0.156
Total N (mg/kg)	728
Available N (mg/kg)	8.05
Available P (Kg/ha)	134.49
Available K (Kg/ha)	742.25
CEC (c mol $_{(+)}$/ Kg of soil)	8.7
Organic matter (%)	0.938

Greenhouse Study: The study was carried out at the Department of Agricultural Chemistry, University of Jaffna. The experimental design was completely randomized design and each treatment was replicated four times. The treatments were:

- Control (T_0)
- Charred biomass (T_1)
- Inorganic fertilizers (NPK) (T_2)
- Charred biomass mixed with inorganic fertilizers (T_3)

Nitrogen and Phosphorus were applied as basal and top dressing to all treatments at the rate of 330 and 395 kg/ha respectively. Nitrogen was applied in the form of urea while Phosphorus was in the form of triple super phosphate. Potassium was applied in the form of muriate of potash as basal at the rate of 125 kg/ha. The amendments were thoroughly mixed with the soil. Charred biomass was applied at 20 tons/ha. In T_3 both amendments were applied half of T_1 and T_2. The soils were kept at field capacity throughout the period of the study. Crimson Glob beetroot variety was used as the test crop. The beetroot was planted at 3-seeds per pot and thinned to 1 after one week of planting. Pots were arranged on plastic container and excess water was applied to collect leachate third and sixth week after planting. Nitrate content in collected leachate was determined by colorimetric method [7]. Beetroot from each pot was harvested after three months. The harvested beet root fresh weight, diameter of tuber and dry matter content was analyzed separately.

Incubation Study: 250g of air-dried soil was placed in transparent plastic bottles. Complete randomized design was used with four treatments and three replicates. The treatments were control (T_0), CB (T_1), NPK fertilizers (T_2) and ½ CB + ½NPK fertilizers (T_3). Inorganic fertilizers were applied at following rate: urea 165kg/ha, TSP 270kg/ha and MOP 125kg/ha. CB was applied at the rate of 20 t/ha. In T_3 (Combination), CB and NPK fertilizers were applied at half of T_1 and T_2 rate.

Soil Analysis: pH and Ec, were measured at two weeks interval until two months of incubation. Available K, N and P were measured after 2 weeks. Soil pH was determined in distilled water using a soil: solution ratio of 1: 5. Total N and available N were determined using the method of Bremner Mulvaney [8]. Available phosphorus was determined using the method of Olsen and Sommers [9]. Available K was measured by flame photometer [10].

Statistical Analysis: Results were analyzed by SAS package and the mean separation was done by LSD at p=0.05.

RESULTS AND DISCUSSION

Incubation Experiment

Soil pH: At second week significantly higher pH was recorded in T_1(CB) followed by T_3 (½ biochar + ½ NPK fertilizer) while lowest pH was recorded in T_2 (NPK fertilizer) (Figure 1). All treatments were significantly different. Similar trend was observed throughout the incubation period (Figure 1). Verheijen *et al.* [11] and Chan and Xu [12] discussed that biochar increases the pH of soil due to its higher pH and also it contains varying concentrations of ash alkalinity that is directly added into the soil as Ca, Mg, K and Na oxides, hydroxides and carbonates. Inorganic fertilizers decrease the soil pH after application due to acidification resulting from dissociation of urea to produce H^+ ions [13].

Electrical Conductivity: Until eighth week significantly highest EC was recorded in T_2 (NPK fertilizer) and lowest in T_0 (control) (Figure 2). EC of T_3 (Combination) and T_1(CB) were not differ significantly. Electrical conductivity decreased with time in all treatments. The reason may be the soluble nutrient content of inorganic fertilizers increased EC in T_2. Immobilization of nutrients, ammonia volatilization and adsorbtion by clay particles due to increased CEC would have contributed to reduced EC with time).

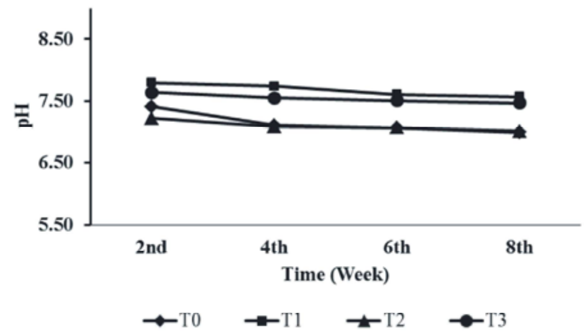

Fig. 1: Effect of different treatment on pH with time. T_0 – control, T_1 – CB, T_2 – NPK fertilizer, T_3 – Combination.

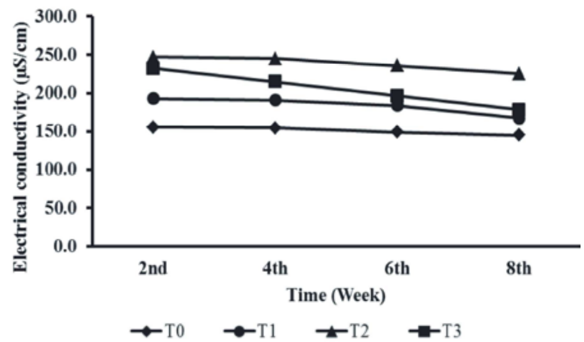

Fig. 2: Effect of different treatment on electrical conductivity with time. T_0 – control, T_1 – CB, T_2 – NPK fertilizer, T_3 – Combination.

Available Nutrients (N, P and K): Available N significantly higher in T_2 (NPK fertilizer) than other treatments (Table 2). However there was no significant difference between T_2 (NPK fertilizer) and T_3 (Combination) and also between T_3 (Combination) and T_1(CB). This may be due to the lower available N content of biochar (Table 2) compared to fertilizer. Biochar increases the N availability through both the direct nutrient additions by the biochar and greater nutrient retention [14] and it can also due to the effect of changes in soil microbial dynamics.

P availability was significantly increased with T_1(CB) and T_3 (Combination) compared to all treatments. All the treatments were significantly higher than T_0 (control) (Table 2). This may be due to the nutrient content in char and microbial activity. Nishio [15] stated that application of charcoal stimulates indigenous arbuscular mycorrhiza fungi in soil and thus promotes plant growth.

Highest available K was recored in T_1(CB) followed by T_3 (Combination) the lowest in T_0 (control) (Figure 3).

Table 2: Effect of different treatments on selected properties of soil

	T_0(control)	T_1(CB)	T_2(NPK fertilizer)	T_3 (combination)
Available N(mg/kg)	7.741 ^{b}	11.250 ^{b}	15.907 ^{a}	11.901 ^{ab}
Available P(kg/ha)	125.5 ^{d}	217.626 ^{a}	131.158 ^{c}	175.377 ^{c}
Available K(kg/ha)	755.012 ^{c}	1038.811 ^{a}	867.461 ^{b}	910.298 ^{b}
Cation exchange capacity (cmol(+)/kg)	8.68^b	9.46^a	8.67^b	9.1^a
Microbial biomass C(µg/g)	925.32^c	1393.57^a	1207.8^b	1108.34^b

Same letters with in rows are not statistically different by the LSD at p=0.05.

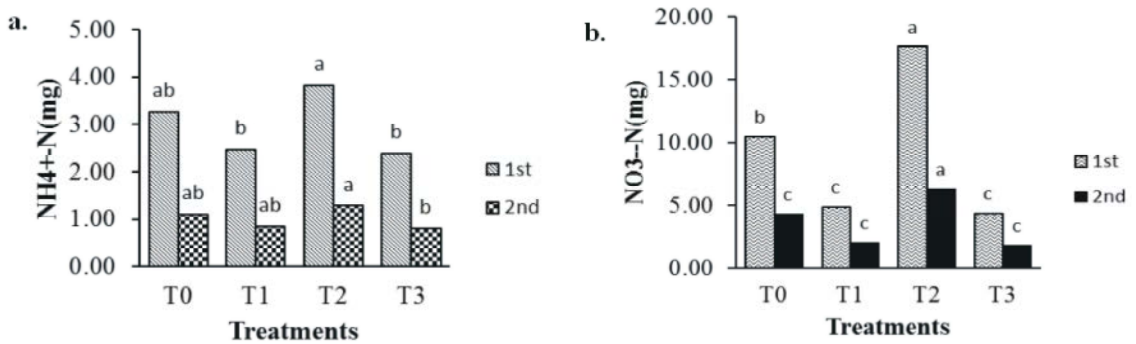

Fig. 3: Effect of different treatment on ammonium a) leaching b) nitrate leaching
T_0 – control, T_1 – CB, T_2 – NPK fertilizer, T_3 – Combination. Bars with same letters within similar column are not statistically different by the LSD at p=0.05.

All treatments were significantly higher compared to T_0 (control). This is due to the higher K content of biochar. The supply of available K in biochar is typically high and increased K uptake as a result of biochar application has been frequently reported [16].

At the end of incubation CEC of soil was significantly high in T_1 (CB) and T_3 (½ biochar + ½ NPK fertilizer compared to other treatments and there was no significant different between T_0 (control) and T_2 (NPK fertilizer) (Table 2). The high specific surface area, oxidation of the biochar itself and adsorption of organic matter to biochar surfaces may contribute to the high CEC found in soils containing biochar [17].

Significantly higher microbial biomass carbon was observed in T_1 (CB) compared to other treatments (Table 2). There was no significant difference between T_3 (Combination) and T_2 (NPK fertilizer). It is generally accepted that biochar-C is largely unavailable to soil microbes, but changes in soil physicochemical properties and the introduction of metabolically available labile-C compounds associated with the biochar may shift the soil microbial community structure [18]. Investigation of this interaction has predominantly shown that the soil microbial biomass and/or microbial activity have increased with biochar additions [19]. It has been hypothesized that biochar can provide a microbial refuge due to its porous nature [20].

Pot Experiment

Ammonium and Nitrate Leaching: Highest ammonium leaching was observed in T_2 (NPK fertilizer) and lowest in T_3 (Combination) (Figure 3) during 1st and 2nd analysis. However there was no significant difference between T_3 (Combination) and T_1 (CB). Similar trend was observed in nitrate leaching. The leaching analysis clearly indicates that addtion of biochar reduces the leaching loss of nitrogen either ammonium or nitrate. The biochar application to soil affects nutrient leaching through several mechanisms, by increasing the retention of water in the rooting zone, by directly binding or sorbing nutrients or by interacting with other soil constituents and by facilitating the movement of attached nutrients when fine biochar particles are transported in percolating water [21].

Yield Parameters: Beet root was harvested 90 days after planting. The yield of beet root was increased by 156.36%, 60.41% and 126.43% in T_1 (CB), T_2 (NPK fertilizer) and T_3 (Combination) respectively compared to control. Highest tuber weight was obtained in T_2 (CB) and lowest in T_0 (control) (Figure 4). All the treatments were significantly higher compared to T_0 (control). However there was no significant difference in yield among T_1 (CB) and T_3 (Combination). Similar trend was obtained in the tuber perimeter analysis. In dry matter production anlysis,

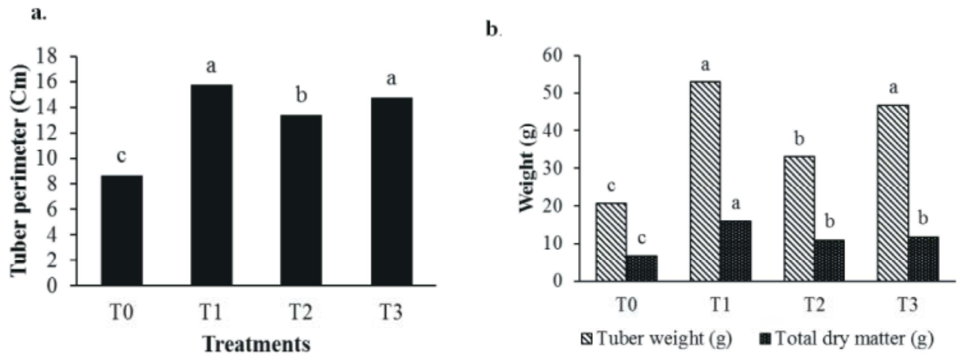

Fig. 4: Effect of different treatment on a) Tuber perimeter b) Tuber weight and dry matter of beet root. T_0 – control, T_1 – CB, T_2 – NPK fertilizer, T_3 – Combination. Bars with same letters are not statistically different by the LSD at p=0.05.

T_1 (CB) was recorded significantly higher followed by T_3 (Combination) and T_2 (NPK fertilizer) compared to control. Therefore result of pot trial indicates that the yield, dry matter and size of beet root were significantly improved by biochar addition. Beneficial effects on crop yields have been also documented in a number of pot and field trials [22, 23, 24, 25 and 26]. Reduction in soil activity, improvements to soil cation exchange capacity (CEC), pH and water holding capacity and improved habitat for beneficial soil microbes are the most likely causes of productivity improvements [27].

CONCLUSION

The charred biomass has ability to improve soil fertility characteristics as well as yield of beetroot. Though charred biomass alone increase the pH initially, with time pH is decreased. T_3 (combination) significantly reduce pH up to 4th week. Charred biomass addition T_1(CB) and T (combination) increase the available N, available K, available P, cation exchange capacity, microbial biomass compared to control. T_3(combination) shows better results compared to T_1(CB). Even though charred biomass addition has the potential to improve fertility of soil, it also increases the pH of the soil when applied alone. Appling charred biomass mixed with inorganic fertilizer could overcome this effect. Results of pot trial exposed that leaching loss was reduced and yield, dry matter and size of beet root were significantly increased due to the addition of CB. Results therefore reveal that addition of charred biomass has potential in terms of increasing the yield of beet root through improving the soil fertility parameters in tested soil series.

Suggestions: It is suggested that experiments be carried out to study the effect of biochar under real field conditions with wide range of crops. Further research is needed to study the appropriate biochar rate to obtain optimum yield. Soil microbial study in relation to biochar addition is also suggested.

REFERENCES

1. Nagaraja, S., B.N. Emerson, V. Abeykoon and S. Yogalingam, 1988. Water quality of wells in Jaffna and Kilinochchi districts. Tropical Agriculturist, 144: 15-20.
2. Vanlauwe, B., 2004. Integrated Soil Fertility Management Research at TSBF: the framework, the principles and their application In: A. Bationo, (ed.). Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Academy Science Publishers, Nairobi, Kenya, pp: 324.
3. Palm, C.A., C.N. Gachengo, R.J. Delve, G. Cadisch and K.E. Giller, 2001. Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. Agric. Ecosyst. Environ., 83: 27-42.
4. Glasser, B., J. Lehmann and W. Zech, 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal-a review. Biol Fertil Soils, 35: 219-230.
5. Lehmann, J., 2007. A handful of carbon. Nature, 447: 143-144.
6. Lehmann, J., J. Gaunt and M. Rondon, 2006. Biochar sequestration in terrestrial ecosystems. Mitig. Adapt. Strat. Glob. Change, 11: 395-419.

7. Vendrell, P.F. and J. Zupanii, 1990. Determination of soil nitrate by transnitration of salicylic acid. Comm. soil science and plant analysis, 21: 1703-1705.
8. Bremner, J.M. and C.S. Mulvaney, 1982. Nitrogen-Total. In: Methods of soil analysis part 2 Chemical and microbiological properties, Agronomy monograph no.9, 2nd edition, Page, A.L., Miller, R.H. and Keeney, D.R. (Eds.), ASA-SSSA, Madison, Wisconsin, USA., pp: 595-616.
9. Olsen, S.R. and L.E. Sommers, 1982. Phospherous. In: Methods of soil analysis part 2 Chemical and microbiological properties. 2nd edition, Agronomy monograph no.9. Page, A.L., R.H. Miller and Keeney, D.R. (Eds.), ASA-SSSA, Madison, Wisconsin, USA., pp: 404-407.
10. Knudsen, Pratt and Peterson, 1982. Lithium, sodium and potassium. In: Methods of soil analysis part 2 Chemical and microbiological properties, 2nd edition, Agronomy monograph no.9, A.L. Page, R.H. Miller and D.R. Keeney, (Eds.), ASA-SSSA, Madison, Wisconsin, USA, pp: 228-230.
11. Verheijen, F., S. Jeffery, A.C. Bastos, M. Van der Velde and I. Diafas, 2010. Biochar Application to Soils: A Critical Scientific Review of Effects of Soil Properties, Processes and Functions, JRC Scientific and Technical Reports*,* EUR 24099, 2010.
12. Chan, K.Y. and Z.H. Xu, 2009. Biochar-Nutrient properties and their enhancement. In: Biochar for Environmental Management: Science and Technology (eds. J. Lehmann and S. Joseph). Earthscan Ltd. London.
13. Yeboah, E., P. Ofori, G.W. Quansah, E. Dugan and S.P. Sohi, 2009. Improving soil productivity through biochar amendments to soils. African Journal of Environmental Science and Technology, 3(2): 034-041.
14. Lehmann, J., D. Kern, L. German, J. McCann, G. Martins and A. Moreira, 2003b. Soil fertility and production potential. In: Amazonian Dark Earths: Origin, Properties, Management (eds. J. Lehmann, D.C. Kern, B. Glaser and W.I. Woods) Kluwer Academic Publishers, Netherlands, pp: 105-124.
15. Nishio, M., 1996. Microbial fertilizers in Japan. In: National Institute of Agro Environmental Sciences. Ibaraki. Japan.
16. Lehmann, J., J.P. da Silva, C. Steiner, T. Nehls, W. Zech and B. Glaser, 2003a. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. Plant Soil, 249: 343-357.
17. Liang, B., J. Lehmann, D. Solomon, J. Kinyangi, J. Grossman, B. O'Neill, J.O. Skjemstad, J. Thies, F.J. Luizão, J. Petersen and E.G. Neves, 2006. Black Carbon Increases Cation Exchange Capacity in Soils. Soil Sci. Soc. Am. J., 70: 1719-1730.
18. Condron, L.M., C.R. Anderson, T.J. Clough, A. Stewart, R.A. Hill1 and R.R. Sherlock, 2011. Newzealand 2011 biochar opportunities, risk and acceptance 10-11, Massey university, Palmerson north, NewZealand.
19. Kolb, S.E., K.J. Fermanich and M.E. Dornbush, 2009. Effect of Charcoal Quantity on Microbial Biomass and Activity in Temperate Soils. Soil Science Society of America Journal, 73(4): 1173-1181.
20. Pietikainen, J., O. Kiikkila and H. Fritze, 2000. Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus. Oikos, 89: 231-242.
21. Collison, M., L. Collison, R. Sakrabani, B. Tofield and Z. Wallage, 2009. Biochar and Carbon Sequestration: A Regional Perspective. Low Carbon Innovation Centre, UEA, Norwich.
22. Asai, H., B.K. Samson, H.M. Stephan, K. Songyikhangsuthor, K. Homma, Y. Kiyono, Y. Inoue, T. Shiraiwa and T. Horie, 2009. Biochar amendment techniques for upland rice production in northern Laos. Field Crops Research, 111: 81-84.
23. Chan, K.Y., L. Van Zwieten, I. Meszaros, A. Downie and S. Joseph, 2007. Agronomic values of greenwaste biochar as a soil amendment. Australian Journal of Soil Research, 45(8): 629-634.
24. Chan, K.Y., L. Van Zwieten, I. Meszaros, A. Downie and S. Joseph, 2008. Using poultry litter biochars as soil amendments. Australian Journal of Soil Research, 46(5): 437-444.
25. Major, J., J. Lehmann, M. Rondon and C. Goodale, 2010. Fate of soil-applied black carbon: downward migration, leaching and soil respiration. Global Change Biology, 16: 1366-1379.
26. Van Zwieten, L., S. Kimber, S. Morris, K.Y. Chan, A. Downie, J. Rust, S. Joseph and A. Cowie, 2010. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant and Soil, 327: 235-246
27. Blackwell, P., G. Reithmuller and M. Collins, 2009. Biochar application to soil. In: Biochar for Environmental Management: Science and Technology (eds. J. Lehmann and S. Joseph). Earthscan.