FINAL REPORT for APN PROJECT
ARCP2009-12NSY-Karve

Biochar for Carbon Reduction, Sustainable Agriculture and Soil Management (BIOCHARM)

Asia-Pacific Network for Global Change Research

The following collaborators worked on this project:
Dr Priyadarshini Karve and Mr Ramakant Prabhune Appropriate Rural Technology Institute (ARTI), Pune, India, Email: priyadarshini.karve@gmail.com
Dr Simon Shackley, Sarah Carter, Dr Peter Anderson, Dr Saran Sohi, Dr Andy Cross and Professor Stuart Haszeldine, UK Biochar Research Centre (UKBRC), University of Edinburgh, Edinburgh, Scotland, UK
Email: simon.shackley@ed.ac.uk, sarah.carter@ed.ac.uk
Dr Stephan Haefele, International Rice Research Institute (IRRI), Los Banos, Philippines, email: s.haefele@CGIAR.ORG
Tony Knowles, SME Cambodia, Phnom Phen, Cambodia
John Field and Paul Tanger, PhD researchers, Colorado State University, Fort Collins, CO, USA, email: john.l.field@ColoState.edu, paul.tanger@ColoState.edu

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OVERVIEW OF PROJECT WORK AND OUTCOMES

Non-technical summary

Biochar is the solid remains of heating biomass in an oxygen-depleted environment. Unlike the carbon found in most organic matter, biochar carbon is chemically altered during the heating process and forms into 'benzene-type' ring structures that are very resistant to attack by microorganisms. As a consequence, biochar carbon can remain stabilized for long periods of time – hundreds to thousands of years – and could be an important way of storing carbon that has been scavenged from the atmosphere during photosynthesis. What is more, biochar can enhance soil 'health' and has been demonstrated to promote plant growth in some situations. In this project we evaluate the benefits of using two different forms of biochar in terms of: a) how much carbon dioxide (and other greenhouse gases) are reduced and removed from the atmosphere across the biomass life-cycle (i.e. from growth to soil incorporation); and b) agronomic benefits of the biochar in rice and vegetable cultivation.

Biochar can be produced from modern technological systems used for generating fuels and/or electricity from biomass, such as gasification and pyrolysis. In this project, we explored the use of carbonized rice husks (CRHs) which are the by-product from small- to medium-sized (150 – 300 kW) gasifiers located in rice mills utilizing rice husks as the fuel as well as use of char produced from sugarcane leaf litter and maize cobs using up draft gasifier kilns. CRHs do not have a clear use at present and there is already a surplus of rice husk ash relative to requirements. Hundreds of kilograms of CRHs are produced daily from the gasifiers and very large piles build-up (c. 1000 tonnes at one site). Such piles are largely inert, but could generate a pollution risk through leaching or wind or water erosion into air, water or ingestion by animals, etc. The agricultural waste feedstock such as sugarcane leaf litter and maize cobs (after gain removal) are plentifully available and are not being used for any specific purpose.

The carbon and energy balance of the rice husk gasifiers was calculated and the physio-chemical properties of the two biochar samples were examined. The unstable carbon – that component which is expected to be lost through decomposition in the time-scale of hours to decades – has been estimated using laboratory techniques, so permitting an estimate of the carbon which would be stored in the long-term. We found that between 0.9 to 1 tonne of CO_2 is removed and avoided per tonne of rice husk gasified. India is the world's second largest rice producer at 132 million tones (Mt) paddy rice in 2009-10; while Philippines produced 14 Mt and Cambodia 7 Mt. Assuming 22% of this paddy rice production is rice husk (which is typical), then the potential carbon abatement from use of CRHs - assuming that an arbitrary 1/3rd of the rice husks could be made available - is: c. 9 MT CO_2 (India), 1 Mt CO_2 (Philippines) and 0.5 Mt CO_2 (Cambodia). If we compare CRHs to some other existing uses of rice husks, such as incorporation into irrigated rice fields, then the greenhouse gas benefit of converting to biochar becomes more significant. This is because some of the carbon in rice husks added to soil converts to methane, a potent greenhouse gas. Including such an evaluation of alternatives, increases the greenhouse saving by two or more times per tonne of husk. On an area-basis, the conversion to CRH may reduce greenhouse gas emissions up to five times compared with adding husks to irrigated fields.

The agronomic results provide a mixed-picture of the effectiveness of biochar in existing agricultural contexts. The pot trials in Cambodia demonstrate that biochar can have a strongly positive effect upon yields. There was a statistically significant (95% confidence level) response to increasing

biochar additions for lettuce (harvestable mass, root mass, number of leaves and stem length) and for harvest and stem length in the case of cabbage. The irrigated rice field trials showed a statistically significant increase in paddy yield with a 41tha^{-1} addition of CRHs in the case of one farm, but not in another farm that used the same variety and was located close by (100m). We cannot account for the difference in response. A variety of non-replicated exploratory trials with vegetables and irrigated rice also gave positive results with respect to yield. The Indian pot trials did not show such a clear result as those in Cambodia. Three applications stand out as increasing fresh biomass relative to the untreated control: biochar at 20 tha^{-1}, biochar at 20 tha^{-1} with chemical fertilizer and chemical fertilizer only. Higher biochar applications (40, 60 and 80 tha^{-1}) appear to reduce overall fresh biomass weight compared to the 20 tha^{-1} level and/or synthetic fertilizer applications. The Indian maize field trials using ARTI's single-kiln derived biochar from sugarcane trash and corn cobs did not show any statistically significant yield response. However, there was some evidence (not statistically significant) of a declining yield with biochar additions beyond 20tha^{-1}. The increase in maize yield for the 20tha^{-1} biochar application was significant at the 92% confidence level compared to the control.

The value of the stored carbon in the CRHs is c. \$12 t^{-1} assuming a carbon price of \$10 tCO_2^{-1}. Including the value of the avoided carbon emissions from production of bio-energy, the carbon value per tonne of CRHs increases to c. \$26. If the alternative use of rice husks is aerobic or anaerobic decomposition, the carbon abatement value per tonne of CRH can range from \$37-69. The agronomic value is currently highly uncertain, but our trials suggest it is in the order of \$3 – 13 t^{-1}.

Objectives

The main objectives of the project were:

1. To explore availability of biomass for producing biochar in each country and suitability of the agricultural context for applying biochar to soil.
2. To evaluate gasification of rice husks as a biomass-bioenergy-biochar ('gasification-biochar') system with respect to its impact on net carbon abatement and its economic performance.
3. To evaluate the physio-chemical and structural properties and stability of the carbon in the biochar samples produced and used in the project.
4. To evaluate the environmental and health & safety impacts arising from the gasification-biochar system.
5. To explore other simpler technologies for producing biochar.
6. To evaluate the impacts of biochar on crop yield (and other biological indicators) in demonstration (non-replicated) field trials and in replicated pot and field trials on a range of crop types and with a range of other soil amendments.

Amount received and number years supported

The Grant awarded to this project was: US\$ 40,000 for 1 Year 1.12.2009 to 30.11.002010.

Activity undertaken

The project involved five work packages as described below.

Work Package 1: Identification of biochar sources and technologies: gasification of rice husks, fast growing tropical trees, corn cobs and other bio-waste products, in the partner countries.

Work Package 2: Identification of agricultural opportunities for incorporating biochar, in each partner country.

Work Package 3: Organisation and management of field trials in each partner country.

Work Package 4: Examination of organizational and financial models for making biochar cost-effective and implementable at multiple sites in partner countries, including Life Cycle Assessment.

Work Package 5: Examination of requirements for obtaining biochar carbon credits from: a) CDM, and b) voluntary carbon market. Discussions with experts in both markets and identification of partnerships.

Relevance to APN's Science Agenda and Objectives

The project has focused upon three key aspects of APN's science agenda: climate change, land use and sustainable use of resources. The results have implications for carbon mitigation strategies, sustainable food production and efficient land-use strategies, bioenergy technology deployment and associated environmental impacts. A range of disciplines have been drawn-upon during the research, including soil science, analytical chemistry, bioenergy engineering, agronomy and socio-economic assessment.

Self evaluation

The team feels that the project was a great success. As the length and detail of the report demonstrates, a lot of data has been collected, much of it original. Evaluation and integration of data has also been effective, allowing some strong key messages to be conveyed. Particularly successful at communicating the activities and results of the research in an on-going fashion has been the blog site created and maintained by Sarah Carter. The two dissemination events organized as part of the project - an e-seminar attracting a wide international audience and the Indian National Consultation on biochar, were both very successful. Organisation and integration of the project was sometimes difficult due to the inevitable challenge of working across countries, institutions and time-zones. More face-to-face meetings of the research team would have helped, but were limited due to budgetary constraints.

Potential for further work

There is a high potential to take forward the work undertaken in the BIOCHARM project. The three priorities are:

- further and more extensive agronomic evaluation of CRHs in Cambodia and other countries where there are excess supplies to demonstrate a robust application method and level per crop and a robust value;
- further exploration of biochar production from under-exploited agri-residue feedstocks such as rice straw; and,
- further development of a methodology for capturing the value of CRHs in the voluntary carbon market with potential application to the Clean Development Mechanism of the Kyoto Protocol.

In November 2010 we were approached by the International Biochar Initiative (IBI) with a request to supply information on the project's work for a report that the IBI and Cornell University are preparing for the World Bank on the potential use of biochar in developing countries. We have sent the IBI and Cornell pre-publication copies of a paper and report and will in due course send them this report.

Publications

Shackley S, Carter S, Haefele, S, Knowles T, Middelink, E. and Sohi S (2010) Sustainable Gasification-Biochar Systems? A Case-study of Rice-Husk Gasification in Cambodia. *Energy Policy* (submitted)

Three other papers are in preparation: one on the pot trial results in Cambodia; one on the field trial results in India and Cambodia; and one on a techno-economic evaluation of the gasification technology.

Acknowledgments

Funding was provided by the UKBRC, University of Edinburgh, to support Sarah Carter's work on the project in Cambodia and to cover Simon Shackley's work time spent on the project. We acknowledge additional financial support from Carbon Captured Limited (UK) for supporting two research trips by Simon Shackley. We also thank Ankur Scientific Energy Technologies Pvt. Ltd. for providing technical information. Thanks to all those who were involved in the organization of the Cambodian on-farm trials, particularly: Julie Becu, Lam Boramy, Bruce Todd (Cambodian Agribusiness Development Facility (CADF)), Kong Vanthat, Bun Mith (Sangkheum Centre), Deborah Groves, Ho Chanty, Ratha Ong (Helping Hands), Scott & Chris Coats, Dale Novotney (TrailBlazer Foundation). Many thanks also go to the farmers and laborers who we worked with on the farm. Thanks go to all the staff at the APSARA research farm for taking care of the plants in the pot trials, to Dr Tan Boun Suy for his technical input and, in particular Vicheth Srin, for his assistance in monitoring. Thanks to Bevan Rakoia and Picheth Seng and Simon Gulemarah (Nagathom Fund) for working with us on the rice trials. Also thanks to Prokrotey Khoy for assisting us in recruiting farmers. Particular thanks go to Tankeo Vichida, who was translator and an excellent guide for the duration of the trials. We are grateful to Mr. R.N. Prabhune for supervising the on-field trials and data collection at ARTI, India, Ms. Saili Jahagirdar and Ms. Geeta Poptani (interns at ARTI) are thanked for assistance in logistics of the various meetings and events organized as a part of this project in India.

TECHNICAL REPORT

Minimum 15-20 pages (excluding appendix)

Preface

Biochar is a charcoal-like solid that can be created from most types of organic matter. It is of interest, inter alia, as a long-term carbon store and for its agronomic properties. While there has been much discussion of biochar as a sustainable strategy in developing countries, there have as yet been very few detailed case-studies from feedstock to field deployment. This report presents original field trials results using carbonized rice husks (CRHs) and sugarcane trash and corn cob char. It aims to evaluate systems of feedstocks – energy conversion technologies – and agricultural use of biochar.

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1.0 Introduction

It is vital to increase the involvement of developing countries in greenhouse gas mitigation, especially in activities which can generate a carbon abatement revenue stream for local communities. Opportunities for local carbon mitigation remain untapped and communities are not benefiting from the Clean Development Mechanism, one of the flexibility mechanisms of the Kyoto Protocol of the United Nation's Framework Convention on Climate Change (UNFCCC).

What is biochar?

Biochar has emerged as a potential option for long-term storage of carbon. While there is no single definition of biochar, a useful working definition for this project is that biochar is: "….. the porous carbonaceous solid produced by thermochemical conversion of organic materials in an oxygen depleted atmosphere which has physiochemical properties suitable for the safe and long-term storage of carbon in the environment and, potentially, soil improvement" (Shackley & Sohi, 2010). Biochar is produced from technologies including gasification and pyrolysis, which yield between 2 and 35% by weight of the biomass as biochar. A good proportion of the carbon so produced will remain in soils for hundreds and, possibly, thousands of years. A number of studies have demonstrated that the Mean Residence Time (MRT) of biochar is frequently from 100s to 1000s of years (Verheijen et al. 2009). The explanation for the high stability of biochar arises from the change in the chemical structure of the cellulose, hemi-cellulose and lignin which takes place at temperatures above about 300^{o}C. Aromatic rings are created in which carbon atoms are attached to each other with strong double bonds which are resistant to microbial attack, though eventually biochar does degrade and the carbon oxidizes to be returned to atmosphere.

Woolf et al. (2010) estimate that the 'maximum sustainable technical potential' for carbon abatement from biochar is 1.6 GtC per year by 2050. This compares with current total anthropogenic carbon emissions at 7.8 GtC per year. Hence, biochar can be an important component of a global response to carbon abatement, though the challenges of achieving such a large-scale utilization of biochar would be considerable.

Different carbon fractions within biochar

There are (at least) four carbon fractions within biochar: a) super-labile, which mineralizes to CO_2 within the short term (hours to a few days); b) labile, which mineralizes over the medium-term (e.g. weeks to months); c) unstable, which mineralizes over the long-term (months to years); d) recalcitrant / fixed, which remains non-mineralised in the long-term (e.g. > 100 years). This can be demonstrated graphically in Figure 1. In calculating the recalcitrant carbon fraction, which is the one that is relevant to carbon abatement, it is necessary to measure the extent of the super-labile, labile and unstable fractions. The Carbon Stability Factor (CSF) is defined as the proportion of the total carbon in freshly produced biochar which remains fixed as recalcitrant carbon over a defined time period (10 years, 100 years, etc. as defined) (equation 1). A CSF of 0.75 means that 75% of the carbon in the fresh biochar remains as fixed carbon over the defined time horizon and that 25% of the carbon has been converted into CO_2.

$$CSF = 1 - C_{lab} - C_{unstab} \qquad \text{Eq. (1)}$$

C_{lab} is the fraction of carbon that is superlabile and labile (lost in < 2 weeks)

C_{unstab} is the fraction of carbon that is unstable as determined by accelerated ageing methods

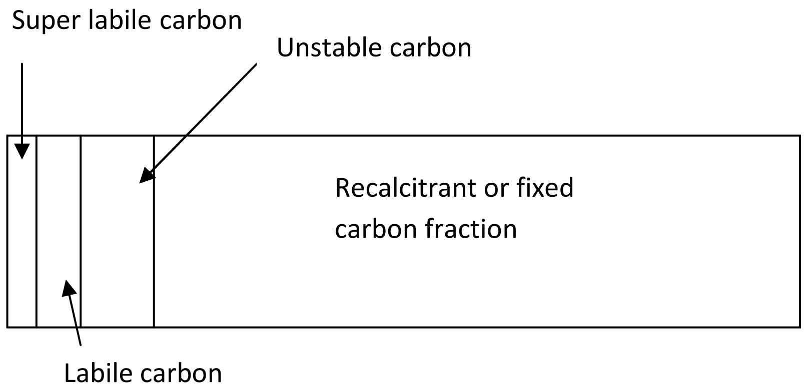


FIGURE 1: DIAGRAMMATIC REPRESENTATION OF THE POTENTIALLY DIFFERENT CARBON FRACTIONS WITHIN BIOCHAR (STILL PARTLY SPECULATIVE)

Calculating Net Carbon Abatement from Use of Bioenergy-Biochar Systems

Equation (2) can be used to calculate the net carbon abatement arising from the use of biomass that is used in bioenergy systems with resultant production of biochar and compared with alternative applications (combustion, direct field incorporation on dry soil, or direct field incorporation into irrigated fields, etc.) (Shackley et al., 2010):

$$CO_{2na} = CO_{2av} + CO_{2fix} + CO_{2avoid} - CO_{2rel} \quad \text{Eq. (2)}$$

Where:

CO_{2na} is net carbon eq. abatement

CO_{2av} is carbon eq. emissions avoided by replacement of fossil fuels

CO_{2avoid} is carbon eq. emissions avoided by thermochemical conversion rather than waste disposal with methane production

CO_{2fix} is carbon eq. fixed in the long-term (100 years)

CO_{2rel} is carbon eq. released by the biomass feedstock processing

(All expressed in $tCO_2eq.t^{-1}$ feedstock)

Meanwhile:

$$CO_{2fix(100)} = BM_{tot} \times BC_{yield} \times CO_{2tot} \times CSF \quad \text{Eq. (3)}$$

Where:

$CO_{2fix(100)}$ is CO_2 eq. fixed over 100 years

BM_{tot} is biomass total dry weight

BC_{Yield} is biochar yield (ratio)

CO_{2tot} is total CO_2 eq. content of fresh biochar

CSF is Carbon Stability Factor over 100 years

(All expressed in $tCO_2eq.t^{-1}$ feedstock)

These equations will be used in Work Packages 1 and 4 to calculate and compare use of CRHs as biochar with alternative uses of rice husks.

Potential impacts of biochar upon soils

Interest in the impacts of biochar on soils and plant growth was first stimulated through studies of *terra preta* soils in Amazonia. These are human-created soils that contain large amounts of charred vegetable and animal matter, along with pottery and other midden-waste. *Terra preta* soils are noticeably more fertile than the adjacent tropical soils, which are frequently depleted and with much nutrient having been leached out, even after hundreds of years. The reasons for this unusual degree of enduring soil fertility are not fully understand at present. Some possible reasons which help to account for the impacts of biochar on soils are:

- Increase in pH of acidic soils (since biochar is typically alkaline)
- Increase in water retention, especially in sandy and silty soils
- Provision of nutrients in the ash contained within the biochar
- Enhancement of the Cation Exchange Capacity (CEC) of the soil, so increasing nutrient use efficiency
- Enhancement of microbial communities within biochar, including bacteria, mycorrhizae and fungal hyphae, with knock-on benefits to soil processes
- Benefits to soil physical structure through, e.g. increasing the porosity of soil to water incident at the surface

There is some evidence that biochar can reduce the run-off of agricultural inputs such as nitrates as well as suppressing N_2O and CH_4 emissions from the soil to atmosphere (Singh et al., 2010; van Zwieten et al., 2010, Sohi et al., 2010). In this way, biochar may act to improve the efficiency of the use of nitrogen in the soil. It is important to note that the properties of biochar in soils are dynamic, due to the physico-chemical and biological changes which occur over time. One attempt to depict these changes is shown in Figure 2.

A meta-analysis of trials where biochar has been incorporated into soils has been undertaken by Verheijen et al. (2009), see Figure 3. In summary, this meta-analysis showed the following:

- A small, but positive, effect on crop productivity with a grand mean of c. 10%;
- No statistically significant increase in yield with increased biochar additions, though a trend is there in some cases;
- Wide variance in the response to biochar addition – probably due to different biochar, crop, soil types and management;
- Means for each application rate are positive;
- No single biochar application rate had a statistically significant negative effect on crop productivity;
- Studies are heavily skewed towards (sub-) tropical conditions.

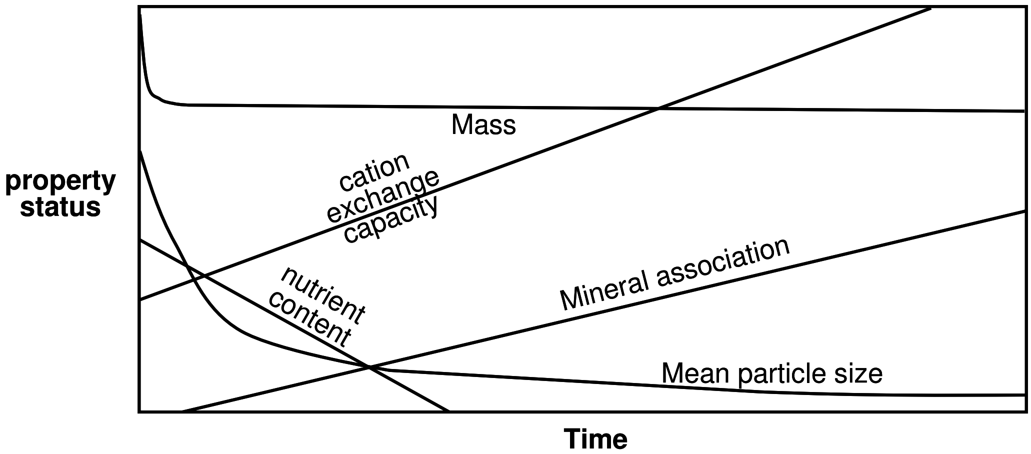


FIGURE 2: SCHEMATIC TO ILLUSTRATE THE CHALLENGE OF UNRAVELLING MULTIPLE FUNCTIONS OF BIOCHAR WHOSE POSSIBLE TRAJECTORIES STRONGLY DIFFER (AFTER SOHI ET AL., 2010).

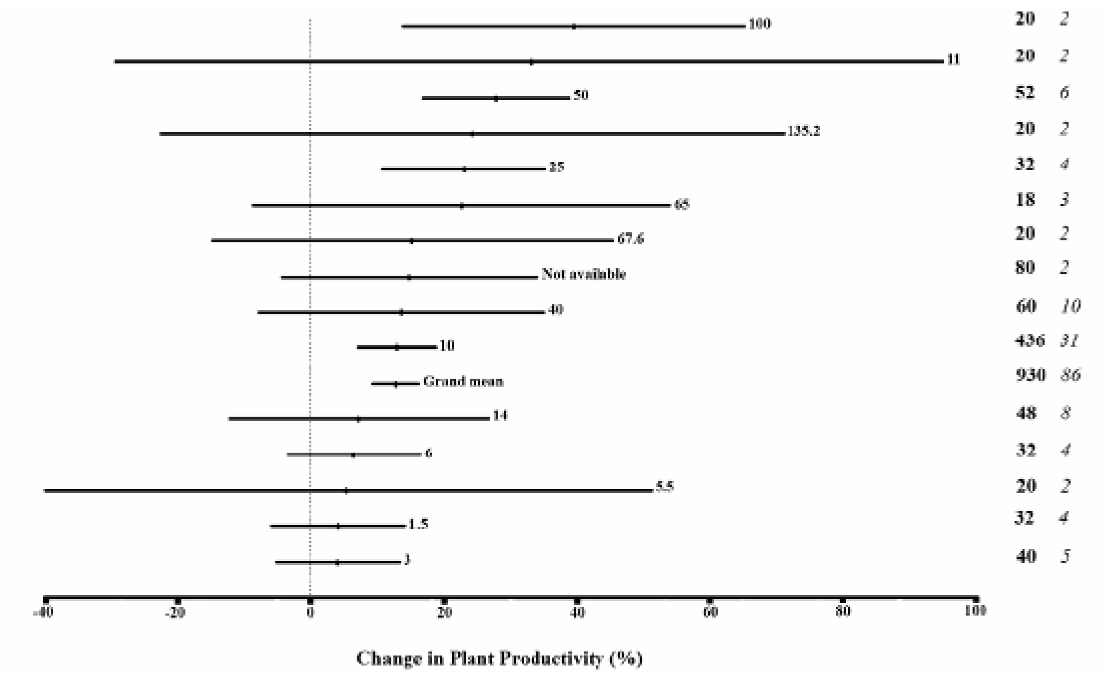


FIGURE 3: THE PERCENTAGE CHANGE IN CROP PRODUCTIVITY UPON APPLICATION OF BIOCHAR AT DIFFERENT RATES, FROM A RANGE OF FEEDSTOCKS ALONG WITH VARYING FERTILISER CO-AMENDMENTS. POINTS REPRESENT MEAN AND BARS REPRESENT 95% CONFIDENCE INTERVALS. NUMBERS NEXT TO BARS DENOTE BIOCHAR APPLICATION RATES (T HA-1). NUMBERS IN THE TWO COLUMNS ON THE RIGHT SHOW NUMBER OF TOTAL 'REPLICATES' UPON WHICH THE STATISTICAL ANALYSIS IS BASED (BOLD) AND THE NUMBER OF 'EXPERIMENTAL TREATMENTS' WHICH HAVE BEEN GROUPED FOR EACH ANALYSIS (ITALICS) (FROM VERHEIJEN ET AL. (2009))

At the present time, there is a high degree of uncertainty regarding the impacts of biochar upon soil processes and plant productivity. This is not surprising given that the mechanisms by which biochar has impacts upon soils are not currently well understood; not only is the system highly variable and complex, but also biochar has multiple impacts. There does seem to be reasonably good evidence that the impacts of biochar are greatest in poor and degraded soils and that its impacts are much less evident in more highly optimized agricultural systems where high levels of inputs and irrigation and other best management practices are adopted.

The Key Research Questions

The aim of the BIOCHARM project was to explore some of these research questions in relation to the specific situation in three Asia-Pacific countries: India, Cambodia and Philippines. Our focus was upon what feedstocks might be suitable and readily available; what technologies might be appropriate for the formation of biochar; what properties the biochar samples exhibited; what were the agronomic impacts of the biochar addition; and what were the overall system benefits of biochar addition from the perspective of carbon abatement and cost-effectiveness. The key research questions that guided the research are set out below.

What types of biomass are most suitable for conversion to biochar and what are the most cost-effective supplies of such biomass?
What is the permanency of elemental biochar carbon in different soil types and conditions?
What is the overall carbon abatement per tonne of feedstock used?
What are the agronomic benefits of biochar for a range of crops, soil types and growing conditions?

The main objective of the project was therefore to gain a better understanding of the role of biochar for carbon storage and agricultural improvements in a range of environmental, socio-economic and material contexts in three countries which themselves reflect a range of circumstances and policy conditions. A secondary objective was to make policy recommendations for further development of biochar as a component of national climate change, sustainable energy and agricultural policies.

2.0 Methodology

The project followed a variety of activities under five work packages, in the three countries. Based on local conditions and priorities of the host organizations, there was a different emphasis in different work packages.

Work Package 1

Identification of biochar sources and technologies: gasification of rice husks, fast growing tropical trees, corn cobs and other bio-waste products, in the partner countries.

Anecdotal data was collected through site visits and meetings in each country. Resource assessments were undertaken where data was available in the public domain. More systematic data collection was done in Cambodia, as the host organization is associated with promotion of a main source of biochar in the country – rice husk operated gasifiers for powering rice mills (Figure 4). Data on the gasifiers was provided by SME Cambodia and by the manufacturer, Ankur Scientific (Vadodara, India). In addition, the project greatly benefited from the involvement of two PhD students from the Colorado State University, USA (John Field and Paul Tanger). They undertook a detailed engineering-focused analysis of the Ankur gasifiers in situ, including measurement of necessary parameters to undertake a full energy and carbon balance of the equipment (e.g. char yield and fuel properties, syngas yield and properties).

Field burning of rice straw is still widely practiced in many Asian countries. Observations from the field indicated that a considerable amount of biochar is produced during the field burning. At IRRI in the Philippines, trials were conducted to simulate this common practice and to measure the amount of biochar produced. Samples before and after field burning were taken to analyse moisture content (3 sub-samples for each material; oven drying for 48 hours at 80 °C), and elemental composition. IRRI also undertook some experiments to attempt to gasify rice straw, a large resource which is not fully utilized in other ways.

FIGURE 4: RICE HUSKS BEING LOADED INTO AN ANKUR GASIFIER NEAR SIEM REAP, CAMBODIA

Work Package 2

Identification of agricultural opportunities for incorporating biochar, in each partner country.

Site visits were carried out to identify potential test locations, and final trial site(s) were selected on the basis of practical considerations. In India, ARTI's field station at Phaltan (Maharashtra) provided the ideal context for undertaking the trials. In Cambodia, it was decided to focus the field trials in the Siem Reap province (SR). This was because: there are gasifiers using rice husks close to SR providing a convenient source of carbonised husk char (CRH); SR province has many poor quality degraded soils; there are a variety of agricultural crops in the SR area, including irrigated and rain-fed rice and vegetables (serving the local and tourist markets around SR). There are a large number of subsistence and low-income farmers so that agronomic benefits from biochar incorporation (at sufficiently low cost) would be keenly appreciated. Experiments in the Philippines were conducted at IRRI's research facility at Los Baños.

Some exploration was also carried out to determine the knowledge available among farmers and agriculture focused organizations, so as to explore potential of future agricultural opportunities. Due to the limited time and manpower resources available, extensive and exhaustive data collection was not possible. Consultations and discussions were carried out to get a broad idea of the agricultural opportunities, particularly in India and Cambodia.

Work Package 3

Organisation and management of field trials in each partner country.

We undertook physical inspection of biochar using Scanning Electron Microscopy (SEM) available at the School of GeoSciences, University of Edinburgh. We examined the following materials with the SEM: CRHs, rice husks, rubber tree char, corn cob char and sugarcane trash char. Chemical analysis of biochar was undertaken in order to ensure that we did not introduce any potential contamination into soils and to establish some of the key properties of the biochar samples. The following chemical analysis of char was carried out:

Test	Variables measured	Measurement unit	Details of tests	Laboratory undertaking test
pH	pH	pH units	Electrochemical	CLARRC
Moisture	Moisture	% of fresh mass	1. 105°c for 48 hours (oven-dry)	UKBRC
			2.thermogravimetric	CLARRC
			3.thermogravimetric (80°c for 48 hours)	IRRI
Loss on ignition (LOI)	Non-ash content	% of fresh or oven-dry mass	Thermogravimetric	CLARRC
Ash	Ash content	1 – LOI	Deduction	n.a.
Elemental analysis	C, H, N, S	% of oven-dry mass		CLARRC IRRI
Exchangeable cations	K, Na, Ca, Mg	$cmolkg^{-1}$ (dry weight)	ICP-OES	CLARRC
Cation exchange capacity (CEC)	Sum of above	$cmolkg^{-1}$ (dry weight)	ICP-OES	CLARRC
Metals (total)	Al, As, Ba, Be, Cd, Cr, Cu, Mo, Ni, Pb,	$cmolkg^{-1}$ (dry weight)	ICP-OES	CLARRC IRRI

	Sb, Se, Zn, Hg, B, Ca, Co, Fe, K, Mg, Mn, Na, Si, V, Sr, Ti		Ashing at 750^{o}C followed by Aqua Regia extraction	
BETX	Benzene, ethylethylene, toluene, xylene	mgkg^{-1} (dry weight)	HS-GC-MS	CLARRC
Phenols	Phenols	mgkg^{-1} (dry weight)	GC-MS	CLARRC
PAHs	16 USEPA PAHs	mgkg^{-1} (dry weight)	ASE, GC-MS	CLARRC
Lower heating value	LHV	MJkg^{-1}	Adiabatic bomb calorimeter	DOST, Phils

TABLE 1: CHEMICAL ANALYSIS OF THE BIOCHAR SAMPLES

Abbreviations

ASE: accelerated solvent extraction (DCM-acetone as extractant)
CLARRC: Contaminated Land and Remediation Research Centre, University of Edinburgh / University of Strathclyde
GC-MS: gas chromatography mass spectrometry
ICP-OES: inductively coupled plasma optical emission spectrometry

The soils used in the field trials were also analysed as indicated in Table 2.

Test	**Variables Measured**	**Measurement unit**	**Details of tests**	**Laboratory undertaking test**
pH	pH	pH units	Electrochemical	CLARRC
Moisture	Moisture	% of fresh mass	1. 105^{o}c for 48 hours (oven-dry)	UKBRC
			2. thermogravimetric	CLARRC
			3.	
Loss on ignition (LOI)	Non-ash content	% of fresh or oven-dry mass	Thermogravimetric	CLARRC
Ash	Ash content	1 – LOI	Deduction	n.a.
Elemental analysis	C, H, N, S	% of oven-dry mass		CLARRC
Exchangeable cations	K, Na, Ca, Mg	cmolkg^{-1} (dry weight)	ICP-OES	CLARRC
Cation exchange capacity (CEC)	Sum of above	cmolkg^{-1} (dry weight)	ICP-OES	CLARRC
Metals (total)	Al, As, Ba, Be, Cd, Cr, Cu, Mo, Ni, Pb, Sb, Se, Zn, Hg, B, Ca, Co, Fe, K, Mg, Mn, Na, Si, V, Sr, Ti	cmolkg^{-1} (dry weight)	Ashing at 750oC followed by extraction with aqua regia; ICP-OES	CLARRC
BETX	Benzene, ethylethylene, toluene, xylene	mgkg^{-1} (dry weight)	HS-GC-MS	CLARRC

Phenols	Phenols	$mgkg^{-1}$ (dry weight)	GC-MS	CLARRC
PAHs	16 USEPA PAHs	$mgkg^{-1}$ (dry weight)	Extraction with DCM-acetone; ASE, GC-MS	CLARRC

Table 2: Chemical Analysis of Soils

Methodologies for field trials in each country are as described below

India

Biochar was produced from the agricultural waste of sugarcane and maize crops using the ARTI single barrel charring kiln. Agricultural trials were carried out on an experimental farm, managed and overseen entirely by the project staff. Follow up pot trials were carried out on ARTI's own premises.

Farm Trials

Crop: Maize (Variety: Local Yellow)
Individual plot size: 5 m x6 m = 30 sq. meters, Total area required: 800 sq. m
Date of planting: 16 April 2010, Date of harvesting: 04 Aug 2010

Treatment	Treatment Name	Treatment Description
IT1	Untreated Control	No additives – either biochar or fertilizer
IT2	Biochar – 20	20 tons/ha (60 kg/plot) biochar addition
IT3	Biochar – 40	40 tons/ha (120 kg/plot) biochar addition
IT4	Biochar – 60	60 tons/ha (180 kg/plot) biochar addition
IT5	Biochar – 80	80 tons/ha (240 kg/plot) biochar addition
IT6	Biochar – 20 + V	20 tons/ha (60 kg/plot) biochar + 8 tons/ha (24 kg/plot) vermicompost addition
IT7	Chemical fertilizer addition only	50:50:50 NPK/ha at the planting as a basal dose and 50 kg N at 1 month after planting Recommended dose)

Table 3: Details of treatments in Indian field trial

Three replications were used. Plant to plant spacing was 20 cm and row to row distance was 50 cm. The plot layout was as follows created using a randomized block design.

Farm yard Manure Pit			**R-I T-1**	**R-I T-2**	**R-I T-3**	**R-I T-4**
R-III T-5	**R-III T-3**	**R-III T-1**	**R-III T-4**	**R-I T-7**	**R-I T-6**	**R-I T-5**
R-III T-6	**R-III T-2**	**R-III T-7**	**R-II T-3**	**R-II T-1**	**R-II T-4**	**R-II T-2**
ARTI's Sugar Cane Nursery				**R-II T-6**	**R-II T-7**	**R-II T-5**

Table 4: Field layout of Indian field trials

FIGURE 5: PLOT LAYOUT – SCHEMATIC AND PHOTOGRAPH

Parameters analysed: Germination (visual observations) Grain yield, cob weight, fodder weight

Pot Trials

Pot trials: Crop: Cabbage (Variety: SANT, Monsanto Holdings Pvt Ltd)
Pot size = 0.051 sq.m. , Number of pots = 72, Number of treatments = 12 with 6 pots/treatment
Unimproved nursery soil was used for these trials.
Planting Date: 28 Aug 2010, Harvesting Date: 01 Dec 2010

Treatment	**Treatment Name**	**Dose/ ha**		**Dose in g/pot**	
		Biochar	**Additional additive**	**Biochar**	**Additional additive**
IPT1	Biochar -20	20 t	-	100	
IPt2	Biochar -40	40 t	-	200	
IPT3	Biochar -60	60 t	-	300	
IPT4	Biochar -80	80 t	-	400	
IPT5	Biochar-20 + synthetic fertilizer	20 t	333 kg (15:15:15 NPK) + 108 kg Urea	100	17 (15:15:15 NPK) + 5 Urea
IPT6	Biochar-20 + compost	20 t	10 t compost	100	50 compost
IPT7	Biochar-40 + synthetic fertilizer	40 t	333 kg (15:15:15 NPK) + 108 kg Urea	200	17 (15:15:15 NPK) + 5 Urea
IPT8	Biochar-20 + V	20 t	8 t vermicompost	100	40 vermicompost
IPT9	Chemical Control		333 kg (15:15:15 NPK) + 108 kg Urea	Nil	17 (15:15:15 NPK) + 5 Urea
IPT10	Untreated control		Nil	Nil	Nil

IPT11	Compost Control		10 t	Nil	50 compost
IPT12	Vermicompost Control		8 t	Nil	40 vermicompost

TABLE 5: DETAILS OF TREATMENTS IN INDIAN FIELD TRIAL

Note that the quantities of biochar to be incorporated were calculated from the surface area of the pots.

Parameters measured: Growth (visual observations over time), total biomass

FIGURE 6: LAYOUT OF POT TRIALS

Cambodia

Three methods were used in order to assess the impact of the carbonised rice husk (CRH) on agricultural systems in Cambodia.

1. Pot experiments
2. Managed rice biochar trials
3. On farm biochar investigations with horticultural crops

Biochar farm trial plots and controlled pot trials were carried out in the North West of Cambodia, in Siem Reap and Pouk districts within Siem Reap Province. This area was selected because soils were reported to be depleted in many areas, so efforts to increase agricultural yields would bring benefits to farmers. In addition it is a major rice growing region, and therefore existing supplies of rice husks and of CRHs are available from gasification used commonly to generate power for rice mills. In addition, testing of CRHs on rice soils is particularly interesting as it represents a 'closed system', and allows a modified form of the crop residues to be incorporated back into the farm. The biochar used for all trials was the carbonised rice husks from a 150kW capacity continuous feed gasification unit (supplied by Ankur Scientific Energy Technologies Pvt. Ltd.[1]) at the EAP Sophat ice factory in Kralanh

[1] www.ankurscientific.com

District Town, Siem Reap Province. Gasification temperatures are between 900 and 1100°C (Shackley et al 2010). The rice husk feedstock is abundant and is collected from nearby rice mills. The pH of the biochar at 7.79 was unusually low compared with other gasifier rice husk chars tested (with a mean value of 9.63 for four samples analysed (Shackley et al 2010)).

Pot experiments

Treatment	Name	Biochar (g Kg^{-1})	Lake sediment (g Kg^{-1})	Compost (g Kg^{-1})	EM
CPT1	Unimproved soil	0	0	0	X
CPT2	Unimproved with biochar	50 (80 t ha^{-1})	0	0	X
CPT3	Improved soil	0	12.56 (20 t ha^{-1})	25 (40 t ha^{-1})	Yes
CPT4	Improved with low biochar	25 (40 t ha^{-1})	12.56 (20 t ha^{-1})	25 (40 t ha^{-1})	Yes
CPT5	Improved with medium biochar	50 (80 t ha^{-1})	12.56 (20 t ha^{-1})	25 (40 t ha^{-1})	Yes
CPT6	Improved with high biochar	150 (167 t ha^{-1})	12.56 (14 t ha^{-1})	25 (28 t ha^{-1})	Yes

Table 6 Soil improvement details of levels of additions to the unimproved soils

Treatments were set up in conical plastic pots (20 cm deep, and a diameter from 20 cm at the top and 16 cm at the bottom) which were filled to the top with the growing substrate in addition to 200 g of stones in the bottom to improve drainage. The air dried substrate components were crushed finely and mixed thoroughly before being lightly packed into the pots. The weight of the filled pot in each case was 5000 g, however because of the high bulk density of biochar, for the highest biochar addition rate trial (T6), weight was 3500 g. The amount of residual water in the biochar pores (after air drying – determined by oven drying at 105°C) is <2% and was not taken account of. Double the required number of pots were set up (8), half being put aside to replace any seedlings which did not survive, or grow well. The pots were put on raised platforms which allowed drainage from the pots, and netting was suspended above to reduce the sunlight exposure, and rain damage to the plants.

The pots were arranged in a block design, with one pot of each treatment in each position within each group. Each pot was given 0.25 litre of water, 2-3 times per day depending on the weather. Weeding and other management practices were undertaken when necessary.

The pot trials were set up in February 2010 and ended in June 2010. After set-up, soils were left for 13 days before the first lettuce were planted into the biochar amended plots. The lettuce were grown for a total of 46 days. The seeds were germinated in seed trays, then planted out into the pots for the remaining 29 days. After the plants were harvested the pots were left fallow for 18 days before cabbage were planted for the second trial cycle. The cabbages were grown for a total of 30 days, 21 days in the treatments. The pots were left fallow for another 16 days before the third cycle of lettuce again were planted. These were grown for a total of 42 days, 28 days in the treatments.

Soil and amendments analysis

All chemical analysis of the samples was undertaken at the Contaminated Land Assessment & Remediation Research Centre (CLARRC) laboratories at University of Edinburgh / University of Strathclyde, UK. Samples were air dried and stored in cold conditions during transportation. Physical analysis of the soil was done at Phnom Phen National Agriculture Laboratories, Cambodia.

Plant analysis

For each cycle, above ground biomass was weighed on the date of harvest. Roots were washed of soil and dried off then weighed the same day. Plant height was measured after harvest from the base to the tip of the tallest leaf. The number of leaves were counted.

Managed rice biochar trials

Rice farmers were selected from outgrowers of the Nagathom Fund rice mill. These farmers are given seeds for rice variety Phka Rumduol. It is a Cambodian *indica* rice cultivar (*Oryza sativa* L.) (Tong & Yoshida 2008). Another farmer was also selected to participate who was also using this same variety. An area of land was selected which the farmer advised would provide consistent yields. Rice was grown during the wet season using the usual methods as practiced by the farmer.

Rice biochar treatments were set up following most aspects and application rates recommended in the methodologies used in Knoblauch et al (2010). Six plots (5m x 5m), three control and three amended with 41.1 t ha^{-1} biochar, were set up in a Latin square layout on each farm. A 1 m gap in between each plot was left untreated and a 50 cm border around the plot was not harvested, leaving a harvested area of 4 m x 4 m again to account for the edge effect. Rice was planted according to the farmers' schedule up to a week after the char was added. The CRHs were incorporated using traditional methods - an oxen plough, and this was undertaken 1-3 times after spreading the biochar.

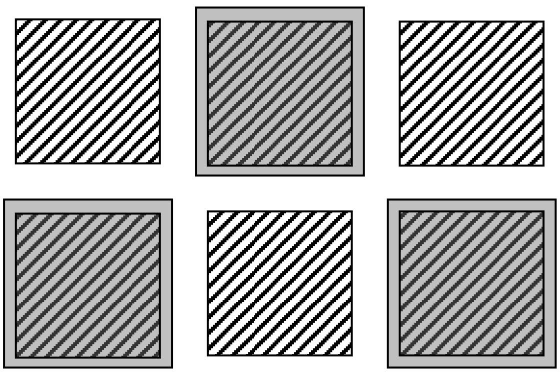


FIGURE 7: LAYOUT OF BIOCHAR AND CONTROL PLOTS. GREY SQUARES REPRESENTS BIOCHAR ADDITION. THE STRIPED AREA IS THE HARVESTED AREA WHICH PROVIDED THE DATA USED.

FIGURE 8: BIOCHAR ADDITION TO RICE FIELD AND HARVESTING PLOTS

The rice was harvested in the traditional manner - using a hand scythe. The farmers harvested leaving 30 cm of stubble in the field. The total biomass was weighed, and then was threshed, so grain and straw weight could be measured. Soil samples were taken for analysis at a depth of 15 cm using a soil corer, in 3 randomly selected areas within the plot for analysis. This data is not yet available.

Farm code	**Location†:**	**Date char added**	**Date Harvested**	**Soil amendments**	**Comments**
1	V: Chireve C: Chireve D: Siem Reap P: Siem Reap	02.08.2010	25.11.2010	0	Transplanted into rows. Significant rat damage.
2	V: Kouk Cherei C: Sasadom D: Siem Reap P: Siem Reap	25.06.2010	20.11.2010	Compost	Transplanted randomly. Good harvest
3	V: Kouk Cherei C: Sasadom D: Siem Reap P: Siem Reap	14.07.2010	20.11.2010	0	Transplanted randomly. Good harvest

† V = Village, C = Commune, D = District, P = Province.

TABLE 6: RICE BIOCHAR FIELD LOCATION AND DETAILS

On farm biochar investigations with horticultural crops

Unlike greenhouse / pot trials or intensively managed farm trials, these trials aim to replicate real life scenarios, and the conditions which would be easily replicable by farmers. In this context, we can predict the impacts that farmers are likely to see if they add biochar to their land, and observe the difference it makes to crop growth and soil properties. Due to the less rigorous methodology of these trials, they were less resource-intensive to conduct, and hence a broad range of crops were able to be tested in these trials. Commonly grown horticultural crops were selected in agricultural areas around Siem Reap town for convenience of monitoring.

A range of application rates were used (from 7.8 to 47.6 t ha^{-1}), and these rates were measured using standard bags filled with biochar, which were added to plots of varying sizes. This is more representative of the methods which farmers may use to add biochar to the land, since not each farmer is aware of the exact size of the land, or is prepared to weigh the biochar (which is not easy since it is particularly bulky). In addition it is probable that the biochar will not be spread exactly evenly by farmers, so the range of application rates covers this possibility of some areas having higher application rates than others. A range of soil types, and farming methods (irrigation systems, pest management, weed management and soil amendments) could be tested using this methodology.

The Philippines

Agricultural trials to be conducted by IRRI under the project proposal had already been carried out when the project started. The work carried out during the project period therefore involved analysis and reporting of previously conducted biochar field experiments.

Statistical Analysis of Results

The key trials in India and Cambodia were replicated and Analysis of Variance (ANOVA) was undertaken of the results. The Statistical Package for the Social Sciences (SPSS) was used.

Work Package 4

Examination of organizational and financial models for making biochar cost-effective and implementable at multiple sites in partner countries, including Life-Cycle Assessment.

In Cambodia, a considerable number of rice husk gasification plants reactors have been installed in the past few years (more than 33), and are operating on a fully commercial basis. Information on the energy properties of the gasifiers was collected and this was combined with information on the elemental properties of the CRHs to calculate the life-cycle net carbon abatement. A baseline outlining the alternative use of the rice husks had to be calculated in order to provide a credible calculation of the net carbon abatement arising from conversion of rice husks through gasification to CRHs. From the net carbon abatement, we estimated the value of the CRHs in terms of carbon storage. We used some of the field trial data to provide a preliminary estimate of the economic value of CRH as a soil amendment.

In addition, the operational performance of a few of the gasifiers was measured by the Colorado State University team. This included analysis of the syngas gas composition and properties; some of the analytical work is on-going since it proved difficult to complete all the laboratory tests. The project has limited itself to an economic evaluation of the application of the biochar as a long-term carbon store and as a soil amendment. It was not intended to include an economic assessment of the gasifiers as a source of bio-electricity. Nevertheless, the Colorado State University team did collect relevant information on the cost-effectiveness of the technology in the Cambodian context, hence we have included some summary information here.

Work Package 5

Examination of requirements for obtaining biochar carbon credits from: a) CDM, and b) voluntary carbon market. Discussions with experts in both markets and identification of partnerships.

ARTI had several interactions with The Society of Biochar Initiatives (TSBI), India and Nexus Carbon for Development, on potential future collaboration for obtaining carbon credits from biochar. As a result of these interactions, ARTI is collaborating with TSBI to test and optimize a 'gasolysis' method for converting agricultural waste into biochar and liquid fuel. ARTI is a member of the Nexus Carbon for Development, which is an alliance of NGOs striving to bring carbon finance to the grassroots level organizations. Nexus experts have expressed willingness to assist and collaborate on efforts to develop methodologies for generating carbon credits from biochar production and deployment.

Discussions have also been on-going with international experts who are working on development of a carbon market for biochar. In particular, Dr John Gaunt of Carbon Consulting Ltd. was consulted, as he (together with Keith Driver) has been developing a Biochar Protocol (BP) for inclusion of biochar into carbon markets (Biochar Protocol, 2010). The main aim of the BP at present is to establish biochar within the Voluntary Carbon market and the project has very usefully provided guidance on the key steps which will need to be gone through.

A one–week long 'e-seminar' was held via the HEDON network in October 2010 and one of the discussions related to carbon markets. The National Consultation on Biochar in India was held in Pune on November 22nd and 23d 2010, representing the major stakeholder- / policy-maker dissemination and dialogue event for the BIOCHARM project, and this included a session on carbon markets. Several useful contributions and ideas were provided through both of these routes.

Dissemination, Consultation and Communication Activities

Table 7 lists the dissemination, consultation and communication activities which have been undertaken during the course of the project, in addition to the three internal project meetings which occurred in December 2009 (Cambodia), May 2010 (India) and November 2010 (Cambodia).

In addition to the core BIOCHARM events, two related workshops took place, one in Cambodia and one in India. These were primarily organised as part of a parallel project: 'Participative Distributed Innovation Processes and Biochar: Smoke Reduction, Sustainable Agriculture and Soil Management'.

The focus of the two workshops was biochar production in improved cook stoves, but also included discussions on other biochar production methods, feedstock availability and addition to soils. Several of the project leaders from the BIOCHARM project attended and were able to discuss and contribute using information from the project activities. Therefore we have drawn upon some of the workshop discussions where they are especially pertinent to the BIOCHARM project also.

Event title	**Dates**	**Location**	**Type of participants**	**Number of participants**
1. E-seminar, via Hedon network; Biochar; the potential in Asia Pacific.	24 - 29th October 2010	E-seminar based; attracting international participation from Asia-Pacific and Europe	Policy maker, researcher, practitoner, scientists, agricultural extension / agronomy analysts, members of IBI	68
2. National Consultation on Biochar	22 - 23rd November 2010	BAIF, Pune, Maharashtra, India	Practitioners, research scientists, agronomists, policy makers, agricultural support analysts	30
Related workshops (as part of the Biochar-Innovation project - Biochar: Smoke Reduction, Sustainable Agriculture and Soil Management)				
3. Biochar: production and use	16 - 17th September 2010	ARTI'S Rural Entrepreneurship Development Centre, Phaltan, Maharashtra, India	Practitioners, research scientists, agronomists, development NGOs	34
4. Biochar: production and use	22 +23rd November 2010	Siem Reap, Cambodia	Practitioners, policy makers, agronomists, development NGOs	29

TABLE 7: COMMUNICATION AND OUTREACH ACTIVITIES CONDUCTED AS PART OF BIOCHARM PROJECT

3.0 Results & Discussion

Work Package 1: Identification of biochar sources and biochar-production technologies

1.1. Identification of biomass resources that might be available and suitable for producing biochar

Very large quantities of rice husk are produced globally every year – c. 120 million tonnes (c. 20% of total rice production by weight) (Bronzeoak, 2004). These are sometimes used as a fuel and they have a market value in some rice-producing countries such as Thailand and India (of c. $31-39 in recent years) (Parnphumeesup & Kerr, forthcoming). However, in other regions and countries, the rice husks can become a waste problem and may be burnt in field or even tipped into water bodies.

There is c. 800 million tones of agricultural biomass produced per year in India. In terms of residues, this amounts to the following (figures courtesy of Dr Sai Bhaskar Reddy of Geoecology Energy Organisation (GEO) Hyderabad):

Rice Straw:	13 million tones
Wheat straw:	15.4 million tones
Sugarcane trash:	21.6 million tones
Ground nut trash:	3.3 million tones
Mustard residues:	4.5 million tones
Cotton residues:	11.8 million tones
TOTAL:	70 million tones

At stakeholder event (2), participants evaluated feedstocks in India for their potential in biochar production and the results are show in Table 8.

Feedstock	High availability[a]	Competing use	Resulting biochar use[b]
MSW	Urban	Energy / biogas	E / L / C
Paper mill waste		Pollution!	Ag / B
Fish waste		Cattle feed / fertilisers	Ag
Rice straw Rice husk	N	Cattle feed	Ag
Banana leaves Banana stems			Ag
Sugarcane leaves Bagasse	MS	Compost / electricity Manure / paper making	Ag

Press mud		Energy / fertilizer	
Coconut coir Coconut fronds Coco peat		Charcoal briquettes	Ag / E
Pulses stalks	MS		Ag
Cotton stalks	MS, AP, TN	Fuel	Ag
Maize trash	TN		Ag
Tobacco stalks	GJ, KA	Fuel	Ag
Cashew shell			Ag
Sunflower husks			Ag
Ground nut shells	TN, GJ		Ag
Oil palm Stalks Empty fruit branches Oil cake		Construction	Ag
Bamboo leaves Bamboo stem		Not compost	Ag
Sugar palm			Ag
Coffee shells		Animal feed	Ag
Sugar palm			Ag
Prosopis juliflora			Ag
Dhencha plantation waste		Green manure	Ag
Mangroves	Coastal	Coastal erosion	N/A

TABLE 8: EVALUATION OF FEEDSTOCKS IN INDIA FOR THEIR POTENTIAL IN BIOCHAR PRODUCTION

[a] MS = Maharashtra, N = North India, S = South India, TN = Tamil Nadu, AP = Andhra Pradesh, GJ = Gujarat, KA =Karnataka

[b] E = energy, L = landfill, C = carbon storage, Ag = agriculture

If we assume a net carbon abatement of between 0.5 and 1 tCO_2 abatement per tonne of feedstock used in pyrolysis-biochar systems (PBS), as reported by a number of published life-cycle studies (e.g. Roberts at al., 2010; Hammond et al., 2011, Gaunt & Downie, 2009), then this could represent between 35 to 70 million tones of CO_2 abatement per year in India. This assumes, however, that all the feedstock would be used in a PBS, whereas in reality there will be many competing uses for the same feedstock and use for biochar production might necessitate substitution of the residue by a different source of biomass, potentially with attendant greenhouse gas emissions that would need to be accounted for. On the other hand, the list above is far from complete and does not, for example, include rice husks or any sources of wood which might be suitable (i.e. sustainably sourced and safe to use). The current estimate of GHG emissions in India is 1,900 million tCO_2e per annum, hence it can be seen that biochar could contribute between 2 – 4% reduction.

Estimates of biomass resource in Cambodia are more difficult to come by, though we do know that paddy rice production has increased in the last few years to about 7 million tones per year, which is associated with production of c. 1.4 million tonnes of rice husk.

A critical issue in assessing suitable feedstocks is to evaluate whether they are sourced sustainably or not. This might be especially pertinent where a market for biochar was to emerge through the availability of a carbon credit. A situation could be envisaged whereby because biochar has a value, project developers are encouraged to produce it from available resources. These resources might otherwise not have been exploited at all, or may have been utilized for other purposes, in which case their use in a PBS might well necessitate the use of some other biomass resource in its place. In a worst-case scenario, giving biochar a value might even encourage greater and unsustainable use of woody biomass for biochar production. A further risk is that biochar might be used as a fuel instead of as a soil amendment, so nullifying the carbon abatement associated with the sequestered carbon. Enforcing a clear distinction between charcoal and biochar would be very difficult in a distributed production and application context, such as might occur at the rural household or village scales.

1.2. Alternative Uses of Biomass

Because of the limited availability of biomass resources in many circumstances, evaluation of appropriate use depends upon understanding the value and impacts of the alternative uses. This can be illustrated through analysis of alternative uses of rice husks and rice straw.

1.2.1. Rice Husks

Rice husks have a number of different applications or disposal routes including:

- Burning in field
- Collection and combustion in boilers or other power or heat generating units (e.g. widely used in brick-kilns in Cambodia)
- Addition to irrigated rice fields
- Addition to non-irrigated rice fields and to other agricultural soils
- Poor quality feed for animals

FIGURE 9: RICE HUSKS FROM A RICE MILL IN CAMBODIA.

Burning in the Field

Burning in the field will produce CO_2, but also smaller quantities of other gases such as CO, CH_4 and N_2O in addition to black carbon and particulates (section 1.2.2). If greenhouse gases such as methane and nitrous oxide are generated, along with black carbon particles, the burning of rice husks will have a positive radiative forcing effect due to the global warming potential of such greenhouse gases (CH_4 23 x CO_2 and N_2O 298 x CO_2 per molecule). Open burning of husks is one of the baselines against which production of CRHs from rice husks could be compared in terms of its environmental and socio-economic impacts (e.g. with respect to the net contribution to carbon dioxide equivalent (CO_2(e)) emissions).

Combustion for Energy Generation

While 20 years ago, it was common for rice husks to be burnt in field, this is much less common in many rice producing countries such as Thailand and India. This is, *inter alia*, because of the value of rice husks in generating electricity by combustion in large boilers with steam turbines. In fact, rice husks now have a value of between $31 and $39 in Thailand (Parnphumeesup & Kerr, forthcoming) and prices in parts of India seem to be similar (pers.com., India workshop, Nov. 20100). In these circumstances, comparing gasification-biochar with husk combustion in the field would not be an appropriate baseline. Instead, the emissions associated with the rice husk combustion for bioelectricity generation, and the avoided CO_2(e) emissions associated with offsetting fossil fuel consumption, would need to be calculated.

The combustion of large amounts of rice husk has resulted in considerable effort in finding applications for the rice husk ash produced. Existing markets are as an insulator in the production of high quality flat steel and as a pozzolan in the cement industry; there is a range of smaller-scale applications (water filtration and purification, as a soil amendment, an absorbent of oil and other contaminants, as a way of protecting foods from pests, etc.) (Bronzeoak, 2003; Foo & Hameed et al. 2009). Some proportion of rice husk ash appears to have a similar carbon content to CRHs (35%), presumably the result of oxygen-depleted combustion, but the typical commercial rice husk ash typically has a maximum of 5 – 7% carbon content (Bronzeoak, 2003).

The use of rice husk ash, in addition to rice husk *per se*, also needs to be taken into account in establishing a baseline against which to compare gasification- or pyrolysis-biochar. The carbon content of the ash needs to be accounted for, though it would also be necessary to establish the long-term stability of this carbon through incubation and accelerated ageing studies similar to those described under Section 4. Furthermore, the impacts of rice husk ash upon soils and plant productivity would also need to be identified and compared to the impacts of the CRHs. For example, ash shares at least some of the properties of the CRHs, e.g. it is typically alkaline, is a rich source of nutrients and it has been reported that wood ash can suppress N_2O emissions. A full comparison of rice husk ash and CRHs is clearly complex and is beyond the scope of the present project, but is identified as an area for future research.

Addition to Irrigated and Non-Irrigated Rice Fields

In a study undertaken in part at IRRI, and which took place consecutively with the BIOCHARM project, Knoblauch et al. (forthcoming) investigated the impacts of incorporating rice husks and rice husk char into paddy fields. Rice paddy soils are characterized by anoxic conditions, anaerobic carbon turnover, and significant emissions of the greenhouse gas methane. A main source for soil organic matter in paddy fields is the rice crop residue that is returned to fields if not burned. Knoblauch et al. investigated as an alternative treatment the amendment of rice paddies with charred rice residues. Although charred biomass is seen as almost recalcitrant, its impact on trace gas (CO_2, CH_4) production and emissions in paddy fields has not been studied. The study quantified the degradation of black carbon produced from rice husks in four wetland soils in laboratory incubations. In two of the studied soils, the addition of carbonised rice husks resulted in a transient increase in carbon mineralisation rates in comparison to control soils without organic matter addition. After almost three years, between 4.4% and 8.5% of the black carbon added was mineralised to CO_2 under aerobic and anaerobic conditions, respectively. The addition of untreated rice husks resulted in a strong increase in carbon mineralisation rates and in the same time period 77% to 100% of the added rice husks were mineralised aerobically and 31% to 54% anaerobically. The ^{13}C-signatures of respired CO_2 gave a direct indication of black carbon mineralisation to CO_2.

In field trials the impact of carbonized rice husks or untreated rice husks on soil respiration and methane emissions was quantified. The application of CRHs had no significant effect on soil respiration but significantly enhanced methane emissions in the first rice crop season. The additional methane released accounted for only 0.14% of CRH carbon added. If the same amount of organic carbon was added as untreated rice husks, 34% of the applied carbon was released as CO_2 and methane in the first season. Furthermore, the addition of fresh harvest residues to paddy fields resulted in a disproportionally high increase in methane emissions. Estimating the carbon budget of the different rice crop residue treatments indicated that charring of rice residues and adding the obtained CRHs to paddy fields instead of incorporating untreated harvest residues may reduce field methane emissions by as much as 80%. Hence, the production of CRHs from rice harvest residues could be a powerful strategy for mitigating greenhouse gas emissions from rice fields.

1.2.2. Field Burning of Rice Straw

In traditional rice production systems, rice straw has many uses and is an important resource for farmers (used as cattle fodder, building material, fuel, etc). However, in highly productive and intensive modern rice production systems, the amount of straw produced is huge and there is little time available for its removal. Therefore, field burning of rice straw is widespread, even where it is forbidden, because it is the easiest, quickest, and cheapest way to remove it (see Figure 12 showing rice fields in the surrounding of Los Baños, Philippines). IRRI therefore examined the possible alternative uses of rice straw and set up some experiments to collect data on the two options of field burning and gasification.

On 16th June 2010, a heap of fresh rice straw was burned in the open field at IRRI (Figures 10 and 11). The straw originated from IRRI's farm and remained from recently harvested rice grown in the previous dry season.

FIGURE 10 AND 11 : BURNING OF STRAW IN THE FIELD, SIMULATING THE WIDESPREAD FARMER'S PRACTICE. THE LEFT PICTURE SHOWS THE INITIAL PROCESS WITH OPEN FLAMES, THE RIGHT PICTURE SHOWS A LATER STAGE WHEN THE HEAP IS SMOLDERING WITHOUT OPEN FLAMES.

FIGURE 12: AERIAL VIEW OF RICE FIELDS IN THE SURROUNDING OF IRRI, LOS BAÑOS, PHILIPPINES, SHOWING THE CONCENTRATION OF HARVESTED RICE IN THE CENTER OF EACH FIELD, AND BURNING OF THE RESIDUES AFTER THRESHING, A WIDESPREAD FARMER'S PRACTICE.

The burning (when flames are visible) lasted for about 3 hours but it took another 2 hours until the burning (smouldering combustion) was completed (until the smoking was finished) and the ash/char was formed (see Figure 11). Because of rain following the burning, we also needed to determine the moisture content of the ash.

- Fresh weight straw 362.2 kg, 54.6% moisture content, dry weight straw 164.4 kg;
- Fresh weight charred straw/ash 53.3 kg, 29.1% moisture content, dry weight charred straw/ash 37.8 kg;

This results in a dry weight loss of 77% or a remaining biochar/ash quantity of 23% of the feedstock residues. The contribution of straw burning to atmospheric pollution with CO_2 and fine particles has been shown by e.g., Tipayarom and Oanh (2007) in Thailand. In tests of rice straw burning, Miura and Kanno (1997) found gas emissions of 81% CO_2, 5% CO and 0.43% CH_4 for dry straw (10.6% moisture content), and 57% CO_2, 9% CO and 0.90% CH_4 for wet straw (14.2% moisture content). The respective ash quantity was 15.6% (dry straw) and 18.6% (wet straw). Thus, the straw in our experiment was still very wet which might have caused the higher ash/char ratio. But apart from the gas emissions, incomplete combustion also produces particulate matter which is then distributed in the atmosphere. Recent studies indicated a considerable contribution of black carbon particles in atmospheric soot to global warming because it is an important absorber of visible solar radiation (Ramanathan and Carmichael, 2008; Jacobson, 2010). Gustafsson et al. (2009) indicated that a considerable part of the black carbon particles in the atmosphere in Asia comes from biomass combustion (such as residential cooking and agricultural burning) as opposed to mainly from fossil fuel combustion as was thought earlier. And rice-straw burning emissions were specifically identified as a significant source of atmospheric particulate and polycyclic aromatic hydrocarbons (PAHs) (Lai et al., 2009), and HUmic-LIke Substances (HULIS) (Lin et al., 2010).

Within the particulate matter from incomplete combustion, a distinction is made between: 1) black elemental carbon (BC or EC), which is produced in flaming fires, is most commonly emitted from the burning of biomass, coal, or diesel fuel, and which has a GWP 680 times that of CO_2 (Bond & Haolin, 2005); and 2) organic carbon and/or organic matter (OC or OM), which is generally produced in smoldering fires, consists of light scattering particles/ aerosols that can be white, and that contribute to global cooling (estimated GWP of -50 times that of CO_2) (summarized from MacCarty et al., 2008). Gas as well as particle emissions from rice residue burning is not yet properly included in the analysis in this report and is, again, a topic for further research.

1.3. Analysis of Technologies for Production of Biochar

Several technologies can be used for producing biochar including slow pyrolysis (with char yields of typically 30-35%) and gasification (with char yields of typically <10%). BIOCHARM has focused mostly upon the use of gasification because of the economic viability of this technology in the partner countries. The original inspiration for BIOCHARM was the observation that small-scale (c. 250kW capacity) gasifiers from Ankur Scientific were operating in Cambodia utilizing rice husks to produce syngas that is subsequently used in a gas engine to provide motive power (or electricity) for rice mills or for ice-making factories. In this section we describe three different technologies: Ankur Scientific's commercial technology that is already widely utilized and from which the CRHs utilized in the Cambodian field trials was produced; IRRI's experimental gasifier; and ARTI's single-barrel pyrolytic kiln that was used to produce biochar for the Indian field trials.

1.3.1 Ankur Scientific Energy Technologies Pvt. Ltd. Gasifier

Biomass gasification has been developed successfully in developing and industrialising countries with companies such as Ankur Scientific Energy Technologies Pvt. Ltd. (based in India) manufacturing a range of gasifiers from a few kW to 500+ kW capacity (http://www.ankurscientific.com). Ankur has sold over 1000 gasification units, predominantly in South Asia, but also into Africa, Europe, South America and SE Asia. As of mid-2010, approximately 35 Ankur gasification units have been installed in Cambodia by SME Renewables, which acts as a turnkey contractor. The units are typically 150 – 250 kW in delivered power capacity and most are installed in rice mills and ice-making factories. Rice mills separate the grain from the husks, and a proportion of these husks (typically 1/3rd) are used to power the gasifiers. The gasification occurs at 900 to 1100^{o}C and the feed rate is approximately 100 to 120 kg husks per hour. The electricity production per unit feedstock appears to vary considerably, with one measured system giving a value of 1.48 kg husk per kWh (from observations by Colorado State University team). The gas is cleaned through a series of coarse and fine woody and cloth filters and is introduced to a diesel four-stroke engine where it is combusted, along with a small amount of diesel. The engine crankshaft then provides power to operate the milling machinery. A diagrammatic of the process is illustrated in Figure 13 while information on a few different operational gasifiers is presented in Table 9.

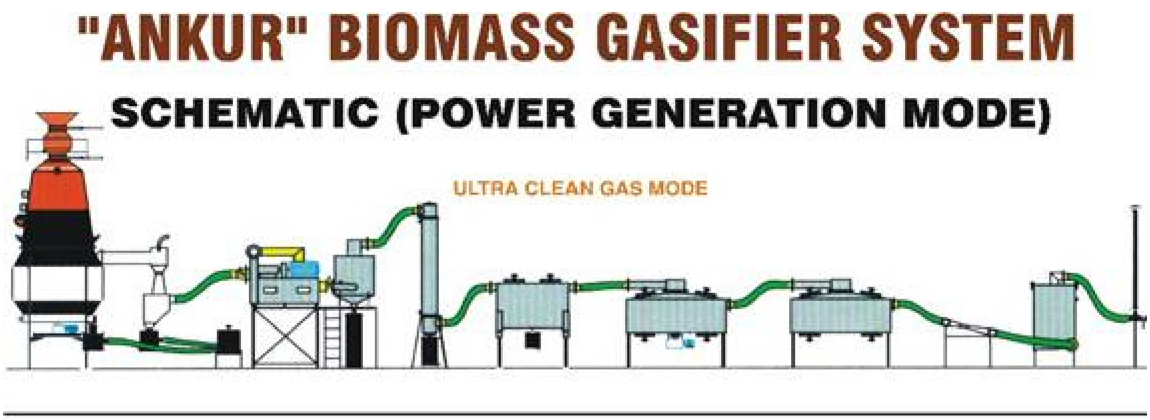


FIGURE 13 : SCHEMATIC OF ANKUR GASIFICATION SYSTEM (POWER GENERATION MODE),COURTSEY: ANKUR SCIENTIFIC LTD

Gasifier ID	Installation date	Capacity (kW)	Avoided diesel (litres y^{-1})	Running hours per year	% total hours	Fuel replacement (litres h^{-1})	Avoided fossil fuel emissions (tCO_2 y^{-1})[1]
1	06.08	200	75,240	3,960		19.00	199
2	11.08	200	91,080	3,960	45	23.00	240
3	01.09	200	165,600	7,200	82	23.00	437
4	01.09	200	71,280	3,960	45	18.00	188
5	11.07	150	165,600	7,200	82	23.00	437
6	08.08	250	110,880	3,960	45	28.00	293

TABLE 9: CHARACTERISTICS OF SIX GASIFIERS INSTALLED IN CAMBODIA BY SME RENEWABLES (SOURCE: SME RENEWABLES)

1. Assumes a Carbon Emissions Factor of 2.6391 kg CO_2 per litre diesel [1]

The syngas can reduce the consumption of diesel by 70 to 75%. Given that diesel costs can constitute up to three quarters of the operational costs of the mill, the increase in diesel costs in 2007/8 were an important driver in the installation of gasification units. Cambodia is not currently an oil or gas producer and tax on gasoline is at 94 cents/litre, above the level in the US of 56 cents/litre (2008 figure) (Victor 2009).

A typical rice mill can save $6000 per month in diesel costs through using rice husks, with an initial upfront investment of $75,000. Therefore a gasification unit can pay for itself within less than two years. The economics of the Ankur gasifiers make sense in the Cambodian context for a few distinct reasons:

- the mills are relatively small and installation of a steam turbine for power generation from rice husk combustion would not be feasible (small turbines not being very reliable or efficient);

- the electricity grid is poorly developed in Cambodia, hence micro-grid and own supply solutions are cost-effective, where this might not be the case in a grid-connected situation;
- even where grid-connection exists, electricity supply in Cambodia is not subsidised as it is in other countries, hence renewables can compete on a more level playing field. In Cambodia there is generally a shortfall of electricity production. In cities, electricity is generally supplied by a small number of large enterprises, the majority being supplied by the state run Electricite du Cambodge (EdC). Electricity from gasifiers can help to fill the gaps in supply.
- Cambodia does not have a targeted government policy or financial strategy to promote biomass energy[2]. However a lack of subsidies or feed-in-tariffs means biomass for electricity generation may be more accessible to private business for own-use rather than for rural electrification.

From the ECN Phyllis database (http://www.ecn.nl/phyllis) the lower heating value (LHV) of rice husk is around 12 – 15 $MJkg^{-1}$ and we assume here a value of 13 $MJkg^{-1}$. Therefore c. 19 MJ in the fuel is used to produce 1kWh, implying an efficiency of c. 19%. While this is a some what low efficiency compared to modern gasification technologies (c. 35 – 40%), given the abundance of the local feedstock at the gasifier site, and the overall favourable project economics, it does not detract from the value of the technology.

The properties of rice husks and associated CRHs are shown in Tables 14 and 15. The CRH yield is c. 35% and the carbon content of the char is also c. 35% (own analysis). Therefore for each tonne of rice husks, 350 kg of CRHs are produced containing 123 kgC or 451 $kgCO_2$. The carbon content of the rice husks is about 38% (own analysis), therefore 32 % of the carbon in the feedstock is conserved. This is much higher than the typical value for gasification of 2.5 to 8% carbon conservation.

Rice husk contains approximately 20% ash, the main constituent of which appears to be silica; the carbon content at 38% is lower than typical biomass (45%) due to the high ash content. The CRH itself is made up of silica and carbon – just over 60% ash to 35% carbon. The high silica content of the CRH may help explain why the conversion of carbon to CO_2 is much lower than in the case of gasification of other biomass. The exterior of rice husks is composed of dentate rectangular units which may form a geometric shield which protects the combustible material, 'cocooning' the carbon such that air circulation is reduced (Bharadwaj et al., 2004). According to one study, the role of silica is "more than just a geometric shield to the combustible material in the sample" and that silica "forms molecular bonds with carbon which are not easily broken at the gasification temperatures" (Bharadwaj et al., 2004: 985-6).

Silicon carbide is not formed since this entails much higher temperature reactions (2500^{o}C) than occur in gasification. From a carbon storage perspective, this feature of rice husk gasification is fortuitous, as it combines the benefits of gasification for electricity generation with carbon conservation that is over 50% of that achieved through slow pyrolysis. The measure of volatiles in rice husks in Table 14 involves heating the husks to 950^{o}C and it shows that c. 40% by mass is recalcitrant material (presumably carbonaceous) that does not convert to CO_2. This is a slightly higher percentage than in the CRHs, presumably because the gasification exposes the rice husks to more extreme conditions.

[2] Cambodia's Renewable Energy Action Plan 2002-2012 (REAP) focuses on grid connectivity, Solar Home Systems (SHSs), and HEP, and the Rural Electrification and Transmission Project (RE&T) is also mainly concerned with SHS and grid connectivity.

In summary, rice husk gasification may be particularly suited for producing biochar because of the high char yield. By contrast, where wood is used as a feedstock, then the char yield is c. 6% (Jain, pers.com., Nov. 2010). Wood char from such gasifiers is also a potentially valuable fuel. This is because wood char has a sufficiently high calorific value (CV) (e.g. 25-30 $MJKg^{-1}$). Experiments are underway at Ankur Scientific to briquette the wood char to produce a viable charcoal that can be distributed (or sold) to villagers. ARTI also has a briquetting facility that it uses to convert char from agri-residues (see table 16) into a fuel. The low char yield, and its value as a fuel, means that wood char from gasification may well not be a viable source of biochar. Where rice husk are used, however, the high silica content limits the CV of the carbonised rice husks (CRHs), hence it has little, if any, value as a charcoal-type fuel and the CRHs can become a waste disposal or pollution problem.

1.3.2. Monitoring program for the gasification plants in Cambodia, conducted in June-July 2010

BIOCHARM was fortunate in that John Field and Paul Tanger, two PhD students from Colorado State University, were able to undertake measurements of a few Ankur gasifiation plants during the summer of 2010. This work provides invaluable empirical data on functioning plants. The energy balance will be presented in this section, while the carbon balance will be reported in section 4 under the Life Cycle Assessment part.

A. Energy balance:

1. Amount and energy in the fresh rice husk;
2. Amount and energy in the carbonised rice husk;
3. Amount and energy in the sludge accumulating in the cooling water;
4. Amount of diesel fuel replaced by the husk gasification;
5. Amount of heat loss estimated from the other four components.

B. Carbon balance:

Input:

1. amount of rice husks going in
2. average C concentration in rice husks;

Output:

1. C concentration and amount of carbonised rice husks;
2. C concentration in carbonised rice husks;
3. C concentration and amount of tar (amount to be determined);
4. Amount of syngas (to be calculated);
5. C concentration in syngas;

Results and discussion

Basic data on the gasifiers monitored are given in Table 10. It shows that all gasifiers chosen had a nominal capacity between 150 and 300 kW, an actual husk feed rate between 100 to 167 kg husk per hour, a diesel replacement rate between 6.90 and 8.44 kg husk for each liter diesel, a husk/char ratio of 9.6 to 34.8 %, and a sludge production of 0.06 to 0.67 liters per kg husk (fresh weight). Analysis of the syngas generated by the reactors is shown in Table A1.

Date		**17/6/10**	**18/6/10**	**20/6/10**	**22/6/10**	**23/6/10**	**24/6/10**
Facility name		**Khiev Moeung**	**Yin Po**	**Eap Sophat**	**Chhay Kimting**	**Yam Loeung**	**Choa Mey**
Facility type			Rice mill	ice factory	rice mill	rice mill	rice mill
Capacity (nom)	ton paddy/hr	2	1.5	NA	2	3	2
Gasifier size (nom)	kW.mech	200	200	150	200	300	200
Capacity (nom)	ton paddy/hr	2	1.5	NA	2	3	2
Husk feed rate	kg/hr	150	103	100	167	166	170
Diesel replacement	kg husk/L	8.44	7.67	-	6.90	5.44	-
Husk to char %	%	9.6	31.7		21.6	34.8	15.4
Diesel replacement	L/hr	17.80	13.47	-	24.17	30.53	-
Sludge production	L/kg husk	-	0.67	0.35	-	0.06	0.25

Table 10: Basic data on the gasifiers monitored in June 2010 in Cambodia

This indicates an overall relatively constant diesel replacement rate but considerable variation in the amount of char and sludge produced. This must be partly explained by differences in how the gasifiers are operated (slower throughput i.e., longer residence time of the husks in the gasifier will reduce the amount of char produced), but measurement errors could also have contributed. Difficult to explain are especially the high sludge rate produced in the Yin Po rice mill and the low value in Yam Loeung.

The basic assumptions used for the economic analysis of a mid size gasifier (150 to 300 kW size) are given in Table 11, and they are based on the data recorded for the same gasifiers shown in Table 10. Using these inputs the, costs and profits were calculated for a 5 year pay back period according to the financing scheme offered by SME (Table 12). The data shows that a substantial down-payment has to be made in the first year but that positive net revenues set in already in the second year. The total profit within these 5 years is 14.000 US$ even though the equipment, its operation, and the maintenance is completely financed within this time frame.

Parameter	Unit	Value
rice husk consumption rate	Tons husk/hr	0.100
hours of operation per day	hr/day	10
Days of operation per year	Days/year	250
annual rice husk cost	$/year	(4,112.50)
annual labor cost	$/year	(1,460.00)
annual electricity cost	$/year	(6,804.53)
annual value of diesel replaced	$/year	29,750.00
annual char revenue	$/year	495.75
annual net revenue	$/year	17,868.72
system cost	$	60,000.00
fraction financed	%	70
loan principal	$	(42,000.00)
one-time fixed capital cost	$	(18,000.00)
loan rate	annual rate in %	13
monthly payment	$	(955.63)
yearly payment	$	(11,467.55)

Table 11: Basic assumptions used for the economic analysis of a mid size gasifier (150 to 300 kW size). Brackets indicate negative values.

Year	1	2	3	4	5	Total
One-time fixed capital costs	(18,000)	-	-	-	-	(18,000)
financing cost	(11,468)	(11,468)	(11,468)	(11,468)	(11,468)	(57,338)
Long-run annual revenue	17,869	17,869	17,869	17,869	17,869	89,344
net profit	(11,599)	6,401	6,401	6,401	6,401	14,006
discounting, 10%	(10,544)	5,290	4,809	4,372	3,975	7,902
discounting, 15%	(10,086)	4,840	4,209	3,660	3,183	5,806
discounting, 30%	(8,922)	3,788	2,914	2,241	1,724	1,744

Table 12: Estimated financing scheme for a mid size gasifier in Cambodia, assuming a 5 year pay back period. Brackets indicate negative values.

1.3.3. Environmental Issue Arising from Use of Gasifiers

The gasification process generates tars, which drop down into barrels below the gasifier and also below the several-stage gas filters. Through the gas cooling and cleaning process, condensates enter the water stream introduced into the scrubber and a 'black water' flows from the scrubber. This is then used for quenching and removing the CRH that are deposited from the reactor; the dirty water is allowed to settle in ponds before being cooled and re-circulated. Visual observation at several of the gasifier sites indicated a tarry liquid effluent outflow from the sludge settling ponds: this appeared to be a consequence of the settling pond overflowing. In several cases the effluent was slowly draining into a local stream.

A sample of the sludge at the bottom of the settling pond was analysed and the results are shown in Table 13, comparing the values against values for a reference contaminated soil sample (BG CLR 17) (Graham et al., 2006) and the mean value for urban soils in England (Environment Agency, 2007). Also show in column 3, Table 13, is a CRH sample extracted from the settling pond.

Element or compound	**Settling pond sludge, Cambodian gasifier (mgkg^{-1} dry weight)[5]**	**Rice husk char extracted from settling pond (mgkg^{-1} dry weight)[5]**	**Contaminated soil reference (BG CLR17) (mgkg^{-1} dry weight)[6]**	**Urban soils, England (mean value) (mgkg^{-1} dry weight)[7]**	**Maximum in product (mgkg^{-1} under Flemish law)**
Organic compounds					
BETX[1]	500 – 1000				
Total phenols[2]	100 – 500				
USEPA 16 PAHs[3]	3223	196.7	629.9	25.7 (22 PAHs)	
Naphthalene	1214	11.04	29.9		2.3
1-Methylnaphthalene	172				
2-Methylnaphthalene	152				
Acenaphthylene	733	6.70	26.8	0.208	
Acenaphthene	73	1.05	10.3	0.131	
Fluorene	114	3.00	42.8	0.139	
Phenanthrene	586	45.94	125.1	1.81	0.9
Anthracene	< 0.01	11.07	51.1	0.256	

Fluoranthene	93	9.62	102.1	5.28	2.3
Pyrene	75.8	8.194	85.8	5.37	
Benzo(a)anthracene	3.5	5.239	41.1	1.19	0.68
Chrysene	4.9	8.354	27.5	1.54	1.7
Benzo(b)fluoranthene	< 0.01	3.459	18.8	1.66	2.3
Benzo(k)fluoranthene	1.1	2.935	16.8	1.26	2.3
Benzo(a)pyrene	0.49	2.939	28.4	1.59	1.1
Indeno(1,2,3-cd)pyrene	< 0.01	1.076	11.9	0.798	1.1
Dibenzo(a,h)anthracene	< 0.01	0.641	2.2	0.854	
Benzo(g,h,i)perylene	< 0.01	1.105	9.3		1.1
Regulatory thresholds in UK			Upper limit for UK PAS100 regulation ($mgkg^{-1}$ dry weight)	Maximum permissible average annual rate of PTE addition over a 10 yr period (kg/ha/yr) (sewage sludge regs)	
Metals[4]					
Aluminium (Al)	3619	259			
Arsenic (As)	< 1.5	< 2.6		0.7	
Barium (Ba)	711.4	40.8			
Beryllium (Be)	< 3.0	< 5.2			
Boron (B)	516	0.52			
Cadmium (Cd)	< 0.3	< 0.5	1.5	0.15	
Calcium (Ca)	227140	1233			
Chromium (Cr)	8.0	< 2.6	100	15	

Copper (Cu)	42.1	9.7	200	7.5	
Iron (Fe)	10518	128			
Lead (Pb)	43.9	1.6	100	15	
Magnesium (Mg)	24498	313			
Manganese (Mn)	2688	271			
Mercury (Hg)		< 2.6	1	0.1	
Molybednum (Mb)	< 1.5				
Nickel (Ni)	32.6				
Potassium (K)	16428	767			
Selenium (Se)	< 3.0				
Silicon (Si)	4581	57.4			
Sodium (Na)	2428	66.6			
Strontium (Sr)	4594	9.0			
Titanium (Ti)	428.9	3.6			
Zinc (Zn)	482.3	15.3			
Vanadium (V)	7.1	< 2.6			

(1) HS-GC-MS

(2) GC-MS

(3) ASE, GC-MS

(4) ICP-OES

(5) analysis undertaken by CLARRC, University of Edinburgh (http://www.clarrc.ed.ac.uk/)

(6) [2], table 3, page 85, ASE method

(7) [3], table 4.7, page 23

Table 13: Potential contaminant contents of gasifier sludge and CRH from settling pond and comparison with contaminated soil samples. Source: (CLARRC), University of Edinburgh (http://www.clarrc.ed.ac.uk/); contaminated soils (Graham et al., 2006; Environment Agency 2007).

It can be seen that the sludge sample has a high BETX, phenol and PAH loading. Polycyclic aromatic hydrocarbons (PAHs) are aromatic hydrocarbons containing more than two unsubstituted benzene rings. Some PAHs are strong carcinogens, i.e. benz(a)pyrene and benz(a)anthracene, while others are mutagenic and/or teratogenic (e.g. Lerda 2009, USEPA 2007). The US Environmental Protection Agency (USEPA) has identified 16 PAHs for which it recommends monitoring. The number of PAHs scrutinized in environmental impact assessment (EIA), monitoring and regulation is sometimes less than this (e.g. 10 under Flemish law) and sometimes more (e.g. 22 in an Environment Agency (2007) report). There are, unfortunately, no agreed standards for determining safe levels of PAHs in soils. There is data on existing PAH levels in soils and this indicates that levels can vary considerably between locations and soil types. In the UK, the range for ∑ 22 PAHs is 0.04 to 167 $mgkg^{-1}$ with a mean of 2.2 $mgkg^{-1}$ and a median of 0.72 $mgkg^{-1}$ (Environment Agency 2007).

The PAH level of the sludge sample is significantly greater than the total 16 PAHs in the contaminated soil sample (column 4, Table 13). Interestingly, the distribution between the 16 USEPA PAHs in the sludge sample varies considerably. There are relatively small quantities of the (generally more toxic) higher molecular weight (HMW) PAHs: benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, benzo(g,h,i)perylene for example; whereas, the contaminated soil sample contains far greater levels of these PAHs. The PAH loading of the CRH extracted from the sludge pond is not as great as the sludge sample. Nevertheless, the level is still above the 50 $mgkg^{-1}$ level that is advised as 'trigger' value for concern in converting contaminated soils for domestic use in the UK (ICRCL, 1987).

Furthermore, the CRH sample from the sludge pond contains higher levels of certain HMW PAHs, such as benzo(a)pyrene, than the sludge. There is, as yet, little guidance available on the appropriate limits for PAHs in soil amendments and few regulatory agencies have attempted to define quantitative thresholds to date. One of the few exceptions has been the Flemish regulatory authority in Belgium, which has defined quantitative limits expressed in terms of mg per kg in material to be added to soils (Ruysschaert & Nelissen, 2010). If these threshold levels were applied, it can be seen in column 6, Table 13 that, for most PAHs, the levels in both the sludge sample and the CRH from the sludge are too high to permit application to soils. Whether the thresholds developed by the Flemish regulator are the appropriate ones to use in this context is currently unclear, however.

The USEPA (2007) ecological soil screening levels (eco-SSLs) make a distinction between low and high molecular weight (LMW, HMW) PAHs. For soil invertebrates and mammals the eco-SSL for low molecular weight PAHs is 29 and 100 $mgkg^{-1}$ respectively; and for high molecular weight PAHs, 18 and 1.1 respectively. It can be seen that the sludge sample has values of LMW and HMW PAHs which far exceed the eco-SSLs for both invertebrates and mammals. The CRHs recovered from the settling pool also have levels of HMW PAHs which look high compared to the eco-SSL for mammals.

Limited guidance is also available in the UK for assessing PAH addition to contaminated soils (Soil Screening Values), though this is unlikely to be appropriate for addition to agricultural soils. Nevertheless, applying the standard developed by the Environment Agency (2007) in England and Wales, the threshold for benzo(a)pyrene value is 0.15 $mgkg^{-1}$. It can be seen from Table 13 that the sludge sample and, even more so, the CRH from settling pond, contains a higher value of benzo(a)pyrene that the SSV. It must be stressed that considerable uncertainty is associated with evaluating the environmental impacts of PAHs so the Eco-SSL and SSVs mentioned above should be regarded as only preliminary guidelines that are far from being definitive or set-in-stone.

There are also quite high levels of metals in the sludge sample, but much lower levels in the CRH from the sludge pond. Comparing the metal concentrations in the sludge with the levels in the CRHs shown in Table 14, it is evident that concentration is taking place in the sludge for elements such as:

K, Cu, Sr, Mn, Ni, Ti, Ba, Na, Ca, Mg, and B. This suggests that these elements are water-soluble and are being leached out of the char and collecting in the bottom sludge.

To test this idea, we collected a sample of the black-water just before it was changed (after having been in circulation for one week) and then just after it was changed. We then measured the concentrations of metals (in mgl^{-1} dissolved and in mgl^{-1} total sample) in both samples using ICP-OES. The pH of the old cooling water was 8.4, while that of the new water was 7.1, confirming that cycling of the cooling water will tend to render it alkaline through contact with the alkaline CRH. The following elements did not vary much between the 'before' and 'after' water change: Al, As, Be, Cd, Cr, Cu, Pb, Hg, Ni, Ti, Zn, V, Ba, Na, Ca, Sr and B. Since some of these same elements are concentrating in the bottom sludge, it suggests that the elements may be being extracted from the cooling water and binding to / sorbing with solid particles in the sludge (possibly small black carbon particles). The bottom sludge is presumably less disturbed by cooling water than the CRHs, which could account for why the metals do not get leached out of sludge in the way that appears to occur for the CRHs. Alternatively, the physio-chemical structure and properties of the sludge particles may exhibit greater binding / sorption potential with metals than do the CRHs.

Other elements appear to concentrate in the 'old' cooling water, namely: Fe (10 x dissolved; 2 x total); Mn (8 x total); Si (1.6 x dissolved); Mg (2 x dissolved); K (2 x dissolved, 1/3 x total). Why these elements appear to respond differently from those listed above is not currently know. It may, potentially, be attributed to the relatively lesser ability of these elements to bind with the sludge black carbon particles

Given the high pollutant load of this black water and the settling pond sludge, it is clearly desirable for a clean-up system to be in place. The manufacturer Ankur Scientific has designed a water filtration system using sand, saw dust and char from the reactor. In addition, Ankur has now developed a 'dry discharge' system for the char, whereby a screw conveyor with a built-in heat exchange unit removes the char without the need for any wet quenching. Both of these improvements should be a considerable benefit in reducing the risk of polluted effluent arising from the facility. It is still necessary for the sludge to be removed from the settling pond periodically. One option recommended by Ankur is simply to dry the sludge and add to the reactor. Likewise, the various materials used for filtering waste water also need to be removed and replaced periodically, and Ankur also recommends that these can be dried and added to the reactor. It appears likely that the process can be made 'clean' therefore if an appropriate environmental management system is in place.

However, a clean-up system has not been observed in operation in Cambodia and there is no requirement or incentive for a gasification unit operator to install such a clean-up system. The environmental and health impacts of the black water and tarry residues from the gasifiers is not currently known. This is, therefore, a major weakness in the sustainability of the gasification system as implemented in Cambodia, albeit not related directly to the use of the CRH as biochar. I.e. the pollution problem arises from the operation of the gasifiers and would occur with or without use of the CRH. One sensible precaution with respect to use of CRHs in field trials is to use only CRH and not mixtures of CRH and sludge and/or other waste streams from the process.

1.3.4. Gasification of rice husk and rice straw in the experimental batch gasifier at IRRI

The objective of this activity at IRRI was 1) to gain some experience with rice husk gasification at this laboratory scale, 2) to measure some basic parameters of the husk gasification process (duration of the process, heat development profile, quantitative estimate of gas production, weight loss and remaining ash / biochar production), and 3) to see if a similar gasification as with husks could be achieved with rice straw. For this we used a batch gasifier available at IRRI.

Rice husk gasification

The rice husk gasification was relatively easy. We used rice husks from the IRRI rice mill. The husks had an average moisture content of almost 7% (see details in Table A2). Total husk weight filled into the gasifier chamber was 16.8 kg, the volume of the chamber was 161.2 l, therefore the husk density in the chamber was 0.1 kg per liter. The husks were set on fire from below the chamber, and when they caught fire the gasifier was closed and a continuous air stream was blown through the gasifier from the top (figures 14 and 15). The temperature at the lower end of the chamber was monitored and the air stream volume was estimated. During initial lighting of the husks considerable smoke developed, but this stopped after a few minutes and the actual gasification was smokeless. During the gasification the flu gas came out of the outlet at the lower end of the chamber and was set on fire. Ash quantity was 3.29 kg, thus the charred husk was only 19.6% of the husk input. Results from the lab analysis of samples are shown in Tables 15 (chemical properties) and A3 (fuel properties).

Figures 14 and 15: Preparation of the gasifier and initial heating up phase. The gasifier chamber was situated in the second barrel from the bottom and had an inner diameter of 0.46 m, a height of 0.97 m, and a volume of 161.2 liter.

Rice straw gasification

The first trials of rice straw gasification did not work well. We loaded the gasifier with 9.67 kg of straw, and lit the charge from the bottom. A fairly thorough carbonization occurred extremely quickly, producing excessive, non-flammable smoke. A total of 2.86 kg char/ash was recovered, corresponding to 29.6% ash/char. Assuming that the low density of the straw fuel was responsible for the poor gasification, we ran another trial with tightly bundled straw (see figure 16). In this experiment, we loaded the gasifier with 14.75 kg straw, which was close to the fuel density in the first trials with husk. As before with the husk, considerable smoke developed during the initial lightening of the straw, but this stopped after a few minutes and the actual gasification was smokeless. During the gasification the flu gas came out of the outlet at the lower end of the chamber and was set on fire. Ash quantity was 2.71 kg, thus the charred straw was only 18.4% of the straw input. Results from the lab analysis of samples are shown in Tables A2 and 15. We concluded that rice straw gasification is possible but that probably some sort of straw compression is needed. This is confirmed by discussions with Ankur Scientific, who advise that straws would need to be pelletised before they might be used as a fuel in gasification (Jain, pers.com. Nov., 2010). Fuel properties of the gas and char produced by the IRRI gasifier are shown in Table A3.

FIGURE 16: WE USED TIGHTLY BUNDLED STRAW IN THE SECOND ATTEMPT FOR STRAW GASIFICATION BECAUSE WE ASSUMED THAT THE LOW FUEL DENSITY WAS THE REASON FOR THE POOR GASIFICATION.

1.3.5. ARTI's Single-Kiln Pyrolyser

The single barrel kiln developed by ARTI (Figure 17) consists of a 200 l capacity metallic drum with lid and chimney. It can produce up to 20kg of biochar per day operating on a 15 minute batch cycle. The kiln is low cost and portable. A pair of operators can operate two kilns simultaneously. Typically it was found that light biomass produces around 20% biochar and woody biomass can produce around 25-35%, both by mass.

FIGURE 17: ARTI'S SINGLE BARRLE KILNS IN OPERATION. FEEDSTOCK USED: SUGARCANE TRASH

1.4. Characterisation and Properties of the Biochar Produced by the above Technologies

1.4.1. Properties of Carbonised Rice Husks Produced by Ankur Scientific Gasifiers

Table 14 presents data on the analysis of rice, rice husks and CRHs from a number of gasification units in Cambodia.

Measurement **(all dry weight)**	**Rice (grain and husk)** **(1 sample)**	**Rice husk (average 3 samples or range shown)**	**Rice husk (average up to 5 samples in ECN Phyllis database)**	**Carbonised rice husk (average up to 4 samples)**	**Conservation of element from husk to carbonised husk (%) (assuming 33% yield)**
Ash (% wt)	6.5	21	19.5	63	
C (% wt)	41	38	40	35	30
H (% wt)	6.5	4.7	5.5	0.17	1.2
N (% wt)	1.4	1	0.85	0.6	20
S (% wt)	0.1	0.04	0.06	0.05	41
Volatiles (% wt)			61		
pH	6.6	6.6		9.63[1]	
Cation Exchange Capacity (cmol+/kg)				45 – 110	
Exchangeable K (cmol+/kg)				11 – 72	
Exchangeable Na (cmol+/kg)				1 – 21	
Exchangeable Ca (cmol+/kg)				4 - 15	
Exchangeable Mg (cmol+/kg)				1 – 13	
PAHs (USEPA 16) mg/kg [2]	0.09	0.23		15 – 104	
BETX (mg/kg)[3]				7.7 – 22.3	
Metals: (all mg/kg) [4]					
Aluminium (Al)	57	37 – 68		92 – 543	82 – 315
Arsenic (As)	< 1.44	< 1.52 - < 2.5		< 1.79 - < 2.5	
Barium (Ba)	5.7	3 – 12		19 -48	53 – 127

Beryllium (Be)	< 2.89	<3.03 - < 3.85		< 3.59 - < 5.00	
Boron (B)	2.14	4.97 – 9.35		1.81 – 5.38	6 – 29
Cadmium (Cd)	< 0.29	< 0.3 - < 0.39		< 0.36 - < 0.5	
Calcium (Ca)	250	389 – 625		609 – 1940	52 – 103
Chromium (Cr)	< 1.44	< 1.21 - < 3.03		< 1.44 - < 2.5	
Copper (Cu)	5.11	1.2 – 5.2		8.2 – 15.3	98 – 297
Iron (Fe)	48	64 – 67		66 – 107	40 – 56
Lead (Pb)	< 1.44	< 1.52 - < 1.93		< 2.32 – 28.2	
Magnesium (Mg)	827	187 – 371		162 – 658	29 – 59
Manganese (Mn)	75.1	125 – 315		135 – 470	25 – 56
Mercury (Hg)	< 1.44	< 1.52 - < 1.93		< 1.79 - < 2.5	
Nickel (Ni)	< 0.87	< 0.89 - 1.95		< 1.39 – 1.5	
Potassium (K)	2604	1923 – 3040		595 – 2418	10 – 27
Silicon (Si)	5.8	3.2 – 26.8		66 – 199	209 – 340
Sodium (Na)	152	62 – 141		76 – 650	36 – 348
Strontium (Sr)	1.13	0.82 – 2.50		1.87 – 9.10	76 – 159
Titanium (Ti)	0.81	0.33 – 1.21		1.79 – 5.25	49 – 537
Zinc (Zn)	22.4	9.84 – 20.9		11.7 – 44.2	27 – 70
Vanadium (V)	< 1.44	< 1.52 - < 1.93		< 1.75 - < 2.5	

TABLE 14: PROPERTIES OF RICE, RICE HUSK AND CARBONISED RICE HUSK (SOURCE: OWN ANALYSIS, EXCEPT FOR COLUMN 4, FROM ECN PHYLLIS HTTP://WWW.ECN.NL/PHYLLIS/). (CLARRC), UNIVERSITY OF EDINBURGH (HTTP://WWW.CLARRC.ED.AC.UK/)

Notes:

(1) Average for 4 samples. One other sample had a lower pH of 7.79.

(2) PAHs (polycyclic aromatic hydrocarbons) analysed using accelerated solvent extraction (ASE)

(3) BETX (benzene, ethylbenzene, toluene, xylene) analysed used HS-GC-MS

(4) Metals analysed using ICP-OES

Conservation and Accumulation of Elements in Biochar

The conservation of an element in the char is calculated by the following formula.

$$Cons_A = \frac{CharYield \times CharA}{FeedstockA} \qquad \text{Equation (4)}$$

Where:

$Cons_A$ is the proportion of element A retained in the char from the feedstock

CharYield is the mass of the char divided by the mass of the feedstock

CharA is the proportion of element A within the char

Feedstock A is the proportion of element A within the feedstock

An assumption in this analysis is that metals are not introduced into the char from the equipment itself. It can be seen from Table 14 that most of the hydrogen and 80% of the nitrogen is lost during volatilisation. More of the sulphur (40%) is retained, but slightly less than reported in other studies (Chan & Xu, 2009). The C/N ratio is 58, comparable to the mean value of 67 in Chan and Xu. As for the metals, the calculation of conservation for three gasifiers, for which the rice husk and CRH were matched, produced some unusual results. The total K concentration is low compared to a range of biochar samples (Chan & Xu, 2009).

For some gasifiers and some elements, the percentage conservation was over 100%, implying some sort of concentration of the element within the biochar. The elements for which this was most evident are copper, silica, sodium, strontium and titanium. There are marked differences between the three gasifiers, especially in comparing gasifier 3 with gasifiers 1 + 2, though some evidence of a tendency to retain and accumulate the same particular elements as shown in Figure 18. This result is quite different from other reported values in the literature; for example, that about 50% of the Na is lost by vaporisation when heated to 673^{o}C (Chan & Xu, 2009).

The temperature of the gasifier is above the melting point of certain metals, such as Zn, Cd, As, Se, K, Na and Mg and it is reasonable to assume that volatalisation of these metals will reduce their concentration in biochar since they will disappear in emissions or in tarry effluents. Figure 17 does show that the conservation of Zn, K and Mg is lower than for other metals, indicating possible volatalisation. Na concentration in char, on the other hand, show a varied response. The wet quenching of the syngas with water may explain such differences, since elements are more likely to be retained than where gases are released directly to atmosphere. Furthermore, levels of metals with much higher boiling points such as B, Fe and Mn also appear to show lower levels of conservation, whereas these metals ought to be conserved. There is evidence of accumulation of metals within the sludge that collects in the cooling pond, as shown in Table 13. Very high concentrations of metals are found within the sludge, especially for Sr, Si, CA and Ti, all of which have high boiling points, hence are unlikely to be volatalised and removed from the reaction in the gas stream.

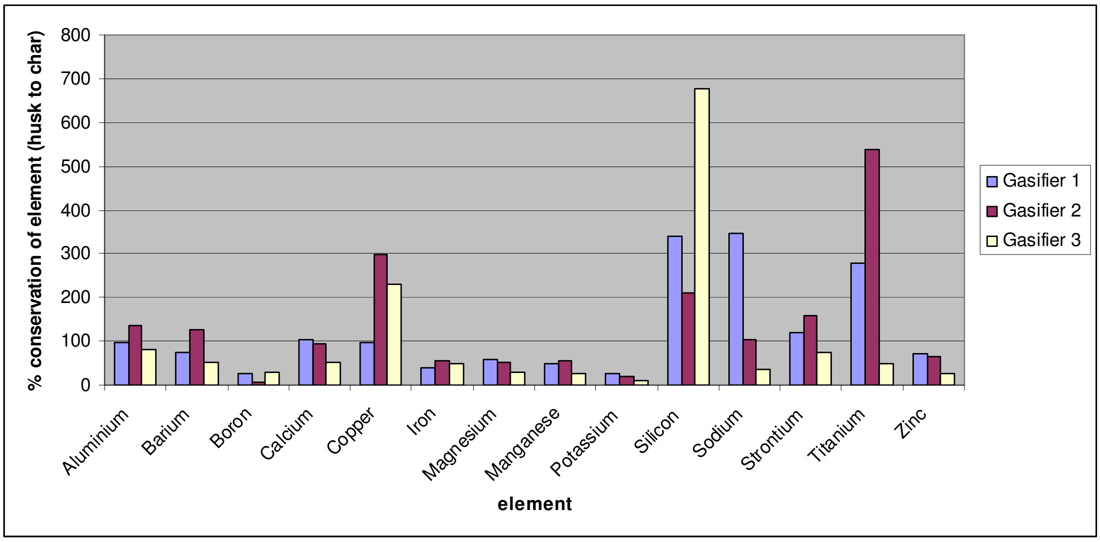


FIGURE 18: RETENTION AND ACCUMULATION OF A RANGE OF ELEMENTS IN CARBONISED RICE HUSKS RELATIVE TO THE RICE HUSK FEEDSTOCKS FOR THREE GASIFIERS (ASSUMING CONSTANT CHAR YIELD)

This retention and accumulation process might have occurred through the circulation of the water used for gas cleaning and then for quenching and removing the CRH from the bottom of the reactor. Elements may have been removed from the hot syngas when it reacts with water in the gas scrubber, into which the hot syngas from the reactor enters, as well as when water quenches the hot CRH. These elements may then be dissolved into, sorbed or otherwise carried within particles or sediments in the cooling water, only to be adsorbed back into the CRH at a later stage. Where there is a tendency for the elements to be leached out of the char, we would expect retention rates to be lower. This appears to be the case for B, Fe, Mg, Mn, K and Zn. Where a stronger bond develops between the biochar and the element, retention and concentration within the char may result, e.g. for Ba, Ca, Cu, Si, Na, Sr and Ti. The data on the metal concentrations of the black-water before and after change-over are partly consistent with the evidence from the metal content of the CRHs. Fe, Mg, Mn and K were all found to be higher in the 'old' black-water stream, consistent with the observation that these same elements have a higher tendency to leach out of char than other elements. One interpretation of the data is that the elements with the lower retention rates are those more readily leached-out of the biochar when it is applied to soils. (Beesley et al.'s (2010) results using a wood char do not appear to show the same properties as the CRHs. In their case, the biochar sorpbed Cd and Zn, but not As and Cu. We found, that the CRHs tend to sorp Cu more than Zn).

The Cation Exchange Capacity (CEC) varies from 44 to 110 cmol+kg^{-1}, generally higher than values reported for charcoal. The variation in the value of the CEC may be partly explained by the uncertain impact of the cooling water. This may also account for the variation in pH for five CRH biochar samples, from 7.79 to 9.97. Clearly, there is significant variability in the composition of the CRH due to the specificities of the gasification technology. This makes deriving an accurate estimate of the composition difficult. A further uncertainty is the variability in the char yield between reactors that was demonstrated in Table 10. This is a further possible explanation for the data on elemental concentrations above.

Particle size distribution

This was calculated by using successive sieves and is illustrated in Figure 19. Three quarters of the rice husk char has a particle size between 0.5 and 2 mm. Wood-based char samples produced in charcoal kilns and batch pyrolysis units typically have a larger particle-size, with 75-95% of particles having a size of > 2 mm. The impact of such particle size differences upon the properties of the biochar is not properly understood at present.

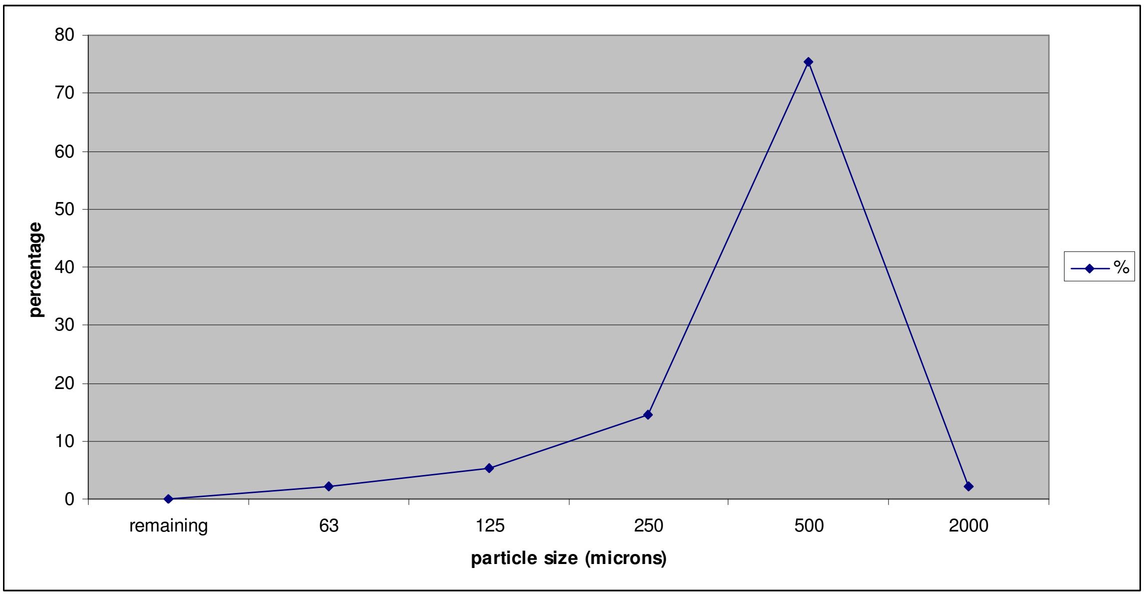


FIGURE 19: PARTICLE SIZE DISTRIBUTION OF THE CARBONISED RICE HUSK

1.4.2. Properties of Rice Husks, Rice Straw, CRHs and Carbonised Rice Straw Produced by IRRI's Experimental Gasifier

Table Appendix 2 presents data on the moisture content of rice straw; table 15 presents data on the composition of the four materials. Note that the low composition of carbon by mass in the case of the CRHs, suggests that the gasification process may have proceeded to smouldering combustion and the production of more rice husk ash than carbonized husks.

There is an expected accumulation of metals of c. 5 times in the CRH for certain elements such as Si, Fe and Ca (given the yield of c. 20%). Many other metals do accumulate in the CRH, but not as much as might be anticipated given the 20% yield. e.g. by 2 to 3 times. In other cases, metals appear to be lost from the system, though it is hard to know where they might have gone. There are very large increases (of c. 12 – 18 times) in the case of Fe and Al and it is possible that metals may have been introduced from the gasification equipment itself.

Material	Sample1	Sample2	Batch	code	C	N	K	P	Zn	S	Na	Mn	Mo	Al	Ca	Cu	Fe	Mg	Si	CEC
					%	%	%	%	Ppm	%	%	ppm	ppm	ppm	%	ppm	ppm	%	%	(me/100g)
Fresh RS	60910	61110	1B	RS1	37.8	1.59	1.86	0.16	27	0.17	0.03	279	1.30	203	0.36	9.0	400	0.20	7.2	
Fresh RS	60910	61110S	2B	RS2	39.1	1.44	1.66	0.13	27	0.17	0.04	168	0.75	276	0.35	6.9	365	0.21	6.6	
Fresh RS	60910	61110S	3B	RS3	40.2	1.78	1.94	0.15	29	0.21	0.03	45	0.38	206	0.39	8.9	252	0.28	5.5	
Fresh RH	61110H	60810	1B	RH1	38.1	0.58	0.48	0.05	13	0.04	0.01	139	0.94	81	0.05	2.4	196	0.05	8.7	
Fresh RH	61110H	60810	2B	RH2	38.2	0.51	0.47	0.04	12	0.04	0.01	139	0.75	85	0.05	2.1	197	0.04	8.9	
Fresh RH	61110H	60810	3B	RH3	38.7	0.53	0.48	0.05	13	0.04	0.01	141	0.81	107	0.05	2.1	210	0.05	8.7	
CRS	61110S	60910	1E	CRS1	10.7	0.39	4.32	0.58	84	0.35	0.10	340	1.90	1569	0.98	26.0	2020	0.68	32.1	
CRS	6410S	60910	2E	CRS2	13.0	0.47	4.42	0.49	134	0.32	0.17	449	4.10	3707	1.73	36.0	8655	0.72	29.7	
CRS	61110S	60910	3E	CRS3	11.4	0.45	4.34	0.50	201	0.27	0.13	411	1.80	2980	1.17	32.0	2919	0.75	29.8	
CRH	60810	61110H	1E	CRH1	1.0	0.02	0.74	0.14	28	0.05	0.04	175	1.90	1296	0.24	7.6	3612	0.09	44.0	
CRH	60810	61110H	2E	CRH2	1.1	0.02	0.69	0.14	22	0.04	0.04	182	1.70	1228	0.23	7.8	2885	0.08	44.1	
CRH	60810	61110H	3E	CRH3	1.0	0.02	0.62	0.14	20	0.04	0.04	177	1.60	1228	0.21	6.9	2468	0.08	44.2	

Table 15: Elemental concentrations of selected elements in samples from the testing of rice straw and husk gasification in an experimental batch gasifier at IRRI, June 2010. Tested were three samples of dry untreated rice straw and husk, and of carbonised rice straw and husk after gasification. We mixed two samples because the quantity for one sample was too small. All elements are given as weight percentage of the element, not the oxide

1.4.3. Properties of Char Produced from Sugarcane Trash, Maize Cobs and Wood by ARTI's Single-Barrel Pyrolysis Kiln

Table 16 provides information on the properties of the char produced from the two feedstocks - sugarcane trash and maize cobs - that were used in the ARTI field trials. For comparison purposes, data on char from the wood *Proposis jutiflora*, as produced in the ARTI single-barrel kiln, is also included, as well as information on the CRH used in the field trials in Cambodia.

Parameter	**Sugarcane Trash Charcoal**	**Maize cobs charcoal**	***Proposis jutiflora* Charcoal (produced by same process, for comparison)**	**Rice husk char (from Ankur gasifiers in Cambodia)**
pH	10.09	9.04	9.92	7.79
Moisture %	9.2	9.7	6.9	34
LOI %	79.1	61.2	96.3	42.2
Ash %	20.9	38.8	3.7	57.8
C (% dry weight)	64.5	52.5	87.4	28.7
H (% dry weight)	2.01	1.71	1.60	0.18
N (% dry weight)	1.38	0.58	0.77	0.65
S (% dry weight)	0.24	0.27	0.06	<0.03
CEC (cmol+/kg)	417.1	254.2	125.3	44.5
Exchangeable K (cmol+/kg)	502.8	134.0	189.2	36.4
Exchangeable Na (cmol+/kg)	57.0	63.4	37.5	1.5
Exchangeable Ca (cmol+/kg)	34.7	80.8	105.4	12.4
Exchangeable Mg (cmol+/kg)	37.6	30.9	8.9	12.8
USEPA 16 PAHs (mg/kg dry wt)	5.2	2.9	0.3	14.6
Al	863	4019	184	92.0
As	<2.8	<4.4	<2.1	<1.79
Be	<5.6	<8.9	<4.3	<3.59
Cd	<0.6	<0.9	<0.4	<0.36
Cr	<2.8	8.4	<2.1	<1.44
Cu	95.1	50.6	17.9	8.15
Fe	1665	5687	45.9	65.6
Pb	96.0	<2.7	9.7	2.62
Mn	29.0	169	8.7	135

Hg	<2.8	<4.4	<2.1	<1.79
Ni	6.23	14.66	1.70	<1.08
Si**	224	65.1	798	66.0
Ti	29.1	380	2.0	1.79
Zn	13.4	22.3	2.3	11.7
V	<2.8	27.7	<2.1	<1.79
Ba	47.1	20.3	6.0	19.3
Na	2996	1116	1238	76.1
Ca	5686	17049	8372	609
Mg	3460	5041	485	162
K	15639	3789	3095	595
Sr	63.4	77.5	111	1.87
B	2.08	19.10	7.99	5.83

TABLE 16: PROPERTIES OF THE BIOCHAR PRODUCED BY ARTI'S SINGLE-KILN PYROLYSIS UNIT FROM SUGARCANE TRASH, MAIZE COBS, *P.JUTIFLORA* AND (FOR COMPARISON) FROM RICE HUSKS (ANKUR GASIFIER)

The wood char has a typically low ash content, while sugarcane trash contains 21% ash and maize cobs 39%; this is reflected in lower carbon contents for sugarcane trash (65%) and maize cobs (53%) compared to wood char (87%). These quite large differences are important in terms of overall levels of carbon abatement. High levels of potentially useful minerals are found within the ash, as indicated in Table 16. Tests are currently being undertaken on the stability of the labile and recalcitrant carbon in the three char samples which will be completed in January 2011.

1.5. Scanning Electron Microscope Images of Char from Rice Husks, Sugarcane Trash and Maize Trash

An SEM image of rice husk is show in Figure 20, while the structure of a carbonised rice husk is show in Figures 21 and 22. It can be seen that there is a close similarity between the structure of the feedstock and the CRH, suggesting the recalcitrance of the silica shell.

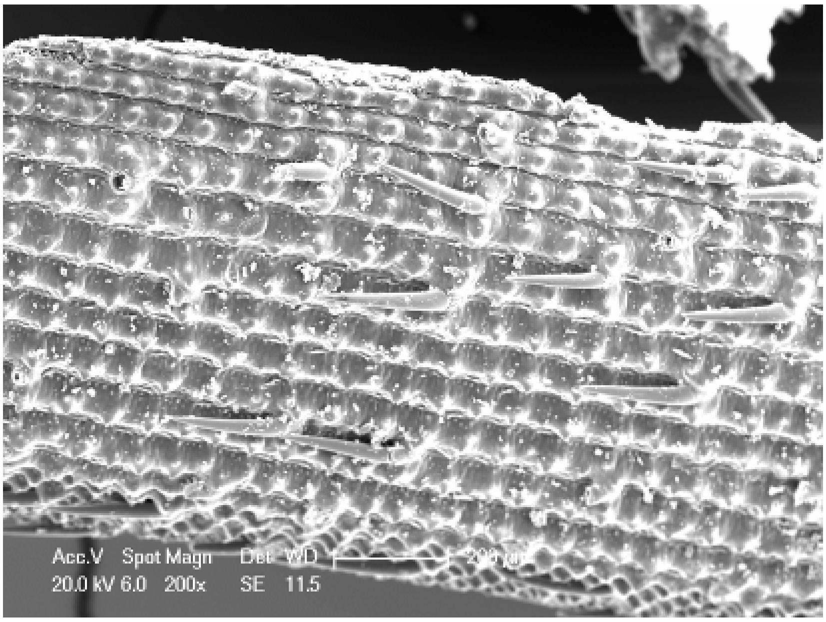


FIGURE 20: SEM OF A RICE HUSK SHOWING DENDATE RECTANGULAR UNITS AND HAIRS (COURTESY OF KYLE CROMBIE, UKBRC)

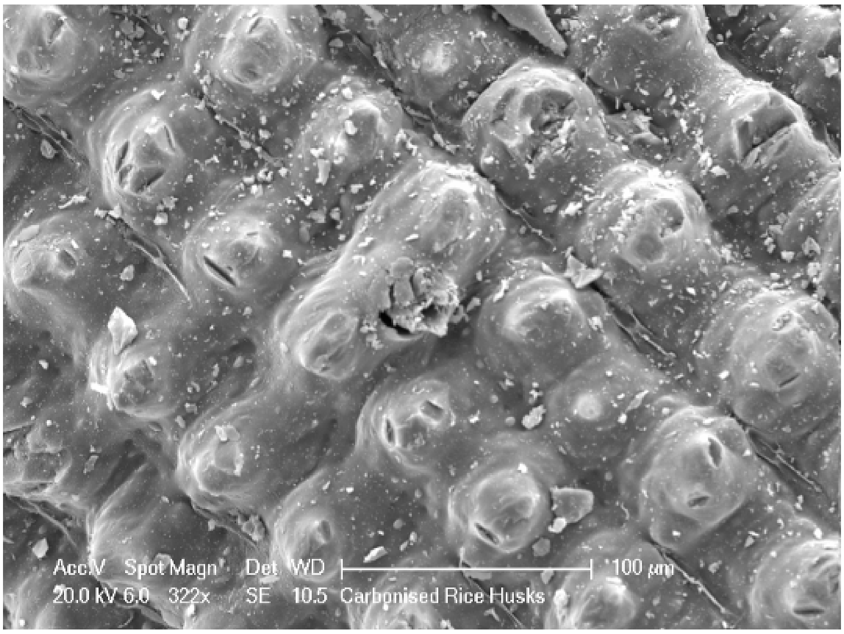


FIGURE 21: SEM DETAIL OF A CARBONISED RICE HUSK SHOWING THE LARGELY INTACT STRUCTURE OF THE EXTERNAL SILICA SHELL

The width of the rectangular units decreases during gasification by approximately 75%, less than might be expected from the weight reduction. The partial breakdown of the shell can be observed in Figure 22, but other images show more clearly the decomposition of the rice husks following gasification. Figure 22 shows what appears to be organic matter in the process of bubbling and volatilizing. Also evident are the macro-pores in the cross-section of the material.

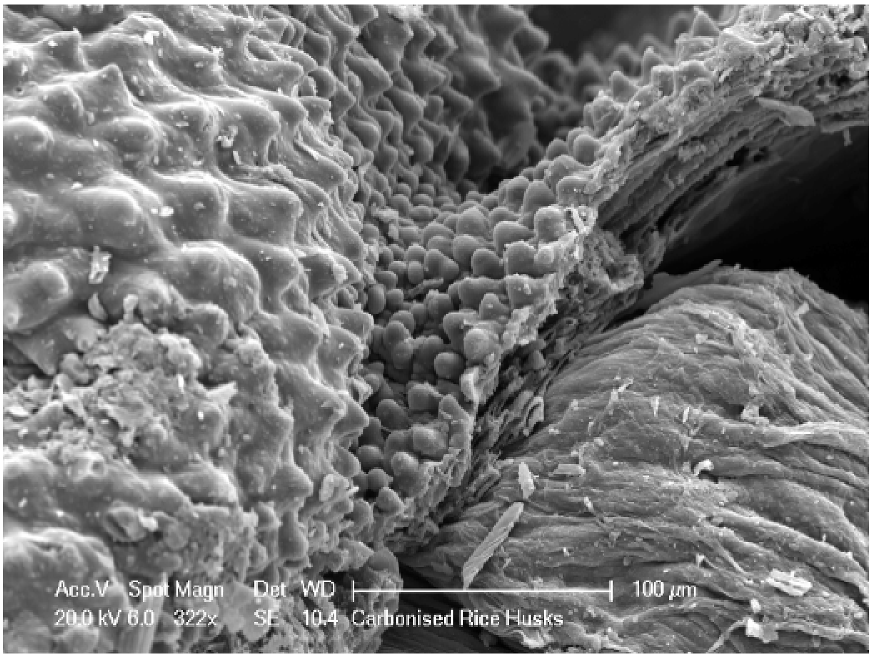


FIGURE 22: SEM OF CRHS SHOWING THE DECOMPOSITION OF THE ORGANIC MATTER

These pores are shown more clearly in Figure 23 where hollow-fibres are evident, some of which appear to have been partially filled with organic matter particles. Other images (not shown) illustrate that the CRH is a quite heterogeneous material, containing also meso- and micro-pores. It has not been possible to examine the sugarcane and maize cob char under the SEM in time to be included in this report. Images will be included on the project blog site in January 2011.

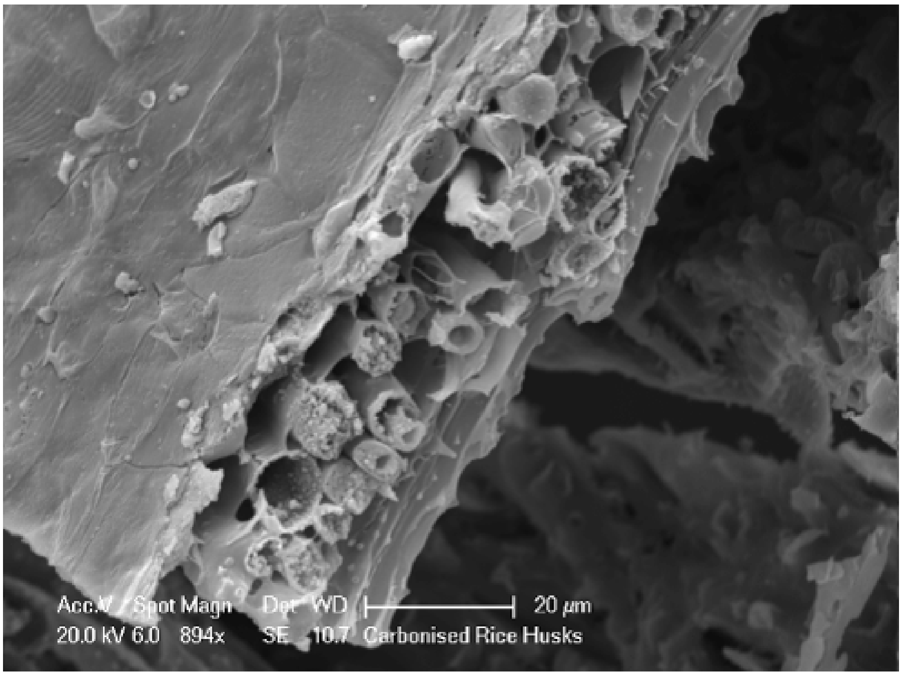


FIGURE 23: CROSS-SECTION OF CRH SHOWING THE PRESENCE OF MACRO-PORES

1.6. Potential Contamination within the CRH, Sugarcane Trash and Maize Cob Trash Biochar

There are two types of contamination in CRHs that need to be considered: potentially toxic elements (PTEs), in particular metals; and organic compounds. In order to evaluate contamination from PTEs, we have used the UK sewage sludge regulations which provide a maximum permissible concentration of PTE in soil in $mgkg^{-1}$ dry solid and a maximum permissible average annual rate of PTE addition over a ten year period ($kgha^{-1}$) (Department of Environment, 1996). No equivalent regulations are available for the Cambodian context and we have used the UK guidance in lieu of anything more appropriate. The values are pH dependent and we have used the lowest values where there is a choice to err on the side of caution. Likewise, we have used the highest values for the PTEs from the five CRH samples analysed. The analysis shows that the PTEs in the CRHs, and in the maize and sugarcane trash and wood char produced at ARTI, do not exceed the levels recommended by the UK government. The element which is closest to the threshold for CRHs is copper but even in this case it would be necessary to add 129 tonnes of CRH per hectare per year to exceed the threshold. Copper and lead are the two elements that come closest to being an issue for the sugarcane and maize cob char, but once again it would be necessary to be incorporate between 70 and 150 tonnes of char per ha per year to exceed the regulatory thresholds set in the UK.

The USEPA 16 PAHs were measured by using an accelerated solvent extraction (ASE) and the concentrations in CRHs were 15 to 104 $mgkg^{-1}$ and lower for the sugarcane and maize cob char (2.9 – 5.2 $mgkg^{-1}$). The detailed speciation of the PAHs in the single sample of sugarcane trash char, maize cob char and CRHs is shown in Table 17. Totals were calculated for the 16 PAHs in the case of four CRH samples, while individual concentrations were calculated for a single sample (which has a ∑ 16 PAH value of 35 $mgkg^{-1}$). Clearly, the CRH contain considerably more PAHs than the average UK soil, but against this it has to be recognised that adding 10 tonnes of CRH to soil only represents 0.25% of the soil mass to a depth of 23cm. Hence, even a very large biochar addition of $60tha^{-1}$ only represents 1.5% of the soil mass and the PAH concentrations in the CRH would be massively diluted (though could be concentrated on biochar particles in soil).

PAH (all in $mgkg^{-1}$)	CRH sample	Maize trash char	Sugarcane trash char	Eco-Soil Screening Levels (USEPA)	Maximum in product ($mgkg^{-1}$ under Flemish law)
USEPA 16 PAHs	35	5.2	2.9		
Naphthalene	10.41	2.33	1.37	29 - 100	2.3
1-Methylnaphthalene	1.77			29 - 100	
2-Methylnaphthalene	1.36			29 - 100	
Acenaphthylene	4.59	0.09	0.05	29 - 100	
Acenaphthene	0.81	0.11	0.03	29 - 100	
Fluorene	0.38	0.16	0.11	29 - 100	

Phenanthrene	7.63	0.57	0.26	29 - 100	0.9
Anthracene	1.21	<0.01	<0.01	29 - 100	
Fluoranthene	3.73	<0.01	<0.01	29 - 100	2.3
Pyrene	2.19	<0.01	<0.01	1.1 - 18	
Benzo(a)anthracene	0.21	<0.01	<0.01	1.1 - 18	0.68
Chrysene	0.39	<0.01	<0.01	1.1 - 18	1.7
Benzo(b)fluoranthene	0.01	<0.05	<0.05	1.1 - 18	2.3
Benzo(k)fluoranthene	0.06	<0.05	<0.05	1.1 - 18	2.3
Benzo(a)pyrene	0.08	<0.05	<0.05	1.1 – 18 0.15 (UK EA)	1.1
Indeno(1,2,3-cd)pyrene	<0.01	<0.05	<0.05	1.1 - 18	1.1
Dibenzo(a,h)anthracene	< 0.01	<0.05	<0.05	1.1 - 18	
Benzo(g,h,i)perylene	< 0.04	<0.05	<0.05	1.1 - 18	1.1

Table 17: Analysis of PAHs in carbonised rice husks, maize trash char, sugarcane trash char and comparison with some regulatory guidance on limits

It can be seen in Table 17 that for the USEPA Eco-SSLs (and for the one SSV for benzo(a)pyrene of the UK Environment Agency) all three biochar samples have acceptable PAH levels, with the one exception of pyrene in the CRH. The Flemish thresholds are more stringent and for three PAHs (naphthalene, phenanthrene and fluoranthene), the levels are too high in the CRH, but not in the maize cob and sugarcane trash char. The UK Environment Agency Soil Screening Values provide a threshold also for toluene (0.3 $mgkg^{-1}$), whereas the value for BETX for two samples of CRHs tested is considerably higher at 7 – 22 $mgkg^{-1}$. The same guidance provides numbers for several other chemicals, but notes that these SSVs are 'currently insufficiently reliable': naphthalene (0.0533 $mgkg^{-1}$, compared to 10.4 $mgkg^{-1}$ in the CRH sample), anthracene (0.02 $mgkg^{-1}$, compared to 1.21 $mgkg^{-1}$ in the CRH sample and a mean value of 0.256 $mgkg^{-1}$ in English soils and benzene (0.2 $mgkg^{-1}$) (Environment Agency, 2007). The problem with relying upon these numbers in assessing PAH levels in biochar is that: a) they are typically developed for contaminated soil amendments; b) they are not currently reliable; and c) they do not account for dilution effects arising from the fact that biochar addition is likely to be only a small percentage of total soil mass.

In summary, the whole issue of organic contaminants in biochar, and whether they may pose risks for soils and ecosystems, is highly uncertain at the current time; hence it is very difficult at present to define acceptable and safe levels of PAHs and other organic molecules in amendments to soil. The CRHs contains higher levels of potentially dangerous PAHs, but the extraction method used in this study is fairly 'aggressive' because of the high sorption properties of the biochar and there is a major question concerning whether biochar will act to retain PAHs in soils. Hence, bio-availability may be much lower than indicated by the values in Table 17. Beesley et al. (2010) found, for example, that bio-available PAHs were half of the 'totals' in contaminated soil, where biochar was used a soil amendment, probably due to sorption of PAHs into the biochar. The PAH and metal contents of the sugarcane and maize cob trash biochar are generally low and well within regulatory thresholds as shown in Table 16 and 17.

More research needs to be undertaken on the issue of potentially toxic compounds and appropriate methods developed for testing biochar samples.

1.7. Potential Health Issues Arising from Use of CRHs in Agricultural Scenarios

Another issue of potential concern is the health impacts arising from exposure to CRH, either in production or deployment. There are a range of possible concerns: silicosis (chronic, accelerated or acute), scleroderma, lupus, arthritis, tuberculosis and kidney disorders and cancer. The International Agency for Research on Cancer (IARC, 1997) undertook an exhaustive review of silica published in 1997 and concluded that:

> "There is sufficient evidence in humans for the carcinogenicity of inhaled crystalline silica in the form of quartz or cristobalite from occupational sources. There is inadequate evidence in humans for the carcinogenicity of amorphous silica" (page 210, IARC, 1997).

The UK Health and Safety Executive has likewise concluded that:

> "The weight of evidence from epidemiological studies, combined with evidence from animal studies and current understanding of the likely toxicological mechanisms underpinning the development of lung cancer in rats exposed to respirable crystalline silica (RCS), supports the view that RCS has the potential to cause lung cancer in humans". (page 5, HSE, 2003).

> "The balance of evidence suggests that heavy and prolonged occupational exposures to RCS can cause an increased risk of lung cancer. ….. of the very many studies available, most of which clearly demonstrate excess mortality and morbidity from silicosis, there are few studies that, taken in isolation, provide reasonably convincing evidence for an increase in lung cancer that can be attributed to RCS. This appears to support the view that RCS is a relatively weak carcinogen, otherwise the evidence for lung cancer would be far clearer and convincing than is the case. (page 5, HSE, 2003).

Crystalline silica is produced from amorphous silica at temperatures > 800^{o}C, hence might be anticipated to form during gasification. In order to explore this, X-ray diffraction (XRD) studies were conducted of both rice husk char and rice husk ash. It proved impossible to distinguish crystalline silica from graphite, however. Further tests are now being conducted to identify whether the rice husks exhibit crystallinity, but this cannot be done in the timescale of the present work.

Work Package 2: Identification of agricultural opportunities for incorporating biochar, in each partner country

Stakeholder Perspectives on Biochar Field Trials

From the first Indian workshop, the requirements for biochar to be effectively incorporated into an agricultural system with appropriate biochar trial management were discussed and the following key points noted.

- Knowledge of the land – what are the limiting factors (pH, nutrients, water availability)
- Feedstock should be available, no competing use, and also in the vicinity to reduce transport costs
- Successful trial plots should be conducted initially
- Even small scale trials can be useful
- A control plot where everything is the same apart from the absence of biochar needs to be used in all cases
- Testing different application rates and different biochars can yield different results

The workshop in Cambodia additionally discussed the use of feedstock as a compost versus thermochemical conversion of the feedstock to biochar. It was agreed that, in general, compost should be used as a method of fertilisation and also to increase the SOC in the soil. Biochar can be used as both a soil conditioner (but mainly to improve structural properties), and also to store carbon. Compost is often a source of methane - particularly where the biomass encounters anaerobic conditions, as is often the case in Cambodia due to water-logging of soils in the rainy season. Biochar is not a fertiliser, and should not be considered as one, although it does contain some useful nutrients. Both composting and biochar production are valid uses of organic waste, and should not be seen as competitors, but used rather in and for different situations and purposes.

The selection of the feedstock is also important: rice husk for example may not be a first choice for a compost feedstock, but is perhaps more suitable for biochar production. Where biochar already occurs as a by-product of another process (e.g. charcoal production) it can be used as a bulking agent for a compost, thus serving the purposes of increasing the amount of compost used, and providing carbon storage properties.

In India several voluntary groups and individual farmers were identified as already experimenting with biochar production and application in agriculture. One of the offshoots of these discussions and contacts has been the formation of The Society of Biochar Initiatives (TSBI) in India, with an objective of creating a network of biochar practitioners for knowledge and experience sharing.

Several practitioners of organic farming (some who had already used biochar and some for whom it was an entirely new topic) participated in the National Consultation on Biochar and Carbon Emission Reduction, organised in India, on November 22-23, 2010. In general, the organic farming community is very keen on exploring the use of biochar in addition to traditional organic fertilizers in the hope of increasing the efficacy of organic farming methods. The only issue of concern is the commercial value of charcoal as a fuel versus the financial benefit of its impact on agricultural yields.

Work Package 3: Organisation and Management of Field Trials

3.1. Pot and Field Trials in India

Analysis of the soils used in the pot and field trials is shown in Table 18.

	Parameter	Value
1	pH	7.42
2	Ele. Conductance	0.96 deci simen / m2
3	Fe	1.16 ppm
4.	Mn	0.21 ppm
5	Zn	0.93 ppm
6	Cu	1.18 ppm
7	Organic Carbon	0.56 %
8	Nitrogen	125 kg / ha
9	Phosphorus	69.52 kg / ha
10	Potassium	242 kg / ha
11	Sodium	1.96 mg / lit
12	Calcium	7.54 %

Table 18: Analysis of the soils used in the Indian pot and field trials

The soil type is Vertisol. Analysis shows it to be slightly alkaline. There will, therefore, be no benefits arising from pH moderation from the addition of biochar, since the char produced is strongly alkaline (see Table 16) and the plants do not require highly alkaline soils.

3.1.1. Field trials

The data for the entire trial is summarized in Table 18.

		Treatment	rep1	rep2	rep3	MEAN
Grain yield (kg)	IT1	Control	0.06	0.05	0.32	0.14
	IT2	20t	0.425	0.31	0.67	0.47
	IT3	40t	0.15	0.27	0.11	0.18
	IT4	60t	0.1	0.095	0.235	0.14
	IT5	80t	0.53	0.045	0.37	0.32

	IT6	20t+ Vermicompost	0.038	0.33	0.04	0.14
	IT7	Chemical Fertilizer	0.038	0.13	4.62	1.60
Fodder weight (kg)	IT1	Control	0.5	0.4	1.3	0.73
	IT2	20t	1.2	1	2	1.40
	IT3	40t	1	1.5	0.6	1.03
	IT4	60t	0.8	1	0.5	0.77
	IT5	80t	1.4	0.45	1.35	1.07
	IT6	20t+ Vermicompost	0.4	2	0.35	0.92
	IT7	Chemical Fertilizer	0.3	1	7	2.77
Cob weight (kg)	IT1	Control	0.08	0.06	0.4	0.18
	IT2	20t	0.55	0.41	0.85	0.60
	IT3	40t	0.21	0.35	0.15	0.24
	IT4	60t	0.15	0.12	0.35	0.21
	IT5	80t	0.7	0.07	0.5	0.42
	IT6	20t+ Vermicompost	0.05	0.42	0.05	0.17
	IT7	Chemical Fertilizer	0.05	0.18	0.57	0.27

TABLE 19: RESULTS FROM THE INDIAN FIELD TRIAL

Figure 24 shows the variation of the three measured parameters with biochar application levels, including the standard errors.

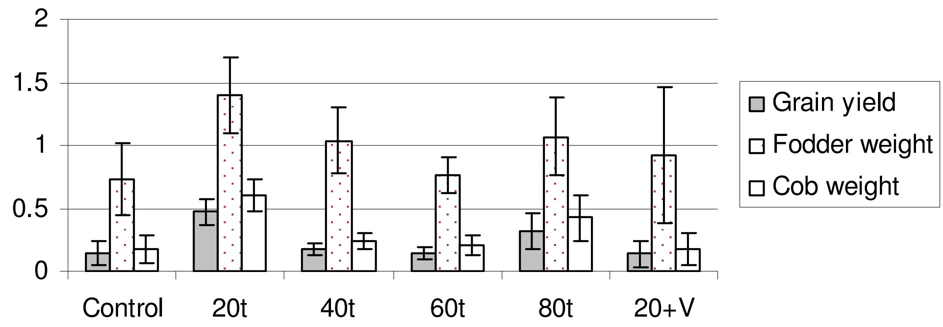


FIGURE 24: FIELD RESULTS INDIA (MAIZE): TONNES PER HECTARE VERSUS BIOCHAR APPLICATION LEVELS

The data from the IT6 and IT7 replicates showed a very high degree of variation and is considered to be anomalous. Hence, it has not been considered in the above analysis. However, the highest yield across the full data set was for one of the chemical fertilizer (IT7) replicates.

The results were analysed using ANOVA in SPSS (table 20) and it was found that there is no statistically significant difference in means between the treatments. However, when the 20tha^{-1} application alone was compared to the control (no treatment), there was clearer evidence of a relationship, in particular for the grain yield and cob weight variables (i.e. significant at 92% probability).

Variable	**All treatments Annova *p* value**	**T1 and T2 (Control and 20 t ha^{-1} biochar) Annova *p* value**
Grain yield	0.132	0.078
Fodder weight	0.445	0.186
Cob weight	0.136	0.068
Total biomass	0.299	0.137

TABLE 20: ANNOVA RESULTS FROM THE INDIAN FIELD TRIAL

The best result appears to occur at the 20 t ha^{-1} dose and there is some evidence (though not statistically representative) of a decrease in yield with application level. The addition of vermicompost does not appear to enhance the effects of the biochar addition, and might even have the opposite effect (indicating that more work is required to test the common view that compost + biochar combinations will be more advantageous (in terms of yields) than either soil amendment alone).

3.1.2 Pot trials

These trials were set up with the same treatments as in the field trials as well as a few additional treatments as described in Table 21. These were set up specifically to compare the effect of biochar with the effects of organic and chemical fertilizers. The results are shown in Table 22 and Figure 23. The individual replicate results are not available here, so the mean result for all replicates is shown. This means that, at present, we are unable to undertake statistical analysis of variance and establish significant difference.

Treatment No.	**Details**	**Visual Observations**
IPT1	Biochar 20 t ha^{-1}	Growth is good but not healthy
IPt2	Biochar 40 t ha^{-1}	Plant growth is lower as compared to treatment
IPT3	Biochar 60 t ha^{-1}	Low vigor
IPT4	Biochar 80 t ha^{-1}	very low vigor and showing some toxic effect on plant
IPT5	Biochar + Recommended chemical fertilizer	Very good growth and healthy plants as compared to above 4 treatments
IPT6	Biochar + Compost fertilizer	Good growth and vigor

IPT7	Bochar + Chemical fertilizer	Good growth but low vigor.
IPT8	Biochar + Vermicompost	Good growth and vigor as compared to treatment 1 to 4
IPT9	Chemical fertilizer recommended	Very good vigor
IPT10	Untreated control	Very poor growth
IPT11	Compost fertilizer	Good vigor
IPT12	Vermi compost	Good vigor

Biomass measurement data*

TABLE 21: DETAILS OF THE POT TRIALS UNDERTAKEN IN INDIA

Treatment No.	Fresh biomass weight in gm	Av plant height	Av no. of leaves per plant	Formation of cabbage	Av Root length per plant in cm
IPT1	220	22.5	11	nil	6.5
IPT2	70	15.0	12	nil	10.5
IPT3	30	17.5	7	nil	6.5
IPT4	40	19.0	8	nil	10.5
IPT5	220	19.0	17	2	11.5
IPT6	60	21.0	14	nil	6.5
IPT7	50	24.0	16	1	8.0
IPT8	30	20.0	10	nil	6.5
IPT9	250	25.5	15	1	12.0
IPT10	40	17.5	10	nil	8
IPT11	70	16.0	13	nil	11.5
IPT12	60	19.0	10	nil	8.5

TABLE 22: RESULTS FROM THE POT TRIALS

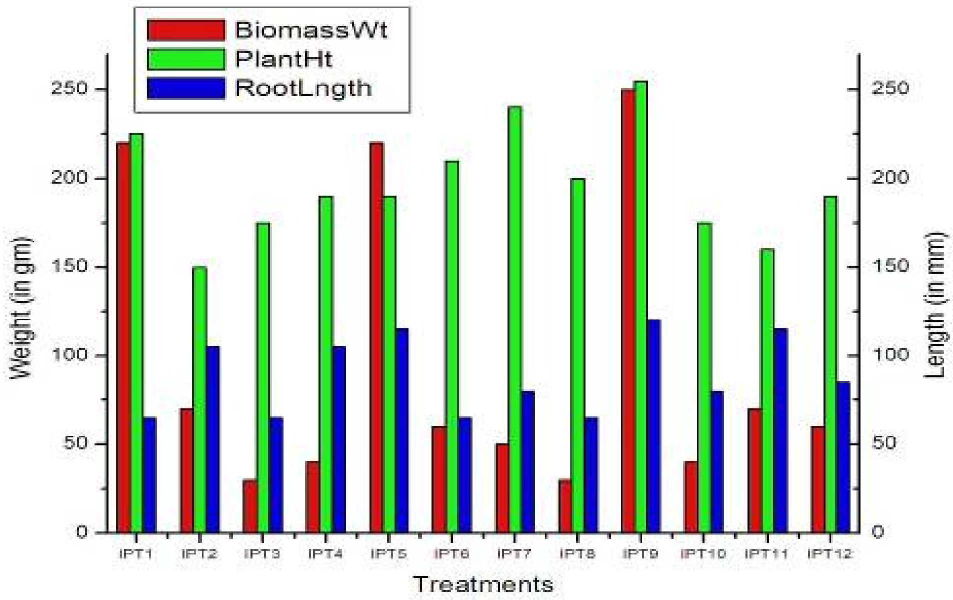


FIGURE 25: THE RESULTS FROM THE INDIAN POT TRIALS

As can be seen from Figure 25, the best growth was observed in IPT9, in which the addition is synthetic fertilizer at the recommended dose. However the next best data is observed in IPT1, in which 20 tha^{-1} of biochar was applied. A high yield was also obtained for IPT5, which combined biochar (20 tha^{-1}) with synthetic fertilizer (same dose as in IPT9). For all other treatments, including different levels of biochar addition as well as combining biochar with chemical or organic fertilizer, the growth (both in terms of biomass weight and plant height) was inferior to treatments IPT1, 5 and 9. Yields were still higher than the control (IPT10, no treatment) in most cases, though whether this difference is statistically significant or not is not presently known. The apparent reduction in yield with higher biochar application levels (40, 60 and 80 tha^{-1}) may indicate over-sorption of nutrients such as bio-available forms of N, though treatment IPT7 is somewhat difficult to interpret in that case since it combines 40tha^{-1} biochar with chemical fertilizer addition. Other pot trials research has shown a similar reduction in plant biomass with high biochar application levels (Ruysschaert and Nelissen, personal communication). As demonstrated in section 3.2.1., however, the Cambodian pot trials did not appear to show this effect – on the contrary, very high levels of biochar addition appeared to continue to have a beneficial impact on plant yield. The potential for over-sorption of plant-available nutrients by addition of too much biochar could be an important constraint that needs to be further investigated.

The pot trial results are more or less consistent with the results for farm trials. It is interesting that even though totally different soil structures and crops were involved, the general trend seem to be similar. This may suggest that the observed effect is due to the biochar addition rather than to another factor. It is important to note that soils in the Indian trials were somewhat alkaline, hence the pH moderation benefit of alkaline biochar on acidic soils would not have occurred.

3.2. Pot and Field Trials Undertaken in Cambodia

3.2.1. Controlled pot experiments

The soil and biochar analysis is provided in Table 23. The biochar has higher levels of exchangeable elements, and overall CEC which is almost double that of both soils. Note, however, that the interpretation of the CEC of biochar needs to be treated with some caution. The measured CEC may be primarily a consequence of the presence of ash in the char, rather than measuring exchangeability of the carbonaceous char surfaces. Furthermore, the CEC of biochar undergoes change once it is introduced into soil; consequently the starting value may not be indicative of the value over time. A number of trace metals are also provided in the biochar which have higher levels than in the soil. The alkaline properties of the char are significant since the soils are highly acidic which is often a limiting factor for crop growth.

Properties / Analyte	Unit	Soil (T1)	Soil plus sediment, compost, & EM (T3)	Biochar
pH	pH unit	4.77	5.39	7.79
Total C	%	0.48	0.03	28.7
Total H	%	0.03	0.02	0.18
Total N	%	0.3	0.15	0.65
Total S	%	0.0	0.0	<0.03
Exchangeable K	Cmol+/kg	1.02	1.73	36.4
Exchangeable Na	Cmol+/kg	11.38	11.98	1.5
Exchangeable Ca	Cmol+/kg	4.58	11.11	12.4
Exchangeable Mg	Cmol+/kg	1.70	3.09	12.8
CEC	Cmol+/kg	18.44	24.24	44.5
Al	Mg/kg	8929	9019	92.0
As	Mg/kg	< 1.53	<1.63	<1.79
Be	Mg/kg	< 3.06	< 3.26	<3.59
Cd	Mg/kg	<0.31	<0.33	<0.36
Cr	Mg/kg	11.0	10.9	<1.44
Cu	Mg/kg	2.02	2.25	8.15
Fe	Mg/kg	4485	4554	65.6
Pb	Mg/kg	5.10	5.39	2.62
Mn	Mg/kg	26.3	53.4	135
Hg	Mg/kg	< 1.53	< 1.63	<1.79
Ni	Mg/kg	3.48	3.92	<1.08
Si	Mg/kg	79.3	92.9	66.0
Ti	Mg/kg	42.4	42.9	1.79
Zn	Mg/kg	6.08	7.15	11.7
V	Mg/kg	19.0	17.9	<1.79
Ba	Mg/kg	14.9	42.3	19.3
Na	Mg/kg	42.3	48.5	76.1
Ca	Mg/kg	85.4	259	609
Mg	Mg/kg	165	226	162
K	Mg/kg	315	428	595
Sr	Mg/kg	2.20	2.74	1.87

B	Mg/kg	< 1.49	<1.54	5.83
USEPA ∑16 PAHs[a]	Mg/kg	-	-	14.6
Clay (<0.002 mm)	%	16.05	17.65	-
Fine silt (0.002-0.05 mm)*	%	18.15	21.95	-
Coarse silt (0.02-0.05 mm)	%	5.10	5.22	-
Fine sand (0.05-0.2 mm)	%	19.52	25.8	-
Coarse sand (0.2-2 mm)	%	41.47	28.89	-

[a] PAHs were not analysed in the soil since it was considered unlikely that there will be significant proportions to be found in the soil since it is not known to be a contaminated site.

TABLE 23: CHEMICAL AND PHYSICAL PROPERTIES OF BIOCHAR AND SOIL USED IN THE POT EXPERIMENT IN CAMBODIA

The experimental design is set out in Table 24 and the set-up is shown in Figure 26.

Treatment	**Name**	**Biochar ($g\ Kg^{-1}$)**	**Lake sediment ($g\ Kg^{-1}$)**	**Compost ($g\ Kg^{-1}$)**	**EM**
T1	Unimproved soil	0	0	0	X
T2	Unimproved with biochar	50	0	0	X
T3	Improved soil	0	12	25	Yes
T4	Improved with low biochar	25	12	25	Yes
T5	Improved with medium biochar	50	12	25	Yes
T6	Improved with high biochar	150	12	25	Yes

TABLE 24: TREATMENT DETAILS OF POT TRIALS IN CAMBODIA

In each treatment four replicates were used and a mean value, with standard errors, is reported in each cropping cycle (Figure 27, Table 25). However, in Trial 2, treatment one, only one plant cabbage plant survived, so this single value was used.

FIGURE 26: IMAGE OF THE CABBAGES GROWN IN DIFFERENT TREATMENTS IN POTS IN CAMBODIA

Biochar application to the soil results in an increase in plant productivity across all measured indicators. The effect of adding 20 t ha^{-1} biochar to unimproved soils is larger than where biochar is added to improved soils. Productivity increase was greatest for the highest biochar application rate (at 150 g kg^{-1}, T6). The difference between the treatments, as tested by one-way ANOVA, separately carried out on the unimproved and improved soil cases, is statistically significant for all treatments except for root weight, and number of leaves in the cabbage plants.

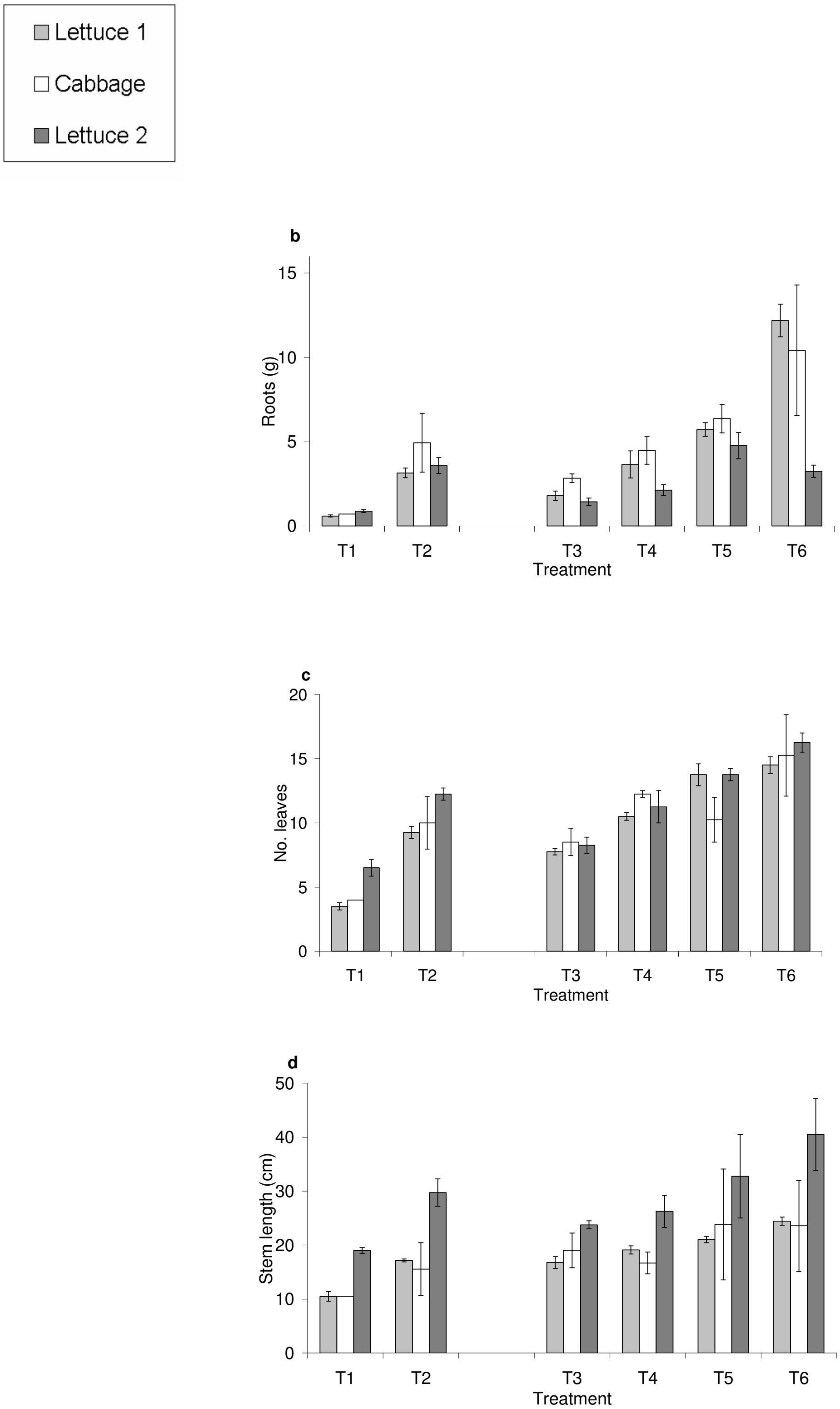


FIGURE 27: LETTUCE CROP 1, CABBAGE AND LETTUCE CROP 2 IN ALL TREATMENTS VALUES AND STANDARD ERROR GIVEN FOR A HARVEST (G) B ROOTS (G) C NUMBER OF LEAVES D STEM LENGTH (CM)

In each case, there was a significant difference in the variables measured in T1 and T2 - the control and soil amended with the lowest biochar application. In the improved soil, the addition of biochar results in significant positive differences, except in the case of the roots and number of leaves of the cabbage cycle.

Crop cycle	Variable	T1 & T2 (unimproved soil) Anova *p* value	Significance	T3, 4, 5 & 6 (improved soil) Anova *p* value	Significance
Lettuce 1	Harvest	0.000	Significant	0.000	Significant
Cabbage	Harvest	N/A[a]	-	0.042	Significant
Lettuce 2	Harvest	0.000	Significant	0.001	Significant
Lettuce 1	Root	0.000	Significant	0.001	Significant
Cabbage	Root	N/A[a]	-	0.101	Not significant
Lettuce 2	Root	0.001	Significant	0.002	Significant
Lettuce 1	No. leaves	0.000	Significant	0.000	Significant
Cabbage	No. leaves	N/A[b]	-	0.124	Not significant
Letuce 2	No. leaves	0.000	Significant	0.000	Significant
Lettuce 1	Stem length	0.000	Significant	0.000	Significant
Cabbage	Stem length	N/A[c]	-	0.040	Significant
Lettuce 2	Stem length	0.000	Significant	0.000	Significant

[a,b,c] Since there is only one value for T1 cabbage, analysis of variance could not be carried out

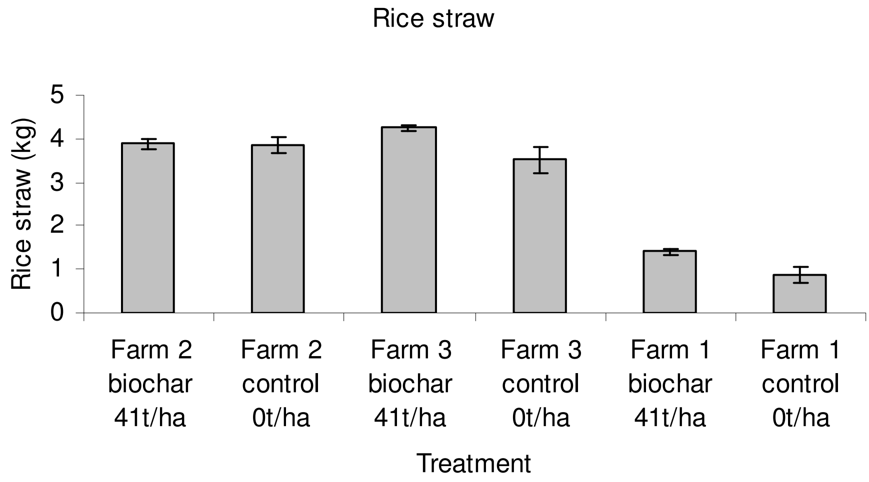
TABLE 25: THE IMPACT ON HARVEST, ROOTS, NUMBER OF LEAVES AND STEM LENGTH FROM BIOCHAR ADDITION TO LETTUCE AND CABBAGE, IN PLAIN AND IMPROVED SOIL.

A paper reporting on the results of the pot trials is being submitted to the journal *Plant and Soil*.

3.2.2. Managed rice biochar trials

As described in the methods sections, two treatments (with and without biochar) were used in three rice farms. In each farm, 3 replicates were tested. The results are shown in Figure 28 and Table 26. The presence of biochar in the soil increases both the paddy yield and the straw yield. In farm 3, there is a significant difference between the yield of paddy on the control and biochar amended plots (p = 0.033). In farm 1 there is a significant difference between the yield of straw with and without biochar (p = 0.042). The low yields of paddy and straw at farm 1 are explained by damage from rats which invaded the field. Farm 2 trials (unlike those at farm 1 and 3) used compost additions as well as biochar. The lack of response at farm 2 invites further research on the effectiveness (or otherwise) of combining biochar and organic amendments.

a)



b)

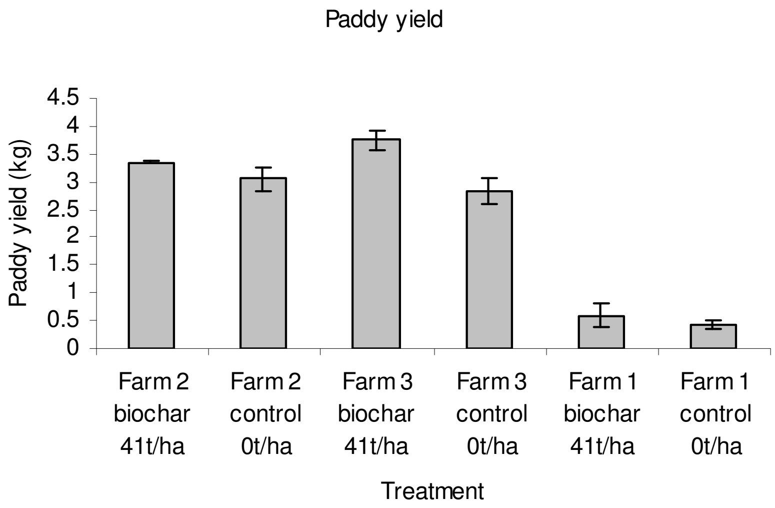


FIGURE 28: THE IMPACT OF CRHS ON A) RICE STRAW YIELD AND B) PADDY YIELD (ERROR BARS SHOWN)

	Mean paddy			Mean straw		
Farm	control (t ha^{-1})	with biochar (t ha^{-1})	*P*	control (t ha^{-1})	with biochar (t ha^{-1})	*P*
Farm 1	0.26	0.37	0.493 (n.s.)	0.54	0.88	0.042 (sig)
Farm 2	1.91	2.10	0.235 (n.s.)	2.42	2.43	0.955 (n.s.)
Farm 3	1.77	2.35	0.033 (sig)	2.20	2.65	0.076 (n.s.)

n.s. = not significant, sig = significant p≤0.05

TABLE 26: RESULTS FROM THE RICE TRIALS IN CAMBODIA

3.2.3. On farm biochar investigation

The farming calendar usually allows for a long period of time during which the soil is being prepared for planting of the next crop; at these times, the biochar could be added. At most farms visited, the land was ploughed by oxen three times before the crop was planted. Biochar can be added by the same methods, and at the same time as, other soil incorporations including compost and manure, which are used commonly by farmers. Because of the lack of replications in these on-farm trials, and / or the primitive methods of recording data, findings can be treated as anecdotal evidence only. Nevertheless, the data provide a preliminary insight into the effects of biochar upon crop yields. At the minimum, the encouraging data suggests that further research on the effects of biochar upon vegetable cultivation in Cambodia (and other countries) is well worth investigating further in replicated trials. Notable yield increases following biochar addition occurred in the case of cucumber cultivation (Figure 29). Five treatments were used for 23 m long raised beds (1 m wide) of cucumbers which were planted on 13.02.10 and grown for 42 days until harvest began on 27.03.10 for 20 days. Other soil improvements – fertilizers and manure - were added, and the cucumbers were regularly weeded and watered. An increase in yield of cucumbers can be seen from addition of biochar up to 30.3 t ha^{-1}; however at 60.7 t ha^{-1} the same yield (132% increase from the control) is seen. It is possible that there is a limiting factor which is causing this to be the maximum yield in these growth conditions.

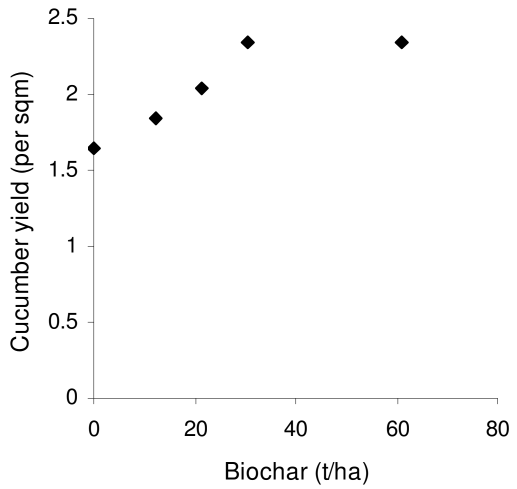


FIGURE 29: IMPACT OF BIOCHAR AMENDED SOILS ON CUCUMBER

Biochar was incorporated into lettuce beds at the Sangkheum centre school and orphanage, in their vegetable garden (Figure 30). Manure and EM were added to these plots, which were hand watered. The land had previously been used for vegetable growing. Two treatments (7 square meter) rows were used for the 'with' and 'without' biochar treatments. The results show that the plots with biochar had an increase in all of the indicators of growth (root, and above ground biomass).

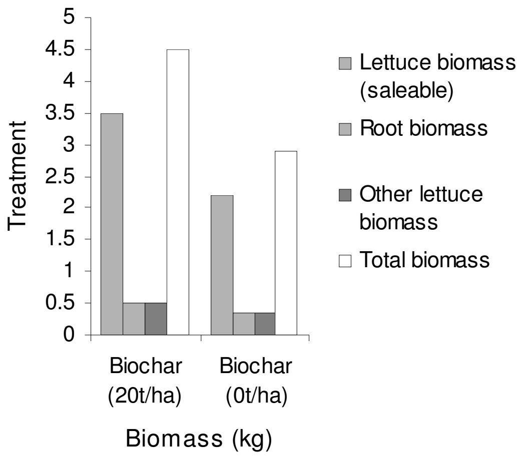


FIGURE 30: IMPACT OF BIOCHAR ON LETTUCE

3.2.4. Conclusions from Cambodian Field Trials

The field trials in Cambodia provide encouraging evidence of the impacts of biochar upon rice grain and straw yields (in replicated trials) and upon vegetable yields (non-replicated). Not all the rice trials did illustrate yield improvements, however, for reasons that are not currently understood. Furthermore, the CRH addition was quite high at c. 40 tha^{-1}: as we saw in the Indian field trials, lower application levels may produce a larger effect upon yield. In future work, it is important to test out lower additions of CRHs (e.g. 5, 10 and 20 tha^{-1} levels) and to include replication in rice and horticultural field trials.

3.3. The Philippines

Agricultural trials had already been carried out by IRRI before the project and some of the results clearly indicated beneficial effects of biochar. It was, *inter alia*, the experience of these trials that was used to plan the trials in India and Cambodia as a part of this project. Analysis and collation of the data collected in the previous projects was carried out during the project period, and two publications have resulted from the same. The summary of results from the field trials is presented below from a MS in preparation for the journal *Field Crops Research* entitled 'The effects and fate of black carbon from rice residues in rice-based systems' by Haefele SM, Knoblauch C, Konboon Y, Wongboon W, Amarante S, Maarifat AA

Abstract: Rice residues constitute a huge and valuable resource, but actual residue management practices do not use their potential adequately and often even cause negative environmental consequences. Bioenergy and biochar could offer new ways to manage and use rice residues, but the fate and effect of biochar in rice production systems has not been studied before. To address these issues, our study intended to i) examine the effect of biochar from rice husks on soil characteristics in a range of different rice soils, ii) investigate the stability of carbonized rice residues under the special conditions of different rice-based systems, and iii) test the agronomic effect of carbonized rice residues applications. Field testing of the effect of carbonized rice residues on rice growth and

soil characteristics was conducted in three different environments and for three to six cropping seasons. The results of our study indicate that black carbon amendments from carbonized rice residues can improve poor soils but may have little effect on fertile soils. No significant effect on plant nutrition could be detected with exception of, in some cases, slightly higher K and Si uptake in the biochar treatments. The applied biochar from rice residues appeared to be relatively stable in various soils and rice environments, but seemed to move down in the soil profile. The speed of the vertical transport was depenent on soil characteristics. We concluded that biochar can improve especially poor rice soils and provides an option to reduce greenhouse gas emissions and to sequester carbon in rice-based systems.

3.4. Comparison of Trials

The results from pot and field trials in Cambodia and India, and those previously undertaken in the Philippines, illustrate quite a divergence in response. This is in many ways consistent with the wide scatter of results illustrated in Figure 3. We have used different biochar types (CRHs, a mixture of corn cob and sugarcane trash char; the previous rice trials undertaken by IRRI are likely to have used CRHs with quite different properties from the gasifier CRHs used in BIOCHARM). The soils have also been quite diverse and a range of crops have been examined. The Cambodian trials gave better results in terms of yield increases than the Indian trials. It is not known why high biochar application levels in the Indian trials may have reduced yields whereas equally high applications in the Cambodian trials did not appear to do so and, in some cases, actually increased yields. Could this be due to a higher sorption potential in the case of the chars produced by ARTI in India compared to the sorption potential of CRHs from gasifiers? Is the slight alkalinity of the Indian soils a possible reason why biochar addition is less effective than where biochar is added to acidic soils? It is also perhaps significant to note that the density of CRH is higher than the density of the char produced from light weight agricultural waste. Thus, there was a difference in the volume of char involved in the same mass dosage in the two countries. Due to the high volume of the biochar used in India it was quite difficult to properly incorporate the char into the topsoil for the Indian trials. The significance of the (very different) methods of production upon the properties of the char is also not currently known.

Another curious difference is that between IRRI's previous work on CRHs in irrigated and rain-fed rice and the results reported here. IRRI's previous work suggested that CRHs had yield benefits when incorporated into poor quality rain-fed soils, possibly due to the water retention properties of CRHs. The results reported here suggest a benefit for rice yield even in irrigated soils, though not consistently. Clearly, much more work needs to be done to tease-out the influence of competing variables upon the plant and soil response to biochar additions.

Work Package 4: Examination of organizational and financial models for making biochar cost-effective and implementable at multiple sites in partner countries, including Life Cycle Assessment.

4.1. Life Cycle Assessment (LCA)

LCA is a technique which can be used for calculating the net carbon dioxide equivalent (CO_2(e)) abatement arising from a given option and comparing it with the same for other options for use of a feedstock, management of a system, use of capital, etc. We have used LCA here to estimate the overall carbon abatement arising from the use of CRHs compared to other alternative options for use of rice husks. The LCA undertaken in this study by Simon Shackley, University of Edinburgh, has been supported by independent and more detailed LCA work undertaken by John Field and Paul Tanger at Colorado State University and Stephan Haefele at IRRI.

4.1.1. Labile Carbon Content and Long-term Stability of the CRH Biochar

The super-labile and labile carbon content of biochar refers to the fraction of carbon which is rapidly lost through microbial decomposition and mineralised to CO_2 (see figure 1). The labile content of the CRH was measured by using an inoculation technique, the description of which is being published separately by two of the current authors (Cross and Sohi, forthcoming). The labile content is c. 0.36% of the carbon fraction. The recalcitrant carbon fraction refers to that proportion which is stable and resists microbial decomposition in the long-term (decadal to centurial). The recalcitrant fraction has been measured by an accelerated ageing technique, the details of which will also be published separately. The preliminary method used suggests that 7 % of the carbon in the biochar is unstable in the long-term (the time period of relevance for climate change). Therefore the recalcitrant fraction is c. 92%.

This compares reasonably closely to the incubation experiments using CRHs undertaken by Knoblauch et al. over several years of 4.4 to 8.5% loss of carbon in the fresh biochar (aerobic and anerobic conditions respectively). However, the samples in the Knoblauch et al. study might have been expected to have demonstrated lower % of carbon reduction, because they were not subject to accelerated ageing. This might be due to differences in the samples, possibly related to the method of manufacture. (Knoblauch et al.'s samples were produced in a much less controlled fashion than the CRH that are obtained from the gasifier). It is also interesting that decomposition is greater under anerobic conditions; could this suggest that anerobic bacteria might be more effective at breaking down biochar than bacteria in aerobic conditions?

Expressed in terms of equation 1 in section 1,

CSF for CRH = 1 – 0.0036 – 0.07 = 0.926.

For one tonne of rice husks, the CO_{2fix} is therefore 1 x 0.35 x 0.35 x 0.926 = 0.1134 x 3.667 =- 0.416 tCO_2t^{-1} feedstock for a 35% char yield.

4.1.2. Estimate of the Net Carbon Dioxide Equivalent Abatement Across the Life-Cycle (University of Edinburgh estimate)

Table 27 presents the net carbon abatement results for burning of rice husks in fields, for gasification-biochar, for aerobic decomposition and a mixture of aerobic and anaerobic decomposition in field. A simple decay function is used to simulate the decomposition of rice husks added to field. Approximately 10% of biomass carbon applied to flooded rice fields is emitted as methane (Knoblauch et al. 2010). For every 1 tonne of applied biomass (straw or rice husks) with a C concentration of 40% (determined for oven dry straw) about 40kg of carbon is converted into methane, producing 53 kg of CH_4 (ibid.) This corresponds to 1,219 kg CO_2 per tonne straw / husk. The rest of the carbon is assumed to decompose aerobically. Biomass replacement is the assumption here, since the rice husk is a residue from agricultural systems and it can be assumed that rice will continue to be cultivated at similar levels in future years.

Indicator	***Burning in field***	***Gasification - biochar (with electricity generation)***	***Direct incorporation of rice husks into field – aerobic decomposition***[2]	***Direct incorporation of rice husks into field – anaerobic + aerobic decomposition*** [3]
Starting feedstock mass (t)	1	1	1	1
Carbon content at start (t)	0.38	0.38	0.38	0.38
C content at end (stabilised) (t)	0.0114[1]	0.1095	Yr. 0: 0.38 Yr. 1: 0.14 Yr. 2: 0.05 Yr. 3: 0.02 Yr. 4: 0.007	Yr. 0: 0.34 Yr. 1: 0.13 Yr. 2: 0.05 Yr. 3: 0.02 Yr. 4: 0.006
$CO_{2fix(100)}$ (tCO_2t^{-1})	0.042	0.416	0.026	0.022
CO_{2av} - Avoided emissions (replacement of fossil fuels)				
Avoided diesel per hour (litres)		23		0
Avoided CO_2 per hour		61		
Rice husk consumption rate per hour		120 kg[4]		

CO_{2av} (tCO_2t^{-1})	0	0.5	0	0
Carbon emission factor: 2.6391 kg CO_2 per litre (diesel)				
CO_{2rel} - CO_2 released by biomass processing				
CO_{2rel} (tCt^{-1})	0.3686	0.2705	0.373	0.334
CO_{2rel} (tCO_2t^{-1})	1.35	0.99	1.38	1.23
Total CO_2 abatement per tonne feedstock (t) assuming no biomass replacement				
CO_{2na} (tCO_2t^{-1})	- 1.31	- 0.07	-1.35	-1.21
Total CO_2 abatement per tonne feedstock (t) assuming biomass replacement				
CO_{2na} (tCO_2t^{-1})	- 1.31	0.92	-1.35	-1.21
CO_2 abatement from decomposition of biomass to methane assuming 40kg of carbon is converted into 53kg of methane (assuming a GWP for CH_4 of 23)				
CO_2 (CH_4) (tCO_2t^{-1})			0	-1.219
Total CO_2 abatement per tonne feedstock (t)				
CO_2 total (tCO_2t^{-1})			0	-2.43

TABLE 27: ASSESSMENT OF CARBON ABATEMENT AND EMISSIONS ASSOCIATED WITH KEY LIFE-CYCLE STAGES OF THE GASIFICATION-BIOCHAR SYSTEM

1. Bronzeoak, 2003
2. Assumes an exponential decay function with a decay constant of 1.0
3. Assumes an exponential decay function with a decay constant of 0.75
4. Equates with information from Ankur that 5kg of rice husk are used to replace 1 litre of diesel [4].

Hence, the total net carbon abatement from rice husk gasification (assuming biomass replacement) is 0.92 tCO_2t^{-1}. This compares to an emission of between 1.31 and 1.35 tCO_2t^{-1} for burning and aerobic decomposition respectively, and of 2.43 tCO_2t^{-1} where rice husks are added to irrigated paddy fields. Where rice husks are used as a fuel, e.g. in brick factories or combustion for bioelectricity, they can be considered to be effectively carbon neutral. Hence, compared to alternative uses of the rice husks, the gasification-char option results in net carbon equivalent abatement of between 0.92 tCO_2t^{-1} (husks as a fuel), 2.22 tCO_2t^{-1} (husks burnt or aerobic decomposition) and 3.35 tCO_2t^{-1} (anaerobic decomposition). Assuming an average use of 4000 tonnes of rice husks per gasifier per year, and 35 operational gasifiers, this amounts to 30,800 tCO_2 eq. for the existing fleet (against a baseline of burning without energy recovery or aerobic decomposition). With a nominal carbon price of \$10 $tCO2^{-1}$, this carbon abatement could be worth \$300K. Given that there are c. 0.8 – 1.3 million tonnes of rice husks in Cambodia, the theoretical carbon equivalent abatement from use of rice husks amounts to c. 1 to 3 million tCO_2 equivalent depending on the baseline selected.

The upstream emissions in producing and transporting the feedstock have been omitted from the LCA (given that the husks are very low value relative to the rice grain itself). We have used an overly-simple method for calculating the avoided carbon emissions associated with use of the rice husks – namely, we have used data from SME on the replacement of diesel fuel and worked out the avoided CO_2 emissions. This method may not fully account for process-based emissions. For example, tar that is produced during the process is collected and burnt, hence generating additional carbon equivalent emissions. Upstream emissions associated with construction of the plant have also not been accounted for. We also have not accounted for transport emissions associated with movement of the rice char from the factory to the field. This is likely to be low, however, because suitable agricultural locations are very likely to be situated close to rice husk gasifiers given the highly rural character of Cambodia. If we assumed a 25km round trip, and a CEF of 0.272 $kgCO_2km^{-1}$ for a 3.25 tonne diesel-fuelled vehicle, this would only be c. 3.5 $kgCO_2^{-1}$ per tonne char.

On the other hand we have not included some potentially important additional carbon abatement arising from the inclusion of biochar in soils arising from the priming of soil organic carbon in soils. There may also be some suppression of other soil GHG flux (nitrous oxide or methane emissions) arising from biochar addition but we have not attempted to include these due to uncertainty. The field trials are being undertaken with subsistence farmers who largely do not use synthetic fertilisers, which tend to be the largest source of N_2O (although organic amendments do also generate some GHGs). There is a high degree of uncertainty associated with the indirect impacts of biochar in soils, with estimates in the literature ranging from zero to 40% of the overall CO_2 eq. abatement (Shackley et. al, 2011). Without empirical studies of the impacts of the CRHs upon the specific soils in Cambodia and under typical agricultural management practices, we decided that it would be preferable to leave out the indirect impacts.

The net carbon abatement of CRH at 0.9 tCO_2t^{-1} feedstock is similar to the equivalent value obtained in other studies of biochar, e.g. Hammond et al (2011) at 1 to 1.4 tCO_2t^{-1} and Roberts et al. (2010) at 0.8 tCO_2t^{-1} for a range of feedstocks. Those studies have assumed pyrolysis as the thermochemical conversion technology, rather than gasification. As we noted above, the gasification of rice husks shares some similarities with pyrolysis, this being due to the shielding of the carbon matter by the silica in the rice husks and the overall carbon conservation is c. 35% compared to c. 50% in slow pyrolysis and c. 2 - 10% in typical gasification. The CRHs are also high in silica, hence have a lower C content than most forms of biochar (which range from 60 – 80% C). As a consequence, the contribution of the stabilised C in the char to the overall net C abatement is lower than in many pyrolysis-biochar systems (PBS) (but the generation of renewable energy is more efficient than is assumed for many pyrolysis technologies). Therefore, the contribution of the offset carbon emissions from bioenergy generation is higher for the GBS than fo the PBS.

4.1.3. Net Carbon Dioxide Equivalent Abatement (University of Colorado estimate)

The University of Colorado team was able to collect a wide range of specific process data which allowed a more detailed estimate of the net CO_2(e) abatement than the estimate above, which relied upon more generic information from the equipment manufacturer and SME Renewables. The UoC team were also able to include the upstream GHG emissions in their calculations and also took account of the global warming potential of Products of Incomplete Combustion (PIC) arising from biomass burning in field. Field trial and incubation study results from IRRI were also drawn upon which allowed more detailed and empirical analysis of decomposition of rice husks and CRHs when incorporated to soil (rather than relying upon a generic model as in 4.1.2).

Figure 31 shows the preliminary results of an evaluation of the net greenhouse gas emissions per ton of rice husk fed to the gasifier. The calculations take into account capital embodied emissions (based on the Indian industrial intensity in kg CO_2eq/INR), processing emissions (energy needed to transport the feed stock 25 km to run the gasifier), carbon sequestration from husk char applied to soils, avoided CO_2 emissions from diesel not needed to run the rice mill, and avoided baseline emissions (the baseline emission were calculated based on the observed mix of uses like open air storage, open field burning, firing in a brick kiln, and application in rice fields). The resulting balance indicates that using one ton husk in the gasifiers actually saves emissions of one ton of CO_2 equivalents. Not yet taken into account in this calculation are Particulates of Incomplete Combustion (PICs) emissions of any process involved because we did not have any measurements on them. The result shows close similarity to the findings of 4.1.2. and the convergence of the result provides reassurance that it is reasonably robust.

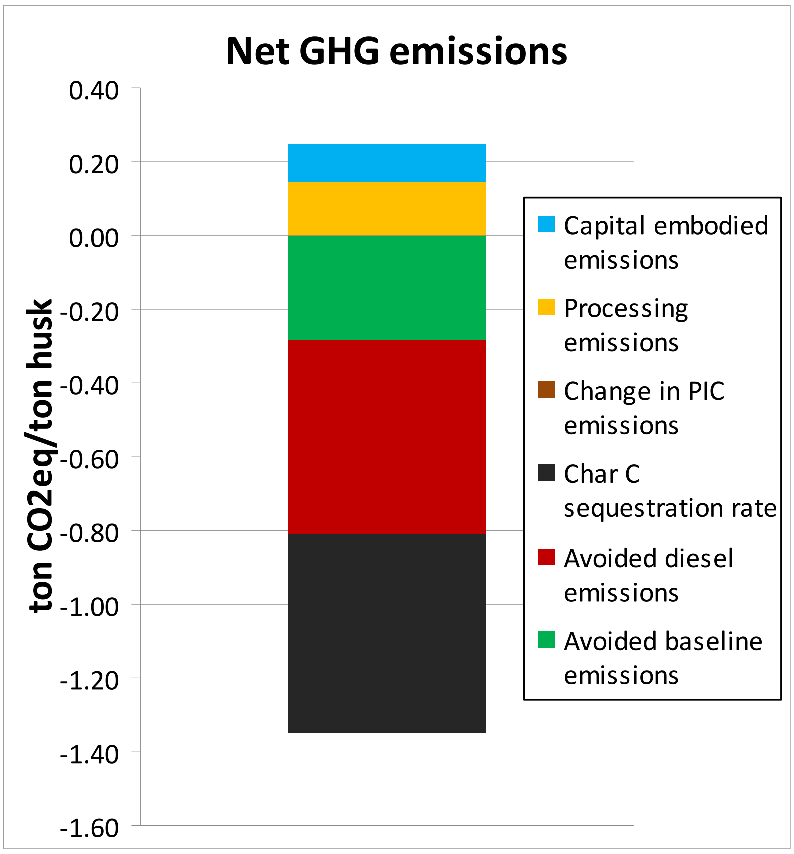


FIGURE 31: ESTIMATED NET GREENHOUSE GAS EMISSIONS PER TON OF RICE HUSK USED IN A GASIFIER BASED ON THE OBSERVED VALUES FROM ALL GASIFIER SITES SURVEYED (SEE TABLE 9).

The values thus estimated for the net greenhouse gas emissions were then used to estimate the GHG fluxes for different scenarios of a rice system production system with a 5 t grain yield per hectare (this means also 5 t ha^{-1} straw and 1 t ha^{-1} roots) according to Knoblauch et al., (2010). The different scenarios were 1) Incorporation of all residues in the soil with subsequent flooding, 2) Open burning in the field of most of the straw and the rice husks, and 3) a bioenergy/biochar system using a gasifier and gasifying all husks and most straw (though gasification of straw is currently not readily achievable).

The resulting gross GHG fluxes as well as the net GHG balance (after subtraction of the CO_2 neutral emissions) are shown in Figure 32. This analysis indicates that the gasification-biochar system has by far the lowest GHG emissions and that residue incorporation has the highest GHG emissions. This analysis does take estimated PIC emissions into account (based on literature values) but might still underestimate the CH_4 emissions of residue burning.

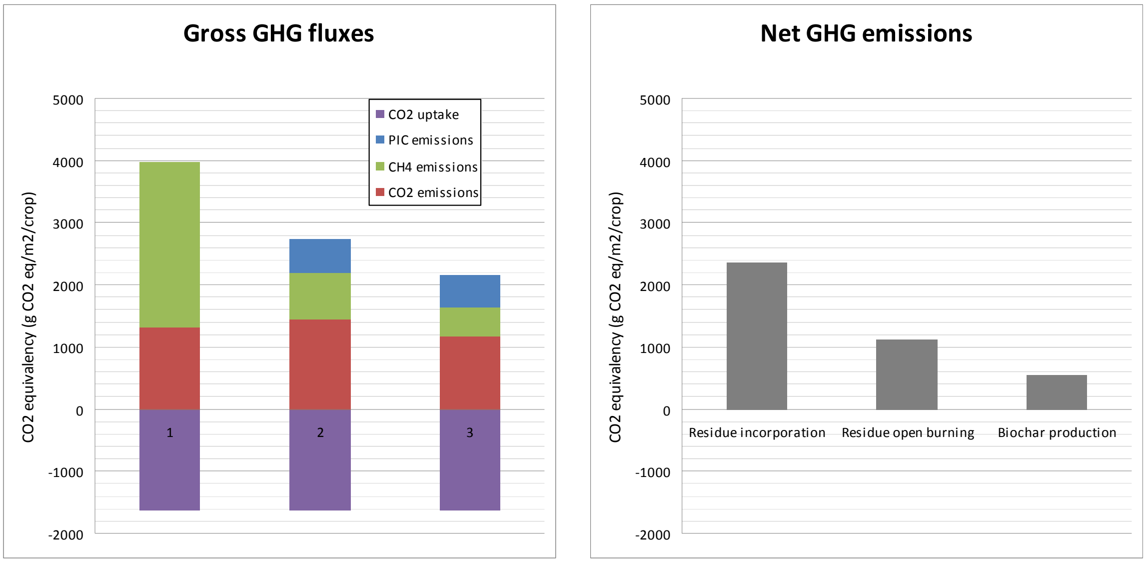


Figure 32: Estimated gross GHG fluxes (in (g CO2 eq/m^{2}crop)) as well as the net GHG balance (after subtraction of the CO_2 neutral emissions) for a paddy rice system with a grain yield of 5 t ha^{-1}.

4.2. Financial Viability of Gasification-Biochar Systems

The rapid adoption in Cambodia in rice mills and ice making factories strongly suggests that they are an attractive investment and enjoy a good return on investment. The UoC work on the economic viability supports this conclusion (see Table 11 and 12). In that sense, the CRHs are a free by-, or waste-product, depending upon whether a market exists for their use. Some mills have succeeded in selling CRHs to farmers at a price of 300 - 400 riel per 25kg bag, or c. \$3-4 per tonne (see Figure 33 for an example of CRHs being utilized locally).

Conclusive results from field trials in situ are not yet available, but we can use the evidence from yield responses to rice in 2010 field trials which indicated a response of between 1 and 3.5% increase in yield per tonne of CRH addition. If we assume a value of \$250 per tonne of unmilled paddy rice, then the value of the CRH is between \$4 and \$14 per tonne. This assumes zero purchase cost and does not take account of transport and application costs. If we assume a low transport and application cost of c. \$1 t^{-1}, then the value of the CRH range from \$3 to \$13 t^{-1}. If the farmer were to pay \$3-4 per tonne, then, at the lower end of the 'value-range' there would be little gain in adding

CRH to irrigated rice fields. On the other hand, at the higher end of the value-range, it is definitely work adding the CRH.

FIGURE 33: CARBONISED RICE HUSKS (CRHS) FROM A GASIFICATION UNIT IN AN ICE FACTORY BEING COLLECTED IN SIEM REAP, CAMBODIA.

A further possible revenue stream is from sale of carbon credits under the Clean Development Mechanism (CDM) or the Voluntary Carbon Market (VCM) – both are speculative at present because biochar is not currently included within these mechanisms. Assuming a carbon price of $10 per tonne CO_2, the value of a tonne of CRH is a product of price CO_2 t^{-1}, 1/char yield, and total CO_2 abatement t^{-1} feedstock. I.e. 10 x 1/0.35 x 0.92 = c. $26 t^{-1} CRH. (Note that this value would be c. $12 t^{-1} CRH if only the stabilised carbon in the char is accounted for and the avoided fossil fuel emissions not included).

If a baseline of burning or aerobic or anerobic decomposition were accepted, then the value could be significantly greater – from $37 t^{-1} to as high as $69 t^{-1}. Hence, a 7.5 t ha^{-1} application rate could generate an income of $195 ha^{-1} ($517 ha^{-1} for an avoided anaerobic decomposition baseline), compared to the agronomic value of the CRH of c. $22 - 97 ha^{-1}. The total value of the CRH is between $29 t^{-1} and $39 t^{-1} CRH ($82 t^{-1} for an avoided anaerobic decomposition baseline) (or $15 to $25 t^{-1} CRH where only the stabilised carbon in the CRH is accounted for). Potentially, therefore, the CRHs can be a significant addition to farm incomes through improving yields and especially if a carbon value for the CRH could be realised.

Where the CRHs are given away for free or at a very low cost, the overall effect could be to bring income to subsistence farmers. CRHs could increase in cost, however, as gasifier operators come to realise their value to farmers. Commercial producers could buy-up the majority of the supply, thereby denying the subsistence farmers the opportunity to benefit from the availability of CRHs. Copy-cat gasifiers using locally available biomass could reduce the availability of such biomass to households that rely upon such biomass for cooking. Such copy-cat gasifiers are already being constructed in Cambodia. More detailed analysis is required to assess the possibility of these adverse impacts becoming a problem.

4.2.1. To what extent is GBS a niche-technology application?

An important consideration is the extent to which the GBS system studied in Cambodia might be something of a niche-opportunity and not amenable to wide scale replication in other countries. There are several features of the GBS using rice husks that might make this case-study a niche.

a) The relatively low CV of the CRHs (c. 13 $MJKg^{-1}$) – the high silica and low carbon content of CRHs compared to woody char results in the CRHs having a low CV. Consequently, the CRHs are unlikely to be briquetted and used as a fuel. Where wood char is produced, it probably makes good sense for this to be briquetted and used as a charcoal in place of fire wood. Ankur Scientific and ARTI have been investigating this possibility. Therefore, only certain high-mineral containing feedstocks are likely to suitable for producing biochar for addition to soils.

b) Where woody biomass is used in the gasifiers, the biochar yield is much lower, typically 4-6% for the Ankur gasifiers. The conservation of carbon is very low, at 3-5% compared to 10% where rice husks are utilized. This means that the net carbon dioxide equivalent abatement will be commensurately lower in the case of woody feedstocks – perhaps 0.1 tonne CO_2 per tonne feedstock from the stabilized carbon in the char.

c) Gasification itself is likely to be something of a niche technology. Where grid-electricity is widely and reliably-available, it is more likely that rice mills would simply used grid electricity instead of installing a gasifier for electricity generation. On the other hand, if grid-electricity were very expensive, and / or if the electricity was not reliably available, then it still may make sense for the mill (or other electricity-using facility, such as an ice-making factory) to install gasification equipment. In Cambodia, both the absence of an effective electricity grid in many locations, and the high cost of electricity pre unit where it does exist, favour installation of gasifiers.

d) Gasification is an effective means of generating electricity from biomass in the 10 to 500 kW scale. Its effectiveness at the large-scale (>500kW) is less clear. Several schemes in the MW scale have been developed and subsequently abandoned due to high capital costs, problems of gas clean-up, or loss of confidence by investors (e.g. see Piterou et al., 2008). A far more proven technology at the large-scale for electricity generation from biomass is use of a biomass boiler to raise steam that is then converted to electrical energy via a steam turbine. The gasifier technology works well in the Cambodian rice mills / ice-making factories, because of the modest scale of these facilities. In neighbouring Thailand, for comparison, the rice mills tend to be much larger and in these situations boilers and steam turbines are likely to be a more cost-effective way of generating electricity.

In summary, biomass gasification is likely to be something of a niche-application and therefore inherently limited in the extent to which it could account for large-scale carbon abatement on the global-scale. On the other hand, most new technologies are deployed through entry via niche applications, as expressed in the multi-level perspective on socio-technical transitions (e.g. Shackley & Green, 2007). In other words, it is generally via adoption within a niche that new technologies find acceptability and wider adoption within socio-technical systems.

4.3. Use of Pyrolsyis-Biochar Systems (PBS)

Most discussions of biochar have centred on the use of pyrolysis-biochar systems (PBS). Pyrolysis involves production of syngas but at a significant energy penalty compared to gasification, due to the production of much larger quantities of char. It is not easy to envisage why PBS would be adopted in the case of rice husks or other feedstocks, if the prime rationale and justification for the facility is electricity generation. The only case where carbonization might make good economic sense is where the CRHs themselves have a reasonably high marketable value. In Japan, for instance, CRHs (known as *Kuntan*) are on the market for c. $250 per tonne and dedicated rice husk carbonization equipment is in operation, as shown in Figures 34 (Mašek et al., 2010).

Figure 34: Carbonised Rice Husks for Sale in 30kg Sacks in Japan (left) and the Carboniser with makes them (right) (courtesy of Mašek et al.,2010).

Kuntan is used to cover and protect rice nurseries, as an additive to the culture medium for ornamental plants, and as a component of growth media for seedlings and hydroponics. It was also reported to function as an absorptive material for moisture and gas and as a water purifier. It is not easy to imagine that such high prices could be charged in developing or emerging economies, however. It is also worth noting that rice husks themselves have value, and that this is likely to vary quite considerably between locations and time. With a value of c. $30-40 per tonne (reported for Thailand and Andra Pradesh, India), the cost of producing a tonne of CRHs would be c. $90-120. This cost would have to be recovered via the sale of the CRHs and associated electricity generation.

It is more likely that PBS would make sense when considering the utilization of other types of organic waste and agri- or forestry-residues that has a much lower (or even negative) value in the market-place. For instance, the Palm Oil Industry (POI) produces large amounts of waste which leads to a waste disposal problem. Considerable interest has been emerging in Malaysia associated with the use of these sources of organic waste through pyrolysis to produce biochar for incorporating back into plantation soils (personal communication and e-workshop correspondence with Sieng Huat Kong and Dr Loh Soh Kheang, Head of Enery & Environment Unit, Engineering and Processing Division, Malaysian Palm Oil Board - July 2010, Siem Reap.).

Work Package 5: Examination of requirements for obtaining biochar carbon credits from: a) CDM, and b) voluntary carbon market. Discussions with experts in both markets and identification of partnerships.

At the time of writing, international negotiations on a new climate treaty to succeed the Kyoto Protocol (KP) have stalled since the weak Copenhagen Accord was agreed in late 2009. Therefore, we do not know what future shape such a treaty might have or what might be the role of the Clean Development Mechanism (CDM), and other 'flexibility mechanisms'. What is clear, however, is that criticism of the CDM has been extensive and that, as a consequence, it is very unlikely to remain in its current form. A few of the key issues arising from possible implementation of biochar within the CDM will be covered below.

Most CDM projects involve calculation of off-set fossil-fuel emissions. For example, using renewable energy generation involves off-setting use of coal, say, and the carbon saving can be calculated. CDM projects entail two accounting and reporting periods.

a) 3 X 7 years OR:
b) 1 X 10 years

(The numbers are 3 x 10 years and 1 x 30 years for forestry projects). The offset carbon equivalent emissions are then calculated on a yearly basis over these reporting periods and can be sold into the Certified Emissions Reduction (CERs) market. Biochar projects entail a number of different carbon abatement 'streams', often including off-set carbon emissions from fossil fuel combustion.

Methodologies approved by the Executive Board of the Clean Development Mechanism are widely available for calculation of off-set carbon emissions. Methods are also available for calculating avoided methane emissions arising from avoided decomposition of biomass. For instance, if landfills are capped, a proportion of the methane generated via decomposition can be collected and used to generate electricity. In such a case, the project developer may utilize an approved CDM methodology to calculate the avoided CH_4 emissions and convert to CO_2 (equivalent) emission savings (in addition to accounting for off-set fossil fuel emissions). This route can be used for biochar where the baseline case involves anaerobic decomposition. For instance, where rice husks are added to irrigated fields.

5.1. Longevity of the Biochar in Soil

Typically the largest single contributor to the net carbon abatement is the stabilized carbon in the char itself. Hence, calculation of the stability of the carbon in the CRH is absolutely crucial to attempting to obtain a carbon credit for biochar. The closest analogue to biochar in this respect is probably Carbon Dioxide Capture and Storage (commonly known as CCS), whereby CO_2 is removed from power plant flue gas emissions and stored below sea-level or land in depleted oil and gas reservoirs, or in saline aquifers. CCS also faces the challenge of longevity since CO_2 in geological formations could in theory leak-out back to atmosphere. The CCS community has agreed that a very low leakage rate should be aimed for, e.g. 0.01% per year, implying a Mean Residence Time of 10,000 years (IPCC, 2005). This is considerably longer than the MRT that is typically quoted for biochar, of c. 100s – 1000s of years.

The methods described in section 4 are an initial attempt to calculate the proportion of the carbon that is stabilized in the long-term via the Carbon Stability Factor. These methods have not, as yet, been calibrated against historical charcoal samples. Hence, they should be treated as tentative measures and, potentially, with a high degree of uncertainty associated with the calculation.

As part-and-parcel of the case for carbon storage via biochar, it will be necessary to undertake thorough field monitoring of biochar stability over time. This could be done through empirical measurements at defined time-periods, but this would be very expensive, possibly prohibitively. A remote sensing approach would be far more efficient if it could be implemented successfully.

5.2. Evaluation of Additionality

The CDM imposes two requirements that a project should be 'additional' to what would happen otherwise. There are two strands to additionality tests: environmental and financial.

Environmental additionality requires that a project should not have deleterious environmental impacts. As noted above, appropriate management practices and incremental technological improvements by Ankur Scientific, should mean that some of the environmental impacts of the gasifiers can be dealt with adequately. The problem remains, however, that where regulation in country is insufficient, these improvements and management practices might remain un-implemented.

Financial additionality refers to the condition that a project should not have been economically favourable without the CDM-derived carbon credits. We know that the installation of gasifiers at rice mills is already financially viable with a good internal rate of return. Hence, it would not be possible to obtain a carbon credit for supporting installation of gasifiers per se. What might be feasible, however, is to obtain a carbon credit for the distribution of biochar to farmers and its addition to soils. Under certain assumptions about agronomic value, biochar could be economically feasible to incorporate into soils as noted in section 4. In those cases, carbon-credits would not be required and the project would be ineligible for the CDM. Yet, other results suggest that the agronomic value of the CRHs is much lower and not statistically significant. In those cases, an argument could be made that the carbon credits from CERs will be required in order to help finance the collection of the CRHs, their transportation from source to site of field application and their actual incorporation into the field.

A next step for the project is to explore whether an application to obtain a carbon credit from biochar might be developed using the CRH gasification-biochar system as the project.

4.0. Conclusions

The main objective of the project was to gain a better understanding of the role of biochar for carbon storage and agricultural improvements in a range of environmental, socio-economic and material contexts in three countries which themselves reflect a range of circumstances and policy conditions. A secondary objective was to make policy recommendations for further development of biochar as a component of national climate change, sustainable energy and agricultural policies. The BIOCHARM project has demonstrated the following.

1. The gasification-biochar system is an efficient and effective way of storing carbon in the long-term (hundreds to thousands of years, so relevant to climate change) (c. 0.9-1 tCO_2 (equivalent) abatement per tonne of rice husks).
2. Questions remain regarding the safety of CRHs for human health. More work needs to be done but it is likely that appropriate precautions and practices can limit the risks adequately. Uncertainty remains in whether such precautions would be implemented and enforced, however.
3. Likewise, there are pollution and contamination issues associated with the production and storage of CRH. Our evaluation to date relates only to use of CRH, not to mixtures of CRH and sludge from the settling ponds. Such sludge contains high quantities of PAHs, some of which are known carcinogens. Before GBS could be further promoted as a sustainable option, far more effective and comprehensive clean-up of the black water, sludge, tars and other waste streams will be necessary. Issues such as burning of tars and sludge in a non-controlled fashion is of concern. Recently, Ankur Scientific has developed gasifiers which discharge the char in dry form. A small part of this dry discharge can be used for water treatment but the large quantity can be put to use as biochar as the dry discharge eliminates the contact between the char and the process water. This innovation is likely to be important in improving the sustainability of the GBS but may be difficult, if not impossible, to retrofit on already-installed units.
4. There are some interesting and encouraging results on the agronomic potential of CRHs and other forms of biochar produced form maize and sugarcane wastes. In replicated trials, statistically significant yield increases occurred in the case of irrigated rice trials and in pot trials with lettuce and cabbage (using CRHs). Yet in other such field and pot trials (maize, cabbage), no statistically significant results were obtained (using sugarcane trash and maize cob char). At the present time, it is not know why different results were obtained. It may, however, have been due to the differences in the soil types, agricultural management practices, biochar type, biochar incorporation method, etc. Large uncertainties remain on the appropriate biochar dose, application methods, timing of application, medium- to long-term effects, combination with manures, greenwastes, most responsive crops, etc.

5. The value of CRHs and of other forms of biochar is currently hard to evaluate because of uncertainty in agronomic value and in whether a carbon market might develop for biochar deployment. Where the CRH or other biochar are ‘free’ then their use almost certainly does provide a good prospect of a positive return on investment. This value will increase greatly if a carbon market can develop which allows for the stabilised and offset fossil fuel emissions to be valued in carbon markets. The carbon abatement value of the CRH looks to be several times larger than the agronomic value.
6. Where the CRH are given away for free or at a very low cost, the overall effect should be to bring income to subsistence farmers. CRHs could increase in cost, however, as gasifier operators come to realise their value to farmers. Commercial producers could buy-up the majority of the supply, thereby denying the subsistence farmers the opportunity to benefit from the availability of CRH. Copy-cat gasifiers using locally available biomass could reduce the availability of such biomass to households that rely upon such biomass for cooking.

The results presented suggest that the biomass (bioenergy)- biochar systems studied here, making use of a readily available agricultural residue (rice husks, sugarcane trash, corn cobs, etc.), offers potential not only as a way of effecting the long-term storage of carbon but also in improving crop productivity. The biomass-biochar system can also, potentially, effect a more sustainable disposal route for waste by-products such as CRHs which otherwise may be a pollutant.

5.0. Future Directions

We feel that the project results are encouraging enough to continue further exploration. More agricultural trials are needed to draw any confident conclusions about the efficacy of biochar in agriculture in all the three countries. Some ideas for future research are as follows.

- Long term monitoring of current sites given that the impacts of biochar are anticipated to be dynamic;
- Further measurement in incubation experiments and in field trials of the impact of agri-residues and char additions to soil upon greenhouse gas fluxes such as CH_4, N_20, CO_2;
- Further testing of the impacts of biochar upon different soil types and in different agro-climatic zones;
- Introduction of multiple plots on each trial site to allow sufficient replication for statistical analysis;
- Use of a wider range of biochar additions to test the effects of different application rates (including lower rates, such as 5 and 10 t ha^{-1});
- Testing of a wider range of arable and horticultural crops;
- The impact of biochar addition in rainfed versus irrigated agriculture needs to be explored;
- Further testing of biochar with a range of organic amendments, including spent mushroom compost, vermicompost and other sources of greenwaste;
- Further testing of biochar with different levels of synthetic fertilizer addition;
- Further trials to explore the effect of application methods – e.g. to compare the impacts of one-time addition vs. incremental addition of biochar every year. (If higher biochar doses

might be immobilizing plant-available N in the soil, for example, this would be a strong case for avoiding high doses, and possibly using incremental doses to build up application levels over time);

- Focusing on high value cash crops including peanuts, soy bean, maize and melon;
- Longer term investigations of the impact of biochar on tree crops;
- Utilisation of alternative sources of biochar than those currently tested in each country and comparison with farmers' 'home-made biochar';
- Comparison of the effect of ash and soot addition to soil from open burning of agricultural waste in the field as against deliberate application of biochar;
- Investigation of the logistical implications and farmer perceptions of biochar incorporation into a farm system in Cambodia
- Life cycle assessment of biochar production and use in India along the lines to that done in Cambodia for the CRHs.

Emerging conceptual and laboratory techniques that are moving towards 'purposeful selection' of biochar could be used to help select trial candidates from the very large universe of possibilities.

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Appendix 1: Conferences/Symposia/Workshops

1. Inception Workshop

Organised by ARTI, India, Hosted by SME, Cambodia

Dates: December 12-13, 2009

Agenda: First meeting of the collaborators, deciding on details of action plan, and discussing financial and administrative issues.

Participants: Dr. Priyadarshini Karve & Mr. R.N. Prabhune (ARTI, India), Dr. Simon Shackley & Ms. Sarah Carter (UKBRC, UK), Dr. Stephan Haffele (IRRI, the Philippines) Mr. Tony Knowels (SME, Cambodia)

2. Mid Term Progress Workshop

Organised by ARTI, India, Hosted by ARTI, India

Dates: May 25-26, 2010

Agenda: Review of work done and preliminary analysis of data, agreeing on next steps to achieve project objectives

Participants: Dr. Priyadarshini Karve & Mr. R.N. Prabhune (ARTI, India), Ms. Sarah Carter (UKBRC, UK, also representing SME, Cambodia), Dr. Stephan Haffele (IRRI, the Philippines) & Dr. Simon Shackley (UKBRC, UK) – by phone and skype.

3. E-Workshop: Biochar; the potential in Asia Pacific?

Organised by the UK Biochar Research Centre, University of Edinburgh and Appropriate Rural Technology Institute-India

Monday 25th - Friday 29th October 2010

Hosted by: Household Energy Network (www.hedon.info).

Conducted By: Sarah Carter, Priyadarshini Karve & Simon Shackley

Agenda: online discussion on biochar, covering technology, use and policy with a focus on the poverty alleviation potential of gasification cook stoves, inviting participation/inputs from project developers, cook stove producers and distributors, academics, policy makers and those with climate change / carbon offset interest.

Contributors: Chris Adam, Stuart Brown, Annette Cowie, Gerbe Dellava, Karabi Dutta, Mamadou Fall, John Field, John Gaunt, Wim Getkate, Stephan Haefele, Bryan Hugill, Graham Knight, Sieng Huat Kong, Prakash Jha, James Joyce, Ron Larson, Lucy Lu, Luca De Moses, Lewis Peake, Sai Bhaskar Reddy Nakka, Ruy Korscha De La Rosa, Trevor Richards, Paal Wendelbo, Kelpie Wilson, Dominic Woolf.

List of registered participants:

User	**Job title**	**Location: continent**
Benson Zeyi	NA	NA
Luka De Moses	NA	NA
Marco Alcalde Cunningham	NA	NA
Peter Russell	NA	NA
Lone Andersen	NA	NA
Christa Roth	NA	NA
Richard Iliffe	NA	NA
Jan Fieten	NA	NA
Karabi Dutta	Biomass Energy Consultant	Asia
Jeremiah Kiplagat	Tutorial fellow	Africa
sahadev kunapuli	NA	Asia
Paulo Lopes	Carbon Management Consultant	Europe
Nitin Pagare	Project Manager	Europe
Paal Wendelbo	Technical adviser	Europe
Baptiste Flipo	NA	Europe
Graham Knight	Director	Europe
Ronal Larson	President	America North
Mamadou Fall	Freelance consultant	Africa
Gerbe Dellava	Project/Product Developer	Asia
Priyadarshini Karve	Project Co-ordinator	Asia
Sarah Carter	Research Assistant	Europe
Mbaari Kinya	Executive Director	America North
Art Donnelly	Director	America North

Clement Aigbogun	Director	Africa
Francesco Vitali	PhD student	Europe
Hamzat Lawal	NA	Africa
Abhishek Saxena	Asst. Professor	Asia
Okechukwu Ugwu	Project Officer	Africa
Sandeep Dungdung	NA	Asia
Tawanda Madovi	Managing Director	Africa
Daya Ram Nhuchhen	Student, M E in Energy Technology	Asia
Wim Getkate	Management Advisor	Africa
Rebecca Rowe	Researcher	Europe
Isaac Zama	NA	America North
Rebeca Ramírez Acosta	engineer	Europe
Kelpie Wilson	Communications Editor for International Biochar Initiative	America North
Vojtech Klusak	PostDoc	Europe
Trevor Richards	NA	Asia
lucy lu	NA	America North
Peter Githinji	NA	Europe
Bryan Hugill	Natural Resource Management Specialist	Asia
Eyobel G/senbet	Energy expert	Africa
Amanda Ravenhil	NA	America North
Hannah Werdmuller	NA	Europe
Dominic Woolf	NA	Europe
Maura Shelton	PhD candidate	America North
Lewis Peake	PhD student	Europe
Kelli Roberts	NA	America North
John Field	NA	America North
Mairi Black	Research Associate	Europe
Nelson Ko	HEDON software development	America North

Grant Ballard-Tremeer	Director	Europe
Sieng Huat Kong	Post-Graduate	Asia
Vinda Levy	NA	Asia
Barakotura Barakotura	NA	Europe
Prakash Chandra Jha	v.p	Asia
Stuart Brown	Lead consultant	Asia
Annette Cowie	NA	Oceania
Salim Mayeki Shaban	President	Africa
Stephan M Haefele	Senior Scientist for soil science and agronomy	Asia
Simon Shackley	Lecturer	Europe
marie hill	Manager	Asia
Robert Holmer	Regional Director, East and Southeast Asia	Asia
Anil kumar Vempaty	Managing Director	Asia
PERSES BILIMORIA	CEO AND FOUNDER	Asia
Sohel Ahmed	Research Associate	Europe
Paul Tanger	NA	America North
Chris Adam	stove designer, appropriate technologiste, PhD Candidate,	NA
Jan Sorensen	Man Dir	Europe
Nick Marshall	Director	Europe
Sai Bhaskar Reddy Nakka	Chief Executive Officer	Asia
Rob Bryant	NA	Europe
Syamasundar Reddy	Asst. Professor	Asia
Reine Marie Ndew DIOH	NA	Africa
Ian McChesney	Director	Europe
Evan Haigler	Executive Director	America North
Juan Pablo Martínez Mansilla	CEO	America South

4. National Consultation on Biochar and Carbon Emission Reduction (NC - BCER)

Organised by: Appropriate Rural Technology Institute (ARTI)

Dates: 22-23 November, 2010

Venue: Dr. Manibhai Desai Management Training Center, Bhartiya Agro Industries Foundation (BAIF), Dr. Manibhai Desai Nagar, National Highway No.4, Warje, Pune

The Programme of the Consultation was as follows:

	November 22, 2010
8.30-9.30	Registration & Breakfast
9.30-10.00	Inauguration and Introduction of Participants
10.00-11.00	Biochar: International Perspective Key note Address by Prof. Simon Shackley (50 min + 10 min)
11.00-11.30	Tea Break
11.30-1.30	Experience Sharing – 1
	ARTI's charcoal making technologies – Mr. N.J. Zende (20 min + 5 min)
	Biochar by gasolysis – Mr. Nilesh Inamdar (20 min + 5 min)
	Biomass Gasification and biochar – Mr. G.P. Nagori (20 min + 5 min)
	Biochar experience from the field – Ms. Nishita Vasanth (20 min + 5 min)
	Introducing Society for Biochar Initiatives – Mr. Perses Bilimoria (20 min)
1.30-2.30	Lunch
2.30-3.30	Biochar Production and Uses Thematic Talk by Dr. Sai Bhaskar Reddy (50 min + 10 min)
3.30-4.00	Open Forum
5.00-7.30	Public Function to Felicitate Dr. A.D. Karve on 75th birthday Venue: Vedshatrottejak Sabha, Near Sanas Ground, Pune.
7.30 -	Dinner
	November 23, 2010
10.00-11.00	Agriculture without fertilizer – new perspectives Thematic Talk by Dr. A.D. Karve (50 min + 10 min)

11.00-11.30	Tea Break
11.30-1.30	Experience Sharing – 2
	WOTR's work in organic farming – Mr. Sushil Bajpai (20 min + 5 min)
	First hand experience of biochar based urban agriculture – Mr. Sunil Bhide (20 min + 5 min)
	Promoting Organic Farming – Mr. Ravindra Karve (20 min + 5 min)
	ARTI's biochar experiments – Mr. R.N. Prabhune (20 min + 5 min)
1.30-2.30	Lunch
2.30-3.30	Biochar, Climate change and Finance
	Introduction to Nexus Carbon for Development – Dr. Priyadarshini Karve (15 min + 5 min)
	International Policy Issues – Dr. Simon shackley (15 min + 5 min)
	Role of Microfinance in Sustainable Technology Promotion – Mr. Saurabh Ekbote (15 min + 5 min)
3.30-4.30	Open Forum
	November 24, 2010
8.00-5.00	Field visit to ARTI training center, Phaltan (Optional)

The list of participants is given below:

	Name	Organisation	Phone	e-mail
1	Dr. Simon Shackley	UK BRC, Univ of Edinborough, UK	NA	simonshackley.ed.ac .uk
2	Mr. Perses Bilimoria	The Society of Biochar Initiatives, Mumbai, Maharashtra	9821050328	earthsoulindia@gma il.com
3	Dr. G.P. Nagori	ankur Scientific, Vadodara, Gujarath	2652783098	gpnagori@ankurscie ntific.com
4	Dr. Saibhaskar Reddy	GEO Engineering, Hyderabad, Andhra Pradesh	9246352018	saibhaskarnakka@g mail.com
5	Ms. Nishita Vasanth	Shola trust, Gudalur, Tamil Nadu	9480322881	nishita@thesholatru st.org

6	Mr. Sahadev Kunapalli	Pravuta Polam Badi (Farmers' Field School), Ghanpur, Dist Warangal, Andhra Pradesh	944579870	k_sahadev@rediffmail.com
7	Mr. Kashinath Nayak	Jivan Sikhshan Pratishthaan, Belgaon, Karnataka	NA	
8	Mr. Ramesh Hagirdarl	Jivan Sikhshan Pratishthaan, Belgaon, Karnataka	NA	
9	Mr. Madhav Sahasrabuddhe	Prayas, Pune, Maharashtra	020 25469859	madhavsahasrabudhe@gmail.com
10	Mr. Sushil Bajpai	WOTR, Pune, Maharashtra	NA	vandana.salvi@wotr.org.in
11	Mr. Nilesh Inamdar	Patpert teknowsystems, Pune, Maharashtra	9011094984	nileshinamdar@patpert.com
12	Mr. Suraj Mundhe	Patpert teknowsystems, Pune, Maharashtra	8888828045	surajmundhe@patpert.com
13	Ms. Rupali Ghate	Green Earth, Pune, Maharashtra	020-25466103	rupalighate@gmail.com
14	Mr. Sourabh Ekbote	Electronica Finance Ltd, Pune, Maharashtra	9637107416	s.ekbote@electronicafinance@org
15	Dr. G.S. Tasgaonkar	Zeal Education Society, Pune, Maharashtra	9822534204	
16	Mr. Milind Patil	Polyfab, Pune, Maharashtra	9823187231	polyfab_eps@vsnl.net
17	Mr. Sanjay Bhosale	Maharashtra Navnirman Sena, Pune, Maharashtra	9890048676	sanjay_bhosale_mns@gmail.com
18	Mr. Hrishikesh Deshpande	Engineer interested in Waste Management, Hyderabad, Andhra Pradesh	9704990147	hrishi_63@yahoo.com

19	Mr. Ravindra Karve	Promoter of Organic Farming, Sangli, Maharashtra	9766607317	ravindrakarvepc@gmail.com
20	Ms. Ushaprabha Page	Promoter of Organic Farming, Pune, Maharashtra	9422647453	ushaprabhapage@gmail.com
21	Mr. Prabhakar Pandit	Science Communicator, Pune, Maharashtra	9326994383	
22	Mr. Sunil Bhide	Organic farmer, Pune, Maharashtra	9420481751	sunbhide@gmail.com
23	Mr. Arvind Chitale	interested in Organic farming, Pune, Maharashtra	9637106566	amchitale@yahoo.com
24	Mr. Suyog Fulbadave	Agriculture Student, Pune, Maharashtra	NA	suyog_fulbadave@gmail.com
25	Mr. Mohiniraj Somany	interested in Organic farming, Pune, Maharashtra	020-26832569	NA
26	Mr. Purushottam Sumant	interested in Organic farming, Pune, Maharashtra	NA	purushottam_sumant@rediffmail.com
27	Dr. Priyadarshini Karve	ARTI, Pune, Maharashtra	9822558743	pkarve@arti-india.org
28	Dr. A.D Karve	ARTI, Pune, Maharashtra	9881309623	adkarve@gmail.com
29	Mr. Narendra Zende	ARTI, Phaltan, Dis. Satara, Maharashtra	9226569688	wtparti@gmail.com
30	Mr. R. Prabhune	ARTI, Phaltan, Dis. Satara, Maharashtra	9423033531	rnpabhune@ymail.com
31	Mr. R.D Deshmukh	ARTI, Pune, Maharashtra	9226894501	arti_pune@vsnl.com
32	Mr. R.K. Yadav	ARTI, Pune, Maharashtra	9923255806	arti_pune@vsnl.com
33	Mr. A.S. Patwardhan	ARTI	9423522991	arti_pune@vsnl.com
34	Ms. Geeta Poptani	ARTI – Intern, Pune, Maharashtra	9730956488	geeta.poptani@gmail.com

5. Final Project Workshop

Organised by: ARTI, India
Venue: Siem Reap, Cambodia

Dates: November 25-29, 2010

Agenda: Collating data from all three countries, collectively analyzing data, discussing results and conclusions, collectively preparing first skeletal draft of final report

Participants: Dr. Priyadarshini Karve & Mr. R.N. Prabhune (ARTI, India), Ms. Sarah Carter (UKBRC, UK, also representing SME, Cambodia), Dr. Stephan Haffele (IRRI, the Philippines)

6. Additional Information dissemination activities

Blog: http://biocharm.wordpress.com

The project blog is open access, and gives information about the current status and activities of the project. It also provides a forum for discussion since interested parties can contact us and leave comments to share information. Total views of the blog as of 20.12.2010 were 3821. The blog will be online after the end of the project, and end of project reports will be available there.

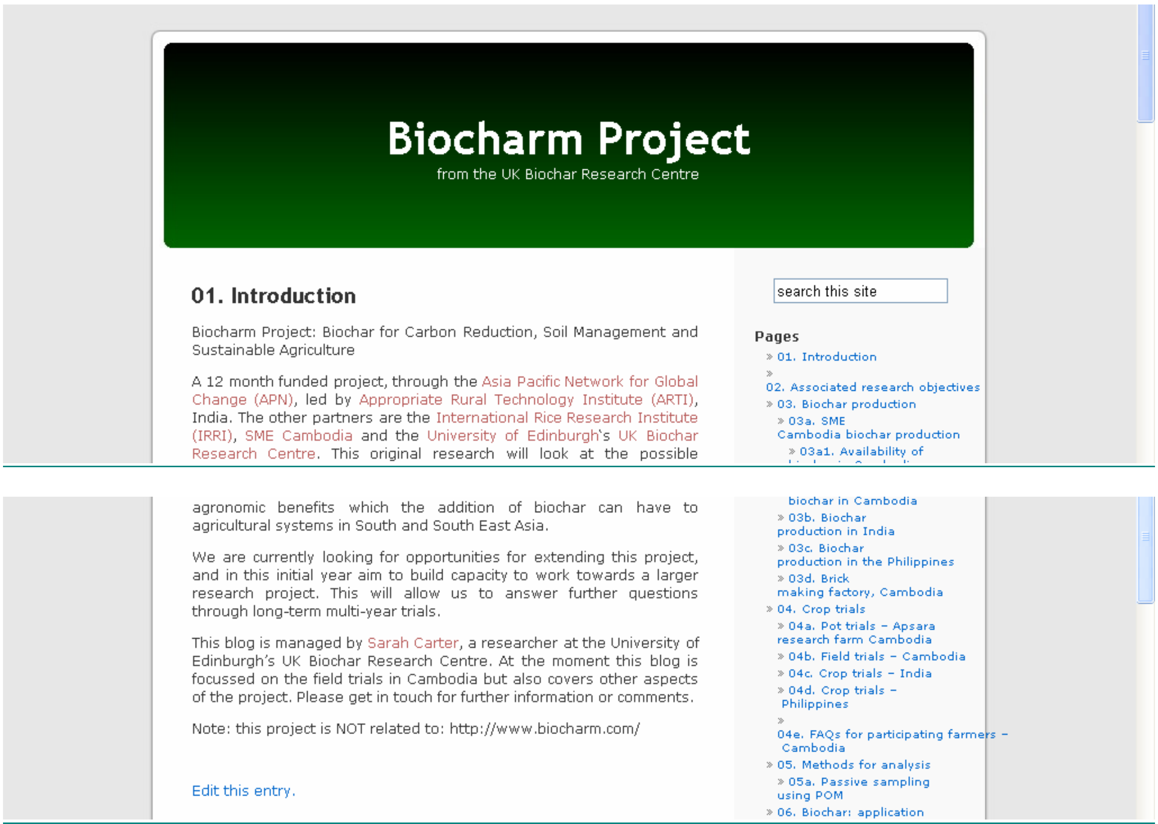

FIGURE A1: SCREEN SHOT OF THE BIOCHARM BLOG SITE

Appendix 2: Funding Sources other than APN

UK Biochar Research Centre, University of Edinburgh
Contribution-in-kind: $35,000

Carbon Captured Limited (UK):
Contribution towards travel and subsistence costs for Dr Simon Shackley: $3000

Appendix 3: Young Scientists

Sarah Carter (scarter@staffmail.ed.ac.uk)

Assignment: Provide on-the-ground assistance for the field trails undertaken in Cambodia, and in general assist in co-ordination of project activities.

It was a great experience to work on this project, and take on new responsibilities, including financial planning, managing field trials and moderating an e-workshop, which was challenging but the hard work paid off! These new skills will be extremely useful and I hope to be able to use them in my next assignment. I also had the opportunities to interact with new organisations, and as a result learned a lot from some experts in different fields. Working in Asia also gave the chance to experience new cultures, and travel to new places, which was an added bonus.

Appendix 4: Reports of Conferences/Workshops

Attached:

EWorkshopReport.pdf
NCBCERReport.pdf

Reports of related workshops (not funded through this project):
BiocharProduction&Use_India2010.pdf
BiocharProduction&Use_Cambodia2010.pdf

Appendix 5: Additional Data

	Sample	H2	O2/Ar	N2	CO	CO2	CH4	Ethane C2H6	Ethylene C2H4	Propane C3H8	Propylene C3H6	N-butane C4H10	C4 Olefins	Hexanes	TOTAL	BTU	Heating value, J/kg
Exhaust –	E1	0.18	9.10	80.14	0.46	10.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	2.3	
Producer	E2	0.19	8.98	80.57	0.50	9.73	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	2.4	
Gas	E3	0.17	8.62	80.61	0.53	10.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	2.6	
	Mean	**0.18**	**8.90**	**80.44**	**0.50**	**9.94**	**0.04**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	100.00	**2.43**	
	SD	0.01	0.25	0.26	0.04	0.19	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.15	
	COV	6%	3%	0%	7%	2%	25%	-	-	-	-	-	-	-		6%	
Producer	E4	11.44	2.79	54.30	18.16	10.21	2.65	0.07	0.28	0.06	0.01	0.01	0.01	0.01	100.00	122.3	
Gas	E5	10.52	4.87	57.18	16.12	8.68	2.24	0.06	0.24	0.05	0.01	0.01	0.01	0.01	100.00	108.5	
	E6	12.81	1.01	52.17	19.66	11.19	2.73	0.07	0.25	0.06	0.01	0.01	0.01	0.02	100.00	131.7	
	Mean	**11.59**	**2.89**	**54.55**	**17.98**	**10.03**	**2.54**	**0.07**	**0.26**	**0.06**	**0.01**	**0.01**	**0.01**	**0.01**	100.00	**120.83**	
	SD	1.15	1.93	2.51	1.78	1.27	0.26	0.01	0.02	0.01	0.00	0.00	0.00	0.01		11.67	

	COV		10%	67%	5%	10%	13%	10%	9%	8%	10%	0%	0%	0%	43%		10%	
Exhaust –	E7		0.01	12.68	82.00	0.00	5.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.0	
Diesel	E8		0.01	12.44	82.27	0.00	5.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.0	
	E9		0.08	13.08	81.7	0.00	5.12	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00		
	Mean		**0.03**	**12.73**	**81.99**	**0.00**	**5.24**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	100.00	**0.00**	
	SD		0.04	0.32	0.29	0.00	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	
	COV		121%	3%	0%	-	2%	173%	-	-	-	-	-	-	-		-	

Table A1: Results from the GC species analysis analyses of gas samples taken at Yam Loeung , 23/6/2010. Samples E1-E3 were from the engine exhaust on gas operation, samples E4-E6 were producer gas, vented through flare port (E6 most reliable sample), and samples E7-E9 were from the engine exhaust on diesel operation. The standard exhaust sample was 60 mL, partially filled from each exhaust manifold.

Material	Lab code	Batch	Fresh weight	Dry weight	Water	MC	Mean MC
			(gms)	(gms)		(%)	(%)
Rice Straw	60910	1B	18.82	17.54	1.28	6.80	**6.75**
Rice Straw	61110	1B	18.63	17.23	1.40	7.51	
Rice Straw	60910	2B	23.04	21.63	1.41	6.12	
Rice Straw	61110S	2B	19.96	18.67	1.29	6.46	
Rice Straw	60910	3B	23.66	21.98	1.68	7.10	
Rice Straw	61110S	3B	27.17	25.41	1.76	6.48	
Rice Husk	61110H	1B	10.26	9.22	1.04	10.14	**6.96**
Rice Husk	60810	1B	32.54	30.78	1.76	5.41	
Rice Husk	61110H	2B	12.89	11.74	1.15	8.92	
Rice Husk	60810	2B	39.09	37.17	1.92	4.91	
Rice Husk	61110H	3B	11.28	10.44	0.84	7.45	
Rice Husk	60810	3B	30.54	29.03	1.51	4.94	
Carbonised rice straw	61110S	1E	45.28	44.60	0.68	1.52	**3.75**
Carbonised rice straw	60910	1E	18.64	17.50	1.14	6.51	
Carbonised rice straw	6410S	2E	56.87	55.88	0.99	1.77	
Carbonised rice straw	60910	2E	19.2	18.14	1.06	5.84	
Carbonised rice straw	61110S	3E	39.22	38.51	0.71	1.84	
Carbonised rice straw	60910	3E	20.88	19.89	0.99	4.98	
Carbonised rice husk	60810	1E	26.57	25.79	0.78	3.02	**2.85**
Carbonised rice husk	61110H	1E	27.76	26.87	0.89	3.31	
Carbonised rice husk	60810	2E	20.66	19.98	0.68	3.40	
Carbonised rice husk	61110H	2E	46.95	46.00	0.95	2.07	

Carbonised rice husk	60810	3E	23.97	23.06	0.91	3.95	
Carbonised rice husk	61110H	3E	63.00	62.15	0.85	1.37	

Table A2: Moisture content of samples from the batch gasifier test runs at IRRI, conducted July 2010. The samples were taken directly before and after the gasification.

Sample code/details	DOST sample code	Heating value, BTU/lb	Heating value, MJ/kg	Literature value, MJ/kg
		(ASTM D2015)		
		Adiabatic bomb calorimeter		
Fresh Rice Straw (RS) 1B 60910 & 61110; 2B 60910 & 61110S and 3B 60910 & 61110S	2010 987- 1 RS	5986	13.9	13.7
Fresh Rice Husk (RH) 1B 61110H & 60810; 2B 61110H & 60810; 3B 61110H & 60810	2010 987- 2 RH	5980	13.9	13-15
Carbonised Rice Straw (CRS) 1E 61110S and 60910	2010 987- 3CRS 1E	851	2.0	
Carbonised Rice Straw (CRS) 2E 6410S and 60910	2010 987- 4CRS 2E	1118	2.6	
Carbonised Rice Straw (CRS) 3E 61110S and 60910	2010 987- 5CRS 3E	1475	3.4	
Carbonised Rice Husk (CRH) 1E 61110S and 60910	2010 987- 6CRH 1E	No Combustion	not detectable	
Carbonised Rice Husk (CRH) 2E 6410S and 60910	2010 987- 7CRH 2E	No Combustion	not detectable	
Carbonised Rice Husk (CRH) 3E 61110S and 60910	2010 987- 8CRH 3E	No Combustion	not detectable	

Table A3: Analyses of samples submitted to Standards and Testing Division, Industrial Technology Development Institute (DOST), September 2010. These were samples from the gasification trials done at IRRI together with John Field using the batch gasifier, July 2010. 2324.4 is the conversion factor from BTU/lb to J/kg, 1,000,000 is for conversion to MJ/kg

1. Defra: 2009 guidelines to defra / decc's ghg conversion factors for company reporting. (2009).
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4. Ankur: 'ankur' biomass gasification systems using rice husk as a fuel (2010).
5. Beesley L, Moreno-Jimenez E, Gomez-Eyles J: Effects of biochar and greenwaste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. Environmental Pollution 158(1) 155-160 (2010).