FINAL REPORT for APN PROJECT

Project Reference Number: ARCP2012-20NSY-Musafer

Sustainable Biochar Systems in Developing Countries

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OVERVIEW OF PROJECT WORK AND OUTCOMES

Non-technical summary

This project had aimed to monitor, evaluate and improve sustainability of biochar systems. Therefore, activities were fallen under APN priorities as food securities, resource utilization and climate stability. Furthermore, this will make key players from rural communities to mitigate climate change. Practical Action (Sri Lanka, Nepal) and Earth Net Foundation (Thailand) are the implementers of this project. These organizations have capacitances and disciplines related to the biochar sector. A sustainable biochar system has potential to improve nutrient cycling, crop yields, immobilize trace metals and carbon sequestration. Use of biochar is becoming a much popularly discussed subject in world agriculture today. Its role in carbon sequestration and climate change mitigations are also being discussed extensively. All biochar materials were not nutrient loaded stuffs. Some type of biochar was capable of holding five times the amount of water as its weight. During the field trials crops performed well and out yielded the recommended fertilizers when biochar was applied conjointly with recommended fertilizers. Results revealed that biochar materials could successfully be used to raise the crop productivity when combined with the normal fertilizer practice. The use of biochar materials together with chemical fertilizers can improve the productivity under field growing conditions. Although biochar caused problems when tested in greenhouse in small pots, field application did not immediately affect crop growth negatively particularly at the some application rates. However, care must be taken when using biochar as a soil amendment continuously and also in pot culture. This Project recommends for the application of biochar together with fertilizer for the cultivation of vegetables so as to improve on chemical properties of soil. This combination will reduce the amount of usage of chemical fertilizer. But for determining the best application ratio there is further need of extensive research with more replications.

Keywords
Biochar, Carbon sequestration, Nutrient, Climate change, Soil amendment

Objectives
The main objectives of the project were:
1. To assess availability & suitability of feedstocks for biochar productions under different sustainability criteria
2. To explore and select suitable production technologies
3. Organizing and managing biochar trails to assess the agronomic benefits of biochar for a range of crops, soil types and growing condition
4. To make economic and environmental evaluation of the biochar system trailed in respective countries (Respective countries are Sri Lanka, Nepal & Thailand)

Amount received and number years supported
The Grant awarded to this project was:
US$ 45,000

Activity undertaken
1. Assessing biomass availability to produce biochar
2. Assessing technologies to produce biochar
3. Organizing and managing biochar trails
4. Environment and economic assessments of biochar
5. Produce and disseminate knowledge products and publications
6. Policy influencing

Relevance to the APN Goals, Science Agenda and to Policy Processes

This research will fall under one of the APN's research priority areas, i.e. resources utilization and pathways for sustainable development as it will look for low-cost sources of feedstocks for biochar production without displacing existing markets or land-uses. The work will cover the broader aim of APN by helping to make rural communities more climate resilient as well as helping them to be a key player in climate change mitigation by putting carbon back to soils in a stable form (compared to organic matter additions) potentially for hundreds to thousands of years (Verheijen et. al. 2009).

Self-evaluation

At the beginning, the project activities had slowed down in all partner organizations due to several circumstances. After re-motivation with partner organizations, Practical Action (Sri Lanka, Nepal) could acquire project objectives who had been working on the project from beginning. Earth Net Foundation (Thailand) had reached for some objectives within limitation of time that had joined later on to the project. Sri Lanka and Nepal had done field trials for two crop seasons while Thailand followed upto beginning of one season. So this report has included all the information within this boundary.

Acknowledgments

We are very much thankful to Asia Pacific Network (APN) for Global Change Research for providing research grant to conduct this action research. We would also like to express our sincere thanks to Dr. Linda Stevenson, Ms. Dyota Condrorini, Ms. Taniya Koswatta and all the members of APN for their cooperation and support. Our gratitude also goes to partner Organizations Practical Action Consulting in Sri Lanka, Nepal & Earth Net Foundation in Thailand for their valuable participation for this project.

A special word of thanks for the untiring efforts of Agriculture Research Station, Kalpitiya, where conducted the two field experiments, Horticulture Department (HORDI), Gannoruwa where we conducted the Greenhouse and Laboratory studies in Sri Lanka.

We also are indebted to Central Department of Environmental Science (CDES) for providing us laboratory facility for soil sample analysis of this research work. We are also thankful to Department of Environmental Science for their support during the field data collection in Nepal.

We are grateful to Sanam Chaikhet Organic Farmers' Group and organic farmers of Mae Tha where we did the practice of making biochar in Thailand.

UK Biochar Centre at the University of Edinburg was involved in the design of the project. We would like to appreciate the contributions made specifically by Dr. Ahmed Sohel (now at London) and Dr. Saran Sohi and Dr. Simon Shackley

We would like to appreciate the contributions made by the distinguished experts from the international and national level scientific advisory panels, members of the Policy Innovation Systems for Clean Energy Security Project and the Department for International Development UK for the matching funds provided.

Many others too contributed significantly toward the successful implementation of the project and we are grateful to all of them.

TECHNICAL REPORT

Preface

Practical Action Consulting (PAC) Sri Lanka, Nepal & Earth Net Foundation (ENF) Thailand are carried out the project “Sustainable biochar systems in Developing Countries”. The project mainly focused on sustainable development making rural communities in climate resilient while being a key player in climate change mitigation and resource utilization related to biochar. Project is aimed at exploring whether biochar can be integrated to selected regional settings as an effective long term climate mitigation and adaptation tool in terms of sustainable resource management, waste management, carbon storage and agricultural improvements under different climatic, environmental, socio economic and policy drivers.

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1.0 Introduction

Climate change is one of the major issues that is making adverse impact on human life in the contemporary world. Increase of global warming, extension of the dry season and reduction of rainfall are some of the main impacts that can make agriculture and farmers more vulnerable to climate change. Climate change and the weather change that comes with it can cause increased weeds and pests in cultivation. Further, rapid population growth in the area can cause high demand for food as well. Due to these two facts, farmers tend to use more chemical fertilizer and pesticide for their cultivation in order to increase the harvest. This practice is leading to many health problems and economic problems. Therefore it is essential to have suitable climate and environment friendly farm management practices in the region and less harmful agricultural intensification has been identified as one of the main solutions. With the aim of achieving this, adoption of soil and crop management practices to improve the soil fertility along with sequestering carbon in soil has been recommended for Asia Pacific Region. Introducing biochar system for farming in developing countries in Asia is one of the sustainable solutions to several problems.

1.1 Characteristics of biochar

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 improve soil functions" (Verheijen et al., 2010). It is the carbon rich product obtained when biomass such as wood, manure or leaves, is heated in a closed container with little or no available air. In more technical terms, biochar is produced by thermal decomposition of organic material under limited supply of oxygen at relatively low temperature (<700^{0}C) (Lehmann and Joseph, 2009). Simply it is a material charcoal application to soils.

The concept of biochar draws increased attention in research areas as its result show it being beneficial from the view of environmental protection and economic benefits. Terra Preta soils have been shown to contain black carbon, down to a depth of approximately 1 meter (approximately double the amount relative to pre-existing soil), and these soils are highly fertile when compared to the surrounding soils. This has led to the idea of biochar being applied to soil to sequester carbon and maintain or improve the soil production function (e.g. crop yields), as well as the regulation function and habitat function of soils. Controlled experiments have been undertaken to look at the effects of different application rates of biochar to soils (Verheijen et al., 2010).

Direct and indirect nutrient properties of biochar are expected to increase plant productivity and growth. The technique of using charcoal to improve the fertility of soils originated in the Amazon basin at least 2500 years ago (Kannan et al., 2013). Terra Preta, as it is known in this area of Brazil, remains highly fertile until today, even with little or no application of fertilizers (Kannan et al., 2013). Biochar when used as a soil amendment, has been reported to boost soil fertility and improve soil quality by raising soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity (CEC), and retaining nutrients in soil (Lehmann et al., 2006; Lehmann, 2007). Another major benefit associated with the use of biochar as a soil amendment is its ability to sequester carbon from the atmosphere-biosphere pool and transfer it to soil (Winsley, 2007; Guant and Lehmann, 2008; Laird, 2008) and it may persist in soil for long period of time because it is very resistant to microbial decomposition and mineralization. This particular characteristic of biochar depends strongly on its properties, which is affected in turn by the pyrolysis conditions and the type of feedstock used in its production. Previous studies indicate that biochar not only leads to a net sequestration of CO_2 (Woolf et al., 2010), but also may decrease emissions of other more potent greenhouse gases such as N_2O and CH_4 (Spokas et al., 2009).
Chemical composition, surface chemistry, particle and pore size distribution as well as physical and chemical stabilisation mechanisms of biochar in soil determine the effects of biochar on soil functions [Verheijen et al., 2010]. The incorporation of biochar into soil can alter soil physical

properties such as texture, structure, pore size distribution, density with implications for soil aeration, water holding capacity, plant growth and soil workability [Downie et al., 2009].

Addition of biochar to soil alters important soil chemical qualities; soil pH changing towards neutral values typically increase soil cation exchange capacity (CEC). Observed increasing trend of bio-available phosphorous and base cations was observed in biochar applied soils [Glaser et al., 2002]. CEC variation in ranges from negligible to around 40 Cmol/gm and has been reported to change following incorporation into soils [Lehmann, 2007]. The increase of CEC with the application of biochar has also been seen [Liang et al., 2006]. The optimal biochar combining fertilizer and carbon storage function in soils would activate the microbial community leading to nutrient release and fertilization and would add to the decadal soil carbon pool. Application of biochar in the acidic coastal soil increase soil pH, soil organic matter, Mn and Ca and decrease S and Zn [Novak et al., 2009]. application boosts up the soil fertility and improve soil quality by raising soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity and retaining nutrients in soil [Lehmann et al., 2006; Lehmann, 2007]. Another major benefit associated with the use of biochar as a soil amendment is its ability to sequester carbon from the atmosphere-biosphere pool and transfer it to soil [Winsley, 2007; Guant and Lehmann, 2008] Significant changes in soil quality, including pH increase, organic carbon and exchangeable cations were observed at higher rates [>50 t/ha] of application. Bio-char addition significantly improved soil fertility in acid and highly weathered soils and it has the potential for widespread application under various agro ecological situations by mobilizing and improving the complex of chemical, physical and biological properties of soil systems.

There is also general trend for concurrent increase in crop productivity with increase in pH on biochar addition to soils [Verheijen et al., 2010]. The biochar loadings upto 140 t/ha has positive yield [Lehmann and Rondon 2006]. The beans [Phaseolus vulgaris L.] showed positive yield effect on application rates up to 50 t/ha that disappeared at on application rate 60 t/ha with negative yield being reported at application rate 150 t/ha [Rondon et al., 2007]. This shows that biochar loading capacity [BLC] is likely to crop dependent as well as soil and climate dependent.

Biochar is formed by thermal decomposition of biomass in low oxygen environments. Traditional biochar production occurs in pits or kilns, where biomass is ignited and allowed to carbonize. Traditional methods are less efficient than larger, modern systems; emission levels from traditional systems can be significant. For example, total suspended particulate (TSP) emissions from an uncontrolled batch kiln can range from 197 grams to 598 grams per kilogram, meaning that between 20 percent and 60 percent of the biomass entering the kiln leaves as TSP. Black carbon (BC) is a powerful climate forcer, and to the extent that BC is associated with TSP from biochar production and use, it will reduce any climate benefits from biochar projects.

Pit kiln and mound kiln method have low productivity & quality. If water table is close to the earth surface or drainage is poor then this method is not practicable. Then this method will be a preferable method as an alternation for the pit method. [Chapter 2, Simple technology for charcoal making, FAO Forestry paper, Food and agriculture organization of the United Nations, February 1984]. Brick kiln is made with bricks which has good insulating nature and resistance of thermal shock. A total of 13-14 days will be sufficient to produce 9-10 tons. [Chapter 7, Simple technology for charcoal making, FAO Forestry paper, Food and agriculture organization of the United Nations, February 1984].
Addition of fuel grate with biochar maker facilitates air flow for combustion. Syngas is formed inside the feedstock chamber during the pyrolysis and routed from the feedstock chamber through the pipe. Combusting syngas prevents the greenhouse gas emission such as methane (CH_4), Particulates

(PM) entering to the atmosphere. [Biochar farms-2010/Design, construction and analysis of a farm scale biochar system, by Robert prins, Wayne teel and John, James Madison University, 2010].

For high biochar yield apart from the feedstock composition low pyrolysis temperature (<400 ^{0}C),high process pressure, long vapor residence time, extended vapor contact, low heating rate, large particle size and optimized heat integration drives the process for a higher biochar yield. [Biomass pyrolysis process-performance parameters & their influence on biochar system benefits, Peter Alexander Brownsort, A dissertation presented for the degree of Master of Science University of Edinburgh, 2009]

When added to soils, biochar has shown to improve moisture retention and nutrient availability, thereby enhancing soil productivity (Lehmann and Joseph 2009; Driver and Gaunt 2010). This characteristic of biochar could be especially important as a tool to adapt to climate change, which can be expected to increase nutrient and moisture stress in many agricultural systems. Over the recent past, unequivocal proof has become available showing that biochar is not only more stable than any other amendment added to soil, but also increases nutrient availability beyond a fertilizer effect (Lehmann, 2009), and these basic properties of stability and capacity to hold nutrients are fundamentally more effective than those of other organic matter in soil. This means, biochar is not merely another type of compost or manure that improves soil properties, but is much more efficient at enhancing soil quality than any other organic soil amendment. This ability is rooted in specific chemical and physical properties, such as the high charge density (Liang et al, 2006), that result in much greater nutrient retention (Lehmann et al, 2003b), and its particulate nature (Skjemstad et al, 1996; Lehmann et al, 2005) in combination with a specific chemical structure (Baldock and Smernik, 2002) that provides much greater resistance to microbial decay than other soil organic matter (Shindo, 1991; Cheng et al, 2008). The use of biochar has been recommended as a substrate for potting mix (Santiago and Santiago, 1989). Morley (1927) says 'charcoal has no equal- it acts as a sponge in the soil, absorbing and retaining water, gases and solutions, as a purifier of the soil and an absorber of moisture.”

There are also many reports to show that biochar reduces the bioavailability and phytotoxicity of heavy metals. Removal of heavy metals from aqueous solutions by biochar derived from anaerobically digested biomass has been reported by Park et.Al (2011). Immobilization of heavy metal ions (Cu++,Cd++, Ni++, Pb++) by broiler litter-derived biochar in water and soil have been reported by Uchimiya et.Al.(2010). Preliminary data collected have shown high sorption capacity of dissolved organic carbon (DOC) from water to walnut shell biochar and a decrease of heavy metals with the application of different types of biochar and bio solids to soil (Namgay et al., 2010; Mohan et al., 2010). In this research, the effect of biochar on the transport of heavy metals and organics in a soil ecosystem were investigated. The results of this investigation contribute to understanding of metal and organic transport on a multi spatial level (i.e. soil aggregate to field to watershed). A possible application of this research is biochar use for remediation of contaminated soils, to prevent leaching into the water supply and harmful plant uptake (Xinde and Harris, 2010).

1.2 Impact on biochar on emissions

Biochar application to soil has drawn much attention as a strategy to sequester atmospheric carbon in soil ecosystems (Yoo G and Kang, 2012). It is being promoted as a climatic change mitigation tool as it has the potential to increase soil Carbon sequestration and reduce soil GHG emissions when applied as a soil amendment (Woolf et al, 2010).
All studies concerning the impact of biochar addition to soil on greenhouse gas emissions have been practiced either on short term or long term laboratory scale or as field studies. However most of these studies are limited only to short term laboratory studies.

Energy production from bioenergy crops may significantly reduce greenhouse gas (GHG) emissions through substitution of fossil fuels. Biochar amendment to soil may further decrease the net climate forcing of bioenergy crop production (Case et al., 2013). Several life cycle assessments demonstrated that producing energy and biochar simultaneously from biomass and applying the biochar to arable crop soil resulted in greater carbon abatement than producing energy alone from biomass or fossil fuel energy production (Gaunt and Lehmann, 2008; Roberts et al., 2010; Hammond et al., 2011). Carbon abatement primarily consisted of increased soil stable carbon content (40 – 66 %) and offsetting fossil fuel energy (14 – 48%). The remainder was credited to indirect effects of biochar on the soil, such as increased fertility use efficiency, reduced soil GHG emissions and increased soil carbon stocks (Case et al., 2013).

CO_2 emissions from soil organic matter resulted from the mineralization of resident soil Carbon and are strongly affected by soil temperature, the form and labiality of soil Carbon and soil moisture conditions (Rustad e al., 2000; Cook and Orchard, 2008).

According to Lehman et al, (2011) in short term, fresh biochar addition may add a large amount of labile C to the soil, increasing soil CO_2 emissions. In long term, biochar is hypothesized to increase recalcitrant soil C and may even increase soil microbial biomass by accumulation of soil organic matter and nutrients onto the biomass surface. Biochar amendment may also reduce the activity of Carbohydrate mineralizing enzymes, therefore reducing soil CO_2 emissions (Jin, 2010). Abiotic reactions may also contribute to the suppression of soil CO_2 emissions. Soil derived CO_2 may precipitate onto the biochar as carbonates, aided by the high pH of the biochar and high alkaline metals (Case et al., 2013). Also, it has been shown that low soil inorganic N content may limit soil C mineralization resulting soil respiration (Norby et al., 2012).
A study from Case et al., (2014) investigated suppressions of soil CO_2 emissions by 33% and annual net soil CO_2 equivalent emissions (CO_2, N_2O and CH_4) by 33% over 2 years under field conditions and they have observed suppressed soil CO_2 emissions by 53% and net CO_2 equivalent emissions by 55% under laboratory conditions.

Contradictory to above results, additions of biochar produced by pig manure to the soil increased soil CO_2 emissions in a short term study (Troy et al., 2013). This was caused by increased rate of C mineralization (Troy et al., 2013). Also results of the studies of Mukherjee et al, (2014) and Mukome et al, (2014) revealed that there were no significant decrease of CO_2 emissions by biochar (produced from oak) amended soil.

Also methane fluxes are mediated by processes known as CH_4 oxidation under aerobic and methanogenesis under anaerobic conditions, and are primarily affected by temperature, substrate availability and the form and content of organic matter (Castro et al., 1995; Le Mer and Roger, 2001). It was observed that biochar improved methane oxidation in both laboratory and field study (Schimmelpfennig et al., 2014). In the case of Karhu et al., (2011) there was an increase uptake of CH_4 emissions when soil amended with birch biochar. Also findings from 2 year field study by Knobauch et al., (2010) revealed that significant increase of CH_4 emissions with rice husk in rice paddy land.

However findings of Shen et al., (2014) revealed that significant reduction of CH_4 emissions when soil amended with straw derived biochar. It may possibly due to a biochar induce increase in soil pH (Shen et al., 2014). Also Rondon et al., (2006) observed that a complete suppression of CH_4 emissions from field plot when they were amended with woody shrub biochar. In most of the experiments soil CH_4 fluxes were below detectable limit (Case et al., 2013; Spokas et al., 2009; Troy et al., 2013;) or were not significantly affected (Spokas et al., 2009; Mukherjee et al., 2014; Diaz-Rojas et al., 2014) when amended with biochar.

According to Khalil et al, (2004), Wrag et al, (2005) and Gillam et al, (2008) N_2O from the soil is produced by three primary pathways, i.e. nitrification, nitrifier denitrification and denitrification. Nitrification is dominant under aerobic conditions whereas under increasingly anaerobic conditions denitrification is the dominant pathway (Bateman and Baggs, 2005). N_2O production is also controlled by temperature, inorganic N content, pH and the form and concentration of labile C (Hofstra and Bouwman, 2005).

Some studies (Karku et al., 2010; Case et al., 2012) have shown that biochar amendment can modify soil physical properties by increasing the water holding capacity, decreasing bulk density of soil and finally result in lower N_2O emissions. Also according to the studies of Clough and Condron, (2010) and Taghizadeh-Toosi et al, (2011) in low inorganic –N soils, fresh biochar may immobilize significant amount of inorganic N, limiting the substrate available to soil nitrifiers and denitrifiers for N_2O production.

A study of Case et al, (2013) observed that the significant suppression of soil N_2O emissions by biochar produced by Miscanthus, biomass energy crop in short term experiments. y. Also cumulative N_2O emissions were significantly decreased in the biochar (produced from oak) amended soil by 92% compared to the control in the study of Mukherjee et al., (2014).

Contradictory to above results, Additions of biochar produced by pig manure to the soil increased soil N_2O emissions in a short term study (Troy et al., 2013). Also significantly higher emission of N_2O was observed by Mukome et al, (2014) by studying the behavior of biochar (produced from oak) and then amended with soil. A study from Case et al., (2014) investigated that there was no significant suppression of soil N_2O under laboratory or field conditions. It was also observed that by Schimmelpfennig et al., (2014) significant reduction of N_2O emissions after addition of biochar in the lab study but not in the field.
In summary, some results discovered the positive impacts of use of biochar on GHG emissions, others related with the negative impacts on GHG emissions. Those studies which provide evidences for the impact of biochar on GHG emissions are contradictory, with increased, decreased and variable effects observed (Kuzyakov et al., 2009; Major et al., 2009; Zimmerman et al., 2011).

Most studies suggest that the application of biochar produced from wood and crop residues, such as saw dust, straw, sugar bagasse and rice hulls, to highly weathered soils under tropical conditions influenced on soil GHG emissions whereas there is insufficient data concerning GHG emissions from soils amended with biochar derived from manure (Troy et al., 2013). Also A study of Yoo and Kang, (2012) have given evidences for varying results of GHG emissions under different laboratory conditions. And they confirmed that the ability of environmentally sound biochar additions to sequester C in soils depends on the characteristics of the receiving soil as well as the nature of the biochar. According to the study of Shen et al., (2014), the authors suggested that the amendment of biochar derived from crop residues to soil as a potential mitigation strategy for tackling GHG emissions in cropping systems. However the applicability of this strategy as a climate change mitigation option is limited by our understanding of the mechanisms responsible for the observed changes in GHG emissions from soils, microbial responses, and soil fertility changes (Yoo G and Kang, 2012).

2.0 Methodology

2.1 Area selections & profiles

Sri Lanka- Sri Lanka's economy with more than 70% of the population living in rural areas is depending on agriculture for their livelihoods. Currently this sector contributes to about 18% of the Gross Domestic Product (GDP) and 30% of the employment. The agricultural productivity has remained relatively stable, except for rice which has reached near self-sufficiency in the recent years.

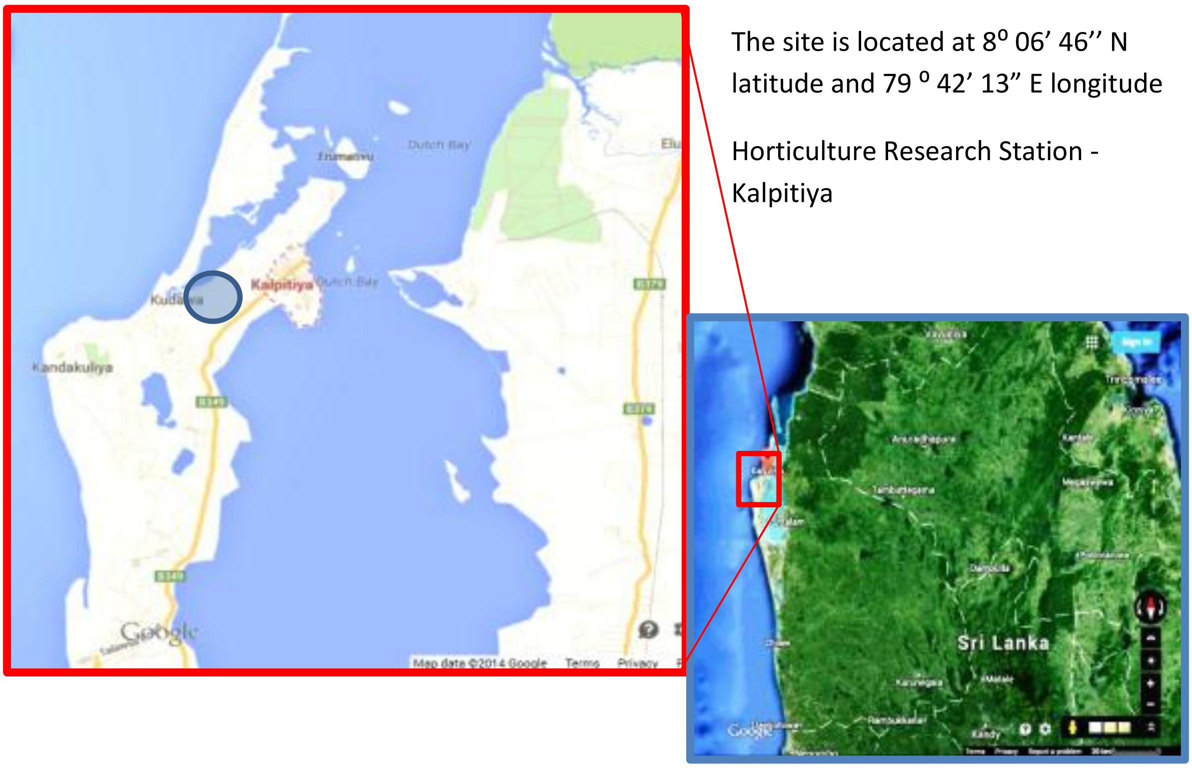


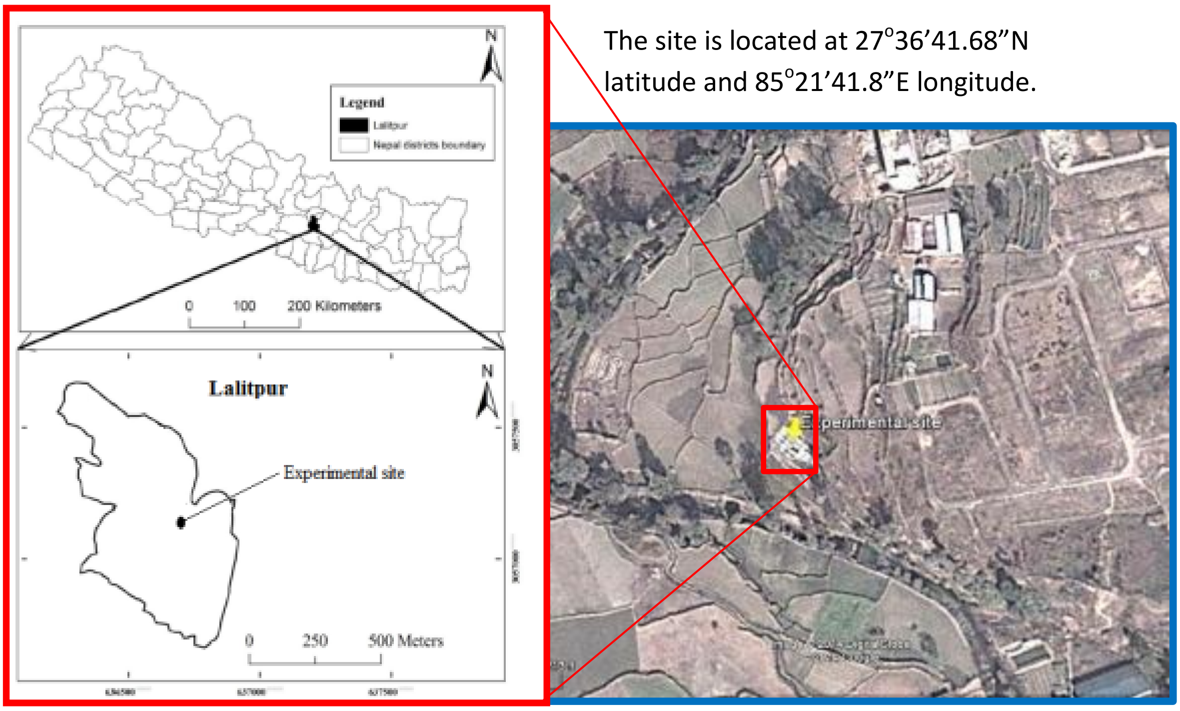
Figure 1: Site Location in Sri Lanka

However, the growth in this sector has been sluggish. Rapid agricultural productivity growth is fundamental for reducing poverty in Sri Lanka as nearly 90 per cent of the poor live in the rural agricultural economy. Therefore, rapid development in food production while protecting the environment, water resources, and bio-diversity needs to be given high priority in the development strategies. This includes removal of existing policy and regulatory constraints which have stifled growth in the agricultural sector.

Initially five sites with various conditions were considered and evaluated. Finally, the area of Kalpitiya was selected for field trials and Gannoruwa for green house experiments. Kalpitiya is a divisional secretariat area in Puttalam District in the North-Western Province. Vegetable cultivation is carried out in large scale and soil is sandy, salty and poor in nutrients. Horticulture Research Station (HRS) was selected to carry out field trails that functions under the Department of Agriculture (DOA) with a high profile community of agricultural scientists and a network of institutions covering different agro ecological regions island wide. Around 8,000 families live in the area extending from Mampuri to Thalawila via Ethalai, Norochcholai, Kalkudah and Senapola. Today about 2,500 hectares are covered with vegetable cultivation while another 300 hectares are cultivated with a variety of fruits and other crops. Around 100 tons of vegetable are said to be traded on a daily basis with buyers from all over the country.

Nepal- The economy of the Nepal is dominated by agriculture. Nepal ranks among the most vulnerable countries to extreme climate events. In general, rural areas where the population heavily depends on agriculture are the most vulnerable. High temperature during summer months and foggy weather combined with prolonged cold temperature spells during winter months often affect vegetable cultivations. [Source, FAO, Seasonal vegetable cultivation in Nepal, 2013-01-07]

According to Statistical Information on Nepalese Agriculture (2008/2009) only 65.6% of people depend on agriculture and 21% of land is cultivated whereas 7% of land is uncultivated. The experimental site was located at Godamchour VDC, Ward no 1 of Lalitpur District. It is located at south east corner of Kathmandu valley, Nepal. The site was previously used by farmers for the production of vegetables like chilli and tomato.



The site is located at 27°36’41.68”N latitude and 85°21’41.8”E longitude.

Figure 2: Site Location in Nepal

Thailand- is the world biggest rice exporter. Thailand perseveres to rely heavily on agriculture with some 50.4 million acres of farm land, of which about 24.7 million acres are under rice cultivation. The demand for vegetables has been growing annually. Vegetables are grown both in upland and irrigated land. Thailand's variable rainfall (and consequent risk) has discouraged farmers from using higher levels of technology, such as the increased use of fertilizer. [Source, FAO, 1998]. However, due to an increase in the domestic demand for the produce and competition for land resources, farmers are obliged to improve yields through the use of more efficient technology, such as better agronomic techniques, improved seeds and other planting materials. The Central plain is the most fertile rice growing area with a hot and humid climate. Hence, Mae Tha was selected as site location Central which is located in Central region of Thailand.

The site is located at 13°39'47.3"N latitude and 101°30'27.3"E longitude. Sanam Chaikhet Organic Farmers' Group

Figure 3: Site Location in Thailand

2.2 Arrangement of socio-economic evaluation

Baseline survey was conducted in Sri Lanka as part of the Socio-economic analysis of the project. The objectives of the socio economic evaluation was to understand existing agricultural practices in the project areas, and to collect baseline information of the indicators in order to measure the impacts of biochar in the future.

This study was also aiming at assessing the Socio-economic status of farmers in the area and their current farming practices of selected areas where farmers cultivate vegetable extensively. Baseline surveys help a project in efficient and effective planning, monitoring and evaluation of its activities. The areas covered from this intervention included basic socio economic information of the household, landownership, information about crops & cultivation practices (including types and way of using fertilizer, pest control methods, watering methods, gender and decision making).This also gave an understanding of the attitudes of farmers on existing cultivation practices and new practices that the project was introducing. The present study had some limitations related to data and the approach, which in turn had implications for both methodology and data. One of the limitations of the study was to collect data on monthly income and expenditure of farmers. Since their income is dependent on agriculture production, it was understood that a assessing an average and regular monthly income was difficult as crop income depends on the weather and market prices and therefore fluctuations in income is very common feature in the area. The other limitation of the survey was the given expenditure for the crop. Therefore, the research team had to make reasonable approximations on the basis of available and provided data.

2.3 Strategy to measure feedstock availability

Research looked into the availability of feedstock for production of biochar in Sri Lanka, Nepal and Thailand with their suitability for biochar production according to the compositions.

Feedstock availability was surveyed focusing two areas in Sri Lanka. Those areas were Paatha Hewaheta in Central Province and Kalpitiya in North Central Province respectively. Mainly, the availability of Sawdust, Rice husk and Gliricidia were focused at the survey while availability of the other feedstock was assessed from secondary information.

In Nepal, there were two types of feedstocks that used to prepare biochar namely mixed biochar and coffee biochar. Mixed biochar was prepared from cutting and pruning waste from forest and coffee char was prepared from coffee seed coat.

There is a considerable amount of feedstock in Sri Lanka, which can be used for biochar production. It comes from a large number of different sources in a wide variety of forms. Most of them can be used with general biochar production technologies and some of them should have specific technologies. The aim of this assessment was to identify the most suitable and available feedstock material for local biochar production.

Composing with organic components specifically, Lignocelluloses is a fundamental need for suitability of biomass for biochar production. Lignocelluloses could contain carbon, hydrogen and oxygen in different proportions. Average element composition of $C_5H_7O_3$ varies according to the type of biomass. It highly affects the yield of biochar produced. Next to that some other characteristics such as moisture content, ash content, volatiles, calorific value, fixed carbon, amount of Cellulose-hemicellulose, lignin, silica, oxygen ,hydrogen and nitrogen plays vital roles in deciding properties of biochar.[Biochar production potential in Ghana, A review, Moses Hensley Dukua, Sai Gua, Essel Ben Haganhjba]

Apart from the chemical composition of feedstock, the selection criteria of feedstock should take into account the availability of drying facilities of raw material if it is necessary, storage facility and transportation. Furthermore, competition for each type of biomass should be considered among their multiple uses since biomass is one of the major energy sources in Sri Lanka, such as providing domestic and industrial thermal energy requirement.

Biomass feedstock can be categorized again under three groups as primary, secondary and tertiary. Primary biomass feedstock includes grains or grain refuse, oil seeds, algae, agricultural residues and primary forestry residues which consist with logging residues, other removal residues and simulated forest residues. The secondary biomass feedstock consists of livestock and poultry waste and Industrial waste as mill waste. Municipal solid waste comes under tertiary biomass feedstock. This assessment mainly considered the primary feedstock

2.4 Technology selection

A new bio-char production unit was specially designed in Sri Lanka for small scale domestic use. This consists of 5 main components. This technology is suitable for production of bio char from solid biomass such as wood chips and with loose biomass such as saw dust, paddy husk. The unit has been specially tested for gliricidia pieces and paddy husk successfully. The system temperature varies from $600^{0}C$ to $900^{0}C$.

- Outer barrel- Outer barrel has been made using a 200 litre empty oil barrel which is available in the open market. As shown in the figure 4, lower part of the barrel has been perforated in-order to supply secondary air required for the combustion. Perforation has been made by three rows of equally spaced holes on the cylindrical surface starting from the bottom. Diameter of each hole is 9mm. Initially three rows of holes are made, but number of rows can be increased or decreased to optimize performance in future improvements. Further, there are equally spaced three square shaped openings for initial firing and supplying primary air required for combustion of fuel.
- Inner barrel- The inner barrel is the chamber in which bio-char making material (wood chips or paddy husk) is packed and processed. The figure 4 shows the isometric view with the lid and inverted sectioned view with basic dimensions.

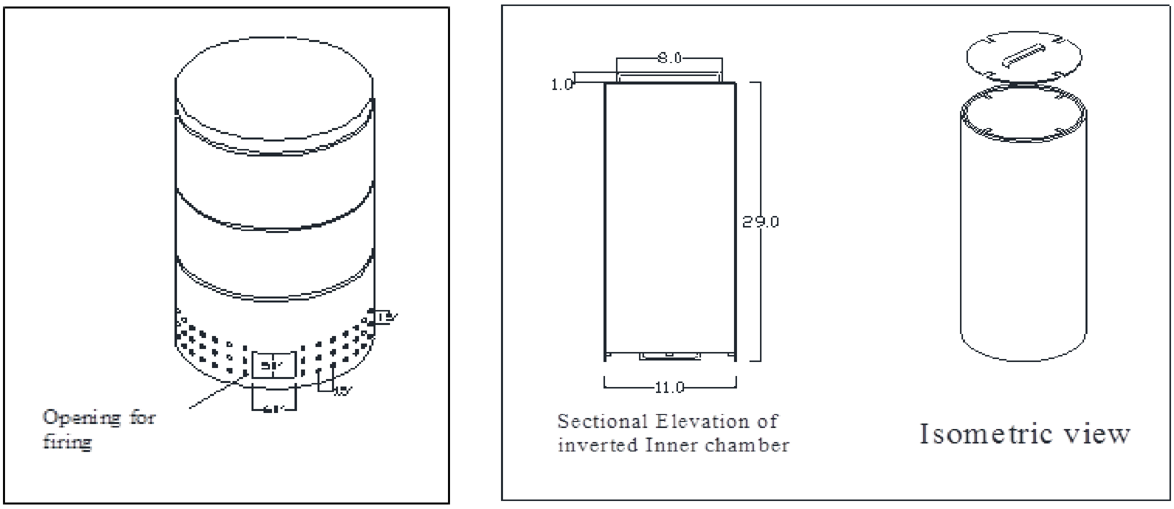


Figure 4: Outer & Inner Barrel

- Fire grate- Function of the fire grate is to stack fire wood in such a way that to supply air properly for better combustion. As shown in the figure 5 below, fire grate is placed between outer barrel and inner barrel. It is 4 inch high from the bottom of the large barrel. Inner barrel is inserted through the center core up to main barrel bottom.

Figure 5: Fire grate at the bottom

- Hinged top lid- For better combustion, it is required to supply sufficient air either by natural draft or by forced draft. But for this type of appropriate technology, supplying forced air is practically difficult as it is not possible to find electricity in the farming fields. . Therefore best method to supply air is to incorporate a chimney. But installing a chimney for this type of portable unit is practically difficult. Because, it need space for loading and unloading the inner barrel which contains bio-char making feedstock material. The top lid has been covered with a layer of HAC 75 refractory material in-order to protect it from heat.

Figure 6: Hinged top lid covered with a layer of refractory material

- Chimney- 5 ft. high chimney with 4” x 4” cross section has been fixed on top of the hinged top lid in-order to create sufficient draft for better combustion.

Before starting the operation, the biochar unit has to be cleaned properly (ash and other residues of previous fire). Then position the unit on a leveled ground and fix the hinged top lid, chimney and place the fire grate in the main barrel.

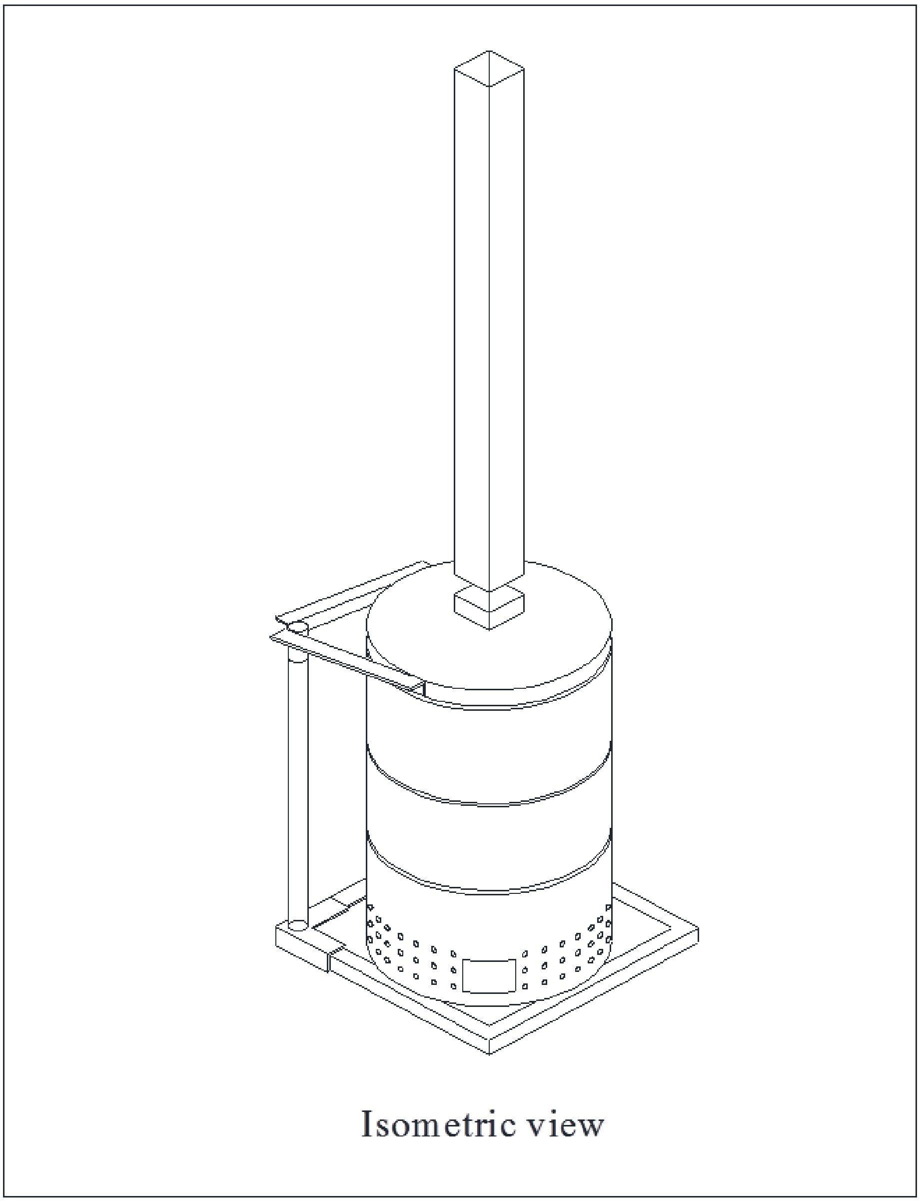


Figure 7: Assembled biochar maker

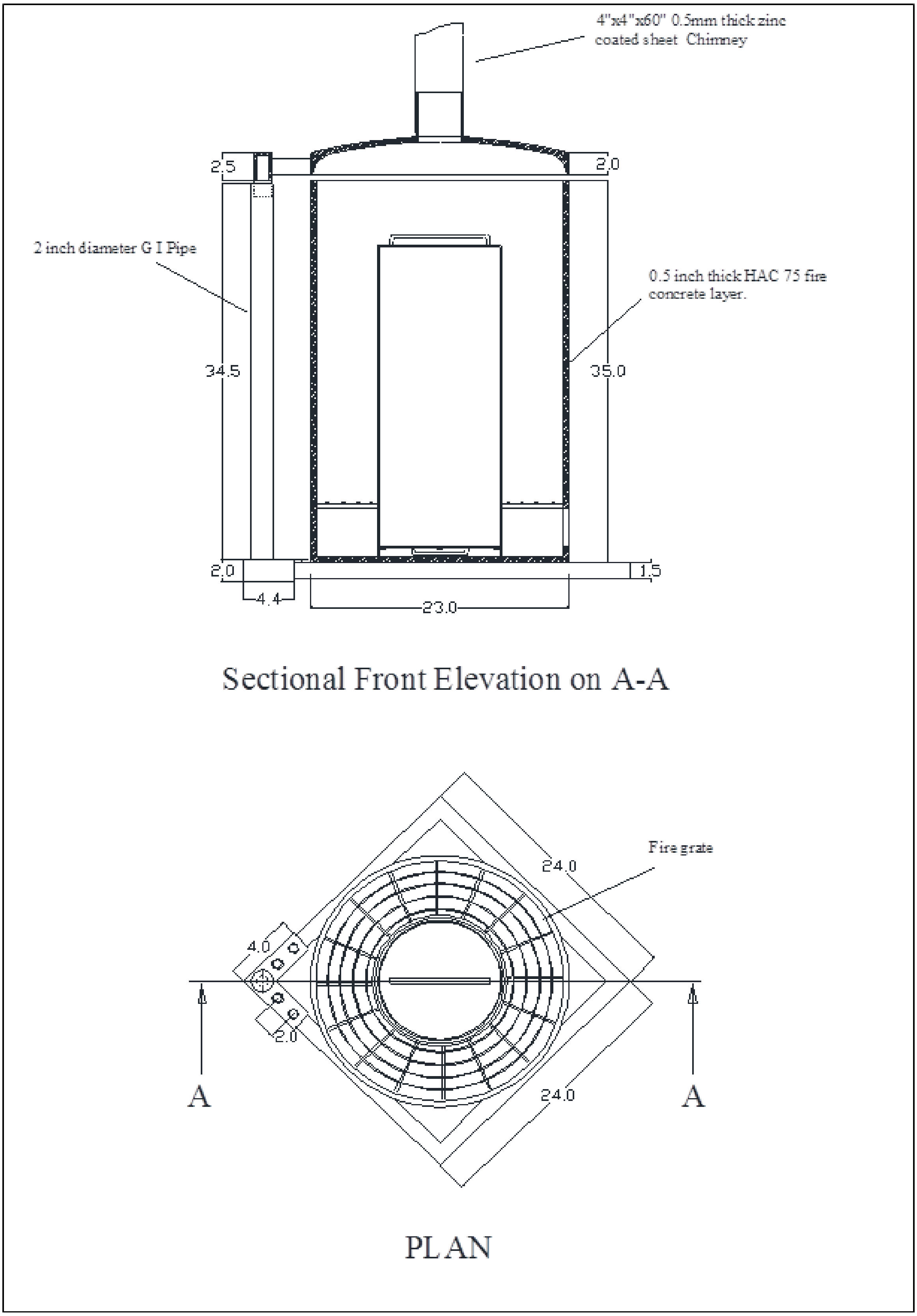


Figure 8: Mechanical drawing of biochar maker

Biochar making feedstock material i.e. wood chips, saw dust, paddy husk etc. to be dried properly (figure 9a) and packed in to the inner barrel (figure 9b). Then close it and lock by pushing down and turning as shown in figure 9c and place in the main barrel in such a way that inverting it to touch the top edge to the bottom of the outer barrel (figure 9d).

Figure 9a

Figure 9b

Figure 9c

Figure 9d

Figure 9: Operation procedure

Biochar making feedstock material is packed in the inner barrel. After placing the inner barrel, pack suitable quantity of fuel wood in the space between two barrels. Any type of dried wood, agro waste etc. can be used as the fuel to heat biochar making feedstock material which is packed in the inner barrel. Now the unit is ready for firing. After rotating the hinged top lid with the chimney to barrel center position, firing can be started through the three squire openings. After about 20 minutes of fire start, syngas emitting around the lower edge of inner barrel can be observed. The fire continues even after fuel wood burning is completed until syngas emission stops. Nearly 3 kg of fuel wood to be added for completing the biochar production process. This process can be optimized by carrying out trials repeatedly and it depends on several factors such as type and quantity of biochar making feedstock material, its moisture content, size, weight and moisture content of fuel wood etc. It takes nearly about 60 -70 minutes to complete heating process per batch. After finishing the fire, it needs to cool for nearly about another 60 -70 minutes. for cooling before opening. If opened early, it will become ash in few minutes due to contact with atmospheric oxygen.

In Nepal, a traditional fixed retort had been used for biochar production process. There were two types of biochar produced, mixed biochar & coffee husk biochar. Main components of the fixed retort are chamber for biomass feeding with exhaust chimney, fire box with exhaust chimney, cover lid & insulation covers.

Basic working mechanism: Biomass is kept in wood chamber and is covered with lid and insulation covers. Firing is done in fire chamber, the hot air and gases generated here is passed through the canals underneath the basal metal plate of wood chamber and finally escapes through chimney 2. The heat from the basal metal plate of the wood chamber continuously passes into the wood chamber and wood is heated. First phase of firing removes the moisture of wood characterized by dense white fume from chimney 1.

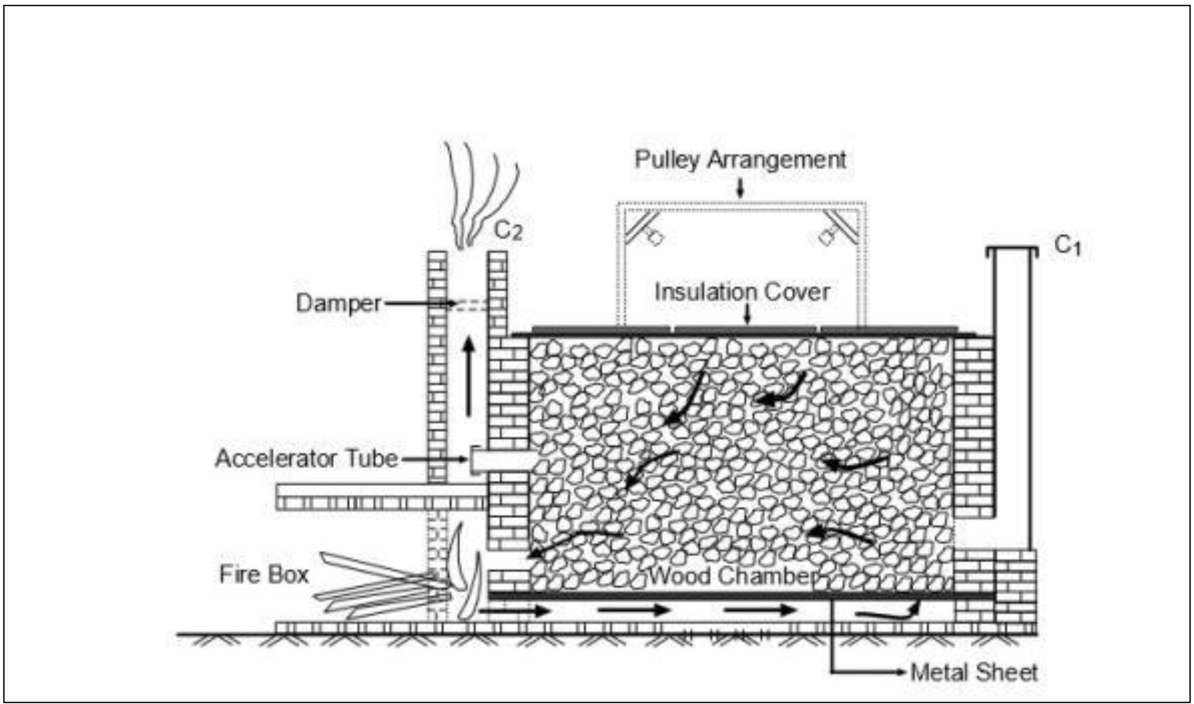


Figure 10: Main components of fixed retort

After the completion of moisture removal phase, pyrolysis phase starts in wood chamber characterized by transparent smoke fumes. This produces combustible volatiles. At this phase the chimney 1 is closed and volatiles inside the wood chamber is pressurized and forced into firebox through 5 nozzles. Peak temperature may be upto 450 ^{0}C. After this, chimneys 1 and 2 are sealed, fire box is also sealed and insulation cover is removed and the retort is left to cool down. Biochar can be unloaded on the following day. Typically the firing duration is 8 to 12 hours.

Figure 11: Traditional biochar making process in Nepal

2.5 Methods for analysis of biochar

Characteristics of biochar were analyzed for saw dust biochar in Sri Lanka. All the chemicals used were of analytical grade. Standard test methods were used to determine physical and chemical properties of saw dust biochar. Scanning electron microscopy (SEM) was used to describe the physical morphological features of the saw dust biochar. The specific surface area and pore size distributions were determined by gravimetric nitrogen Brunauer-Emmet-Teller (BET). Moisture content of the biochar was determined using ASTM D 2867- 97. And the volatile matter content was measured by ASTM D5832 – 97. The percentage fixed carbon was determined as 100 – (moisture content + ash content + volatile matter). Absolute density for biochar was measured by ASTM D2854 -97. The Iodine number was determined based on ASTM D4607 -97. And the pH of the biochar sample was measured by ASTM D2866 – 97. Diffuse reflectance infrared Fourier Transform spectroscopy (FTIR) was used to examine surface chemistry of the biochar sample.

A stock solution of hexavalent chromium (Cr (VI)(100 ppm) : Arsenate (V) (100 ppm) was prepared in distilled water with using KCr_2O_7 and $Na_2H\,AsO_4.2H_2O$ to obtain a solution of heavy metals (Cr(V) 100 ppm: As(V) 100 ppm). And another stock solution was prepared (NO_3^- 250 ppm): (PO_4^{3-} - 25 ppm) by using $NaNO_3$ and $K.H_2PO_4$. All working solution of varying concentrations was obtained by successive dilution.

Batch adsorption studies were conducted in 250 ml conical flasks at pH 7.5. Five gram of washed dry biochar sample was thoroughly mixed in a mechanical rotary shaker at 2 rpm with 250 ml of Cr (VI) 10 ppm: As (V) 10 ppm solution in each conical flask. Samples of 20 ml were drawn from each conical flask at required time interval and filtered by Whattman No.2 filter papers and analyzed for the metal ion. Similarly using another 250 ml conical flasks 5 g of washed dry biochar samples were mixed with 250 ml of NO_3^- (30 ppm): PO_4^{3-} (3 ppm) solution at pH 7.5. Samples of 20 ml were drawn from each conical flask at required time interval and filtered by Whattman No.2 filter papers and analyzed for the anion. pH of the solution was adjusted to the target value by using either HCl or NaOH. The constant volume in the solution was maintained by keeping twelve conical flasks at the beginning of the experiment and taking out 20 ml of sample from each at a fixed time interval.

The following relationship between contact time and percent removal has been used to adsorption kinetic constant for saw dust derived biochar.

$$R = a\,(t)^{b} \qquad (1)$$

Where R – percent removal of metal ion/anion

a and b - Constants

t - Contact time in minute

The linearized form of above equation is

$$\log R = \log a + b \log t \quad (2)$$

Pseudo first and second order models and intraparticle diffusion model were tested.

The bio sorption equilibrium uptake capacity for each sample was calculated according to mass balance on the metal ion express as

$$q = \frac{V (C_0 - Ce)}{M} \quad (3)$$

Where, V – sample volume (l)

C_0 – The initial metal ion/anion concentration (mg/l)

Ce – The final metal ion/anion concentration (mg/l)

M – Dry weight of the adsorbent (g)

q_e – Biomass bio sorption equilibrium metal uptake/nutrient uptake capacity (mg/ g)

Several equilibrium isotherm models are developed to describe the adsorption process. Here we have used Langmuir isotherm model and the Freundlich isotherm model to discuss experimental data.

Column adsorption and desorption studies were carried out using a glass column of 3.5 cm internal diameter and 50 cm in length. About 55 g of biochar was packed in the column upto 45 cm height and glass beads at the top to make sure uniform flow through the column.

For the adsorption studies, the tank containing heavy metal solution (Cr (VI) 10 ppm: As (V) 10 ppm)/ anion solution (NO_3^- (30 ppm): PO_4^{3-} (3 ppm)) at pH 7.5 was placed at a higher elevation allowing solution to flow under gravitational flow. The tank is equipped with valve to maintain constant flow rate. A constant flow rate of 5 ml/min was maintained using the valve equipped with the tank. Samples were collected from the exit of the column at previously determined time intervals and analyzed for residual anion and cation concentrations.

Desorption behavior was studied using distilled water at the same container. Distilled water was passed through the column at the same flow rate and the effluent was collected at specific time intervals and analyzed.

- pH measurements were made using a pH meter (Hanna instruments, H1 2211pH/ ORP meter). Electrode is immersed in the testing liquid and from the calibration pH is measured very accurately at 27^0C.
- Weight of all the samples was measured by analytical balance to greater accuracy.
- The chromium and Arsenic cations were analyzed by using fast sequence atomic adsorption spectroscopy (AA240 FS) with Al acetylene gas/flame and hollow cathode lamps
- The nitrate was analyzed colorimetrically at 570nm and phosphate was measured colourimetrically by using UV visible spectrophotometer (DR 6000, Hach instruments).

2.6 Field arrangements

All three countries Nepal, Thailand and Sri Lanka characterized the selected sites through soil analysis and conducted the field trials in selected areas for selected crops, assessing agronomic performance of crops & assessing the characteristics of soil after adding biochar.

In Sri Lanka field trials were conducted at Kalpitiya while Greenhouse and laboratory incubation studies were carried out at Gannoruwa Horticulture Department simultaneously. Kalpitiya is a low-lying sand peninsula located in the North Western Province in the dry north-west coast of Sri Lanka where annual rainfall is less than 900 mm. Ground water that occurs in the limestone is more saline than in the sand aquifer and, as a consequence, is not developed for water supply. In Kalpitiya there is year round intensive cultivation and farmers use excessive amounts of chemical fertilizer and pesticides with the intention of increasing crop yields. Annual cash crops are grown as monoculture with no intercropping. Kuruppuarachchi, et. al. (1999) report that there is a direct correlation between land use pattern and ground water quality. Liyanage et. al. (2000) found ground water nitrate levels in many wells to exceed WHO drinking water guidelines of 10 mg N/L, while nitrite levels in few wells exceeded the tolerance level of 0.001 mg/L.

Gannoruwa soil was used in the greenhouse and laboratory incubation studies. Classified as the Reddish Brown Latosols (Panabokke, 1996), occur in the wet zone part of the Kandy plateau. Because of their excellent physical properties, their depth and resistance to erosion, they are among the most productive soils of the mid-country. Texture is mostly Sandy Clay Loam and structure is strongly crumbed to granular under natural vegetation and there is a definite loss of structure in most cultivated soils. pH is medium acid, has high water holding capacity and permeability and hence often described as having very good physical properties.

- Crops selection in Sri Lanka- Capsicum annum & red onion were the selected crops for field trails in Sri Lanka. First field trial was done for red onion & second field trial was done for capsicum annum. Field trails took 2 months of period for each one. In Sri Lanka, capsicum is grown throughout the country, particularly in the Northern, Eastern and North Western Provinces. In the Puttalam district, capsicum is a popular vegetable crop among Kalpitiya farmers and is cultivated in rotation with red onion and other vegetable crops. Red onion cultivation has become popular in Sri Lanka because the crop can be maintained vegetatively, avoiding the need to produce true seed. Bulbs from one harvest are planted in the following season to produce new bulbs. Major red onion producing districts are Jaffna and Puttalam.

Research conducted at the Department of Agriculture (DOA) at Gannoruwa, to select suitable nutrient source for organically grown vegetables, different types of organic nutrient sources, cattle manure (20t/ha), poultry manure (10t/ha), vermicompost(40t/ha) and compost (40t/ha,) were tested and compared with DOA recommended NPK on vegetable yield in mix cropping of cabbage, capsicum and knolkhol. Capsicum was found to respond well to all these organic manures. In another study highest fruit yield of capsicum was obtained with green manure + compost+ tea spray. Field, greenhouse, and laboratory studies were conducted in Sri Lanka during the period March to October 2014, to assess the effects of BIOCHAR RISE HUSK (BRH), BIOCHAR SAW DUST (BSD) and BIOCHAR GLIRICIDIA (BGC) application on:

1. The agronomic performance of red onion and capsicum
2. Soil characteristics

- Greenhouse studies in Sri Lanka-

Two parallel experiments were conducted in the greenhouse at Gannoruwa to study the effects of three biochar materials, biochar rise husk (BRH), biochar saw dust (BSD) and biochar gliricidia (BGC) on growth and yield of capsicum (var. CA-8) grown in the Kalpitiya Sandy Regosol and the Gannoruwa. Reddish Brown Latosol soils were collected at a depth of 0-20 cm, air dried and ground to pass a 2.0 mm sieve. 5 kg ground soil was put into plastic pots with an inside diameter of 30 cm. The biochar was tested at three rates of application of 10, 20 and 30 t/ha, when added with and without fertilizers recommended by DOA for capsicum. Thereby, each experiment had 19 treatments arranged in a completely randomized design (CRD) with 3 replications. The BIOCHAR RISE HUSK (BRH), BIOCHAR SAW DUST (BSD) and BIOCHAR GLIRICIDIA (BGC) were ground well and the amount to be added in each treatment was calculated based on the surface area of the pot. The biochar was mixed well into the soil and the pots watered to near field capacity and maintained at this level throughout the experiment. Twenty days old capsicum seedlings were planted. Fertilizer top dressing was applied to relevant treatments according to the DOA recommendation. Plant height was measured at two weeks interval and observations on flowering recorded. Plants were harvested

35 days after planting by separating the shoots from roots. Plant parts were washed well in running water air-dried overnight and total fresh weight of shoots and roots of each pot recorded. Samples were dried in an oven at 60 ^{0}C to constant weight, dry weight recorded and dry matter output from each pot calculated. Soil samples were taken from each pot to a depth of about 10 cm using a small auger and analysed for pH, Electrical conductivity (EC), available P and K and organic matter contents.

Table 1: DOA Fertilizer recommendation for capsicum

Time of application	(kg/ha)		
	N	P_2O_5	K_2O
Basal (at planting)	46	100	40
1 month after planting	46	-	40
2 months after planting	46	-	40

Source: Division of Agricultural Chemistry, HORDI, Gannoruwa

- Field studies in Sri Lanka- Two field experiments were conducted on a Sandy Regosol in Kalpitiya in the Low Country Dry Zone region, to study the effects of BIOCHAR RISE HUSK (BRH) and BIOCHAR GLIRICIDIA (BGC) applied at 10 and 20 t/ha on red onion (var. Vedhalan) and capsicum (var. CA-8). Biochar materials were tested when added to soil with and without the DOA recommended Nitrogen Phosphorous Potassium (NPK) fertilizers for each crop. In the capsicum experiment a no-input control plot was also included, thereby, capsicum experiment had 10 treatments. In both experiments the treatments were arranged in a randomized complete block design (RCBD) with 3 replications as shown in the field lay out plan below.

Replicate 1	Replicate 2	Replicate 3
T2	T8	T3
T4	T2	T6
T6	T1	T7
T9	T3	T5
T7	T9	T8
T3	T6	T4
T5	T7	T2
T1	T4	T9
T8	T5	T1

Figure 12: Field layout for red onion experiment

Replicate 1	Replicate 2	Replicate 3
T1	T10	T5
T3	T8	T4
T2	T9	T3
T4	T6	T2
T6	T7	T1
T5	T4	T7
T8	T2	T10
T7	T1	T8
T10	T3	T9
T9	T5	T6

Figure 13: Field layout for capsicum experiment

- Methodology for Red onion Experiment – After land preparation, a representative soil sample was collected for characterization, from the experiment site at a depth of 0-20 cm using a soil auger. Raised beds of size 2m x 1m were prepared, 9 beds in each block. Prior to planting, the planting material was treated with fungicide as a precautionary measure. Bulbs were planted at a spacing of 10cm x 10cm. At the 2nd, 4th and 5th week stages of the crop, fungicide application was repeated to prevent fungal infestation. Irrigation was done daily up to the 9 week stage using a rubber hose, and thereafter frequency was reduced. Relevant treatments were fertilized according to the DOA recommendation at the appropriate times (Table 2). After 6 weeks plant height was recorded by taking the average height of 5 plants in each plot. After 12 weeks the crop was harvested and bulb weight of each plot recorded.

Table 2: DOA Fertilizer recommendation for red onion

Time of application	(kg/ha)		
	N	P_2O_5	K_2O
Basal (at planting)	30	45	30
3 weeks after planting	30	-	-
6 weeks after planting	30	-	15
Total	**90**	**45**	**45**

Source: Division of Agricultural Chemistry, HORDI, Gannoruwa

- Methodology for Capsicum Experiment - After land preparation, a representative soil sample was collected from the experiment site for characterization, at a depth of 0-20 cm using a soil auger. Raised beds of size 1.6m x 2m were prepared, 10 beds in each block. Prior to planting a nursery was prepared. After 21 days, seedlings were establishment in the field by planting at spacing of 40 cm x 40 cm. At the 4th and 6th week stages of the crop, pesticides were applied to prevent leaf curl diseases. Irrigation was done daily using a rubber hose. Relevant treatments were fertilized according to the DOA recommendation at the appropriate times (Table 1). After 7 weeks, plant height was recorded by taking the average height of five plants in each plot. After 8 weeks harvesting of pods commenced. A total of five picks were obtained at 2 weeks interval and data of each plot recorded.

  Laboratory studies in Sri Lanka- Soil samples collected prior to planting and after harvesting the crop, from the field and greenhouse experiments were air-dried and sieved through a 2 mm sieve. Soil pH and electrical conductivity (EC) were measured using soil: water ratio of 1:1 and 1:5 respectively, total nitrogen by micro-Kjeldahl method (Black1965). Available P by extracting with 0.5M $NaHCO_3$ (Olsen, 1954) followed by spectrophotometry using molybdenum blue method, and available K by extracting with 1M NH4OAc followed by flame photometry. Organic C content was determined by the Walkley and Black (1934). Cation exchange capacity (CEC) in soils was determined by treating with 1M NaOAc (pH= 7) to saturate cation sites with Na. Excess Na remaining in the soil was washed off using 95% ethyl alcohol. Thereafter the exchanged Na was extracted with 1M NH4OAc (pH=7). Na concentration in extract was determined by Atomic Absorption Spectrophotometry. (Hesse, 1971).
- Biochar analysis- Samples of Rice husk, Gliricidia and Saw dust biochar were oven dried at 60^{o}C to constant weight. Dried samples were ground by hand to a fine powder using a motar and pestle prior to laboratory testing. pH and EC were determined in a biochar, distilled water mixture of 1:1 and 1:5 respectively. Nitrogen was determined by micro-Kjeldahl method (Black, 1965). Acid extracts of the samples were prepared by wet digestion with perchloric-nitric acid mixture and dissolving the digest in distilled water (Jackson, 1958).

Aliquots of the acid digest were analysed for P by vanado-molybdate yellow method (Jackson, 1958), and for K by flame photometry. The analytical data are given in results.

- Changes in pH with time- The Kalpitiya and Gannoruwa soils contained in 500ml beakers were mixed with RHB, GLB and SDB, at rates of 10, 20 and 30 t/ha. Distilled water was added to maintain a ratio of 1:1 soil-biochar: distilled water. Changes in pH were monitored during a period of 2 weeks.

- Incubation studies – The Kalpitiya and Gannoruwa soils were incubated separately for a period of four weeks with BIOCHAR RISE HUSK (BRH), BIOCHAR SAW DUST (BSD) and BSD added at 30 t/ha rate. At the end of four weeks soil samples from each treatment were tested for pH, EC, available P and K contents by methods described under section 3.3.1 above.

- Statistical Analysis of data- All data were statistically analysed by ANOVA and mean separation done by LSD using MSTAT statistical software package.

In Nepal, vegetable production was experimented in total land of 180m^2 which was divided into 20 plots of 9m^2 each. The land was taken in rent for the experiment. The site was previously used by farmers for the production of vegetables like chilli and tomato.

- Crops selection in Nepal- Two types of vegetables namely onion and prickly seeded spinach were selected for the experiment based on the growing season between December and April as recommended by National Agriculture and Research Center (NARC), Nepal.

- Field studies in Nepal- Field was ploughed before a month for the plantation of vegetables. Plots of size 3m x 3m (0.0009 hectare) were prepared for each type of treatment. Four bands were prepared in each plot for the plantation and sowing of the vegetables. Twenty different plots were prepared for growing vegetables in different application ratios of biochar.

Figure 14: Field layout for onion & spinach

Biochar Application Ratio- Biochar was applied in plots with different application ratios (treatments). Four treatments were performed for different plots with 5%, 10%, 15% and 20% biochar application ratios (treatments).

Standard total fertilizer required for vegetable = 70 kg N/hectare

= (100*0.0009*70)/20 for .0009 hectare
= 0.315 kg for .0009 hectare
= 315 gm for .0009 hectare

Total fertilizer applied = Biochar + complete fertilizer (N: P: K = 20:20:20)
Details of application ratio of biochar have been given

Table 3: Application ratio of biochar

SN	Application ratio (treatment)	Biochar weight (gm)	Complete Fertilizer weight (N: P: K = 20:20:20)	Total weight (gm) of fertilizer applied
1.	5%	15.75	299.25	315
2.	10%	31.5	283.5	
3.	15%	47.25	267.75	
4.	20%	63	252	

Table 4: Biochar application in experimental plot (t/ha)

SN	Application ratio	Biochar weight (t/ha)
1.	5%	0.0175
2.	10%	0.035
3.	15%	0.0525
4.	20%	0.07

- Methodology of soil analysis in Nepal-

Soil samplings were done two times during the experiment. First soil sampling was carried out before the applications of biochar to generate field-specific baseline information and to understand for fertilizer decisions. During first phase soil sampling and analysis, 180 m^2 land area was divided into five blocks and composite soil samples were taken from all the five blocks with the help of soil auger and spade.

Second stage soil sampling was performed at the time of harvest of vegetables. This time, soil samples were taken representing from all type of biochar applications treatments.

About 1 kg composite soil sample from each plot/block was taken for the analysis (soil up to the depth of 15cm was considered for the sampling). For each soil samples, soil pH, soil organic matter % (OM), available phosphorous (P), available potassium (K), total nitrogen(N), cation exchange capacity (CEC), and exchangeable cations - potassium (K), sodium (Na), calcium (Ca) and Magnesium (Mg) were analyzed in laboratory following the standard methods (Table 5).

Table 5: Method of soil analysis

SN	Soil properties	Method	Reference
1.	pH	1:5 soil water ratio	
2.	% Organic matter	Walkey-Black	NARC, 1996
3.	Available phosphorous (P)	Modified Olsen method	NARC,1996
4.	Available potassium (K)	Ammonium acetate extraction	NARC, 1996
5.	Total nitrogen (N)	Kjeldhal | NARC, 1996	
6.	Cation exchange capacity (CEC)	Ammonium acetate extraction	NARC, 1996
7.	Exchangable cations (K, Na, Ca, Mg)	Ammonium acetate extraction	NARC, 1996

2.7 Environmental assessment of production technology

In this section emission levels were analyzed for Sri Lankan intervention. Flue gas analyzer KM 9106 was used to measure CO, NO_x & SO_x during biochar making process. Two trials were done for gliricidia & rice husk.

The system consists of major three components such as an inner container having fire wood to make bio char, an outer container [45 gal tar barrel] having fire wood for combustion and about 15 feet height rectangular duct to emit flue gas while combustion. The bio char produced by absorbing the generated heat by combusting fire wood content in outer container. Whereas the quantity of fuel charged in to the inner container to produce bio char is 6 kg, the quantity of fuel charged in outer container to produce heat is 7 kg. Gliricidia is used as a fuel for both combustion and bio char production. Time taken to produce a batch is nearly 30 minutes.

Flue gas parameters were monitored at a sample port located on stack at about 6 feet height above the ground level. Two similar tests were carried out while producing bio char using Gliricidia and paddy husk.

The test method and principles used are given in Table 6.

Table 6: Test methods & principles

Parameters	Principle	Test Method
Oxygen (O_2)	Gas sample is continuously extracted from a sampling point and a portion of a sample is conveyed to an instrumental Electro Chemical Cells analyzer for determination of O_2	EPA - Method 3A
Carbon Dioxide (CO_2)	Gas sample is continuously extracted from a sampling point and analyzed for CO_2 using IR analyzer	-
Carbon monoxide (CO)	Gas sample is continuously extracted from a sampling point and a portion of a sample is conveyed to an instrumental Electro Chemical Cells analyzer for determination of CO	-
Nitric Oxides (NOx)	Gas sample is continuously extracted from a sampling point and a portion of a sample is conveyed to an instrumental Electro Chemical Cells analyzer for determination of NOX	EPA - Method 7E
Sulfur Dioxides (SOx)	Gas sample is continuously extracted from a stack and a portion of a sample is conveyed to an instrumental Electro Chemical Cells analyzer for determination	EPA - Method 6C
Flue Gas Temperature	K type Thermocouple incorporated in Flue Gas Analyzer	-

2.8 Approaching to Life Cycle Assessment (LCA)

ISO standardized approaches were used to assess Life Cycle Assessment. LCA aggregates multiple impacts associated with defined product or management alternatives across the project or life product cycle in space and in time to comparatively access the overall potential for environmental damage.

3.0 Results & Discussion

3.1 Socio-economic findings

Majority of the respondents were involved in agricultural related work mainly vegetable cultivation. The sample was drawn from farmers who have cultivated mainly vegetable in their lands. The cultivation of fruits, ornamental plants, fishing, casual work etc. provides supplementary income for the family. The majority of decisions in the household are taken collectively by husband and wife. But regarding the agricultural related work the "decision of the husband" is important. Division of labour also depends on the situation but the young educated families always share their works equally. Labor for work is not a big problem in the area. Wage labour is available for hire in nearby villages where cultivation is not possible. Use of Chemical fertilizer and pesticide for vegetable cultivation is very high in the study area .Almost all the respondents use both extensively for vegetable cultivation. But they have little or no knowledge of how to use and often not even know the name of the product.

All instructions on the use of these are given by boutique owner or the sales assistants. Many of the villagers are willing to use organic fertilizer and many farmers use cow dung for their cultivation to supplement chemical fertilizer. The main problem for the use of organic fertilizer is availability and the cost. The farmers have to transport organic fertilizer from outside so that cost is high. In addition farmers prefer to use chemical fertilizer due to quick result. Further, there is no other alternative for pesticide for controlling pests. The farmers are aware of the dangers of use chemicals extensively for their agricultural production but there is no other option according to them due to the type of soil. It is interesting to note that almost all the farmers interviewed maintain a family vegetable garden separately for their consumption. They never use either chemical fertilizer or pesticide for cultivation in this plot of land. They use cow dung as fertilizer and traditional methods to control pests in their family garden. Out of every one hundred cultivators 90 respondents did not know about biochar. Eight of them explained it as compost and 2 of them have heard the word "Biochar" but had not seen it.

In 2012 for Kalpitiya Area has had 15480 households. Female population was 33,496 and male population was 32,648 out of 66,144 people. Kalpitiya is one of the arid areas in Sri Lanka. Annual average rainfall varies from 680mm to 945mm (Repots of Divisional Secretariat office 2011, 2012 and 2013). The majority population in the area is Muslims (Muslim-28,620, Sinhalese-24,940, Tamils-12,496 and others-188). But according the Divisional Secretariat office catholic population is more active in the area. Population distribution can be done in to 5 groups according to the ages. Those groups are 0-5, 6-14, 15-30, 31-59 and over 60. Most of them are in 31-59 groups. Population density per Sq.m^2 was 429 in 2012.

Table 7: Labour force

Age group	Number	Employed	Unemployed	Foreign Employment			
				Fulltime		Part time	
				Male		Female	
10-18	3,432	3,211	1,328	3	0	7	08
19-60	31,744	21,205	9,432	151	179	641	629
Over61	2,315	979	1,336	6	3	0	0

According to the above data it is clear that one third of the working age people are unemployed and females are predominantly employed in the foreign employment sector. In 2012 the numbers of full time housewives were 6,817 and retired and old age people number was 2,080. There are 407 disabled persons are in the area. In addition 11,425 were students.

Table 8: Unemployment by age group

Age level	10-18 years		19-30		31-40		41-60		Over 61	
Gender	F	M	F	M	F	M	F	M	F	M
Number	696	623	1,722	1,541	1,887	1,380	1,990	912	783	553

In this area 607 females and 609 males have had no school education. But most of them, 2,053 male and 3,440 female have received primary education. According to the available data many drop-out from school after GCE (O/L). In 2012 there were 41 graduates in the area.

According to the available data of the employed people casual workers are the highest (7,883) and the next is self-employment (5,267). The most popular self-employment activities are boutique keeping and dry fish production. The monthly income of 21.35 % families is between LKR 1,000-LKR 3,999 and 22.42 % households are getting Rs 4,000- Rs 7,999 per month. The number of people earning more than Rs 30,000 incomes per month is a very small; around 2.30%. Some families receive government welfare payments and other benefits and that number is 1,134 households. Majority of the families in the study area have permanent and their own houses. Data shows that those as 8,825 and 13,646 respectively .There are 1,256 families who do not have any shelter. As the following table shows, sanitation, electricity and water are available to a majority of the families. Ownership of fixed line telephone lines is below average with only less than 1/3 of the population households having fixed line phones. However, almost every family has a mobile phone.

Table 9: Condition of houses

Toilet facilities		Electricity		Water		Telephone(Landline)	
Yes	No	Yes	No	Yes	No	Yes	No
12,202	2,022	10,807	3,417	10,566	3,658	4,126	10,098

Paddy is not a popular crop among farmers in the Kalpitiya area due to the shortage of water. In 2011 nobody cultivate paddy in any season. In 2012, however, in Maha season they have cultivated 0.40 h. and produce 0.24 Mt. of paddy. It is interesting to note that they have used only rain water for paddy cultivation. Coconut is one of the main crops in Kalpitiya area. In 2012 coconut has extended to over 7,163 acres and produced 6,289 metric tons. Guava, papaya, and banana are the most common crops in Kalpitiya area. In 2012 guava cultivation was in extent of 55.25 acres.

Table 10: Vegetable cultivation in 2012

Name of the vegetable	Cultivation(Acre)	Production(Kg)
Snake beans	792.75	3,805,200
Pathola	58.75	493,500
Vatakolu	58.75	493,500
Brinjol	121	726,000
Chilly(green)	1013.75	1,013,750
Bitter melon	74.25	623,700
Ladies fingers	156.75	877,800
Red onion	2029.5	1,217,700
Capsicum	299	1,435,200

There are many farms in the area and all are privately owned. There are 225 poultry farms 251 cattle farms and 387 goat farms in the area. Not having grass lands, shortage of animal feed are the main problems for animal husbandry.

Table 11: Usage of lands

Crop(acres)	Cultivation (ht)
Coconut	2,900.2
Other permanent crops	103.5
Paddy	0.40
Home gardens	20.6
Natural and cultivated forest	17.3
State lands	9,821.7

There are several large scale and small scale factories in the area. Coal power plant in Norochcholei, Garment factory in Karamba, Sauterne in Narchikaliya, Lanka Ice limited in Kurignanagnanapitiya are some of the large factories and industries. Especially the garment factory has provided many job opportunities for the youth. In addition as a cottage industry salt production is very important. The madel fishing industry is about to vanish in the area. The sea belt is about 74.43 km in length and there are 3,456 fisheries families in the area. Dry fish is one of the most prominent industries related to the fisheries industry. In addition there are 141 prawn farms in the Kalpitiya Divisional Secretariat area and there are no fresh water fisheries. Recently the government has declared the Kalpitiya area a "tourist zone" for the locations that are of historical, environmental and religious importance.

Foot bicycle and Motor bicycle are the common and popular modes of transport of the people in the Kalpitiya area .There is hardly any use of agricultural machinery other than water pumps and pesticide sprayers. Lack of big machines like harvesters for agriculture is due to the lack of large scale paddy land in the area. There is one medium sized hospital which is the district hospital in the Kalpitiya. There are also 4 Central Medical centers and 10 clinics. There are 66 preschools, 38 schools in the Kalpitiya DS division but no higher educational institutes .Though the majorly of people belong to Islam 5 Buddhist Sunday schools are in the area. But Islam and Catholic churches are the most common religious places of worship. Dug wells (4,301) and tube wells (3,213) are the principal sources of drinking water for the civilians in the area. There is no natural water system like streams, canal etc. in Kalpitiya.

Table 12: Population distribution by ethnicity & age group

Village (Grama Niladari) Division	Sinhala						Tamil					Muslim					
	0-5 ys	6-14	15-30	31-59	60<	0-5 ys	6-14	15-30	31-59	60<	0-5 ys	6-14	15-30	31-59	60<	0-5 ys	Total
Daluwa	88	121	241	264	42	21	33	86	93	19	0	1	3	1	0	1	1,020
Nirmala pura	148	355	502	664	127	43	54	82	97	21	0	0	1	0	0	0	2,094
Mampu riya	223	380	610	686	98	91	168	281	287	37	0	0	1	2	0	0	2,864
Narakka lliya	34	93	126	158	22	94	156	398	394	111	20	40	56	63	13	0	1,778

Table 13: General income of the family

GN Division	1000-3999	4000-7999	8000-11999	12000-15999	16000-19999	20000-23999	24000-27999	28000-31999	32000<
Daluwa	18	37	87	62	6	39	9	14	07
Nirmalapura	144	86	97	41	72	46	13	12	16
Mampuriya	118	172	0	107	118	72	64	28	39
Narakkalliya	48	0	150	143	8	4	10	5	0

From Hundred respondents 90 were females and other 10were male respondents. If husband is not around, many women, especially in Muslim households, asked her son to answer the questions. Regarding the age of family members, it is different from family to family but the majority belongs to years 10-20 (62%). Getting married at early age was a common characteristics that researcher noted in the area. It is interesting to note that all respondents have had School education but majority have only a primary education (Up to grade 5). Out of 100 only 7 have studied up to Advanced Level and has higher educational qualifications. Regarding the education level of family members, it is noted that children are more educated than their parents. Further, it was found that people are very keen to send their children to school and give a good education them. The main reason found for this is the unstable income of cultivation. There was only one graduate found. The majority of respondents in the sample were involved in farming activities. There were two families employed in other sectors but they also maintain an agriculture land. There were 5 respondents engaged in fishing related work but they also are owners of cultivated lands.

The types of work people do show a difference across generation. It was noted that 2nd generation are not willing to undertake cultivation as their main livelihood but only as secondary income sources. Therefore majority of employable members of family are working in other sectors such as government, private, etc.

The majority of respondents depend on agriculture and it was difficult to estimate their income with any reliability. Through the discussions it was understood how much it fluctuate depending on weather. In some months they earn a five figure income while in other months they became indebted. However, the above table shows the rough monthly income of respondents and their family. The information in the table also includes the additional income of the family. For example some respondents are involved in fishing, some are doing casual works (workings others farms in daily basis)

Indebtedness is common in the area. Once they have a good agricultural production, they become financially well off. Then they usually buy many consumer items although some seem to be not really necessary in their day to day life. If they face financial losses in the next season due to poor agricultural income, they sell or mortgage what they bought. In addition they buy many thing on pay later basis which includes not only consumer items and farm inputs (fertilizer) but also day today household necessities. Therefore at the end of the harvest, very often all profit goes to the boutique owner. One farmer explained “in some periods we are like kings and in some other periods we are like beggars”

The following figure shows the currently cultivated food crops of the respondents' households in the study areas. The figure was prepared according to the hierarchical order based on study data. GN officers of the 4 areas also agree with this order. Many farmers have grown many crops at once so that it was difficult to present exact the number of acres in figures.

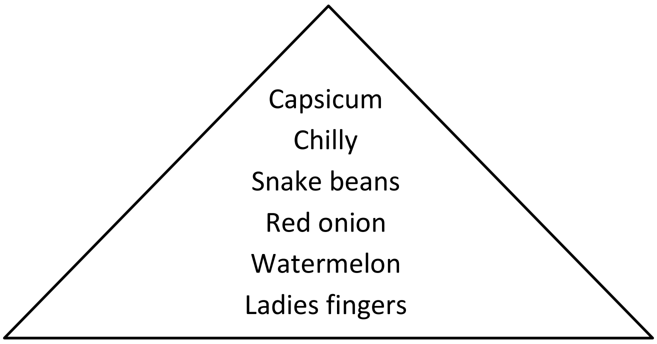


Figure 15: Hierarchical order for crops

In addition to these food crops, many farmers grow tobacco. This gives a higher profit and therefore they can earn much more from tobacco than from food crops. Farmers claim that from their experience they know that tobacco plant can resist any whether condition. According to the local government administrative officer (Grama Niladari), tobacco growing is a new trend.

Cultivation of fruits also is common in the area. The respondents grow Papaya and Watermelon extensively in their lands .In addition Guava is also common in the area. It is interesting to note that "except leeks, all other vegetables grown in Sri Lanka can be grown in the area" (Farmers' statement). Some farmers have tried even to grow Carrot due to the condition of the soil (Loose sandy soil-allows growth of more small yams).

Growing ornamental plants is also popular in the area. Orchids, Croton and Jasmine etc. are some of them. They provide supplementary income to the families.
It is notable that using weedicide is very low in the area. According to farmers weed is not a big problem for the cultivation due to use of strong pesticide and chemical fertilizer. Further, if there are weeds they remove them manually since necessary labour is available. Many labourers doing this work are women. According to some respondents it is essential to use weedicide to control some weeds Eg, Kalanduru plants.

Of the respondents nearly 80 % said they use both organic fertilizers as a supplement to inorganic fertilizer (Chemical fertilizer). But they prefer and use more chemical fertilizer than organic fertilizer. The main reason for that is organic fertilizer is more costly due to transport it from outside. In addition farmers believe that if they use organic fertilizer they have to spend more money for weeding since it breeds more weeds. Other reason is organic fertilizer does not give them quick result as it takes time to get absorbed into soil. Some farmers do not have their own land to cultivate. If they use organic fertilizer the result will come after two or three seasons and in many cases they have cultivation right to one season. However, many farmers use cow dung for their cultivation as a supplement to chemical fertilizer. One tractor load of cow dung costs is around LKR 10,000-12,000. 2 tractor loads are needed for a one acre. 99% of cow dung used in the area is brought from outside.

In addition to using of cow dung as organic fertilizer, kela pohora (Jungle fertilizer) is very famous among farmers. They collect them from canals when they go dry. So it is only during the dry season this fertilizer is available. It is a type of soil that is mixed with dried leaves and black in colour. For this fertilizer, farmers need to pay only transport cost and for labour. Average cost is around LKR 2,000-2,500 depending on the distance.

Some farmers use gliricidia leaves as fertilizer in cultivation. One of the NGOs, has introduced a plant to prepare compost with free instructions but farmers complain that it do not work .Paddy husk also is used by some farmers but not by many due to the cost. Some farmers said that arresting people who transport paddy husk and is a major constraint in using it for fertilizer.

Almost all the respondents use chemical fertilizer for their cultivation as it gives quick results. Some chemical fertilizers used in the area are Urea, soffit, Nilketa, TSP (Ketapohora) Ammonia, MOP, Top crop etc. It is of interest to note that farmers have little knowledge about chemical fertilizer or pesticides. Many farmers do not know even the names of the fertilizer they use. They just use the name of the crop to identify/describe the fertilizer they use e.g. Miris pohora (Chilly fertilizer), me pohora (snake beans fertilizer) etc. All advice regarding fertilizer and pesticide is given by the boutique owner or shop assistants. Agents of some companies also give instruction to farmers. According to the respondents there are no agricultural officers coming to advice on fertilizer and pesticide. But agricultural officers tell a different story and claim that farmers do not listen to them thinking they have no experience. It is noted that nobody use dolomite in the cultivation and nobody tests the soil of their land before deciding the crop they cultivate. Further, according to the respondents, without use of chemical fertilizer extensively they cannot grow any plants in this sandy land.

Majority of farmers apply organic fertilizer on the surface and water over it. There is no special time to use fertilizer for both chemical and organic fertilizer. Around 41% of farmers when using chemical fertilizer, mix fertilizer with soil and spread on the surface. Farmers themselves involve in the application of fertilizer and in most cases it is the task of the male members of the family. However 20% of respondent revealed that they got training in the preparation and application of organic fertilizer through NGOs. But the fertilizer use among the majority of the farmers is determined by practical experience and not by formal knowledge and training.

Hundred percent of the respondents use pesticide to control pests in their cultivation. Generally they spend around LKR2,000-2,500 for pesticide for one acre. Polidol, Kalikot Basudhin Powder are the name of pesticide given by farmers. As mentioned, some farmers even do not know the name of the pesticide they used 'Miris beheth (Pesticide for chilly), Me beheth (pesticide for snake beans) are the names they use. All instructions are given by boutique owners; some areas are full of chemical smell. A small number of farmers use "kem" (Indigenous Knowledge and practices) or traditional methods to control pests. One such method is planting flowers with strong smell around the perimeter of the farm. Daspetthya & Zeeniya are some of them. One farmer said he buried a skull (Dead person's skull) under the soil in his farm. Some farmers use to cut "kirishaka" (tree with milk) before commencing to land preparation.

One of respondent (a lady) who was thriving ornamental plants cultivation in addition to the vegetable cultivation said she never used pesticide for her flower garden. According to the instruction of the NGOs who helped her, she prepares organic pesticide.

The farmers are aware of the danger of extensive and uncontrolled use of chemicals in their agricultural production but there is no other option according to them. It is interesting to note that almost all the farmers interviewed maintain a family vegetable garden separately for their consumption. They never use either chemical fertilizer or pesticide for this land cultivation. Using organic fertilizer like compost and cow dung they neutralize the plants and using traditional methods they control the pest in their home garden.

After explaining about biochar, the farmers were very keen to get more information. As for the feedstock material to produce biochar they suggested garbage of tobacco, chilly plants, slavonia, coconut leaves etc. There is a strong willingness to use biochar if it is available and they expressed their wiliness to help the project too. One suggestion of the respondents is to have a training program related to biochar production. According to them, at least three biochar plants to produce biochar should be established in a village to reduce the transport cost. A landless villager should be made responsible for maintenance and supervision of the plants in order to ensure sustainability and better results.

Overall, the respondents expressed a strong interest and willingness to use biochar technology if they are provided with support. However, it is necessary to have some education program related to biochar before introducing it to farmers.

- Organize community mobilizations / education program to create awareness about biochar.
- Provide publicity through media
- Organize training programs in the preparation of biochar and its use.
- Establish a model biochar plant and model farm in a key area for demonstration.
- Get the assistance and support of NGOs working in the area since many people trust NGOs.
- Obtain support of religious, political and community leaders and government official s of the area.
- Appoint a person from community to look after the model plants and farm once it is established.

3.2 Feedstock availability

In Sri Lanka, total annual agricultural productivity is 7.3×10^6 Mt and 6.7×10^6 Mt of residue was generated during the production process in 2012. Assuming 20% of crop residues availability and estimating the biochar yield as 20%, agricultural residue yield is approximately 2.61×10^5 Mt. Among agricultural crop residues rice straws and coconut shell are available at the highest amount. [Economics and Social static of Sri Lanka-2012, Volume XXXIV, Central bank of Sri Lanka, Statics department, April 2012]

Table 14: Availability of selected agricultural residues in Sri Lanka in the year 2011

Crop	Production × 10^3 Mt)	Moisture %	Residue type	(Product/ Residue) (RPR)	Residue quantity	
					(Wet.×10^3Mt)	(Dry×10^3Mt)
Rice	3,875	15	Straw	1.5	5,812	4,941
Millet	5.5	15	Husk	1.5	8	7
Maize	135	15	Maize stalks	1.5	203	172
Ground nut	17		Nut shell	1.5	25	23
Coconut	2,808	10	Shell	0.6	1,685	1,516
Coffee	15	15	Coffee husk	2.1	32	27
White sesame	5	15	Sesame paste	2.1	10	8.5
Sugarcane	399	75	Bagasse	0.3	120	30
Gram	16	15	Husk	0.6	10	8
Cocoa	2	15	husk / pods	1	2	1.5
Total	7,277				7,871	6,703

Waste during production activities such as in industry, traffic and resource development comes under industrial solid waste category. Municipal Solid Waste (MSW) disposal in Sri Lanka is primarily a responsibility of the public sector (local government) MSW creates employment opportunities for large numbers of laborers. However, major portion of the MSW management cost is allocated for waste collection and transportation rather than for waste disposal and treatment. Therefore if MSW can be used successfully for biochar production this cost can be minimized. Apart from that since MSW is available all over the country this would be a feedstock for biochar with high potential. But the major problem in using MSW as a feedstock is the high amount of moisture it contains. It should also be noted that, only the organic portion can be used for biochar production.

Sri Lanka has 309 local government authorities and the daily collection of MSW in the country is about 2,683 tons of waste. However the generated amount may far outweigh this with almost negligible collection in rural areas of the country. The best estimate of total MSW generation in Sri Lanka was around 6,400 tons/day. But the collection varies within the range 10%-40%, which gives 640 tons to 2,560 tons per day. [Municipal Solid Waste Management, The Sri Lankan Case, Nilanthi J.G.J. Bandara, Department of Forestry and Environmental Sciences, University of Sri Jayewardenepura, Sri Lanka]

Waste generated during production activities such as in industry, traffic and resource development comes under this category. Industrial waste includes solid waste, semi-solid waste, liquid and gaseous waste which are not permitted to be discharged into the environment directly. Based on the components, it can be categorized as organic waste and inorganic waste. Organic component is what can be useful in biochar production. [Types, Amount and effect of industrial solid waste, page 2, Jinhui Li, Department of Environmental Science and Engineering, Tsinghua University, Beijing, China]
Bagasse is one of the main residues from sugar manufacturing plants while other is Cane trash. Cane trash is the field residue remaining after harvesting the cane stalk and bagasse is the fibrous residue left over after milling of the cane, with 45-50% moisture content and consisting of a mixture of hard fiber, with soft and smooth parenchymatous (pith) tissue with high hygroscopic property. Annual sugar cane production in Sri Lanka in 2011 was 2.67×10^5 Mt. Therefore estimated annual bagasse production is 8.01×10^4 Mt. [http://www.bioenergyconsult.com/tag/composition-of-bagasse/2012.10.31]

Most popular livestock in Sri Lanka are cattle, buffaloes, sheep, goat, pig, duck and chicken both in domestic and industrial scales. The feedstock available from livestock are, poultry litter, a mixture of bedding, manure, feathers and spilled feed. The composition and quantity of manure depends on the amount and quality of fodder or feed. In general it has ash content in the range of 15%-20% and average moisture content is 85%. In 2010, dry manure production was 2.54×10^6 tons, while wet production was 20.2×10^6 tons. [Economics and Social Statistics of Sri Lanka-2012, Volume XXXIV, Central bank of Sri Lanka, Statistics Department, April 2012]

Most available and popular fast growing tree in Sri Lanka is “Gliricidia Sepium”. Gliricidia could be grown as a mono-crop plantation or as a mixed crop along with other short/long term crops grown locally. Planting methods, include a spacing 1 m x 1 m double rows with a density of 8,000 trees/ha. [Climate Change Adaptation Sri Lanka.mht /Sri Lankan effort/Gliricidia, Biomass has huge potential for Clean Development Mechanism [Newspaper Article, The Nation English Sri Lanka, Dilanthe Withanage, September 20, 2011]

Gliricidia is adapted to wide-ranging agro-climatic and soil conditions and can be cultivated all over Sri Lanka except in coastal areas, on mountain tops and in arid areas.
It is tolerant to poor soils. Apart from water logged and rocky soils, it can be cultivated in all other types of soil including degraded marginal lands.

In addition to collection and analysis of secondary information, a survey had been carried out at two locations to identify feedstock availability of rise husk, saw dust and Gliricidia under this project. Those two locations were Kalpitiya and Paatha Hewaheta Divisional Secretariat areas from the North Western and Central Provinces respectively.

- Feedstock availability in Paatha Hewaheta Area-

The primary livelihood of the people in Paatha Hewaheta area is agriculture. The main form of agriculture is vegetable cultivation which is very much suited to the terrain of the area. The extent of low lying flat land is limited and therefore paddy cultivation is limited to these areas. Paddy cultivation is done only during one season where the rainfall is higher and in the other season vegetable cultivation is carried out. Out of the vegetables, tomato is the main crop supplemented by mainly Cabbage, Brinjals and Beans. Tea is cultivated in small holdings in few areas and there are no extensive tea plantations. Coconut is planted only in home gardens and there are no coconut plantations. The coconut that is being produced is mostly consumed by the land owners themselves and any excess is sold in local market. The coconut leaves are used to make thatches for roofing and leaf ends, fronds and husk is used as fuel. There are no rubber plantations within this area. Other than this, there is no other major cultivation which could be used to produce feedstock for biochar.
As the rice production in the Paatha Hewaheta area is very small, only a small amount of straw is left after harvesting of paddy. Major portion of this straw is allowed to decay on the same land and is put back to paddy field as fertilizer for the next crop. Only a small quantity is burnt to avoid rodents like rats being spreading. Therefore using rice straw as a raw material for biochar is not possible in this area.

Gliricidia was grown in home gardens and other vacant lands as fencing material and mainly to be supplied to power generation plant established in Walapane. However the power plant seized to operate and the majority of the Gliricidia stems are now used to support Bean and Tomato cultivations as props. Some of stems are transported to other areas like Badulla and Nuwara Eliya districts to be used as bean sticks. Now this has become a good business and income generating activity, hence the villagers are still keen and engaged in growing Gliricidia. When these stems decay, they are added to soil to function as fertilizer.

Only two carpentry shops were found within this area and the quantity of sawdust and wood shavings produced by these workshops are very little. Some of these are taken for poultry farms and balance is burnt. There is no significant amount of sawdust or wood shavings produced by these to be used as raw material for biochar production.
Nine saw mills were found within the Paatha Hewaheta area and the details of sawdust production is provided in the following table.

Table 15: Saw dust production in Paatha Hewaheta area

Grama Niladari Division	Name of Sawmill	Approximate Amount of sawdust produced per week (kg)	Distance from proposed research area (km)	How they are disposed of
Thathuoya	Wijesinghe Saw Mill	1,100	2	Taken to cement factory at Puttalam
Ankelipitiya	Jayawickrama Saw Mill,	400	4	Taken to cement factory at Puttalam and small amount to houses for fuel

ThalathuOya	Jayaratne Saw Mill	1,100	2	Taken to cement factory at Puttalam and small amount to houses for paltry
Pussatenna	Vijaya Saw Mill	600	3	Taken to Soorya Match Factory
Thalathuoya	Herath Saw Mill	150	3	Taken to cement factory at Puttalam
Haragama	Bandula Saw Mill	900	9	Taken to cement factory at Puttalam
Pinnagolla	Ishara Saw Mill	26,000	2	Taken to cement factory at Puttalam
Mihidumtenna	Senanayake Saw Mill	20,000	2.5	Taken to cement factory at Puttalam
Kossinna	Lakshman Saw Mill	8,500	3	Taken to cement factory at Puttalam
Mihiduntenna	Tissa Saw Mill	13,200	2.5	Taken to cement factory at Puttalam
Total		71,950		

The above table shows that the total sawdust production within the selected area is about 71,950 kg per week. In the case of 9 saw mills as described in the above table, the saw dust collected are readily taken to the Cement Factory at Puttalam. The saw mill owners give them free of charge but the workers who work in these mills collect saw dust, fill in bags provided by the collectors and keep ready to be by the collector for which they get paid about Rs 5 per bag including for loading into the lorry. This could vary as there is competition for saw dust collection according to the demand. Saw dust from one saw mill is taken to a match production factory in Digana and the mode of disposal is the same.

During the field study carried out in the Paatha Hewaheta area to assess the availability of rice husk as a feedstock to make biochar, only those areas which are economically viable for transportation were selected. Paatha Hewaheta is not an area which produces rice extensively and therefore only few rice mills are available. There are no large rice mills and are big enough to cater only for the rice that is produced within the area. Rice is not brought into this area from outside to be processed. The following table provides the quantity rice husks produced by these mills

Table 16: Rise husk production by rise mills in Paatha Hewaheta area

Grama Niladari Division	Name of Rice Mill/Owner's name	Approximate amount of husk produced per week (kg)	Distance from proposed research area (km)	How they are disposed of
Kapuliyedda	S.M. Seneviratne	600	9	Part taken to poultry farms & part burned
Thalathuoya	S.M. Tikiribanda	300	7	Part taken to poultry farms & mushroom cultivation
Thalathuoya	K.K.H.M.	600	1.5	For poultry

	Wijeratne			farms and houses for cooking
Kapuliyedda	E.M. Ekanayake	1,200	7	Part taken to poultry farms & part burned
Marassana	Attanayake	1,600	2	Taken for brick kilns
Marassana	A.R.M.T. Bandara	1,000	1.5	Taken for poultry farm
Total		5,300		

According to the above table the total amount of paddy husk produced in the area is about 5,300 kg per week. The above table shows that most of the rise husk produced is taken for poultry faming. Some are taken for mushroom cultivation and brick kilns.

- Feedstock availability in Kalpitiya Area-

Kalpitiya area is a peninsula connected to Puttalam at Kallady extending West and Northwards. It is more or less shaped like a strip slightly broad at Kallady and the length is about 40 km. Sawdust is produced in sawmills where the timber logs are sawn. There are no saw mills within the Kalpitiya area and therefore the sawdust has to be brought from adjoining areas. The closest Divisional Secretariat area is Puttalam which joins Kalpitiya from one end at Kallady. Transporting from other areas would not be economical due to the distance to be covered. The only entrance to Kalpitiya is through Kallady and therefore sawmills from most economical distances were selected for the study. Apart from the sawdust, where carpentry work is being carried out, wood shavings are also produced which also can be used as feedstock. The details of sawmills and feedstock produced is provided in the following table.

Table 17: Saw dust production in Puttalam area

Grama Niladari Division	Name of Sawmill/Carpentry shop	Approximate amount of sawdust produced per week (kg)	Approximate amount of shavings produced per week (kg)	Distance from research site (km)	How they are disposed of
Puttalam 607	Color Furnishers	1,500	50	20	Sawdust taken to cement factory. Shavings burned
Puttalam 617	Hasindu Furnishers	30	20	20	Sawdust taken to cement factory. Shavings taken to poultry farm

Puttalam 607	Hassan Furnishers	6,000	---	20	Sawdust taken to cement factory
Total		7,530	70		

The above table shows that the amount of sawdust produced within Puttalam area within economical distance is about 7,530 kg per week. Almost all the sawdust produced is taken to the cement factory free of charge.

Table 18: Saw dust production in Kalpitiya area

Grama Niladari Division	Name of Sawmill/ Carpentry shop	Approximate amount of sawdust produced per week (kg)	Approximate amount of shavings produced per week (kg)	Distance from research site (km)	How they are disposed of
Kurinnanpitiya South	Kasun Nandana	---	225	6-8	Taken to poultry farm & ice production
Kandakuliya	Chaminda Stores	---	525	25	Taken to poultry farm & ice production
Kandakuliya	Banu Timber Depot	---	225	20	Taken to poultry farm & ice production
Nawakkaduwa	Joseph Sudarshana	---	175	2-4	Burry in the land
SinnaKudiruppu	Tata Stores	---	525	20-22	Taken to poultry farm & ice production
Alankudawa	Lanka Timber Sales	---	120	4-6	Taken to poultry farm & ice production
Alankudawa	Kandy Timber Stores	---	150	4-6	Taken to poultry farm & ice production
Musalpitiya	Abdulla Timber Mill	4,500	---	20-25	Taken to fill pits, coconut plantation & as fuel for cooking
Total		4,500	1,945		

A brief assessment of all sawmills within the Puttalam area reveal that they adopt similar methods for disposal of sawdust which has a high demand by the cement factory situated in Puttalam. All these mills are situated more than 20 km away from the biochar research sites selected. This factor has to be considered to see whether it is economical to transport feedstock from these mills.

There are no large sawmills within the Kalpitiya area but there are 8 carpentry workshops. Major quantity of timber is brought as logs are purchased from the State Timber Corporation (STC) Depot in Puttalam. This is much preferred because if transported from other sources require permits from Divisional Secretaries, which is an elaborate process and they prefer to buy from STC where transport could be done under the permits issued by the STC itself.

There are no rice mills within the Kalpitiya Divisional Secretariat area. Therefore if rice husk has to be used as feedstock for producing biochar, it has to be brought from the nearest place which is within Puttalam Divisional secretariat area. Otherwise the closest area is the Anuradhapura district and which would not be economical.

Table 19: Rise husk production by rise mills in Puttalam area

Grama Niladari Division	Name of Mill	Approximate amount of rice husk produced per week (kg)	Distance from research area	How disposed of	Payment (Rs)
Puttalam South	Pursing Rice Mill	5,000	25-30	Taken for boilers in oil factory, taken to cement factory & for poultry farms	Taken free of charge
Thabbowa	Sampath Rice Mill	3,000	30-32	Taken to cement factory	Taken –free of charge
Mallativu	Laisa Rice Mill	7,000	35-37	Fully used for boilers in the mill	---
Total		15,000			

As per the above table there are only three rice mills within Puttalam Divisional Secretariat area. The first rice mill in the table produces about 15,000 kg of rice husk per week and these are taken away for Oil Factory, Cement Factory and paltry farms free of charge. The second in the table produces about 3,000 kg per week and taken by the Cement Factory free of charge. The third one produce about 7,000 kg per week and this quantity is fully used for the operation of boilers in the rice mill itself and nothing is left. The first two mills in the table allow rice husk to be taken away free as accumulation of rice husk is a problem for them. But it would be possible to negotiate for them to sell at a certain price. However they did not gave a clear indication of the price they would expect or ensure the sale of paddy husk.

All these rice mills are about 35 km away from the proposed biochar application trial sites. Therefore the economics of transport has to be worked out to verify the feasibility. For research it would be possible to manufacture biochar where feedstock is available and transport to testing sites as a large quantity is not required. But when actual applications are done by farmers in their fields, it would not be economical and there is a doubt whether the farmers would take trouble to adopt unless there is a remarkable financial benefit of using biochar.

This area is not suitable for growing Gliricidia because the soil is sandy. Even few trees along some fences are not adequate to produce biochar. The other option is using hay for making biochar, but this is not possible as there are no paddy cultivations within Kalpitiya peninsula. Rice cultivation is not done extensively in the entire Puttalam district but only in places where reservoirs are available. Even these are very much far away from the research sites and cannot be regarded as a possible raw material for making biochar at research sites. Even at large scale field application level it would not be economical.

According to the survey conducted in Sri Lanka, it is evident that there is no adequate quantity of feedstock available which could be obtained for large scale production of biochar. Both sawdust and rice husk that is produced are readily taken away for cement factory, poultry and other uses. Other types of feedstock are not produced in large quantities which are adequate enough to produce biochar in bulk.

However it is possible to manufacture biochar at household level for which many types of biomass waste could be used including rice husk and sawdust. Since the biochar is not required continuously and would be used just before the cultivation period, it is possible for someone to collect feedstock which is adequate enough to produce his own biochar by using household type equipment. For this type of equipment, there are many options of feed stock available locally including sawdust and rice husk. Also available in the vicinities are feedstock such as coconut products (husk, leaves, fronds, coir etc.), other types of combustible material such as firewood, straw, dry leaves, twigs etc.
Therefore, it is recommended that biochar to be produced in the field itself at household level for individual cultivations. For the research trails, which require limited quantities, biochar can be transported from outside to trial sites but not economical for large scale applications. However, if biochar is produced in a large scale at a central place where adequate feedstock is available, transport cost has to be taken into account and worked out to see whether it is economically viable.
It is also recommended to fully investigate the production of biochar which has been done in Paatha Hewaheta which would be useful for present research work. We have heard that similar projects has been carried out in other districts also which should also should be investigated.

Feedstock availability in Nepal

In Nepal, for the production of coffee biochar, feedstock used is mainly coffee seed coat. Coffee biochar can be a partial alternative to forest feedstock biochar as production of coffee is increasing in Nepal (Table 20) and the non-consumable part can be used for the production of biochar. Coffee farming in Nepal is proven as promising due to the availability of soil with appropriate climate especially in the mid hills at an altitude of 1,100 m and above from where the series of Himalayas with fresh and cool air can be experienced - suitable for coffee production. Currently coffee is produced in more than 30 districts in Nepal. The district where this demonstration project was lunched i.e. Lalitpur is also one of the commercially significant coffee production district of Nepal. [CBS, 2013]

Table 20: Coffee production by years in Nepal

Year	Production (000' MT)
1998/99	0.05
1999/00	0.07
2000/01	0.09
2001/02	0.14
2002/03	0.19
2003/04	0.22
2004/05	0.25
2005/06	0.30
2006/07	0.46
2007/08	0.28
2008/09	0.27

2009/10	0.31
2010/11	0.40
2011/12	0.40
2012/13	0.40

For the mixed char production, the raw materials were collected from Padali Community Forest of Lalitpur district. Padali Community Forest is located at Lamatar VDC-6 covering an area of 46 hectares. Most common species identified in the feedstock included Eupatorium adenohorum, Dryopteris sps, Schima wallichii, Myrsine capitellata, Quercus sp., Castonopsis sp., Myrica esculenta, Madhuka indica, Castanopsis tribuloides, Pinus roxburghii etc. Dry and fresh biomass consisting of twigs, small stems and non woody biomass and leaves were considered for making mixed biochar.

3.3 Impact from Technology

Advancements in technology have brought the finer things into peoples' lives. The impact of technology on natural environment results air, land and water pollution, degradation and contamination. Greenhouse gas emissions have brought us global warming, melting glaciers, rising sea levels, air pollution, ocean acidification, disrupted marine and wildlife biodiversity, groundwater contamination, soil depletion. Following results were taken by using a KM9106 flue gas analyzer. Table 21 and Table 22 represent emission statics while making gliricidia and rise husk biochar respectively. Test methods and principles were discussed in section 2.7.

Table 21: Flue gas test results on char producing using Gliricidia

Time (14th October in 2014 at National Engineering Research and Development Centre)	11.28h	11.37h	12.10h
Flue Gas Temperature (^oC)	338	600	439
Oxygen (%)	16.4	15.5	14.8
Excess Air (%)	307	375	245
Carbon Dioxide (%)	3.4	3.4	4.6
Carbon Monoxide (mg/m3)	514	1526	919
Carbon Monoxide (mg/Nm3) [Ref. 6.0 % O2]	3,809	-	-
Sulfur Dioxide (mg/m3) [As Measured]	386	463	446
Sulfur Dioxide (mg/Nm3) [Ref. 6.0 % O2]	1,278	-	-
Nitric Oxides (mg/m3) [As Measured]	24	66	51
Nitric Oxides (mg/Nm3) [Ref. 6.0 % O2]	79	71	-

Table 22: Flue gas test results on char producing using rice husk

Time (14th October in 2014 at National Engineering Research and Development Centre)	14.41h	14.54h	15.07h
Flue Gas Temperature (^oC)	262	483	450
Oxygen (%)	15.3	13.1	14.5
Excess Air (%)	213	167	222
Carbon Dioxide (%)	4.1	6.9	8.2
Carbon Monoxide (mg/m3)	651	1688	1416
Carbon Monoxide (mg/Nm3) [Ref. 6.0 % O2]	3,749	8,931	8,738
Sulfur Dioxide (mg/m3) [As Measured]	55	532	944
Sulfur Dioxide (mg/Nm3) [Ref. 6.0 % O2]	3,196	2,815	5,825
Nitric Oxides (mg/m3) [As Measured]	16	130	47
Nitric Oxides (mg/Nm3) [Ref. 6.0 % O2]	92	688	290

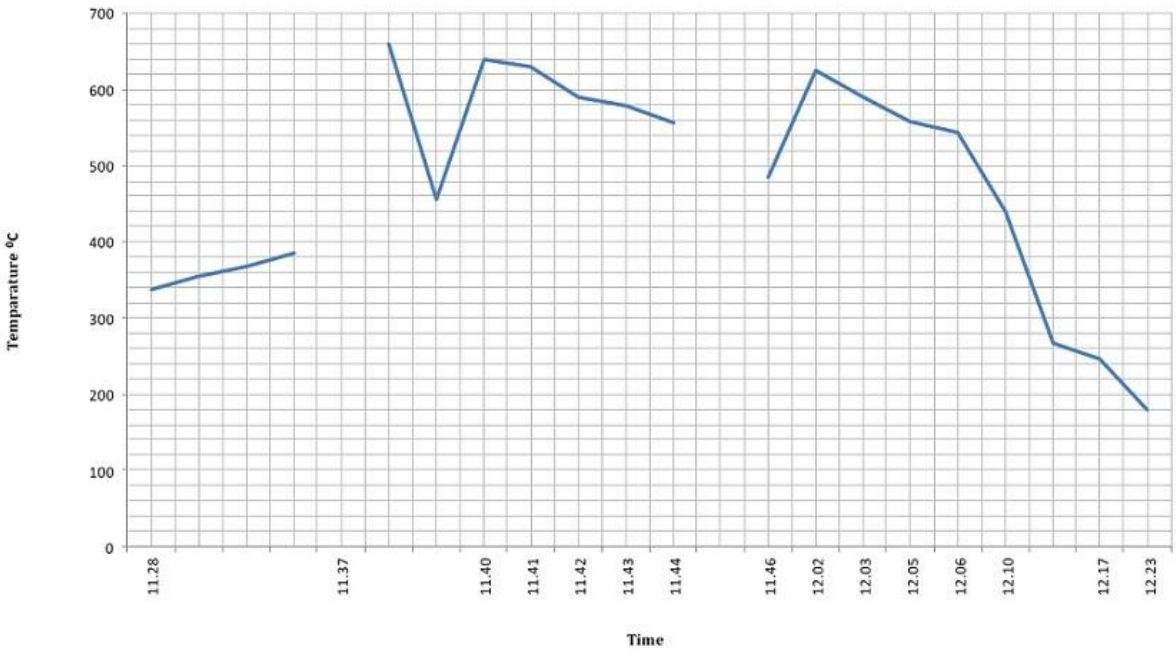


Figure 16: Temperature variations of biochar making from gliricidia

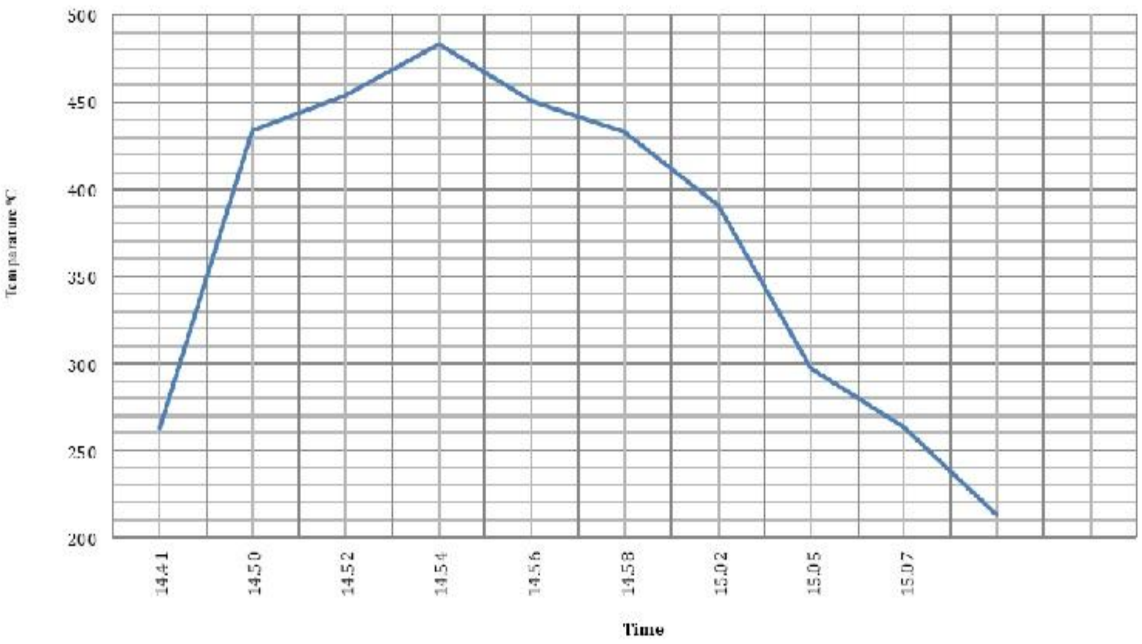


Figure 17: Temperature variation of biochar making from rice husk

Following table 23 has compared biochar maker's emission levels with stack emission standards. Test methods were clarified in section 2.7.

Table 23: Emission results

Parameter	Pollutant base emission standard (Schedule III – Part I)	Average Values	
		Gliricidia	Rice husk
SO_2 (mg/Nm^3) [Ref. to 6% O_2]	1,000	1,278	3,945
NOx (mg/Nm^3) [Ref. to 6% O_2]	500	75	356
CO (mg/Nm^3) [Ref. to 6% O_2]	900	3,809	7,139

Continues gaseous parameters monitoring could not be carried out due to presence of black smoke for a few minutes after starting the firing and also few minutes after intermittent fuel charging. Monitored data revealed the presence of excessive Oxygen and related excess air content in flue gas. This excessive Oxygen may not come from the fresh air supplied to the combustion, since the black smoke presented in the flue gas. The excessive Oxygen content in flue gas might be the filtration air mixed with the flue gas after the combustion zone, probably at the top lid of the combustion chamber unit. Carbon Monoxide (CO) content in flue gas was in a high level. This level had been increased during process. Reason to the high CO levels in flue gas may be the incomplete combustion (partially burning) in the combustion chamber due to less retention time/lack of Oxygen for combustion etc. Therefore the emission of CO levels in flue gas can be reduced by improving combustion. Monitored Sulfur Dioxide (SO_2) levels in flue gas are not within the acceptable levels. In general, SO_2 contents in flue gas of bio fuel combustion systems are very less.

3.4 Qualitative analysis of biochar

The surface morphology of the saw dust biochar by Scanning Electron Microscopy (SEM) images clearly showed that the biochar consisted of irregular fragmented plate like structures and a porous structure which facilitate high adsorption capacity

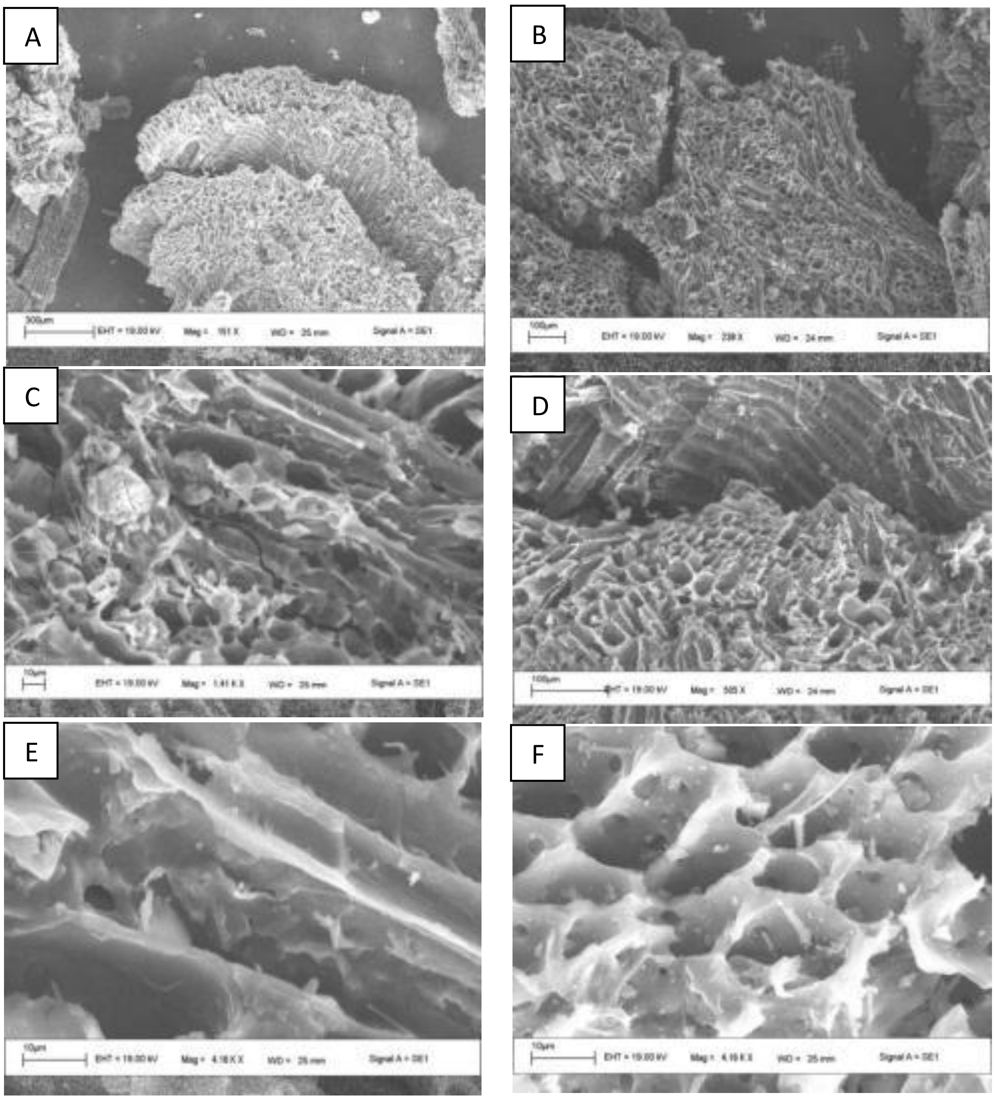


Figure 18: SEM photographs of saw dust biochar at different magnifications: (A)150 x x (B) 238 x (C) 505x (D) 1.41K x (E) 1.46K x (F) 1.46K x

The physico-chemical characteristics of saw dust biochar are shown in table 24 while particle size distribution is presented in the figure 19. The surface area of saw dust biochar (Table 24) further confirmed its porous nature.

Table 24: The physico chemical characteristics of biochar

Properties	Values
pH	8.9
Absolute density g/cm^3	212
Moisture content %	7.535
Volatile matter %	12.02

Surface area m^2/g	185.1
Ash content %	6.265
Fixed carbon %	74.18
Iodine number mg/g	135.1

Also pore size distribution (Figure 19) revealed that that the observed pore size distribution is varied mostly between 12 *4 and 100 range, but highest observed percentage of pore size distribution (42.16%) is in 30*60. According to the International Union of Pure and Applied Chemistry (IUPAC) classification, saw dust with characters described above and considering the adsorption behavior with time is classified as a typical micro porous material.

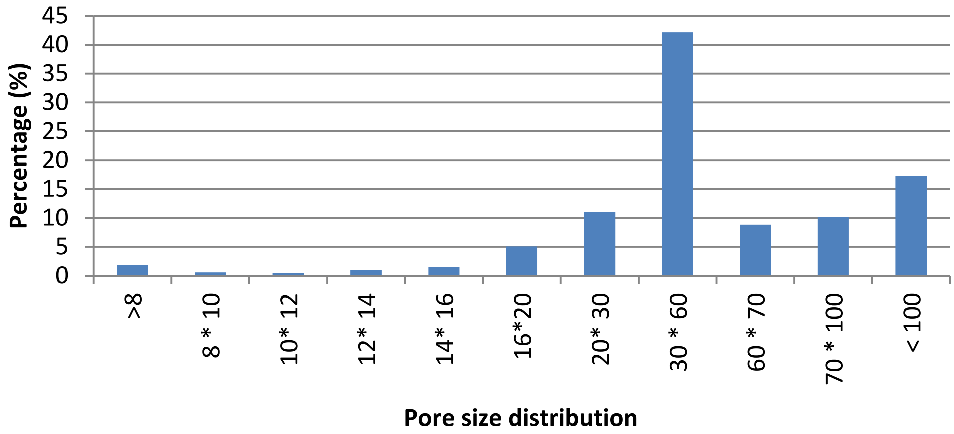


Figure 19: Pore size distribution of saw dust biochar

The Fourier Transform InfraRed (FTIR) spectrum of the biochar (Figure 20) showed a number of adsorption peaks. The broad band centered in the range of 2,700 – 3,300 cm^{-1} is caused by the presence of the hydroxyl stretching (-OH) and peaks at 2,326.39 cm^{-1} and 2,086.14 cm^{-1} assigned to strong and broad N=H and N =C=S bands respectively.

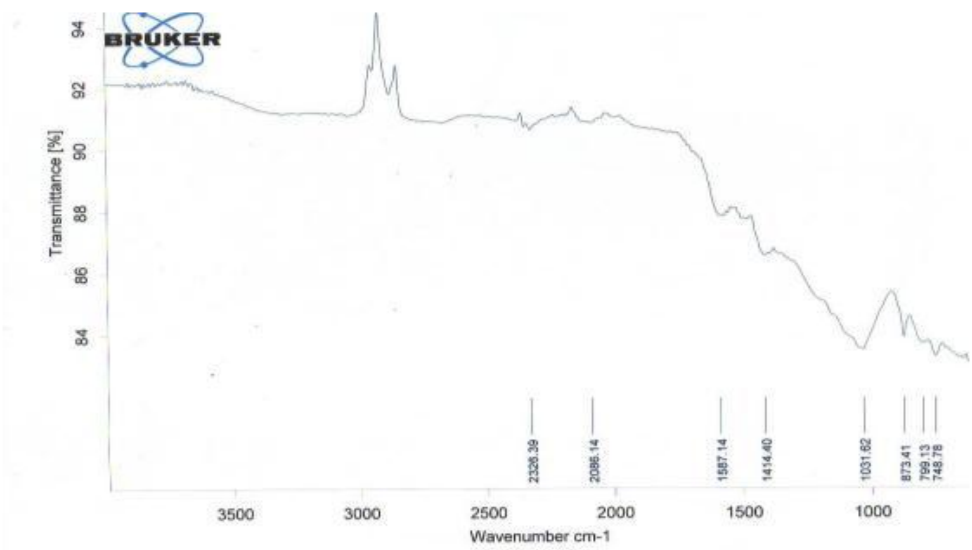


Figure 20: FTIR spectra for saw dust biochar

Those peaks at 1,414 and 1,031 are caused by a strong CO single bond and aromatic C=C stretch; that at 873 cm^{-1} to aromatic C-H bend; that at 784 cm^{-1} to carboxylate (-COO-) deviational vibration and symmetric stretching; and that at 799 cm^{-1} to aromatic stretch of a benzene ring.

These functional groups could form surface complexes with cations like Cr (VI) and As (III) increasing the specific adsorption of those ions by saw dust biochar. Also the incorporation of biochar significantly increased soil cation exchange capacity (CEC) (Jiang et al., 2012). There were plenty of oxygen containing functional groups (i.e. –COO-, -COH and –OH) on the biochar (Yuan et al., 2011), biochar carries a negative charge on its surface and has a large CEC increasing the adsorption affinity of the soil surface for cations, thus help in removal of toxic heavy metals from the polluted water sources.

Binding forces for cations and any ions on biochar may involve π-π primary dispersive interactions, vander waals forces and H bonding via the carbonyl group oxygen, the nitro group oxygen and the highly polar bonds (S. M. Taha et al., 2014).

Biochar contains alkaline substances and can increase pH of acid soils (Yuan et al., 2011). pH is a major factor affecting adsorption/desorption of heavy metals on acid soils. The increase in pH can increase the negative surface charge, and the affinity of the soil and biochar surface for cations is expected to increase (Jiang et al., 2012). Therefore having a high pH value of 8.9 for the tested saw dust biochar increased the pH of the solution as expected.

In addition, biochar has a high content of stable carbon, resistant to decay and remains in soil for a long period of time. Therefore incorporation of biochar into soils offers life-cycle carbon abatement and locks atmospheric carbon in soils through a carbon negative process (Hammond et al., 2011). It contains about 74.18% of fixed carbon and relatively low amount of ash content (6.2%) in selected saw dust biochar and may play an important role as soil conditioner.

Contact time plays a vital role in adsorption dynamics. The effect of contact time on adsorption of Cr (VI), As (III), on to biochar derived from saw dust is shown in figure 21 (A), and (B) respectively.

According to the results obtained by batch adsorption studies, the adsorption of heavy metal ions

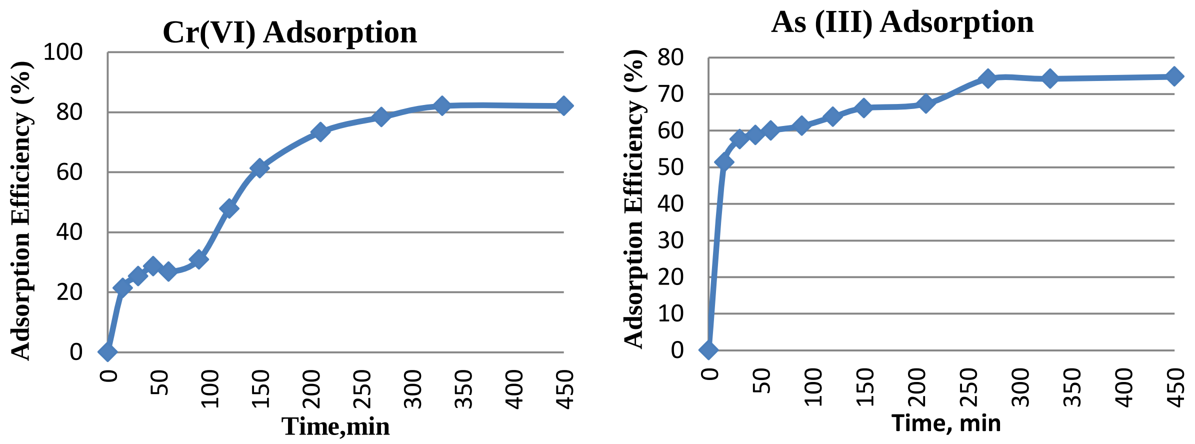


Figure 21: Effect of contact time on (A). Cr (VI) adsorption (B). As (III) adsorption

increase with the time and gradually reach the equilibrium after 330 min by Cr (VI) and 450 min by As (III). As shown in Figure 21 (A) and (B) saw dust biochar show rapid initial adsorption rate followed by a slower rate. Also results show that the rate of adsorption for Cr (VI) is higher than the rate of adsorption for As (III) by saw dust biochar.

It is hypothesized that these results are due to the distribution of the porous structure and the surface area of biochar. The first stage was due to initial accumulation of cations at the surface, as the relatively large area was utilized. And then with the increasing occupation of surface binding sites, the adsorption process slowed. The second stage was due to the penetration of ions to the inner active sites of the adsorbent (N. Chen et al., (2011).

Kinetic models are used to test experimental data and to find the mechanism of adsorption and its potential rate and chemical reaction. Most commonly used kinetic models have been used to discuss experimental data.

In many cases pseudo first and second order model have been used and the pseudo first order model is based adsorption capacity and expressed as

$$\ln (qe - q) = \ln qe - k_1 t \quad (4)$$

Where, qe = Mass of metal adsorbed at equilibrium
q = Mass of metal adsorbed at time t (min)
k1 = first order reaction rate constant

Pseudo-second order model is derived on the basis of adsorption capacity of the solid phase and expressed as

$$t/q = (t/qe) + 1/(K_2 qe^2) \quad (5)$$

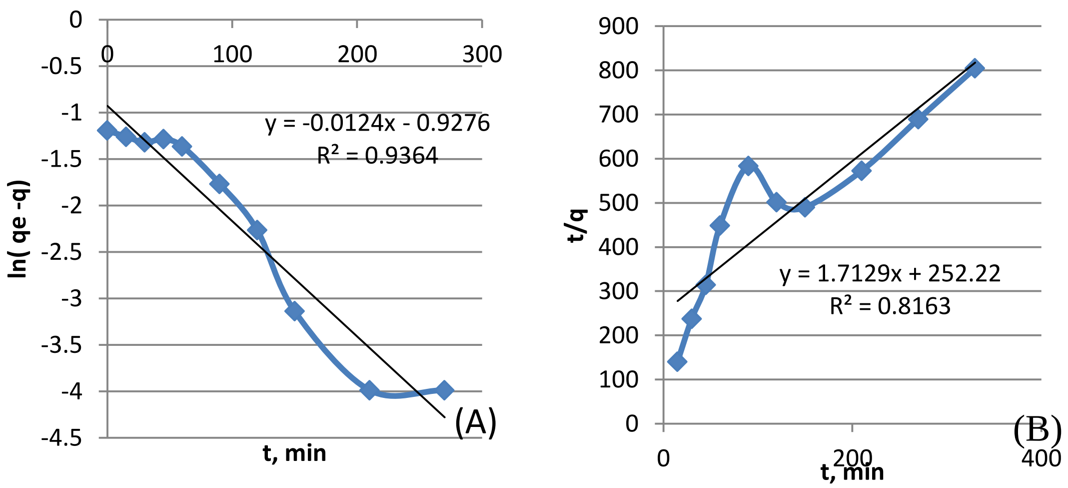


Figure 22: (A).Pseudo first order and (B).Pseudo second order models for Cr (VI) adsorption

According to the results found, pseudo first order is best fit for the adsorption of Cr (VI) ions while pseudo second order model is best suited for the As (III) ions adsorption as shown in figure 22 and figure 23. The values of the reactant rate constants listed in the table 25.

Table 25: Pseudo first order and (B).Pseudo second order constants

Metal ion	Pseudo first order		Pseudo second order	
	qe	k1	qe	k2
Cr(VI)	0.3955	0.0124	0.5838	0.0116
As(III)	0.0100	178.38	2.666	0.00898

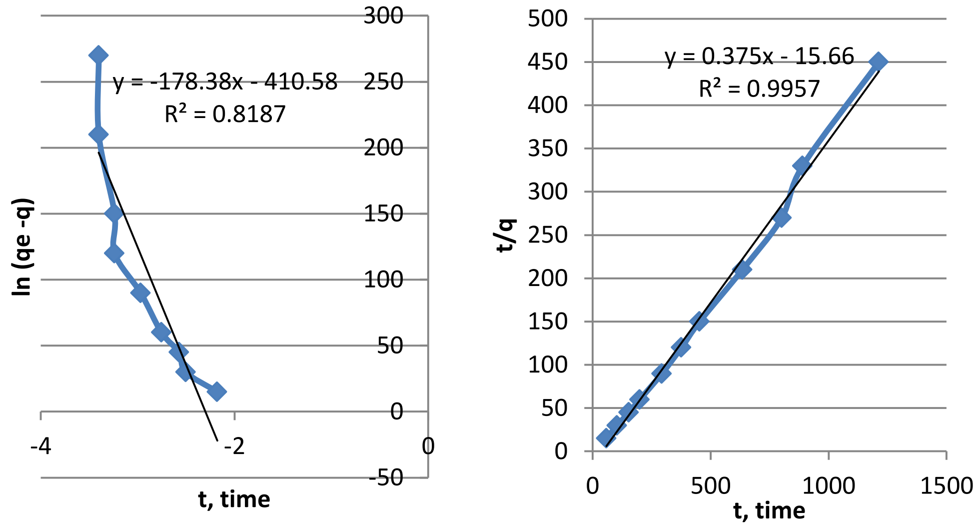


Figure 23: (A).Pseudo first order and (B).Pseudo second order models for As (III) adsorption

When mass transfer is the controlling step it is important to identify the diffusion mechanism so intraparticle-diffusion model is also tested. According to this model, initial rate of the intraparticle-diffusion is given by;

$$K_{int} = q / t^{½} \quad (6)$$

Where, k_{int} = intraparticle-diffusion rate constant (mg/g-min1/2)

q = amount of ions adsorbed (mg/g) at time t (min)

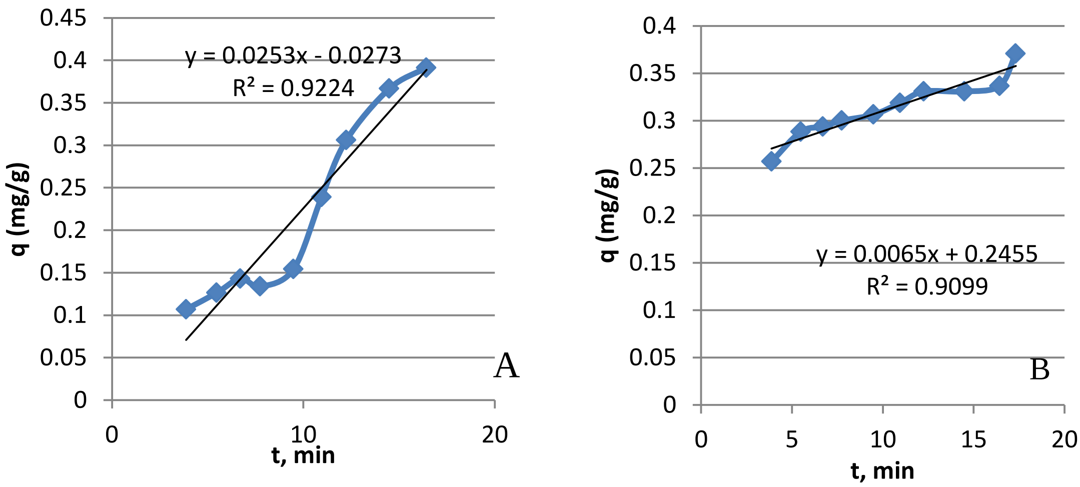


Figure 24: Intraparticle diffusion model for (A) Cr(VI) adsorption (B) As (III) adsorption

According to the results shown in figure 24, it is clear that the adsorption of metals to biochar is not linear over entire time range; indicating more than one process is affecting the adsorption. The interparticle rate constant is 0.0253 for Cr (VI) adsorption process while it is 0.0065 for As (III) adsorption process.

The rate of the adsorption is a good indicator for determining the type of adsorption whether it is a physical adsorption or chemisorption. Adsorption equilibrium is established when the concentration of adsorbate in bulk solution is in dynamic balance with that on the liquid – solid interface. Therefore Langmuir and Freundlich models were used to describe the equilibrium data [N. Chen et al., 2011].
The Langmuir model is based on the hypothesis that uptake occurs on a homogenous surface by

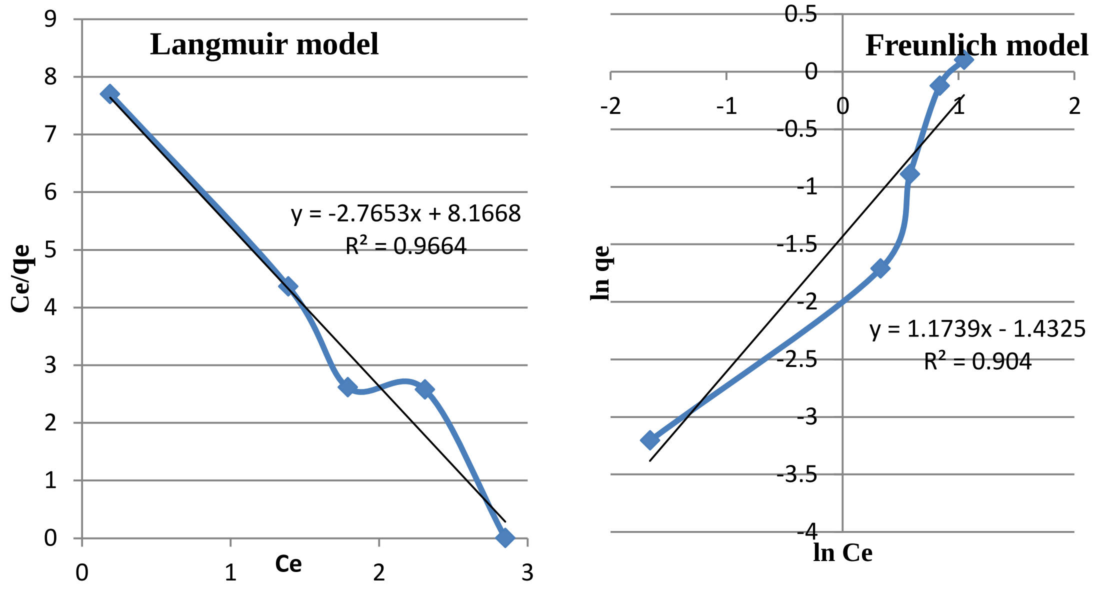


Figure 25: Langmuir and Freundlich isotherm plots for Cr (VI) adsorption

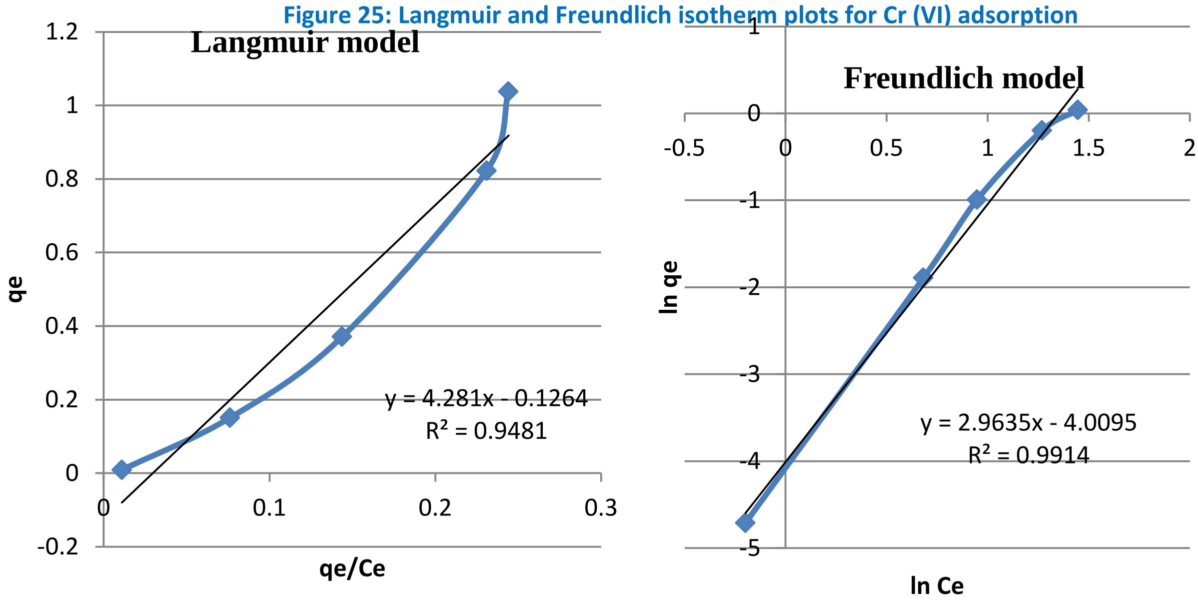


Figure 26: Langmuir and Freundlich isotherm plots for As (III) adsorption

monolayer sorption without interaction between adsorbed molecules (Chen et al., 2011) and is expressed as equation (4).

$q_e = q_m b\, Ce / (1 + bCe)$ (7)

Where, q_e - Equilibrium metal uptake/nutrient uptake capacity (mg/g)
q_m - Maximum adsorption capacity
b - Constant related to affinity and energy of binding sites
Ce - The final metal ion/anion concentration (mg/l)

Equation (4) can be written linearly as

$$Ce/ q_e = (1/ q_m)Ce + 1/ (Ka.\ q_m) \quad (08)$$

$$1/ q_e = 1/ (Ka\ q_m).\ 1/Ce +1/ q_e \quad (09)$$

$$q_e = qm - (1/Ka).(\ q_e /Ce) \quad (10)$$

$$q_e /Ce = Ka\ q_m - Ka\ q_e \quad (11)$$

The freundlich model proposes a multilayer sorption with aheterogeneous energetic distribution of active sites and with interaction between adsorbed molecules (Chena et al., 2011).

Freundlich isotherm model is described by following equation

$$q_e = K\, c^{1/n} \quad (12)$$

It is linearly written as

$$\ln q_e = \ln K + 1/n \ln c \quad (13)$$

Where, q_e = uptake capacity (mg/g) of biochar

c = Equilibrium concentration of adsorbate in solution (mg/l)
k = Adsorption capacity
1/n = Sorption intensity

Figure 25, 26 (A) and (B) show the Langmuir and Freunlich isotherms and experimental data. The isotherm constant K and R^2 values for each model are given in table 26.

Table 26: Langmuir and Freunlich isotherm parameters for the adsorption of Cr (VI) and As (III) by saw dust biochar

Langmuir isotherms			Freunlich isotherms		
	Cr(VI)	As(III)		Cr(VI)	As(III)
q_{max}	0.3616	0.2335	N	0.8518	0.3374
K	0.3386	33.8983	K	0.2387	0.0181
R^2	0.9668	0.9481	R^2	0.904	0.9914

According to the results and R^2 it can be concluded that adsorption data for Cr(VI) ions can be better described by Langmuir isotherm model and adsorption of As(III) ions can be described by Freunlich isotherm model.

According to the obtained results, Cr (VI) has a higher adsorption capacity as compared to As (III). This may be explained by the hydration enthalpy which is the energy that permits the detachment of water molecules from cations, and then reflects the easiness for the ion to interact with the functional groups on biochar (Amarasinghe, 2011).

Biochar contains ample amounts of oxygen containing functional groups like –COO- and – OH on its surface, and these functional groups can form surface complexes and with transition metal ions and thus increase the specific adsorption (Yuan et al., 2011). Also Cr (VI) has higher affinity than As (III) and hence showing higher adsorption capacity.

Several authors (Aslam, 2004; Gaikwad, 2004 and Sciban, 2006) discuss the adsorption heavy metals at different pH values and according to their finding at high pH values (i.e., pH = 7 or above), metal complexes forms and results in the precipitation of metal salts. Therefore the metal removal may be due to this mechanism in addition to ion exchange.

The effect of contact time on adsorption of NO_3^- on to saw dust biochar is shown in Figure 27.

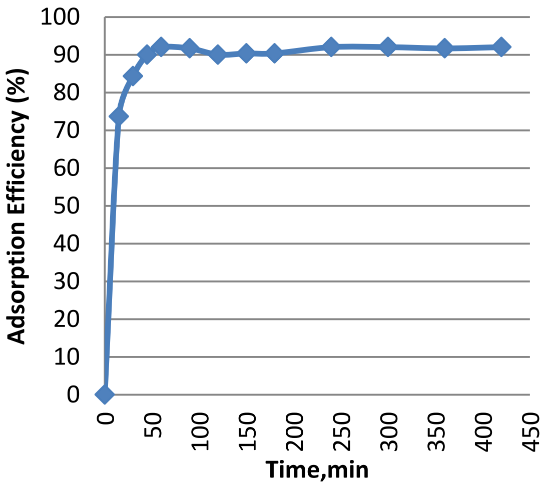
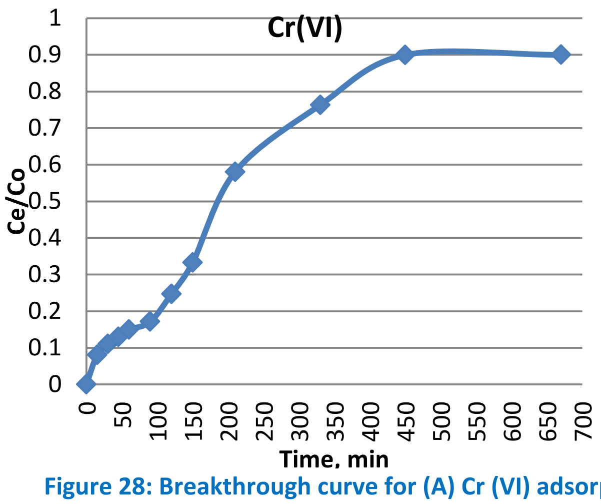


Figure 27: Adsorption of NO_3^- on to saw dust biochar

Biochar micro pores provide a huge internal ion adsorption capacity for both anions and cations. Also having a complex structure with large molecules with multiple C rings incorporated with anions and cations, ions in the soil – water system can caught and held by its electric charges.

The breakthrough curve for a column was determined by plotting the ratio of Ce/Co against time as shown in the figure 28.



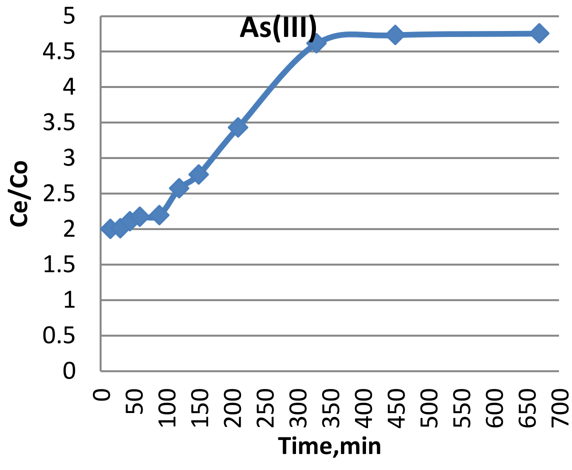


Figure 28: Breakthrough curve for (A) Cr (VI) adsorption in fixed bed column (B) As (III) Adsorption in fixed bed column

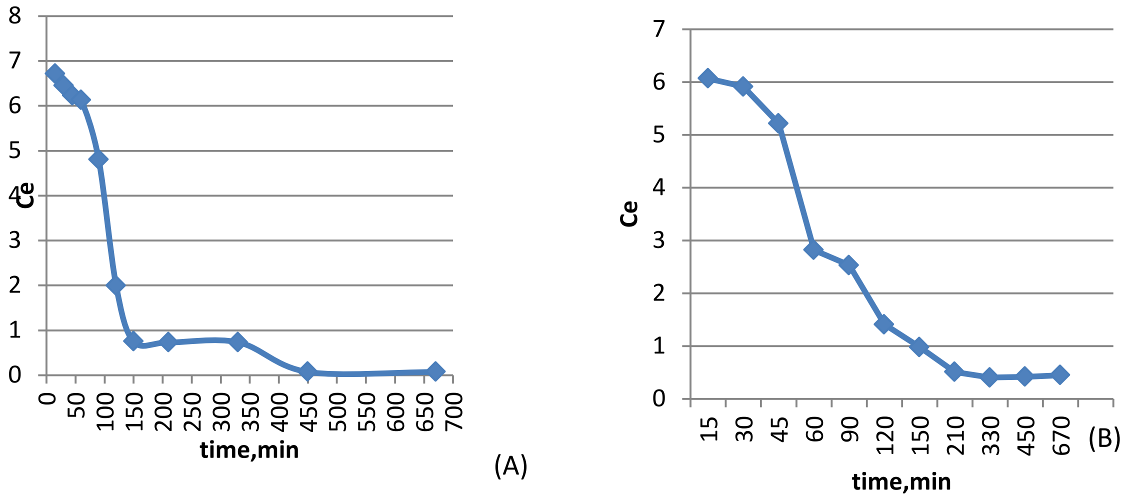


Figure 29: Column desorption behavior (A). Cr (VI) desorption (B). As (III) desorption

3.5 Agronomic performance

Basically as the field measurements, height & weight of the plants were taken at the time of harvest from each experiment. These parameters result productivity of the vegetables.

Greenhouse studies results in Sri Lanka-

Greenhouse studies were taken at Horticulture Research Station, Gannoruwa. This was aimed to treat plants and measure their characteristics under greenhouse stage by using Kalpitiya soil and Gannoruwa soil as growing media. So, these greenhouse studies were done for two crop (red onion and capsicum) seasons simultaneously with field trials. Following results were taken from these studies.

Kalpitiya soil- Changes in plant over a period of 10 weeks in the different treatments in the Kalpitiya soil are shown in Figure 30 to 32. It is evident that in all three BRH+NPK treatments there is a marked increase in plant height with time. In the Biochar Saw Dust (BSD) treatments, there is evidence only in the 10 BSD+ NPK (Nitrogen, Phosphorous and Potassium) treatments. Without NPK, both BRH and BSD have no effect on plant height. The effect of BIOCHAR GLIRICIDIA (BGC) on plant height is quite different. Irrespective of whether NPK is added or not, BIOCHAR GLIRICIDIA (BGC) has no effect at all on plant height.

Gannoruwa soil- Changes in plant height over a period of 10 weeks in the different treatments in Gannoruwa soil are shown in Figures 33 to 35. It is evident that in all the BIOCHAR RISE HUSK (BRH) treatments, irrespective of whether NPK was added or not, there is a marked increase in plant height with time (Figure 33), a trend similar to that seen in the Kalpitiya soil. A similar trend is seen in the BIOCHAR GLIRICIDIA (BGC) treatments, although, without NPK the increase is not as marked as with NPK (Figure 35). BIOCHAR SAW DUST (BSD) on the other hand shows an increasing trend only when added with NPK. Without NPK, the BSD treatments have no effect at all on plant height.

Shoot and Root dry matter yield-

Kalpitiya soil – Data on shoot and root dry matter yield are shown in Figures 36 and 38 respectively. Although the trends of the shoot and root data are similar, with all biochar materials, root yield was greater than shoot yield. BIOCHAR RISE HUSK (BRH) seemed to perform best in both cases with BIOCHAR SAW DUST (BSD) ranking next and BIOCHAR GLIRICIDIA (BGC) showing very poor performance.

Gannoruwa soil -

Data on shoot and root dry matter yield are shown in Figure 38. Performance of BIOCHAR RISE HUSK (BRH) and BIOCHAR GLIRICIDIA (BGC) were comparable and better than that of BIOCHAR SAW DUST (BSD).

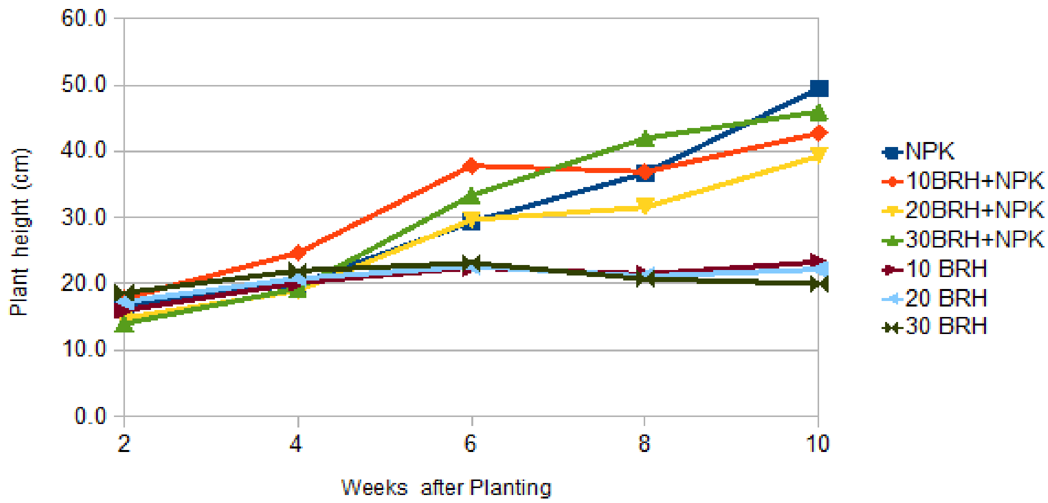


Figure 30: Effect of BRH on capsicum plant height in Kalpitiya soil

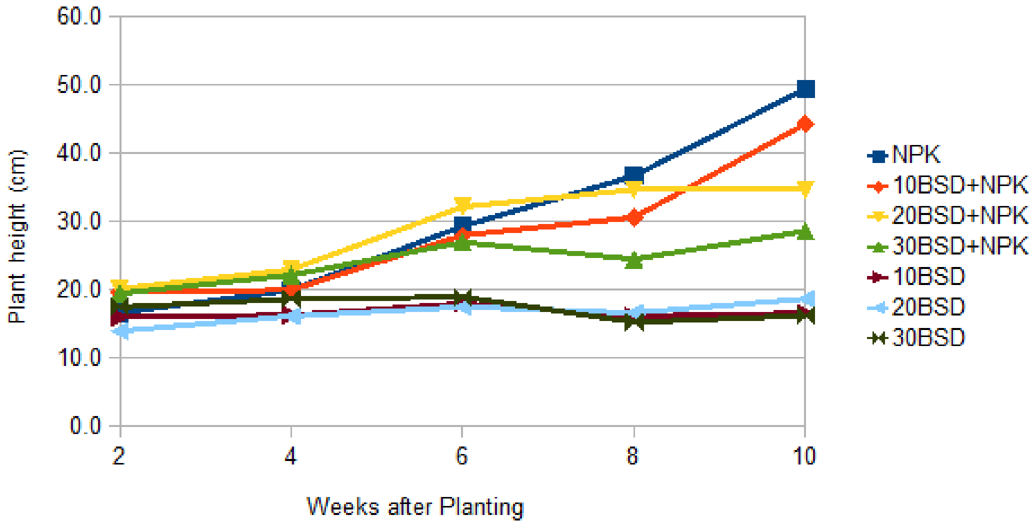


Figure 31: Effect of BSD on capsicum plant height in Kalpitiya soil

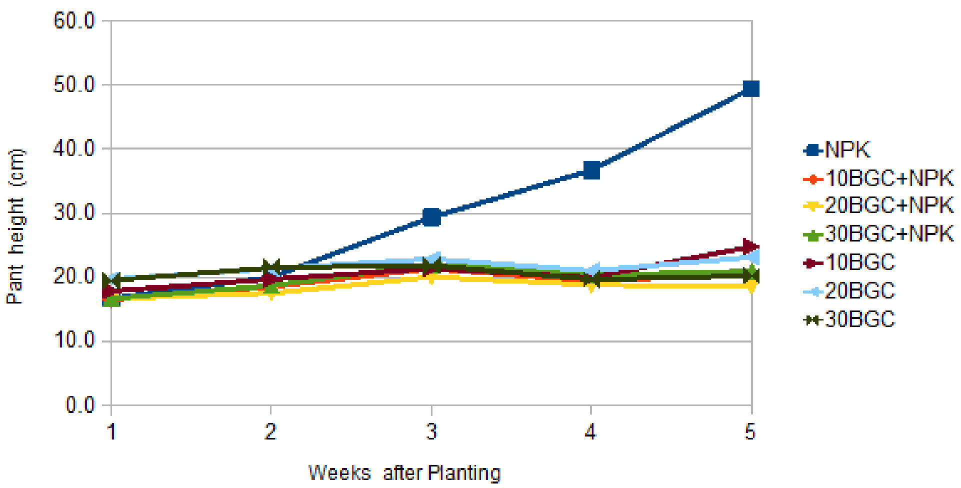


Figure 32: Effect of BGC on capsicum plant height in Kalpitiya soil

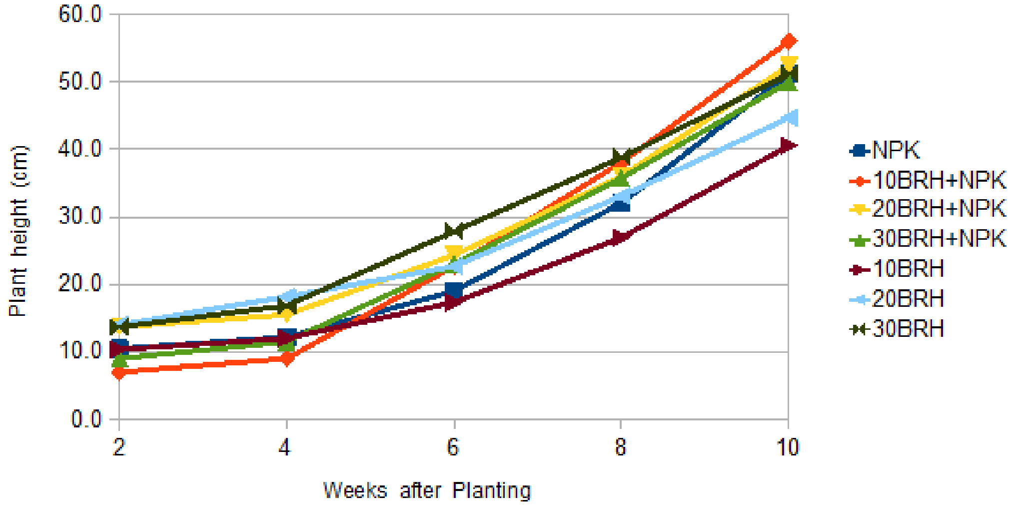


Figure 33: Effect of BRH on plant height in Gannoruwa soil

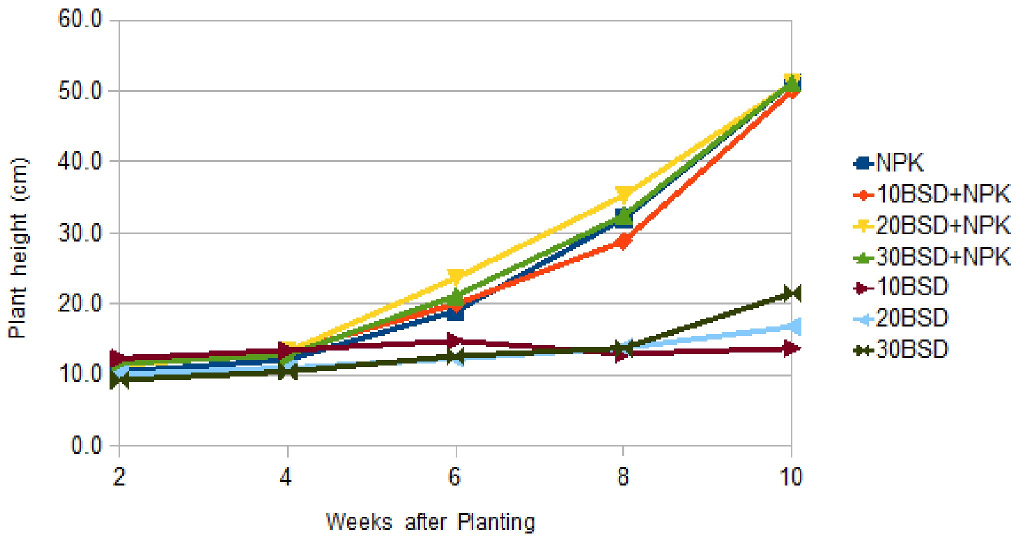


Figure 34: Effect of BSD on plant height in Gannoruwa soil

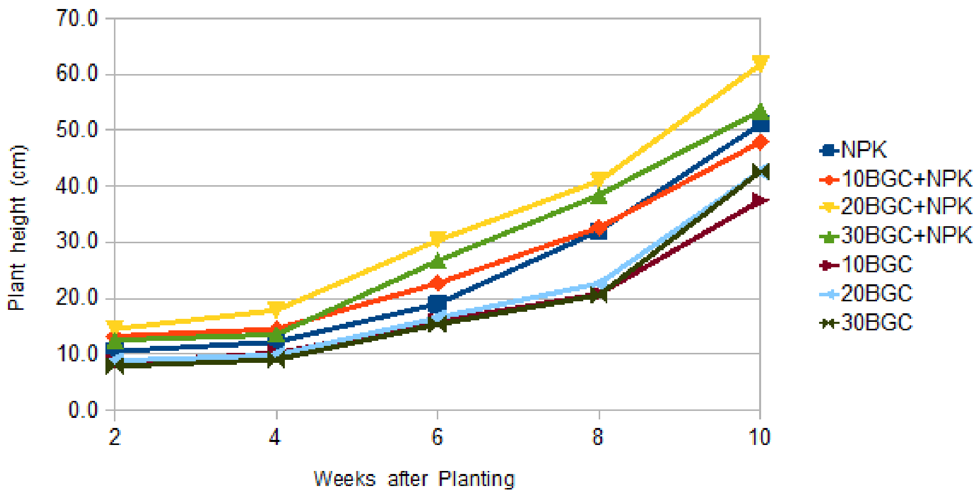


Figure 35: Effect of BGC on plant height in Gannoruwa soil

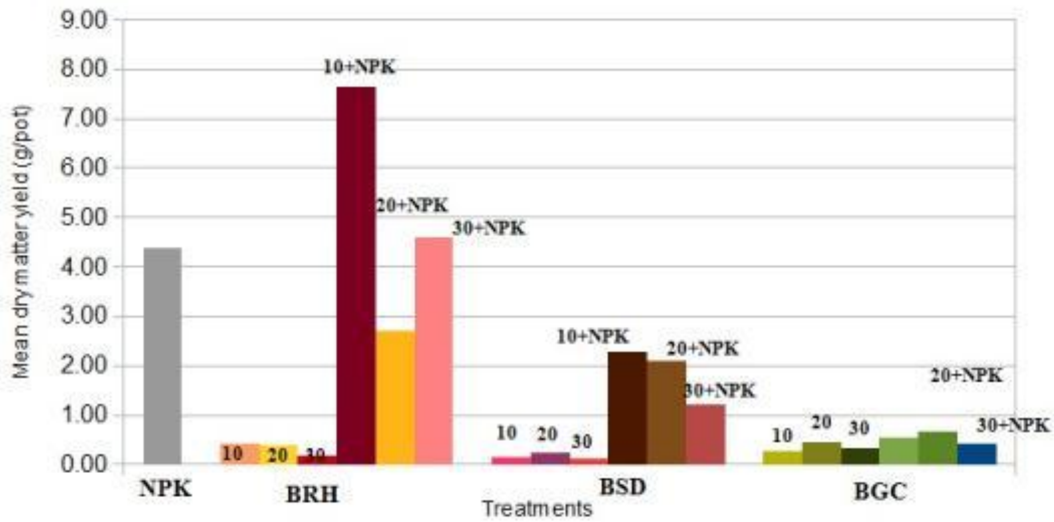


Figure 36: Effect of Biochar on Capsicum dry matter yield in Kalpitiya Sandy Regosol

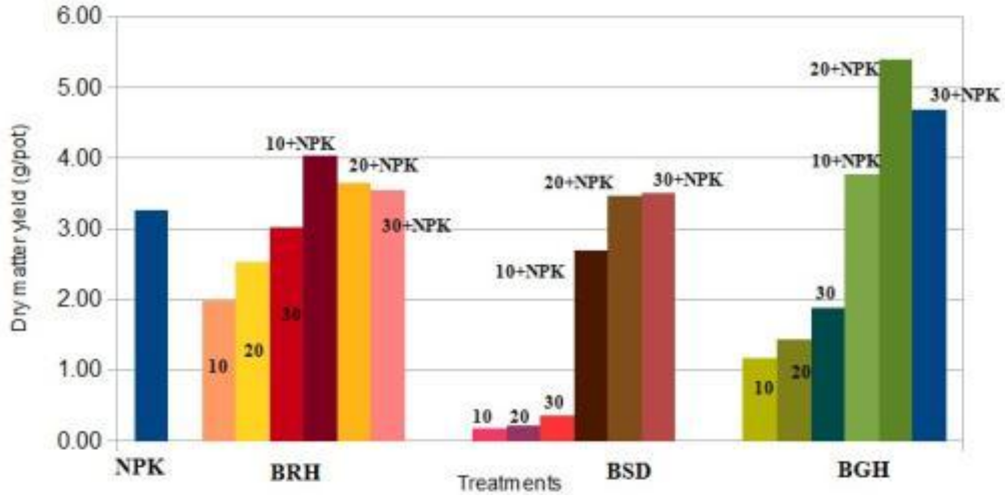


Figure 37: Effect of Biochar on Capsicum dry matter yield in Gannoruwa Reddish Brown Latosol

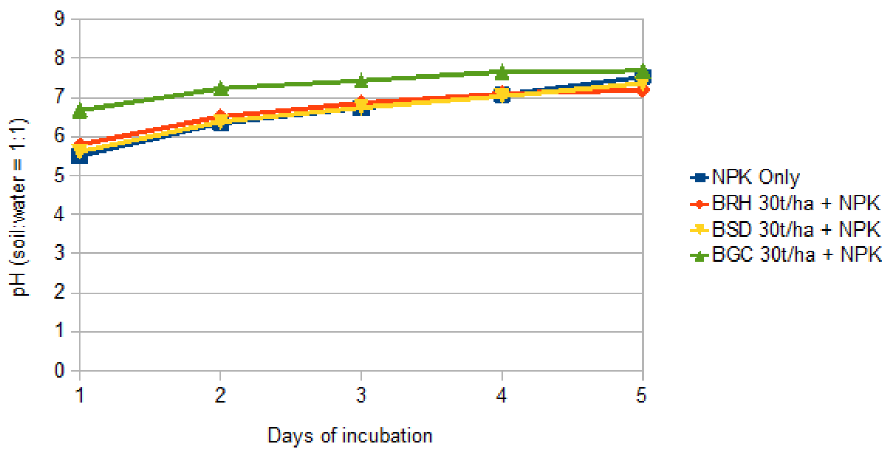


Figure 38: Root dry matter yield

Red Onion Experiment- Plant growth and vigour

About 10 days after planting plots to which only biochar was added, plants showed signs of yellowing. However, this gradually disappeared, and by the end of the third week, plants recovered fully. Yellowing symptoms were not observed in any of the other treatments. In contrast, in all the NPK added plots, plants were bright green in colour. By the end of the 6th week, plant growth and vigour was observed to be best in the biochar+NPK plots. Also plants were bright green in colour when compared to those in the other plots.

Table 27: Effect of biochar application on plant height and yield of red onion

Treatment	Plant height 5 WAP (cm)	Mean bulb yield (t/ha)
DOA Rec. NPK	25.80 a	17.75 abc
10 BRH	21.80 b	11.65 d
20 BRH	22.83 b	12.72 d
10 BRH+NPK	21.53 b	19.66 ab
20 BRH+NPK	21.90 b	21.39 a
10 BGC	25.40 a	14.76 cd
20 BGC	25.63 a	14.08 cd
10 BGC +NPK	26.87 a	15.42 bcd
20 BGC +NPK	26.97 a	18.14 abc

Mean bulb yields followed by the same letter are not statistically different at p=0.05 by DMRT

*WAP= weeks after planting

Plant height - Plant height at 5 WAP is given in Table 27. In the NPK added plots, plant height was significantly higher than in plots to which only biochar was added. BGC+NPK performed best.

Bulb yield - Data is given in Table 27. The positive effects of adding NPK with biochar was also evident in the yield data. With only biochar yields were lower than in biochar + NPK.

Capsicum Experiment

Table 28: Effect of biochar application on plant height and yield of capsicum

Treatment	Plant height (cm)		Mean fruit yield (t/ha)
	4 WAP	8 WAP	
No fertilizer Control	22.2	40.0	2.40 b
DOA Rec. NPK	21.9	47.1	3.83 b
10 BRH	22.5	37.2	2.15 b
20 BRH	21.8	39.7	4.08 b
10 BRH+NPK	23.3	44.6	4.85 b
20 BRH+NPK	23.9	45.1	8.12 ab
10 BGC	20.3	42.5	2.01 ab

20 BGL	25.1	47.1	5.11 ab
10 BGC +NPK	24.1	44.2	5.03 b
20 BGC +NPK	27.9	45.5	8.20 ab

Mean bulb yields followed by the same letter are not statistically different

at p=0.05 by LSD

Plant height increased in all treatments, the increase being generally greater in the NPK added plots. The effects of both BIOCHAR RISE HUSK (BRH) and BIOCHAR GLIRICIDIA (BGC) were similar. Mean fruit yield was highest in the 20BRH+NPK and 20BGC+NPK treatments. Here again the performance of BIOCHAR RISE HUSK (BRH) and BIOCHAR GLIRICIDIA (BGC) were comparable.

Laboratory studies

Table 29: Soil characteristics

Soil	WHC (%) Dry basis	pH_{H2O} (1:1)	EC (1:5) (dS m^{-1})	Olsen P (ppm)	Avai K (ppm)	OM (%)	CEC (cmol/kg)	Texture *
Sandy Regosol (Kalpitiya)	28.5	6.6	0.18	4.6	14	0.1	3.28	S
RBL (Gannoruwa)	59.67	5.2	0.10	5.7	143	2.1	10.69	SCL

* Texture determine by feel method. S – Sand; SCL – Sandy Clay Loam

Table 30: Biochar characteristics

Biochar	WHC (%) Dry basis	pH_{H2O} (1:5)	EC (1:5) (dS m^{-1})	Total Nutrients (%)			CEC (cmol/kg)
				N	P_2O_5	K_2O	
Rice husk	512.7	9.5	1.78	0.32	0.97	1.91	173.9
Saw dust	68.3	8.3	0.53	0.26	0.18	0.79	66.3
Gliricidia	226.1	10.3	14.14	0.14	1.47	3.28	83.5

Kalpitiya soil was very low in acidity but recorded high EC. Water holding capacity, nutrient contents (P and K) and organic matter contents are also very low. In addition the nutrient retention capacity of this soil is also very low.

In contrast, the Gannoruwa soil is moderately acidic, low in EC, moderate in K and organic matter contents and has good cation retention capacity as seen by the CEC value and also good water retention ability. This is expected due to clay and organic matter contents in this soil. However, available P is very low in the Gannoruwa soil too.

Biochar Characteristics (Table 30) – Of the three biochar materials tested, BIOCHAR RISE HUSK (BRH) has the highest water holding capacity, moderately rich in N, P and K contents and high in cation retention capacity. The high cation retention capacity of biochar has been explained by many as being due to the extremely large number of pores in these materials (Lehmann and Joseph, 2009).

Table 31: Chemical analysis of Kalpitiya soil in greenhouse experiment after harvesting crop

Treatment	pH_{H2O} ((1:5)	EC (1:5) (dS m^{-1})	Available P ppm	Available K ppm
Kalpitiya soil	6.6	0.17	4.9	14
NPK	6.3	0.08	33.0	15
10 BRH+NPK	6.6	0.09	65.0	59
20 BRH+NPK	6.78	0.10	49.0	88
30 BRH+NPK	6.8	0.10	49.0	88
10 BSD+NPK	6.6	0.08	47.0	44
20 BSD+NPK	6.8	0.07	35.0	29
30 BSD+NPK	7.0	0.06	42.0	88
10 BGC+NPK	7.2	0.11	51.0	103
20 BGC+NPK	7.4	0.15	52.0	307
30 BGC+NPK	7.6	0.17	56.0	220
10 BRH	7.5	0.05	15.0	117
20 BRH	7.8	0.06	15.0	59
30 BRH	8.0	0.07	23.0	117
10 BSD	7.7	0.05	4.0	44
20 BSD	7.9	0.05	9.0	29
30 BSD	8.0	0.05	7.0	29
10 BGC	8.1	0.07	13.0	103
20 BGC	8.6	0.12	13.0	176
30 BGC	8.7	0.12	9.0	220

Table 32: Chemical analysis of gannoruwa soil in greenhouse experiment after harvesting crop

Treatment	pH_{H2O} (1:5)	EC (1:5) (dS m^{-1})	Available P ppm	Available K ppm
Gannoruwa soil	5.2	0.10	5.7	143
NPK	5.1	0.15	15.0	103
10 BRH+NPK	5.1	0.18	22.0	205
20 BRH+NPK	5.1	0.19	30.0	220
30 BRH+NPK	5.3	0.16	15.0	235
10 BSD+NPK	5.3	0.18	26.0	132
20 BSD+NPK	5.3	0.18	17.0	161
30 BSD+NPK	5.5	0.18	19.0	176
10 BGC+NPK	5.7	0.20	12.0	308
20 BGC+NPK	6.2	0.20	20.0	308

30 BGC+NPK	6.9	0.28	15.0	469
10 BRH	5.7	0.07	11.0	147
20 BRH	6.0	0.06	4.0	191
30 BRH	6.0	0.07	4.0	235
10 BSD	5.7	0.11	4.0	161
20 BSD	5.9	0.09	5.0	117
30 BSD	6.1	0.10	4.0	176
10 BGC	6.1	0.10	5.0	264
20 BGC	6.5	0.18	5.0	381
30 BGC	6.9	0.22	4.0	454

Nepal research outcomes and results have been presented in following sub sections. based on the field measurement of the vegetables grown and soil samples analysis before and after biochar treatments.

Effect of application of biochar on vegetable productivity in Nepal

Productivity of vegetables were measured based on the heights at different times and weight after the harvest.

Productivity of onion

Productivity based on the mean height gained by onion in various months of plantation with different application rates (treatments) is shown in the Table 33.

Onion was harvested after 126 days of plantation. Mean height gained by onion in the fourth month of harvest was taken for the analysis of productivity.

At the time of harvest, maximum of the mean height gained was 39.42 cm in 5% application followed by 20% of coffee biochar treatment (Table 33 and Table 34). Among two types of biochar applications, mixed biochar gave better performances in gaining maximum mean height of onion.

Table 33: Mean height of onion in plots treated with mixed biochar (in cm)

Month		Treatment				
	5% mixed biochar	10% mixed biochar	15% mixed biochar	20% mixed biochar	5% mixed biochar (replication)	5% mixed biochar (replication)
First	9.74	10.74	10.96	10.57	10.21	10.00
Second	16.96	16.51	17.88	16.87	18.11	16.79
Third	28.66	30.44	30.38	31.25	30.25	30.08
Fourth (harvest)	37.91	37.72	38.05	36.49	39.42	36.51

Among the treatments, maximum of the mean height for the first month was found for biochar application of 15% (with the mean of the height gained 10.96 cm), 18.11 cm with the application rate of 5% mixed biochar in replication plot during the second month. Similarly, in the third month, maximum of the mean height was 30.44 cm was observed with the application rate 10% mixed biochar and in the fourth month of harvest maximum of the mean height was 39.42 cm observed in the replication plot treated with 5% mixed biochar.

Likewise, minimum of the mean height was observed with the application rate of 5%, 10%, 5% and 20% in the first, second, third and the fourth month of harvest respectively.

Among the treatments with coffee biochar, maximum of the mean height gained was 10.16 cm in the first month with the application rate of 10%, 17.55 cm in the second month with the application rate 15%. Similarly, in the third month maximum of the mean height of 30.82 cm was observed with the application rate 15% and in the fourth month of harvest maximum of the mean height was 38.27cm observed in the replication plot treated with 20% of coffee biochar (Table 34).

Table 34: Mean height of onion in plots treated with coffee biochar and control plots (in cm)

Month	Treatment				Control	
	5% Coffee biochar	10% Coffee biochar	15% Coffee biochar	20% Coffee biochar	No biochar 100% fertilizer	No biochar no fertilizer
First	9.96	10.16	10.09	9.97	10.10	9.77
Second	16.55	17.46	17.55	17.48	17.48	16.66
Third	29.26	30.62	30.82	30.46	30.02	30.72
Fourth (harvest)	37.20	37.53	38.16	38.27	37.25	37.06

Likewise minimum of the mean height of the onion, 9.77cm was observed from the plot with control plot having no biochar and no fertilizer for the first month. Similarly, in the second, third and fourth month of harvest with the minimum of the mean height measurement were 16.55 cm, 29.26 cm and 37.20 cm and was observed with the application concentration 5% (Table 34).

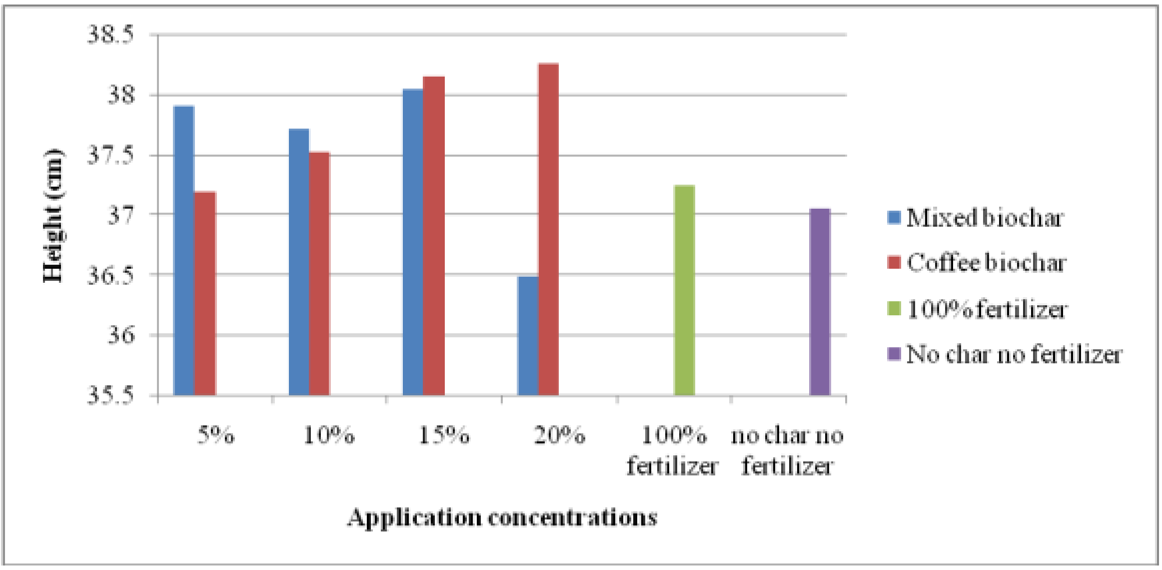


Figure 39: Height of onion at harvest with application concentrations and different biochar types

Therefore the results showed that at the time of harvest, maximum of the mean height was observed from the replication plot treated with 5% mixed biochar with the mean height 39.42 cm, followed by 20% coffee biochar application with maximum of the mean height 38.27 cm.

All the application concentration gives the better result than in the control plot with the application of fertilizer only except the application concentration 20% of mixed biochar.

Table 35: Weight of onion at harvest with mixed biochar (kg/plot)

Application		5% mixed biochar	10% mixed biochar	15% mixed biochar	20% mixed biochar	5% mixed biochar (replication)	5% mixed biochar (replication)
Weight (kg)		2.36	2.40	2.43	2.51	2.17	2.32

On mixed char application, the maximum weight observed was 2.51 kg per plot from the plot with the application concentration of 20% and the minimum was 2.17 kg in 5% application concentration in replication plot.

Table 36: Weight of onion at harvest with coffee biochar and control (kg/plot)

Application		5% Coffee biochar	10% Coffee biochar	15% Coffee biochar	20% Coffee biochar	Control	
						No biochar 100% fertilizer	No biochar no fertilizer
Weight (kg)		2.36	2.44	2.30	2.92	2.38	2.30

On coffee biochar application, the maximum weight observed was 2.92 kg from the plot with the application concentration of 20% and the minimum was 2.30 kg in 15% application concentration and no biochar no fertilizer plot.

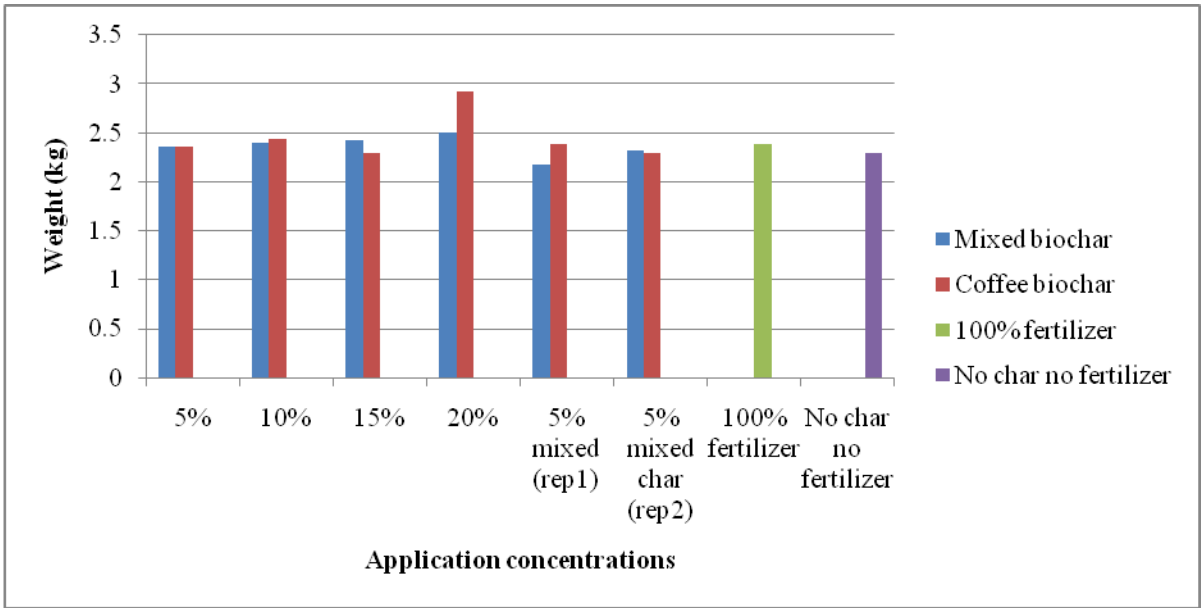


Figure 40: Weight of onion at harvest with application concentrations and types

Among all treatment plots, maximum weight observed was 2.92 kg from the plot with application concentration of 20% of coffee biochar and the minimum was 2.17 kg from 5% mixed biochar in the replication plot.

Productivity on spinach

Among all treatments, maximum of the mean height obtained was 16.6 cm with 10% application of mixed biochar followed by 10% application of coffee biochar (Table 37 and Table 38). Comparing similar application concentration between mixed and coffee biochar, plots treated with mixed biochar had maximum mean heights. Mean difference was observed between treated plots and control plots. However significant difference was not seen between them.

Table 37: Mean height of prickly seeded spinach in plots treated with mixed biochar at harvest (in cm)

Application	5% mixed biochar	10% mixed biochar	15% mixed biochar	Control	
				No biochar 100% fertilizer	No biochar no fertilizer
Mean height (cm)	13.5	16.6	10.5	11.6	11.2

Maximum of the mean height of prickly seeded spinach at harvest was observed to be 16.6 cm with 10 % application concentration of mixed biochar and minimum was observed to be with 15% application ratio with an observed height of 10.5 cm. Heights gained by prickly seeded spinach at application concentration of 15% mixed char was found less than in control plots.

Table 38: Mean height of prickly seeded spinach in plots treated with coffee biochar and control plots at harvest (in cm)

Application	5% Coffee biochar	10% Coffee biochar	15% Coffee biochar	Control	
				No biochar 100% fertilizer	No biochar no fertilizer
Mean height	12.30	14.70	9.42	11.60	11.20

Maximum mean height of prickly seeded spinach at harvest observed was 14.7 cm with 10 % of application concentration of coffee biochar and minimum observed was with a 15% application concentration. Heights gained by prickly seeded spinach at application concentration of 15% coffee char was found to be less than in control plots.

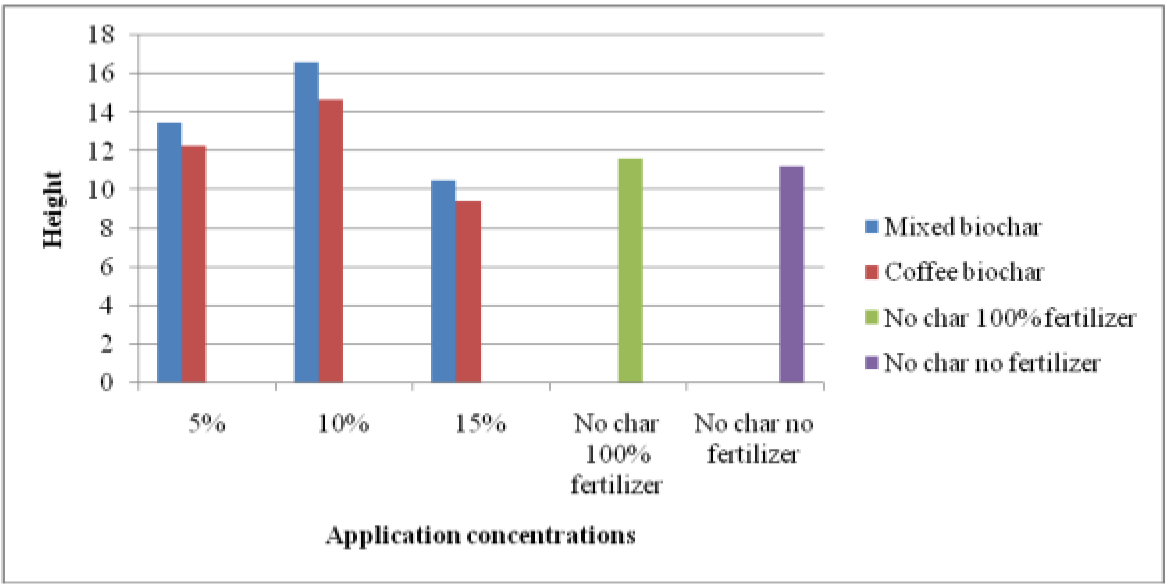


Figure 41: Height of spinach at harvest with applications and different biochar types

Among all treatments with two types of biochar, maximum of the mean height of prickly seeded spinach was observed with application concentration of 10% mixed biochar and the minimum in the

15% coffee biochar. Height gained at 15% concentration was less than in the height gained in control plots.

Maximum weight of prickly seeded spinach was observed in the plot treated with 10% application of mixed biochar followed by 5% application of coffee biochar with weights 3.5 kg and 3.2 kg respectively.

Maximum weight of prickly seeded spinach was obtained at 10% application concentration of mixed biochar and minimum at 15% coffee biochar with 3.5 kg and 2.3 kg respectively. Control plots treated only with fertilizer gave 3.0 kg whereas plot without fertilizer as well as no biochar gave2.1 kg of prickly seeded spinach (Table 39 and Table 40)

Table 39: Weight of prickly seeded spinach on harvest treated with mixed biochar and control

Application concentration	5% mixed biochar	10% mixed biochar	15% mixed biochar	Control	
				No biochar 100% fertilizer	No biochar no fertilizer
Weight (kg)	3.4	3.5	2.3	3.0	2.1

Table 40: Weight of prickly seeded spinach on harvest treated with coffee biochar and control

Application	5% Coffee biochar	10% Coffee biochar	15% Coffee biochar	Control	
				No biochar 100% fertilizer	No biochar no fertilizer
Weight (kg)	3.2	2.3	2.1	3.0	2.1

Maximum and minimum weight of prickly seeded spinach in 9 m^2 plot was obtained at 5% and 15% application concentrations of coffee biochar with 3.2 kg and 2.1 kg respectively. Control plots treated only with fertilizer gave 3.0 kg whereas plot without fertilizer as well as no char and no fertilizer gives 2.1 kg of prickly seeded spinach.

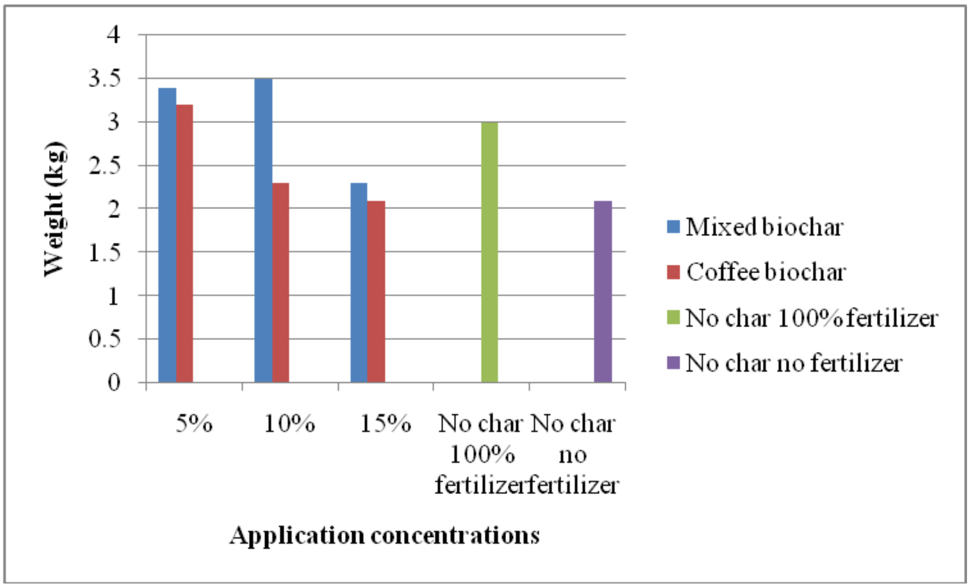


Figure 42: Weight of spinach at harvest with application concentrations and different biochar types

No significant difference was observed between the treated plots and control plot in the determination of productivity of both vegetables. It is however, important to note that increase in application of biochar does not increase the yield of the vegetables.

Effect of Biochar on Soil Properties

Soil analysis was done before and after the application of biochar in the experimental site. First soil sampling and analysis was done during September 2013 and November 2013 and second soil sampling and analysis was done after harvest of vegetables in April 2014 and May 2014. pH, %OM, %N, available K, available P and exchangeable cations (Na, K, Ca, and Mg) were analyzed. pH value ranges from 5.9 to 6.5 before the application of biochar in experimental site, which implies that soil was slightly acidic. After the harvest of vegetables the pH value ranges from 8.3 to 8.5 in biochar applied plots. This indicates soil is moderately basic after the application of biochar in different concentrations. Value of %N before the application of biochar ranges from 0.05% to 0.13% indicates the lower concentration to medium. After the application of biochar the observed values ranges from 0.14% to 0.24 % with increased value after the application of biochar. After the application, % N is moderate in all applied plots with increased value than before the treatment.

CEC value of mixed biochar and coffee biochar used in the treatment were 14.7me/100gm and 11.9/100gm respectively. The value of CEC before the application of biochar ranges from 7.5me/100gm to13.5 me/100gm. This is the large variation in CEC seen before the application of biochar in the experimental site. After the application of biochar the value of CEC ranges from 6.4 me/100gm to 7.8 me/100gm. Maximum value was observed in the plot with 20% application and 10 % application of coffee biochar. Minimum value of CEC was observed in the plot with no biochar and no fertilizer (Table 41)

Table 41: Soil properties of experimental field before treatment

Plot	pH	%N	K (mg/kg)	% OM	CEC (me/100gm)
Plot 1	5.9	0.10	48.3	3.4	7.7
Plot 2	5.9	0.07	56.0	3.3	7.5
Plot 3	6.4	0.10	73.2	4.0	13.3
Plot 4	6.3	0.05	74.0	4.0	13.5
Plot 5	6.5	0.13	89.0	4.5	13.4

Soil chemical properties were analyzed before the application of biochar on the experimental site. pH value ranged from 5.9 to 6.5 implies that soil was slightly acidic. % Nitrogen ranged from 0.05 to 0.13. % organic matter ranged from 3.3% to 4.5%. Available potassium varied from 48.3 to 89.0. Similarly, CEC varied from 7.5 to 13.5me/100gm.

Table 42: Soil properties of experimental field after harvest

Type	Application %	pH	% N	P (kg/ha)	K (kg/ha)	% OM	CEC meq/ 100gm	Exchangeable cation me/100gm			
								K	Na	Ca	Mg
Coffee	5	8.8	0.22	31.75	47.50	4.4	6.8	0.5	0.1	3.75	1.75

biochar						5					
Coffee biochar	10	8.44	0.23	93.83	52.67	3.92	6.4	0.5	0.1	4.5	1.5
Coffee biochar	15	8.42	0.23	77.18	52.67	4.19	6.7	0.4	0.1	5.75	0.75
Coffee biochar	20	8.82	0.24	118.06	44.91	4.45	7.4	0.3	0.1	3.75	1.5
Mixed biochar	5	8.77	0.23	116.04	65.60	3.92	7	0.2	0.1	4.75	1
Mixed biochar	10	8.34	0.21	40.33	55.25	4.19	7.4	0.5	0.1	4.25	1
Mixed biochar	15	8.76	0.22	89.29	57.84	4.19	7.8	0.5	0.1	4.75	1.5
Mixed biochar	20	8.85	0.16	65.06	55.25	4.08	6.8	0.2	0.1	4.75	1.25
no char (100% fertilizer)	0	8.69	0.22	60.02	60.43	3.77	6.9	0.2	0.1	5.25	1
No char no fertilizer	0	8.73	0.14	38.82	44.91	4.19	6.4	0.5	0.1	3.25	0.5

		pH	% N	Available P (ppm)	Available K (ppm)	% OM	CEC meq/100gm	K meq/100 gm	Na meq/100 gm	Ca meq/100 gm	Mg meq/100 gm
Mixed char		8.89	0.028	0.170	2.045	0	14.7	0.5	0.3	10.25	2.5
Coffee char		8.58	0.042	0.047	2.045	0	11.9	0.5	0.8	7.25	1.25

After the treatment with biochar, pH value ranged from 8.34 to 8.8. %N ranged from 0.14 to 0.24. Available phosphorous ranged from 31.75 kg/ha to 118.06 kg/ha. Available potassium ranged from 44.91 kg/ha to 65.60 kg/ha and percentage organic matter ranged from 3.92 to 4.45. CEC of soil from different treated plots were 6.4me/100gm to 7.8me/100gm.

4.0 Conclusion

4.1 Life Cycle Assessments

For Life Cycle Assessment (LCA), ISO-standardized approach, the inputs, outputs and potential environmental impacts of a system within the system's entire life cycle was considered (figure 43). Life cycle assessment (LCA) is a tool devised to quantify the total environmental impact of a product or process (International Organization for Standardization, 2006). LCA has been widely employed to assess the climate change impacts of bioenergy systems (Cherubini et al., 2009; Cherubini, 2010).

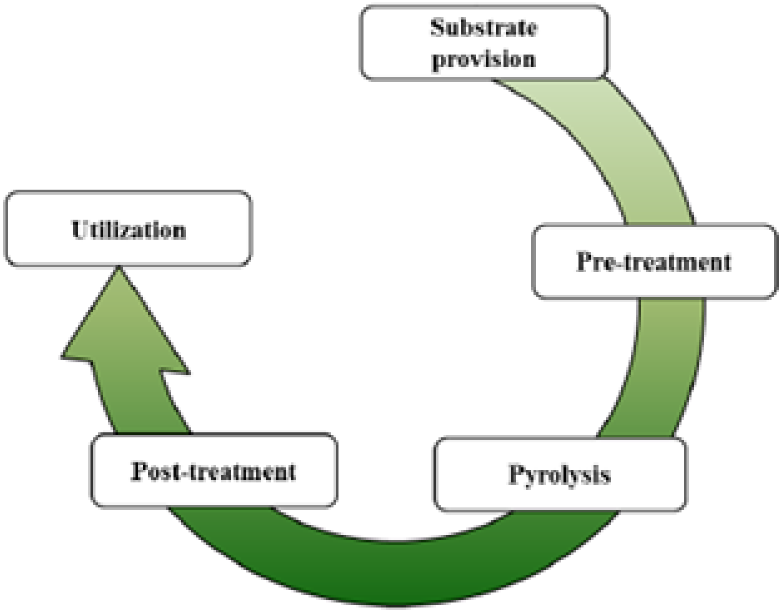


Figure 43: Life cycle stages of biochar production and utilization (HAWK, 2013)

Several studies employing LCA or partial LCA approaches have been used to quantify the climate change impacts of biochar production and use (Gaunt & Cowie, 2009; Roberts et al., 2010; Woolf et al., 2010; Hammond et al., 2011). LCA assesses the GHG emissions and sequestration across the biochar life cycle including aspects highlighted in the previous sections - such as changes in soil and biomass carbon stocks due to procurement of biomass; fossil fuel use in harvesting, processing, transport and application of biochar; and indirect emissions such as from fertilizer manufacture. Emissions of all relevant GHG are included, that is, N_2O and CH_4 as well as CO_2. The net impact of biochar is determined by comparing the biochar life cycle with the applicable reference system, representing the conventional soil amendment and use of the biomass, and, where the biochar production process produces an energy co-product, the conventional energy source.

LCA studies have estimated net emissions reduction for different biochar scenarios at 0.7-3.1 Mg CO_2-e per Mg (dry) feedstock, if indirect land use change is omitted (Gaunt & Cowie, 2009; Roberts et al., 2010; Hammond et al., 2011). However, where purpose-grown biomass is used for biochar, and indirect land use change is assumed to occur, the benefits are reduced, and emissions could even be increased (Roberts et al., 2010). The wide variation in these assessments results from differences in the biochar scenarios (feedstock, design and scale of pyrolysis plant, displaced fossil energy source) and differences in assumed impacts of biochar. Uncertainty is high, particularly for the impacts of biochar on plant growth, fertilizer requirements and nitrous oxide emissions.

Biochar from wood residues have a greater emission mitigation potential than biochar from manures, because manure biochar have a shorter mean residence time in soil than that of wood biochar (Singh & Cowie, 2010). In general, there is greater benefit from biochar made from residues than from purpose-grown biomass crops, due to additional fossil fuel inputs and losses of soil carbon in producing the biomass, and due to the decomposition emissions assumed to be avoided where residues are used (Roberts et al., 2010).

Temperature of the pyrolysis kiln affects the stability of the biochar and the yield of biochar vs. syngas: at higher temperatures, the biochar produced is more resistant to decay in soil (Singh & Cowie, 2010), but there is less biochar produced. Beneficial use of syngas released during the pyrolysis process to displace fossil energy is an important contributor to the abatement value of biochar systems. Displacement of GHG-intensive energy sources such as electricity from brown coal, gives greater abatement than displacement of less GHG-intensive sources such as electricity from natural gas (Cherubini et al., 2009).

Reduction in nitrous oxide emissions from agricultural soils is an important contributor to abatement, so assumed benefits are greater for crops with high nitrous oxide emissions, such as irrigated crops with high-nitrogen fertilizer requirements.

The major contribution to abatement arises from carbon storage in the biochar (Roberts et al., 2010; Hammond et al., 2011). The contributions of organic matter stabilization, avoided nitrous oxide emissions from soil, avoided methane emissions from landfill, and displacement of fossil fuel emissions vary between alternative scenarios, and are highly dependent on the assumptions employed (Wu et al., 2008; Gaunt & Cowie, 2009; Roberts et al., 2010; Hammond et al., 2011). The total abatement value can be greater than the CO_2 sequestered in biomass, and can be greater than if the biomass was used solely for bioenergy (Woolf et al., 2010; Hammond et al., 2011).

There is potential for biochar systems to generate carbon credits in emissions trading markets and, thus, provide a financial incentive for the adoption of biochar technologies (Gaunt & Cowie, 2009). Acceptance of biochar in emissions trading schemes will require confidence in the calculation and verification of the abatement claimed. Sustainability certification, discussed below, could contribute to confidence in biochar as a legitimate offset.

LCA of biochar production in Nepal- includes inputs, outputs, and the potential impacts of a product system which are assessed and evaluated throughout the product's life span.

The process of biochar making links up with the following steps (Figure 7b):

- Biomass Collection
- Pyrolysis Facility
- Soil Application

Biomass collection for biochar production in Nepal is usually carried out from the community forests of Nepal. Community forestry program is mostly successful in Nepal. The following table 43 shows the changes in status of community forestry in between 2008 and 2013.

Table 43: Status of community forestry in Nepal

Categories	2008	2013 (June)	% Change (2008-2013)
User groups	14,431	18,133	25.7
Households	1,660,000	2,237,195	34.8
Forest area (ha.)	1,230,000	1,700,048	38.2

(MoFSC, 2014)

Cutting, pruning and cleaning activities are practiced annually in community forests of Nepal as a part of sustainable forest management. Therefore these activities annually generate large amount of biomass which has been used/can be used to produce biochar in small scale by many community forest user groups (CFUG). For example in case of biochar produced from Padali Community Forest of Lalitpur the biomass can be obtained from cutting, pruning and cleaning activities of the species like Alnus nepalensis, Castanopsis indica, Castanopsis tribuloides, Choerospondias axillaris, Eurya acuminate, Fraxinus floribunda, Gravellis robusta, Lyonia ovalifolia, Madhuka indica, Maesa chisia, Myrica sp., Myrsine capitellata, Myrsine semiserrata, Osyris wightiana, Persea sp., Pinus roxburghii, Pinus wallichiana, Prunus cerasoides, Pyrus pashia, Quercus glauca, Rhododendron sp., Rhus javanica, Saurauria nepaulensis, Schima wallichii, Syzygium cumini and Zizyphus recurva. Similarly the use of biomass from used of residues of rice, coffee, sugarcane, wheat etc. is also in increasing trend.

Biomass pyrolysis and biochar returned to soil is a possible strategy for climate change mitigation and reducing fossil fuel consumption. Pyrolysis with biochar applied to soils results in four co-products: long-term carbon (C) sequestration from stable C in the biochar, renewable energy generation, biochar as a soil amendment, and biomass waste management. The details of biomass pyrolysis and biochar production mechanisms have been described in Chapter One.

The greatest problem in assessing biochar may be the uncertainty of data involved. As biochar systems are still relatively novel and have not been implemented widely, there are only few reliable data available for specific biochar production units, effects of biochar application in soil etc. The LCA approach introduced in the project combines latest results to assess the potential of biochar utilization. Biochar are considered for enhancing crop productivity, improving soil tilth (Physical condition), fertility, water retention, reducing soil erosion and reducing need of fertilizer inputs.

Environmental Impacts of Biochar Production-
Health impacts from particle emissions originating from biochar production (particles and volatile organic compounds, methane and carbon monoxide are emitted).

An emission of Respirable Suspended Particulate Matter (RSPM) was monitored during biochar production (Table 44). The values ranged from 0.04 mg/Nm^3 to 19.02 mg/Nm^3 for different technologies and during different activities. RSPM concentration was mainly problematic during charcoal unloading while it was rather low during charcoal firing in all assessed three technologies. The highest concentration was observed during charcoal unloading in pit kiln which largely exceeded the guideline 3 mg/Nm^3 (ACGIH, 1998). Similarly, heat stress may also be problematic in the working environment as it may pose serious threat to workers in summer seasons.

Table 44: RSPM concentration (mg/Nm3) exposure to workers during charcoal firing and unloading under different technologies

Technology	RSPM concentration (mg/Nm^3 with 8-hours' time weighted average TWA)	
	Firing	Unloading
Earth pit	0.31	19.02
ICR	0.50	3.90
PCK	0.04	0.57

Biochar production from raw materials obtained from community forest may lead to deforestation and diminishing wildlife population. According to Nepal Biodiversity Strategy (NBS) 2002, unrestricted collection of dead wood and leaf litter from community forest during cutting, pruning activities, which form important microhabitats for invertebrates, mosses, fungi and lichens may lead to reduced biodiversity (MoFSC/GoN, 2002). Many CFUGs have included phrases such as "removal of unwanted species" in their forest operational plans, yet these species may be ecologically important and biodiversity may suffer as a result of their removal (MoFSC/GoN, 2002).

Alteration can be in the nutrient dynamics of the area from where the biomass is collected for the production of biochar.

Application of biochar on soils acts as an effective agents for sequestering Carbon (C) in soils. Although hydrochars (Char from hydrothermal carbonization) and low-temperature biochar contain some bioavailable Carbon (Remaining carbon from raw material), it is generally more stable in soils than C in the original biomass, the C in moderate and high temperature biochar is overwhelmingly stabilized against microbial decomposition and hence will persist for hundreds if not thousands of years in soils. However, the net greenhouse gas (GHG) impact due to biochar applications to soil is also influenced by changes in net primary crop productivity, increases in the efficiency of residue mineralization or humification, soil organic matter cycling, and emissions of CH_4 and N_2O (ASA et al., 2012).

Overall production process & life cycle of biochar

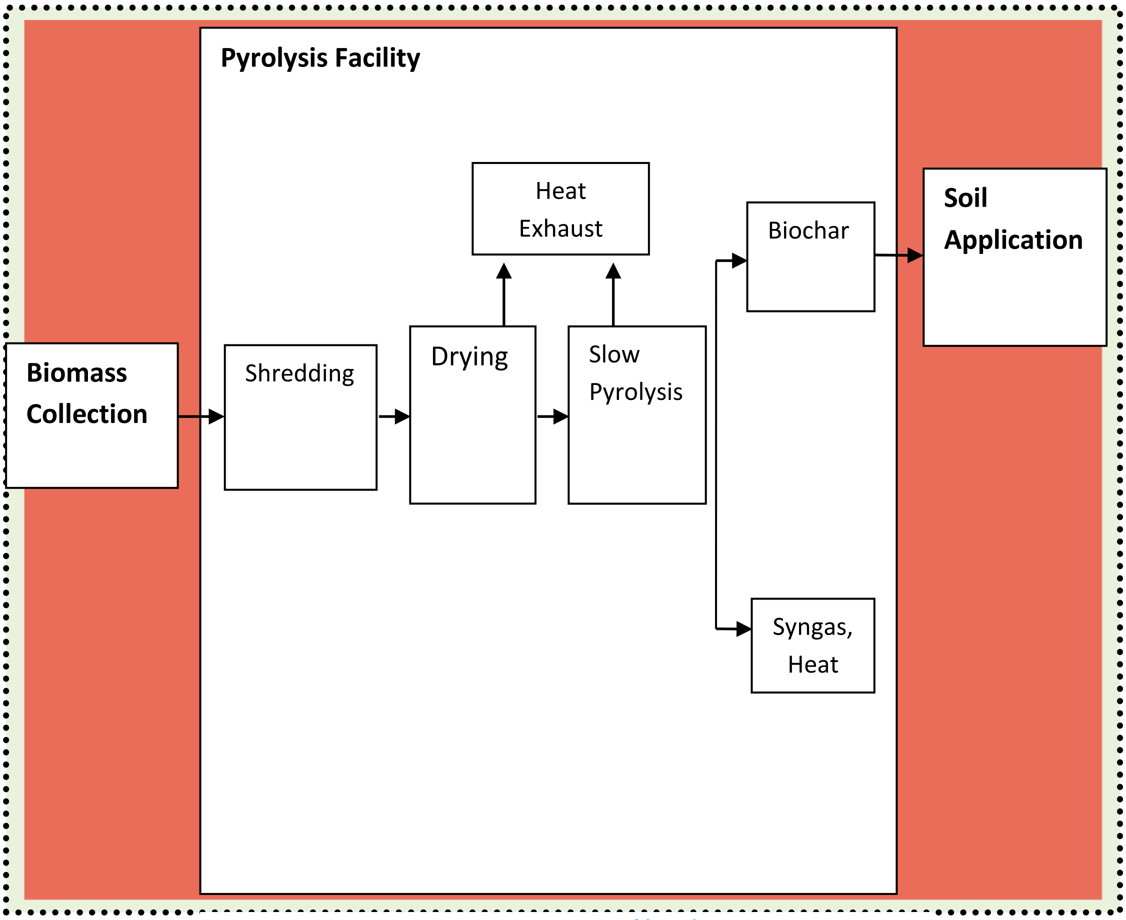


Figure 44: LCA of biochar

4.2 Acts, Policies and Regulations

Seed Act, No 22 of 2003 & Seed and planting material Act no2013 (SL) - This Act aims to protect & regulate the quality of seed and planting materials, to protect the rights of users of seed and planting materials, to formalize the activities and protect the rights of seed and planting material handlers, to develop the seed and planting material industry, to safeguard and conserve the genetic resources of indigenous seed planting materials important to agriculture, to provide for matters connected therewith or incidental thereto, and repeal the seed Act No 22 of 2003.

Control of pesticides (Amendment) Act No 6 of 1994 (SL) – This Act amended control of pesticides Act 33 of 1980. This is an Act to provide for the licensing of pesticides; to regulate the import, packing, labeling, storage, formulation, transport, sale and use thereof; for the appointment of a licensing authority for pesticides for the establishment of a pesticide technical and advisory committee and for matters connected therewith or incidental thereto.

Soil conservation Act, No 25 of 1951 & 29 of 1953 (SL) - This is an act to make provision for the enhancement and substance of productive capacity of the soil, to restore degraded land for the prevention and mitigation of soil erosion, for the conservation of soil resources and protection of land against damage by floods, salinity, alkalinity water logging, brought, and to provide for matters connected therewith or incidental thereto.

Plant protection Act, No 35 of 1999 (SL) - The Minister may make regulations with respect to any matter required by this Act. This is to be prescribed or in respect of which regulations are required or authorized to be made, for the prevention of introduction into Sri Lanka, or for the eradication, or for the prevention of spreading therein of, pests, and for the export of plants, plant products or organisms from Sri Lanka, for restricting or prohibiting the importation into Sri Lanka of any plants, plants products and organisms and for restricting or prohibiting the entry points at which they may be landed, for restricting or prohibiting the landing in Sri Lanka of plants, plant products and organisms, either absolutely or conditionally, for providing for the importation of organisms under special license and conditions, for inspecting and or testing plants, plans products and organisms at, before, or after, the time of landing, for testing, cleaning, fumigating, or disinfecting, at the expense of the importer and or the owner and if expedient, destroying at, before, or after, landing and without compensation, all plants, plant products and organisms, or the packages, cases, pots, or coverings in which they may be packed, and which are found to be infected with any pest or pests and for the recovery of prescribed fees for such destruction from the importer and or owner, for requiring the quarantine of plants, plant products and organisms imported or to be imported, in special areas, and for fixing the conditions of such quarantine and the fees to be charged therefor, for preventing the outbreak or dissemination of any pest within Sri Lanka, for declaring any area to be an infested area, and for the proper quarantine of an specified area declared as being infested with any pest, for testing, treatment, destruction and proper disposal, of plants or plant products affected or likely to be affected with any pest, for restricting or prohibiting the cultivation of any plant or plants for a specified period or periods within any specified area or areas in Sri Lanka, for regulating the transfer of plants, plant products or organisms from one locality in Sri Lanka to another, for the constitution of committees to advise the Director-General and the authorized officers, and to take such other action as may be necessary to ensure the effective administration of the provisions of this Act, for ensuring the phytosanitary status of the plants, plant products or organisms exported from Sri Lanka and for charging fees for implementing the provisions of this Act and the regulations made thereunder.

Interim Constitution of 2007 (Np),

The Interim Constitution of Nepal ensures that “every person has the right to live in a healthy environment.” In its State Policies, the constitution expresses that "the state shall make necessary arrangements to maintain the natural environment. The State shall give priority to special protection of the environment, and rare wildlife, and prevent further damage due to physical development activities by increasing awareness of the general public about environmental cleanliness. Provisions shall be made for the protection of the forest, vegetation and biodiversity, their sustainable use and equitable distribution of benefits derived from them.

Agriculture Perspective Plan (APP), 1995-2015 (Np)
The APP has emphasized the importance of environment for sustainable growth of agriculture. The Plan recognizes that programs to accelerate agriculture growth may have adverse impacts on environment. APP argues that the intensification of farming in more favorable areas would reduce the need for cultivating marginal lands and reduce environmental degradation. APP advocates for the plantation of tree and fruit crops on the steep slopes of hills and mountains for minimizing environmental problems. The Plan also recommends the adoption of Integrated Pest Management (IPM) technologies to avoid environmental problems associated with increased use of pesticides.

The Interim Three Year Plan, 2010/11-2012/13 (Np)
This Plan has devoted a separate chapter for environment and climate change. The Plan aims to promote the concept of green development by encouraging human and development activities to be environment friendly. The Plan also aims to maintain natural beauty of the rural areas. Programs include, among others, adoption of bioengineering in infrastructure development projects for controlling soil erosion, safe disposal of harmful pesticides, and streamlining EIA procedures.

Sustainable Development Agenda for Nepal (SDAN), 2003 (Np)
The Government of Nepal (GoN) prepared a sustainable development agenda in 2003 as a follow up to its commitments to the United Nations Conference on Environment and Development (1992) and the 2002 World Summit on Sustainable Development. The SDAN aims to guide national level development plans and policies up to 2017. The SDAN requires environmental impact assessment and analyses of alternatives for all projects. It also argues for the protection of land against degradation, biodiversity conservation, conservation of rangelands, and promotion of sustainable harvest and management of non-timber forest products.

National Fertilizer Policy, 2058 (Np)
This policy recommends the adoption of Integrated Plant Nutrients System (IPNS) to prevent deterioration of soil fertility and minimize adverse impacts on environment caused by the use of chemical fertilizers. IPNS encourages farmers to make balanced use of chemical fertilizers based on soil test. It also encourages farmers to use organic manures.

Forestry Sector Policy, 2000 (Np)
The objectives of the forestry sector policy include contribution to food production through effective interaction between forestry and farming practices; and protection of land from degradation by soil erosion, landslides, desertification, and other ecological disturbances. This policy forbids conversion of forest, shrub, and grasslands into cultivation. The policy aims to manage and utilize land and forest resources according to their ecological advantage. The policy states that forests in the mountains would be managed with users' participation. It introduces the concept of collaborative forest management in Terai where the government and households living adjacent to forests will form a partnership in managing forests.

Climate Change Policy, 2011 (Np)
This policy incorporates climate adaptation and disaster risk reduction measures. The policy advocates for the adoption of low carbon development path by encouraging use of renewable energy and increasing carbon sequestration through proper management of forests. Bridges, dams, river flood control, and other infrastructures would be made resilient to climate change. Drought and flood resistant crop varieties would be developed and disseminated. A Climate Change Fund would be established and at least 80 percent of this fund would be allocated to program implementation at community level.

Environmental Protection Act, 2053 (1996) and Regulations, 2054 (1997) (Np)

These Act and regulation are the main legislation guiding environmental management in Nepal. The Environment Protection Act (EPA) requires projects to conduct an Environmental Impact Assessment (EIA), or the Initial Environment Examination (IEE) depending on the size and scope of projects.

Seeds Act, 2045 (1988) and Regulations, 2054 (1997) (Np)

This Act aims to increase crop production by making high quality seeds available. This Act has established a National Seed Board. The Act also made provisions for the established of seed certifying agency and a central seed testing laboratory. As per this Act, the government can specify minimum germination level and purity of seeds and can prohibit the sale of seeds not meeting such specifications. The Act can also prohibit export and import of seeds notified by the government. However, Seed Act is hardly implemented in practice.

Plant Protection Act, 2029 (1972) and Rules, 2031(1974) (Np)

This Act requires individuals and organizations importing plant products, biological control agents, beneficial insects, and medium for growing plants such as soil to obtain permission from the designated authorities. As per the Act, the government can declare certain area as pest affected areas and adopt necessary measures to destroy pests in those areas.

Pesticides Act, 2048 (1991) and Regulations, 2050 (1993) (Np)

This Act requires all importers, exporters, users, sellers, and producers of pesticides to register such pesticides with the authority designated by the Government. The government publishes names of such pesticides in the national Gazette. As per the Pesticides Regulation 1993, the registration agency needs to evaluate the impacts of such pesticides on human, animal, and environment. The authority can cancel such registration any time if the general use of those pesticides is found to make adverse impacts on human, animal, and environment. Pesticide retailers and sprayers also need to be registered. National Plant Quarantine Office is the designated authority.

4.3 Conclusions

In Sri Lanka, The two soils used in the experiment were contrastingly different. Being a sandy soil Kalpitiya soil has very low organic carbon content and also shows low cation exchange capacity. Gannoruwa soil is acidic and the Kalpitiya soil is nearly neutral in pH. However, Kapitiya soil shows comparatively higher available P content than the Gannoruwa soil. The available K content is very low in the Kalpitiya soil when compared to Gannoruwa soil. The three sources of biochar used were also contrastingly different. BRH showed the highest CEC of 173.9 cmol/kg and BIOCHARGLIRICIDIA (BGC) the second highest which is about half the CEC of BIOCHAR RISE HUSK (BRH). Water Holding Capacities (WHC) of the three materials were contrastingly different too. RHB showed the highest capacity of five times of its weight while the second highest BIOCHARGLIRICIDIA (BGC) is capable of holding only twice its weight of water. WHC of BIOCHAR SAW DUST (BSD) is only 0.6 times its weight. The most interesting fact is the variation in electrical conductivity of the three biochar and BIOCHARGLIRICIDIA (BGC) amounting to 14.14 ds/M in 1:5 ratio of determination. This indicates the possible salinity damage at very high levels of application. When considering the nutrient contents, all three sources are low in nutrient content and BIOCHAR SAW DUST (BSD) is the lowest among the three.

Thus, all three biochar materials when added alone had almost no effect on plant growth in the Kalpitiya soil. However, addition of fertilizer (NPK only) helped the plants to grow rapidly when compared to the other treatments. This shows that none of the biochar materials were capable of providing the essential plant nutrients in sufficient quantities for the sustenance of plant growth. The major nutrient contents in all three biochar materials testify this behavior, and Gliricidia biochar has the lowest N content and this is one of the essential nutrients for plants. The Kalpitiya soil with its low organic matter content and coarse textured characteristic has very low N supplying ability. Under such conditions the external supply of N would markedly influence the plant growth. The interesting observation is that even the combined use of biochar + NPK was not as effective as NPK applied alone in promoting plant growth in the pots. Comparing the three biochar materials, BIOCHAR RISE HUSK (BRH) is superior to the other two sources while the performance of BIOCHARGLIRICIDIA (BGC) was the worst. The result clearly shows that increasing the rate of biochar application from 10 to 30 t/ha has markedly reduced plant height. This could possibly be due to some unfavorable characteristic of the biochar. Data shows that all three biochar sources have high pH and EC. Sandy Kalpitiya soil itself is not acidic and also shows comparatively high EC. Hence, increasing the rate of biochar added would have drastically reduced the impact of the material due to the changing soil micro climate of pH and EC affecting plant growth.

Data shows that pH and EC of the Kalpitiya soil were increased due to application of biochar. The increase in pH in Kalpitiya soil perhaps limits the availability of several micronutrients essential for crop growth. In addition the high CEC of the biochar material would have not contributed positively in Kalpititya soil, instead would have had a negative effect as higher CEC might have resulted in the retention of greater quantity of ions in the soil- biochar -root interface making the soil solution more concentrated and affect root uptake of water and nutrients.

The behaviour in Gannoruwa soil is also similar, but the unfavourable influence of biochar seems to have been buffered by the high clay content in this soil. Hence, the high pH and EC of the biochar materials would have not been as unfavourable as in the Kalpitiya soil.

In Gannoruwa soil however, in the biochar only treatments, increasing rate of application from 10 to 30 t/ha, showed an increasing trend of dry matter production with all three sources of biochar. This could mostly be due to the release of comparatively higher quantity of nutrients from biochar sources with the increasing rates of application. This trend is directly related to the nutrient content of the material itself. Here too the superiority of BIOCHAR RISE HUSK (BRH) was seen clearly as

BIOCHAR RISE HUSK (BRH) alone was able to produce more than double the amount of dry matter to the second best option of BIOCHAR GLIRICIDIA (BGC). BIOCHAR SAW DUST (BSD) alone produced the least amount when applied without fertilizer. However, picture changed with the combined application of fertilizer with biochar in Gannoruwa soil. Then BCG out yielded the performances of the other two sources and also the fertilizer alone treatment. This indicates that BCG biochar is a better option for clay rich soils though it may not be equally effective in coarse textured soils like Kalpitiya.

There was an increasing trend of root dry weight with the increasing rate of application of biochar in Gannoruwa soil whereas no such trend could be observed in the Kalpititya soil. Application of fertilizer enhanced root growth in both soils with BIOCHAR RISE HUSK (BRH) and BIOCHAR SAW DUST (BSD). However root growth in Kalpatiya was not improved due to the addition of BIOCHAR GLIRICIDIA (BGC) with fertilizer. As discussed under the shoot dry matter formation of the crop the same reasons i.e. high soil salinity and pH condition would have affected the root formation with BIOCHAR GLIRICIDIA (BGC). Root formation with BIOCHAR SAW DUST (BSD) was lower than with BIOCHAR RISE HUSK (BRH). Here again the pattern is similar to shoot dry matter production. The low P content in BIOCHAR SAW DUST (BSD) and in the Gannoruwa soil, may have contributed to the poor root formation in the BIOCHAR SAW DUST (BSD) treatments. However, application of NPK (where P source is TSP, a soluble P source) had improved root dry weight in the BIOCHAR SAW DUST (BSD)+NPK treatments in Gannoruwa soil.

Field testing of biochar was carried out using two crops at Kalpitiya however only two biochar materials were used namely RHB and BCG. The two crops used in the experimentation were red onion (shallots) and capsicum.

Field experiment with shallots showed promising results of using biochar in Kalpitiya soil. Data shows that addition of biochar alone (BIOCHAR RISE HUSK (BRH) and BIOCHAR GLIRICIDIA (BGC)) was not capable of sustaining the crop at satisfactory level despite the fact that red onion is a very short term crop. Pot trials with Capsicum also showed the inability of different biochar sources to act as a fertilizer material in Gannoruwa and Kalpitiya soils. However, results showed that onion yield could be increased by nearly 4 tons ha^{-1} with the application of 20 t ha^{-1} BIOCHAR RISE HUSK (BRH). The influence of BIOCHAR GLIRICIDIA (BGC) however was not as great as BIOCHAR RISE HUSK (BRH) when combined with fertilizer for red onion. This could possibly be associated with the high CEC of the BIOCHAR RISE HUSK (BRH) which probably compensates the very low CEC of the Kalpitiya soil.

Behaviour of onion with biochar in the Kalpitiya field experiment is somewhat different to that observed in the greenhouse with capsicum experiment. It could be due to difference under which the plants were grown. In the greenhouse the negative effects of biochar would be more pronounced due to the restricted growing environment especially for the root system. Another aspect would be difference in root distribution of the two crop species. Red onion has a very shallow fibrous root system mostly confined to the surface while capsicum has a deeper root system. It is quite possible that the confined area affected the crop growth when grown in pots under greenhouse condition compared to the field grown condition. In fact, capsicum grown in the field was not as badly affected as in the greenhouse even with the application of 20 t/ha BIOCHAR GLIRICIDIA (BGC). Behaviour of Capsicum in the field at Karapitiya was different to that observed under pot trials.

Under field conditions negative effects of biochar was not pronounced at the 20 t ha^{-1} rate of application. However, care has to be taken when the biochar materials are added continuously to neutral or high pH soils in particular. In addition, it is advisable to monitor the changes in soil EC in situations where biochar is applied continuously even for clay rich soils. Following the same trend, pod yield of Capsicum also showed marked increase with the application of both sources of biochar when combined with NPK. Perhaps under field conditions the positive characteristics of biochar (high water holding capacity and high CEC) would have surpassed the negative parameters (pH and EC) probably due to the dilution effect under field conditions. However, data shows that under field conditions, the application of biochar alone was not sufficient to obtain satisfactory capsicum yields. This confirms the results of the red onion field experiment and also the greenhouse experiments.

It can be postulated that irrigation also played major role in determining the effectiveness of biochar in the field. Contrary to the greenhouse experiment, irrigation water was supplied in abundance (this is the usual farmer practice) for the field experiment. Whereas in the greenhouse experiment only the predicted quantity of water that evaporated from the soil and plant was added to the pots. Under pot trials no leaching was observed but under the field condition of Kalpitiya there would have been a fair degree of leaching taking place resulting in a dilution effect of the soil solution.

All three biochar materials (Rice husk biochar, Saw dust biochar and Gliricidia biochar used in this study do not contain sufficient quantity of plant nutrients and hence cannot be used as sole plant nutrient sources for growing crops. The use of biochar materials together with chemical fertilizers can improve the productivity of both red onion and capsicum under field growing conditions in both Gannoruwa (medium textured) and Kalpitiya (coarse textured) soils. The efficacies of biochar material differ. Rice husk biochar was the best among the three feed stocks tested.

In Nepal, Productivity analysis based on the measurement of height and weight of vegetables revealed that there is mean difference in productivity of vegetables in different application concentrations of biochar on vegetables: onion and prickly seeded spinach. However no significant difference was observed among the different treatments and control plots.

Soil productivity analysis was conducted based on the change in soil properties before and after the application of biochar in the experimental plots. Soil analysis showed change in pH, %N, OM and CEC after the application of biochar. Significant change was observed in pH and %N of soil.

5.0 References

1. Chapter 2, Simple technology for charcoal making, FAO Forestry paper, Food and agriculture organization of the United Nations, February 1984
2. Chapter 7, Simple technology for charcoal making, FAO Forestry paper, Food and agriculture organization of the United Nations, February 1984
3. Biochar farms-2010/Design, construction and analysis of a farm scale biochar system, by Robert prins, Wayne teel and John, James Madison University, 2010
4. Biomass pyrolysis process-performance parameters & their influence on biochar system benefits, Peter Alexander Brownsort, A dissertation presented for the degree of Master of Science University of Edinburgh, 2009
5. FAO, Seasonal vegetable cultivation in Nepal, 2013-01-07
6. Biochar production potential in Ghana, A review, Moses Hensley Dukua, Sai Gua, Essel Ben Haganhjba
7. Economics and Social Statistics of Sri Lanka-2012, Volume XXXIV, Central bank of Sri Lanka, Statistics Department, April 2012
8. Municipal Solid Waste Management, The Sri Lankan Case, Nilanthi J.G.J. Bandara, Department of Forestry and Environmental Sciences, University of Sri Jayewardenepura, Sri Lanka
9. Types, Amount and effect of industrial solid waste, page 2, Jinhui Li, Department of Environmental Science and Engineering, Tsinghua University, Beijing, China
10. http://www.bioenergyconsult.com/tag/composition-of-bagasse/2012.10.31
11. Climate Change Adaptation Sri Lanka.mht /Sri Lankan effort/Gliricidia, Biomass has huge potential for Clean Development Mechanism [Newspaper Article, The Nation English Sri Lanka, Dilanthe Withanage, September 20, 2011
12. ACGIH, 1998. TLVs and BELs threshold limit values for chemical substances and physical agents. American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati.
13. ASA, CSSA and SSSA, 2012. Environmental Benefits of Biochar, American Society of Agronomy, Crop Science Society of America and Soil Science Society of America. Journal of Environmental Quality, pp. 967-972.
14. CBS, 2013. Environmental Statistics of Nepal, Central Bureau of Statistics, National Planning Commission Secretariat, Government of Nepal.
15. Chan, K. Y., Xu, Z., 2009. Biochar: Nutrient Properties and Their Enhancement. In: Biochar for Environmental Management: Science and Technology (Eds. Lehmann, J. & Joseph, S.), Earthscan.
16. Downie, A., van Zwieten, L., Doughty, W., and Joseph, F., 2007. Nutrient retention characteristics of chars and the agronomic implications. Proceedings, International Agrichar Iniative Conference, 30th April - 2nd May 2007, Terrigal, Australia.
17. HAWK, 2014. Life Cycle Analysis of Biochar Production and Utilization, Hochschule für Angewandte Wissenschaft und Kunst (accessed on www.biochar-interreg4b.eu March,2014).
18. Gaunt, J., and Lehmann, J., 2008. Energy balance and emissions associated with sequestration and pyrolysis bioenergy production. Environ. Sci. Technol. 42:4152-4158.
19. Glaser, B., Lehmann, J., and Zech, W., 2002. Ameliorating physical and chemical properties of highly weathered soils in the Tropics with charcoal – A review. Biol. Fertility. Soils 35:219–230
20. Kannan, P., Arunachalam P., Prabukumar G., and Govindaraj M., 2013. an alternate option for crop residues and solid waste disposal and climate change mitigation, African journal of Agricultural Research. Vol. 8(21) , pp. 2403-2412
21. Laird, D. A., 2008. The charcoal vision: A win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. Agron. J. 100, 178-181.

22. Lehmann, J., 2007. A handful of carbon. Nature 447:143-144.
23. Lehmann, J., 2007. Bio-energy in the black. Front. Ecol. Environ. 5, 381-387.
24. Lehmann, J., and Joseph, S., 2009. for Environmental Management. Internatioal Institute of Environment and Development and Earthscan, USA and UK .
25. Lehmann, J., and Rondon, M., 2006. Bio-char soil management on highly weathered soils in the tropics. In: Uphoff NT (Ed.), Biological approaches to sustainable soil systems. CRC Press, Boca Raton. P. 517-530
26. Lehmann, J., Gaunt, J., and Rondon, M., 2006. Bio-char sequestration in terrestrial ecosystems-A review. Mit. Adapt. Strat. Global Chang 11, 403-427.
27. Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O Neill, B., Skjemstad J., Thies, J., Luizao, J., Petersen, J., and Neves, EG., 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J. 70:1719-1730.
28. MoFSC, 2014. Nepal Fifth Assessment Report to CBD. Ministry of Forests and Soil Conservation, Government of Nepal.
29. MoFSC/GoN, 2002. Nepal Biodiversity Strategy, Ministry of Forests and Soil
30. Conservation, Government of Nepal.
31. NARC, 1996. Soil and plant analysis manual. NARC, Khumaltar Nepal.
32. Novak, JM., Busscher, WJ., Laird, DL., Ahmedna, M., Watts, DW., and Niandou, MAS (2009). Impact of amendment on fertility of a southeastern coastal plain soil. Soil Sci. 174:105–112.
33. Rondon, M.A., Lehmann, J., Ramírez, J. and Hurtado, M., 2007. Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with bio-char additions. Biology and Fertility of Soils 43(6): 699-708.
34. Spokas, K. A., Koskinen, W. C., Baker, J. M., and Reicosky, D. C., 2009. Impacts of woodchip additions on greenhouse gas production and sorption/degradation of two herbicides in a Minnesota soil, Chemosphere 77, 574-581.
35. Verheijen, F.G.A., Jeffery, S., Bastos, A.C., van der Velde, M., and Diafas, I., 2009. Application to Soils - A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. EUR 24099EN, Office for the Official Publications of the European Communities, Luxembourg, 149pp.
36. Winsley. P and bioenergy production for climate change mitigation 2007. New Zealand Sci. Rev. 64:5-10.
37. Woolf, D., Amonette, J. E., Street-Perrott, F. A., Lehmann, J., andJoseph, S., 2010. Sustainable to mitigate global climate change. Nature Comm. 1, 56-64.
38. Yamato, M., Okimori, Y., Wibowo, IF., Anshori, S., Ogawa, M., 2006. Effects of the application of charred bark of Acacia mangium on the yield of maize, cowpea and peanut and soil chemical properties in South Sumatra, Indonesia. Soil Sci. Plant. Nutr. 52:489-495.
39. Baldock, J. A. and Smernik, R. J. 2002. Chemical composition and bioavailability of thermally altered Pinus resinosa (Red pine) wood. Organic Geochemistry, 33:1093–1109
40. Cheng, C. H., Lehmann, J.,Thies, J. E. and Burton, S. D. 2008. Stability of black carbon in soils across a climatic gradient', Journal of Geophysical Research. 113:G02027
41. De Silva, Ajantha. 2014. Field Crops Research and Development Institute, Department of Agriculture, Maha illuppallama unpubl.
42. Dharmakeerthi, R.S., J.A.S.Chandrasiri and V.U.Edirimanne. 2012. Effect of rubber wood biochar on nutrition and growth of nursery plants of *Hevea brasiliensis* established in an Ultisol.
43. Dharma-Wardana, M.W.C., S.L. Amarasiri, N. Dharmawardene and CR Panabokke. 2014. Chronic Kidney Disease of Unknown aetiology and ground-water ionicity; study based on Sri Lanka
44. Hossain, M. K., V. Strezov, K.Y. Chan & P.F. Nelson. 2010. Agronomic properties of wastewater sludge biochar and bioavailability of metals in production of cherry tomato (Lycopersicon esculentum). Chemosphere. 78: 1167-1171.

45. Jackson, M.L. 1958. Soil Chemical Analysis. Prentice-Hall. Inc., Englewood Cliffs N.J.
46. Kuruppuarachchi, D.S.P & Fernando W.A.R.N. 1999. Impact of agriculture on grundwater quality: leaching of fertjlizers to groundwater in Kalpitiya peninsula. Journal of Soil Science Society of Sri Lanka. 11: 9-16.
47. Lehman, J., da Silva Jr. J. P., Steiner, C., Nehls, T., Zech, W., & Glaser, B. 2003. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. Plant and Soil 249: 343-357.
48. Lehmann, J., Liang, B., Solomon, D., Lerotic, M., Luizão, F., Kinyangi, F., Schäfer,T.,Wirick, S. and Jacobsen, C. 2005. Near-edge X-ray absorption fine structure (NEXAFS) spectroscopy for mapping nano-scale distribution of organic carbon forms in soil: Application to black carbon particles, Global Biogeochemical Cycles, vol 19, pGB1013
49. Liang, B., Lehmann, J., Kinyangi, D., Grossman, J., O'Neill, B., Skjemstad, J.O., Thies, J., Luizao, F.J., Peterson, J., & Neves, E.G. 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J., 70, 1719–1730.
50. Liyanage, C.E., M.I. Thabrew and D.S.P. Kuruppuarachchi 2000. Nitrate pollution in ground water of kalpitiya: an Evaluation of the content of nitrates in the water and Food items cultivated in the areaJ. Natn. Sci. Foundation Sri Lanka. 28(2): 101-112
51. Olsen ,S.R., C.V.Cole, F.S.Watnabe and L.A.Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S.Dept. Of Agric. Circ. 939.
52. Park, J.H., GK Choppala, NS Bolan, JW Chung. 2011. Biochar reduces the bioavailability and phytotoxicity of heavy metals. Plant and Soil 348.1-2: 439-451.
53. Rajapakse, RMG . 2014 . CKDU REVISITED. oral presentation at the Mid Term Technical Session of the Soil Science Society of Sri Lanka, SRICANSOL Centre, Peradeniya, Sri Lanka . 28 August 2014. unpubl.
54. Reichenauer, T.G, Panamulla, S., Subasinghe, S., & Wimmer, B. (2009). Soil amendments and cultivar selection can improve rice yield in salt-influenced (tsunami-affected) paddy fields in Sri Lanka. Environ. Geochem. Health, 31, 573–579.
55. Shindo, 1991; Shindo, H. 1991. Elementary composition, humus composition, and decomposition in soil of charred grassland plants. Soil Science and Plant Nutrition. 37:651–657
56. Uchimiya, Minori, et al. Immobilization of heavy metal ions (CuII, CdII, NiII, and PbII) by broiler litter-derived biochars in water and soil. Journal of Agricultural and Food Chemistry, 58.9: 5538-5544.
57. Walkley, A., and T.A.Black. 1934. An examination of the Degtjarett methos for determining soil organic matter and a proposed modification of the chromic acid titration method. |Soil Sci. 37:29-38.