Developing Fuel Efficient Biochar Stoves and Ovens for North Vietnam Trip Report- Dec

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SEM Images C. Chia

THE UNIVERSITY OF NEW SOUTH WALES

The Objectives of the Trip

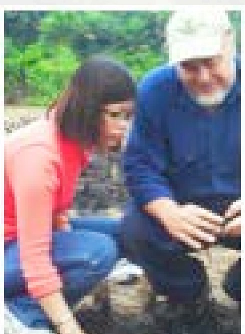
- Refine the the design and the operating procedures of the TLUD pyrolysis oven to reduce the pyrolysis temperature to below 500C and to increase the yield to greater than 20%.
- To test the new stove developed by PED at the metal workshop and to carry out modification to minimise emissions.
- Retest the drum and the stove at to determine their performance and the reactions of potential users of the technology.
- To review the baseline survey developed by PED and SFRI and finalise its content for pretesting implement this and then set up a monitoring and evaluation plan.
- To survey the home gardens and fields where the biochar trials are to be carried out and assist in development of a field trial plan

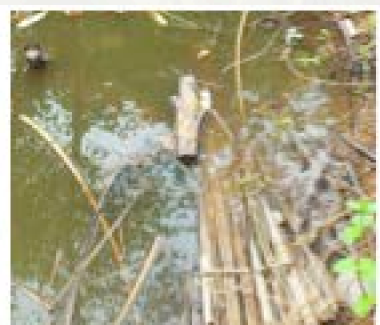
Biochar Produced From Open Field Burning and Open fires

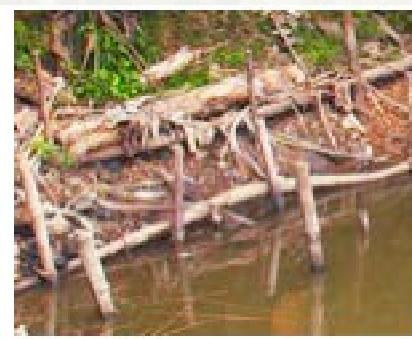
Burning of most of the straw occurs in some fields and in others there is none or very little

Many household soak their wood and bamboo in a nutrient mineral rich pond before burning in a fire.

The mineral matter that soaks into the biomass slows the combustion process and makes a large amount of biochar and ash.



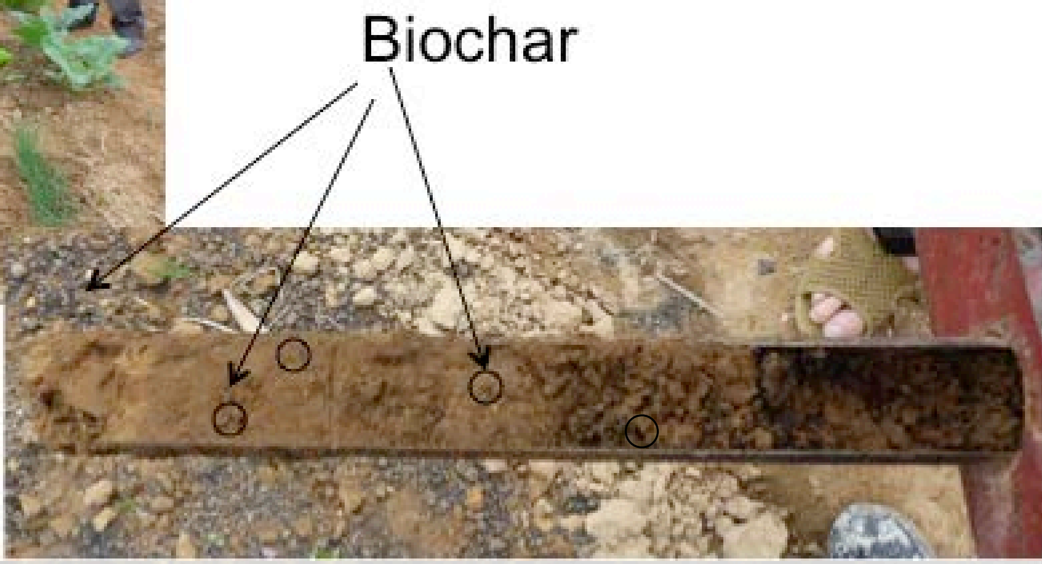




Soil samples from burnt and unburnt areas

Wood is aged underwater held down by bamboo

The Context; Farmers Have Been Using Biochar for over 40 years



Farmers have added biochar from the field and from open fires with NPK fertiliser for at least 40 years.

Farmers also use it for germination and growing rice seedlings. They say that adding biochar raises the temperature in the seedling bed.

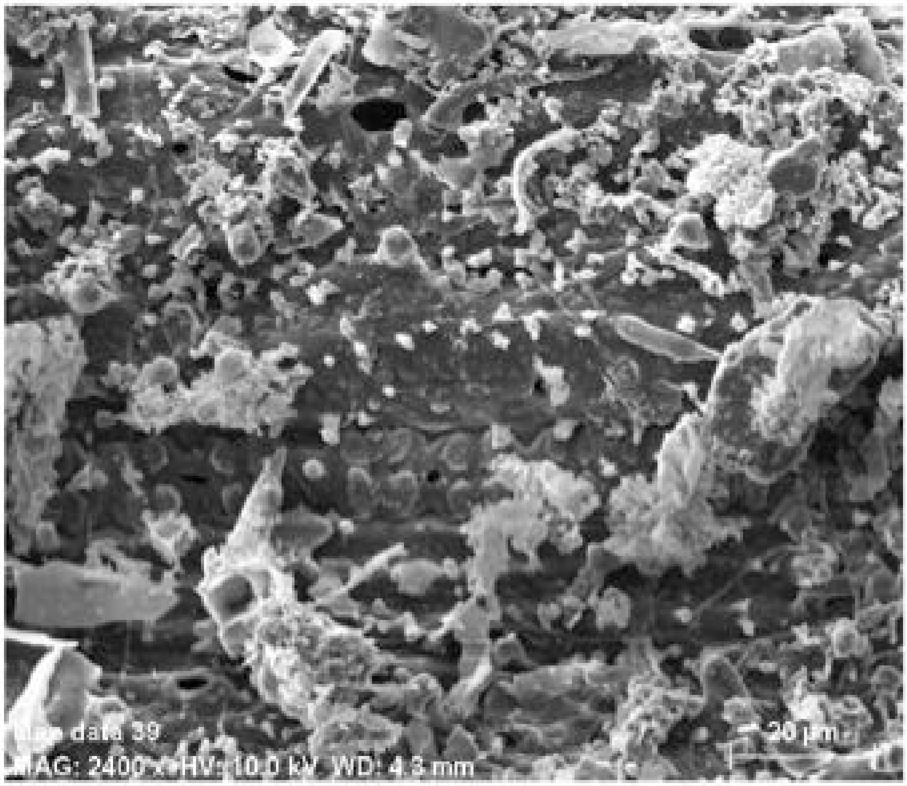
Soil sample indicates that biochar has now penetrated at least 150mm into the soil.

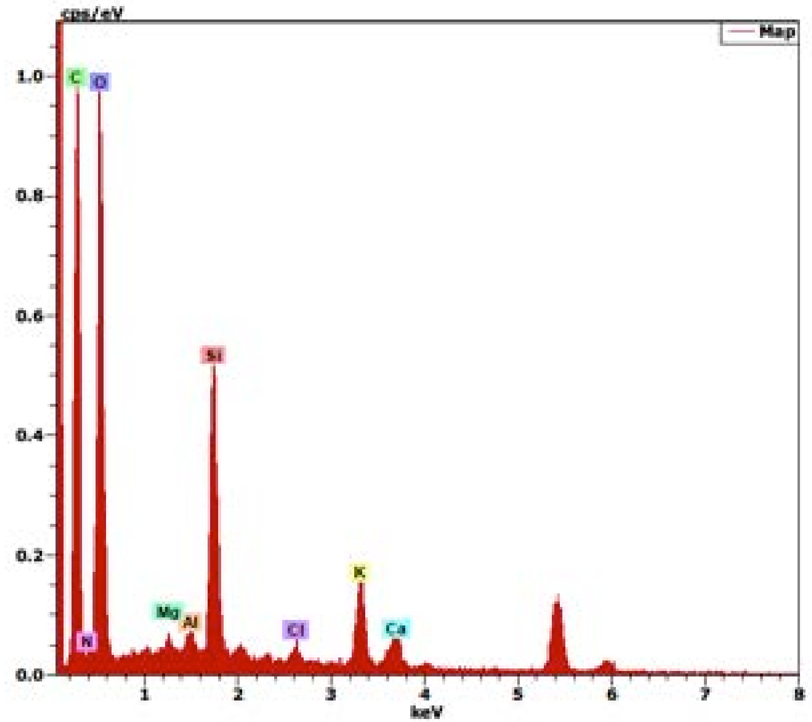
The Context; Farmers Have Been Using Biochar for over 40 years

Rice straw biochar from the field with NPK fertiliser around the spring onion seedlings

Biochar from open fire (produced possibly around 500-550C – temperature measurement taken in the char/ash layer of the open fire)

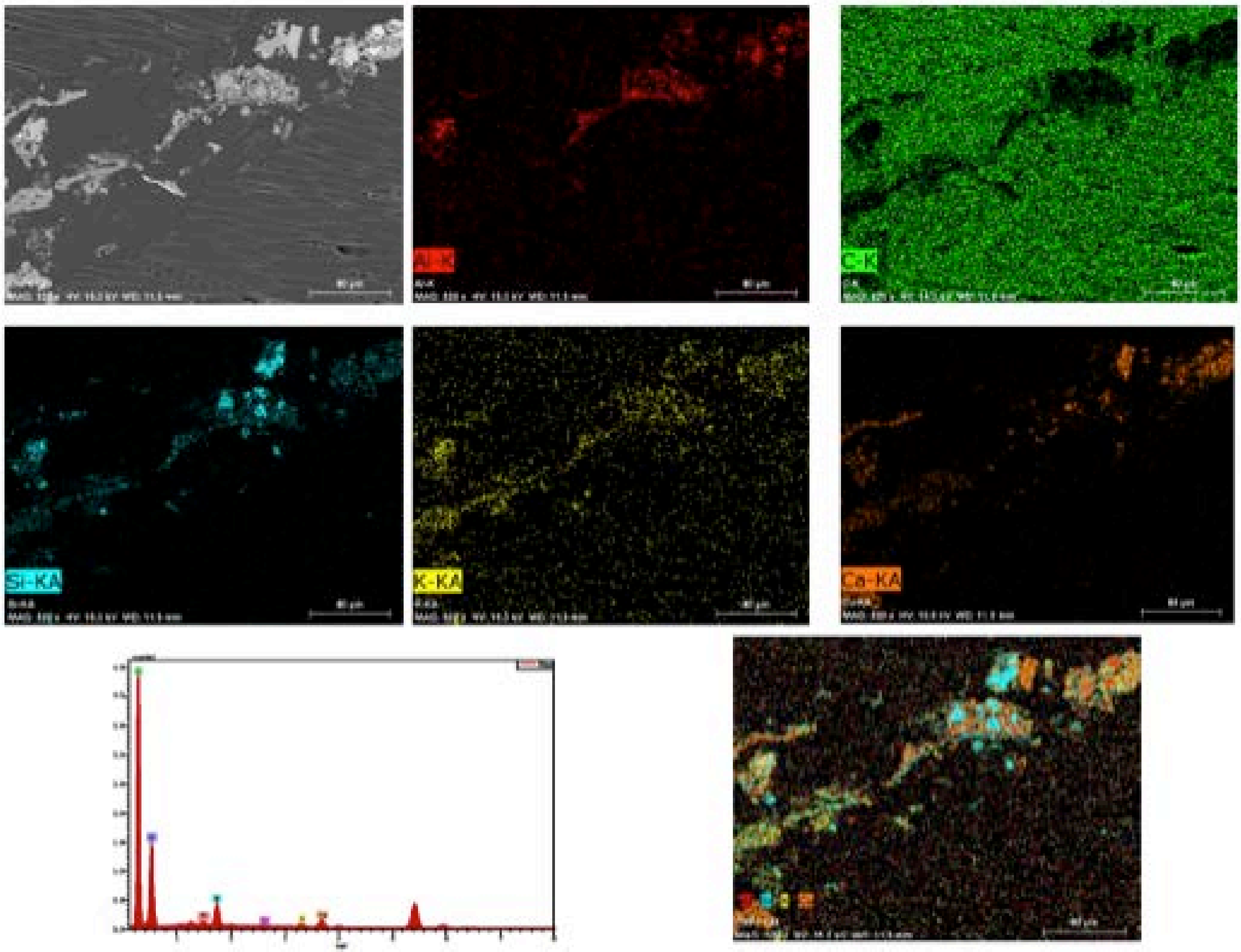
The Unusual Properties of some of the Biochar made from anaerobically treated wood/bamboo





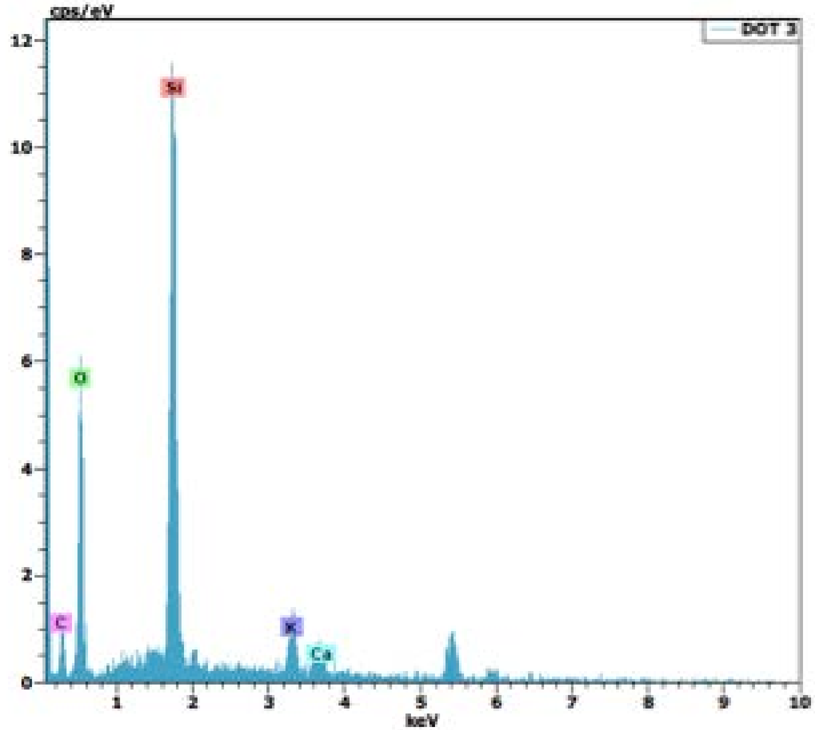
Wood and Bamboo are soaked in ponds for up to 1 year before using in fire. SEM with EDS analysis of biochar shows mineral phases rich in K Ca Mg and Si have deposited on the biomass and then reacted with the surface when heated in a fire with limited O2

The Unusual Properties of some of the Biochar



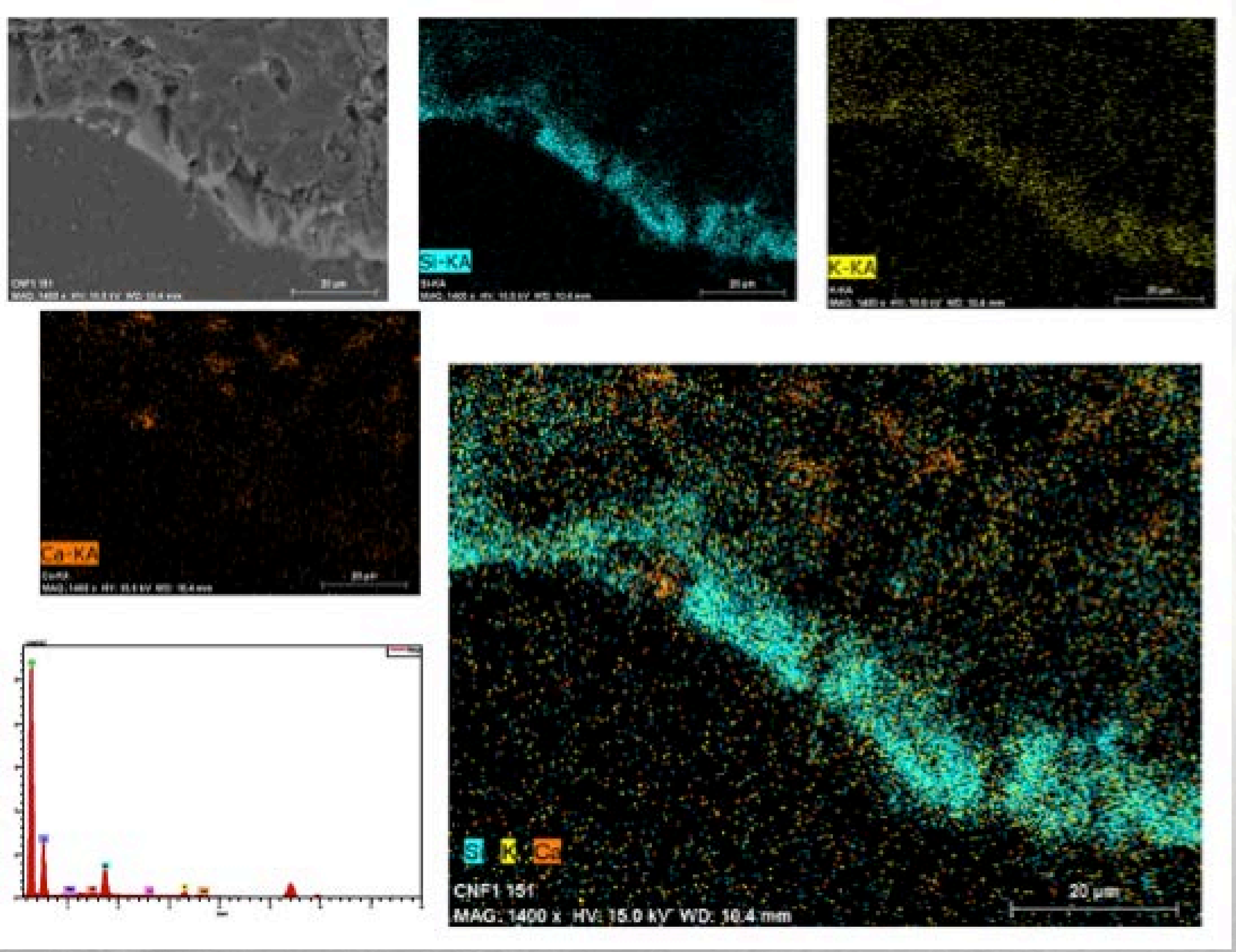
Aged Wood Biochar Sectioned showing the distribution of minerals internally in the pores

Rice Straw Biochar has a Protective layer of silica and other minerals

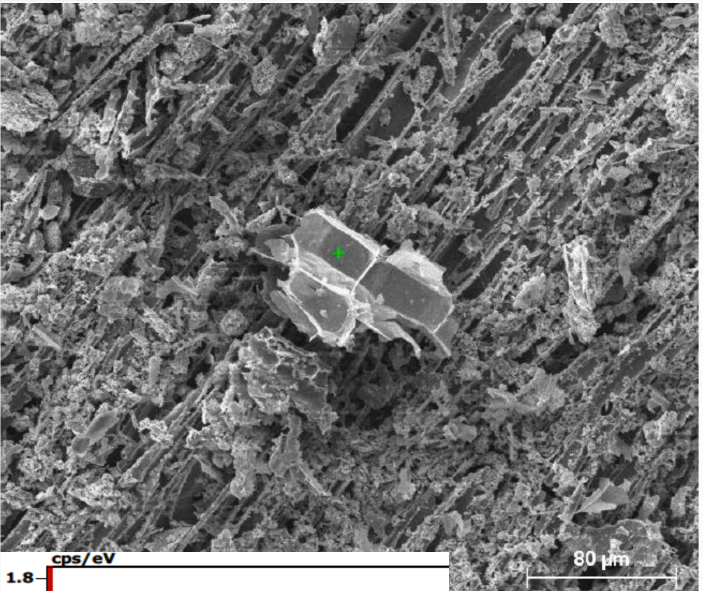


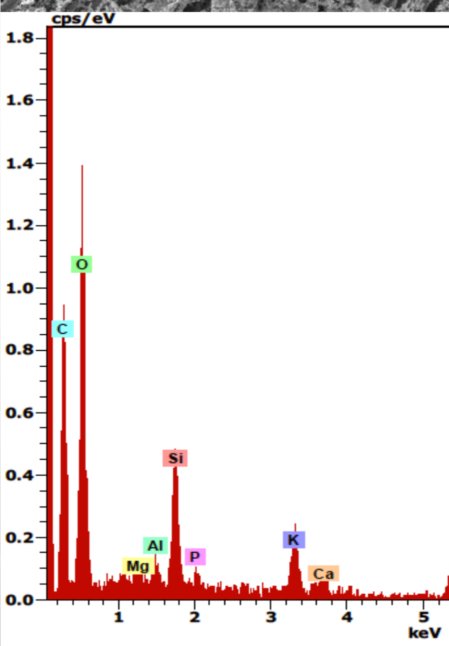
Rice Straw biochar can vary in color from deep black to grey and is produced at a range of temperatures. The surface is coated in amorphous silica with a interstitial K and possible calcium carbonate as a separate phase

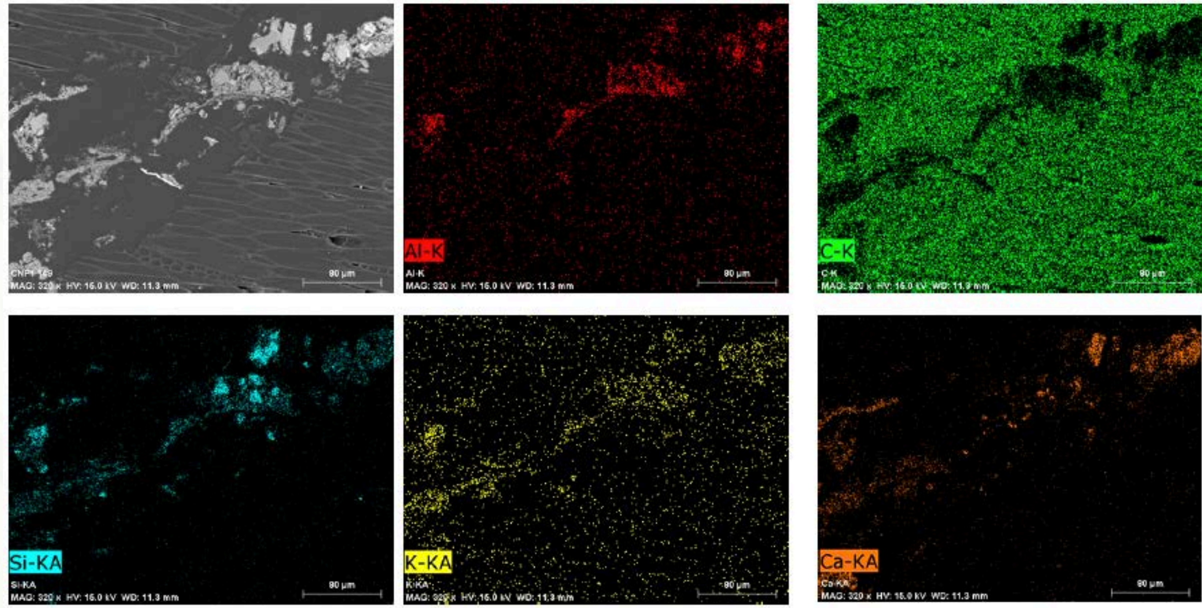
Rice Straw Biochar has a Protective layer of silica and other minerals

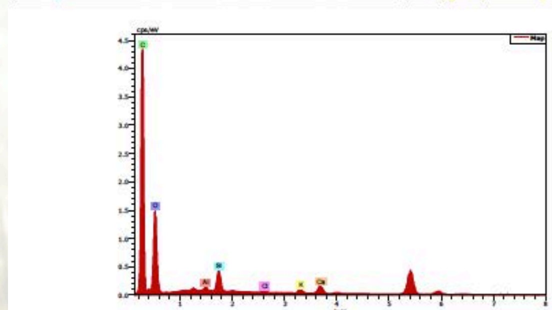


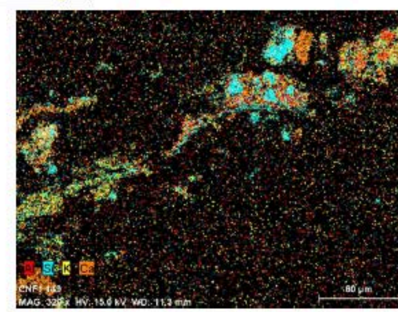
Wood Biochar has a surface and pores that are coated with minerals











Analysis of some of the Biochars produced from straw and aged bamboo and wood

Sample ID:		Bamboo			
BVITA Sample ID:		972017			
Mass Received:	(g)	11.0			
Analysis Basis			(ad)	(db)	(daf)
Proximate Analysis					
Moisture	(%)		5.3		
Ash	(%)		12.1	12.8	
Volatile Matter	(%)		17.0	18.0	20.6
Fixed Carbon	(%)		65.6	69.3	79.4
Ultimate Analysis					
Carbon	(%)		70.3	74.2	85.1
Hydrogen	(%)		2.63	2.78	3.18
Nitrogen	(%)		1.02	1.08	1.23
Total Sulfur	(%)		0.27	0.29	0.33
Oxygen (by difference)	(%)		8.38	8.85	10.15

Sample ID:		Rice Straw			
BVITA Sample ID:		972018			
Mass Received:	(g)	15.0			
Analysis Basis			(ad)	(db)	(daf)
Proximate Analysis					
Moisture	(%)		6.4		
Ash	(%)		35.6	38.0	
Volatile Matter	(%)		10.5	11.2	18.1
Fixed Carbon	(%)		47.5	50.7	81.9
Ultimate Analysis					
Carbon	(%)		50.2	53.6	86.6
Hydrogen	(%)		0.92	0.98	1.59
Nitrogen	(%)		0.85	0.91	1.47
Total Sulfur	(%)		0.14	0.15	0.24
Oxygen (by difference)	(%)		5.89	6.29	10.15

Ash Constituent Analysis (%dry basis)

Silicon	as	SiO_2	56.1
Aluminium	as	Al_2O_3	4.78
Iron	as	Fe_2O_3	1.58
Titanium	as	TiO_2	0.31
Calcium	as	CaO	13.2
Magnesium	as	MgO	1.42
Sodium	as	Na_2O	0.38
Potassium	as	K_2O	14.7
Phosphorus	as	P_2O_5	2.61
Manganese	as	Mn_3O_4	0.82
Sulfur	as	SO_3	3.36
Barium	as	BaO	0.07
Strontium	as	SrO	0.02
Zinc	as	ZnO	0.15
Vanadium	as	V_2O_5	0.03

Rice straw has a high mineral content which is similar to most high mineral ash biochars such as chicken manure.

Pond aged bamboo biochar has a higher mineral ash content than if biochar was made from fresh bamboo. Nitrogen is high and possibly comes from the pyrolysis of micro-organisms that have grown inside the bamboo

XPS Analysis of Functional Groups and Minerals on the Surface of Wood, Straw and Bamboo biochar

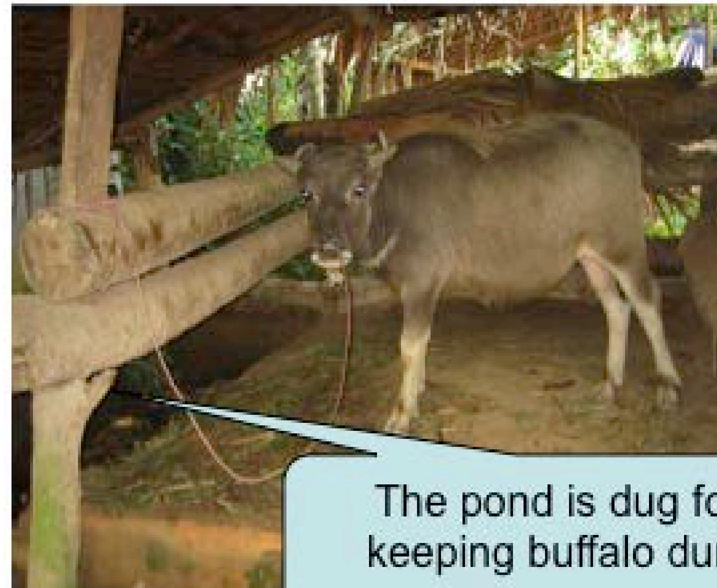
	Rice Straw			Bamboo				Wood			
Name	Peak BE	At. %		Name	Peak BE	At. %		Name	Peak BE	At. %	
C1s A	284.97	47.67	C-C/C-H	C1s A	284.97	57.9	C-C/C-H	C1s A	284.93	48.93	C-C/C-H
C1s B	286.47	10.72	C-O groups	C1s B	286.47	13.78	C-O groups	C1s B	286.43	11.89	C-O groups
C1s C	287.97	3.07	C=O groups	C1s C	287.97	3.13	C=O groups	C1s C	287.93	4.4	C=O groups
C1s D	289.17	2.92	O=C-O groups	C1s D	289.31	1.9	O=C-O groups	C1s D	289.29	3.11	O=C-O groups
C1s E	290.8	2.86	Carbonates	C1s E	291.03	0.84	Carbonates	C1s E	290.84	2.09	Carbonates
K2p3 A	294.09	4.68		K2p3 A	293.68	1.05		K2p3 A	293.55	3.99	
Ca2p3 A	348.28	0.6		Ca2p3 A	348.05	0.23		Ca2p3 A	347.63	0.52	
N1s A	401.07	0.56	Amino Acid N	N1s A	400.7	1.1	Ammonium N	N1s A	400.76	0.86	Ammonium N
N1s B	398.83	0.41	N-C	N1s B	399.15	0.52	N-C	N1s B	398.93	1.22	
O1s	533.56	20.18		O1s	533.18	17.78		O1s	533.08	18.51	
Al2p	75.5	0.3		Al2p	75.61	0.18		Al2p	nd		
Si2p	104.52	5.18		Si2p	104.37	1.19		Si2p	103.88	3.6	
P2p A	134.41	0.31		P2p A	134.05	0.19		P2p A	133.68	0.17	
Cl2p3 A	198.8	0.17		Cl2p3 A	198.31	0.1		Cl2p3 A	198.23	0.61	
Cl2p3 B	200.19	0.35		Cl2p3 B	199.96	0.11		Cl2p3 B	200.43	0.09	

Soaking wood and bamboo in nutrient rich ponds results in biochar with a relatively large concentration of oxygenated functional groups and relatively high mineral content. (n.d. = not detected)

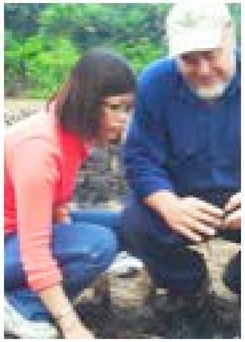
Fields also have variable amounts and types of biochar and dung

1) Practices of burning and applying different sources of dung vary between farmers. Farmers who have buffalo for ploughing land remove most of the straw for feed. They then apply buffalo dung and straw back to the field. Those farmers who use mechanical ploughing burn all of the straw on the fields.
   They will apply dung from pigs and other animals on the fields.
2) There are probably different levels of biochar in different fields
3) Farming practice can vary from field to field. Some farmers dry their fields while others keep them flooded (see above). The pH and Eh of the wet and dry fields along with nutrient content are probably different (see G. Kirk 2004 The biogeochemistry of submerged soils. Wiley)
4) The high variance could significantly effect the results of agronomic trials. It was agreed that at least 5 replicates should be used for a given treatment during the field trials.

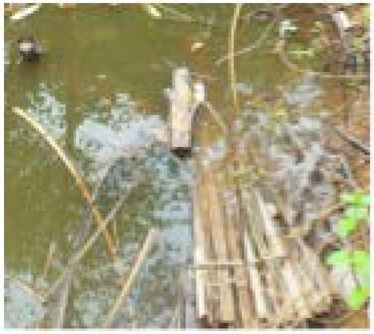
Some Farmers Have Pits Where Composting Of Manure Can Take Place



Possible Experiments and Trials With Biochar, Straw, Lime and Dung




Soil samples from burnt and unburnt areas

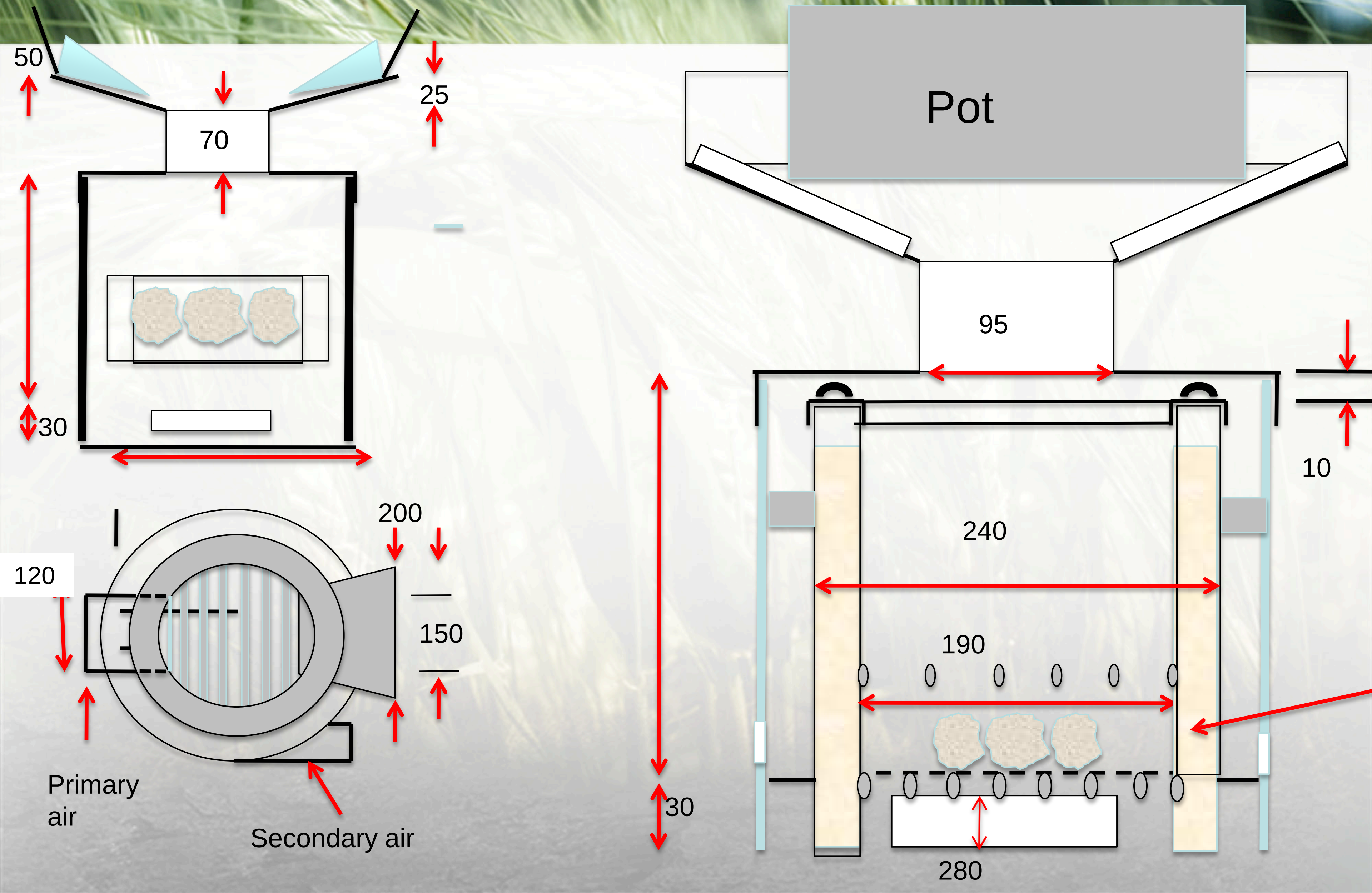



Wood is aged underwater held down by bamboo

There are a number of important questions to answer within the Vietnam farming system when undertaking trials

1) Is there a significant affect from the biochar already in the ground?
2) Is there a difference between biochar that is made from pond aged wood and bamboo, and from fresh dry wood and biochar?
3) Is there a difference between the biochar made in either the drum or the new stove, and that taken from the open fire or produced during burning of the field?
4) Can the properties of biochar be improved by composting with dung, and if so is there a difference between the types of dung used and the method of composting (aerobic/anaerobic, combination)?
5) What are the affects of coating the straw with clay and lime to moderate the pyrolysis temperature?

DK-B3 Built in first Trip November



New Stove DK-B2

1) PED had designed a new stove (a) that had less components and was easy to assemble and to disassemble to remove the biochar. Longer pieces of wood can be used

1) They had inserted an inner cone that protruded into the neck of the stove and had considerably increased the volume and area of the pyrolysis chamber (b). Before pyrolysis the stove performed well with little smoke and controllable output (a, c).

1) Once pyrolysis started there was a large increase in flame and the carbon monoxide emissions increased (d). There was insufficient combustion volume between the pot and the top of the inner conical section.

1) They had not been able to purchase the necessary sheet metal working equipment to accurately make the components to produce seals at the joins. Thus pyrolysis gases could escape around the outside of the top (e).

Modifications to New Stove DK-B1

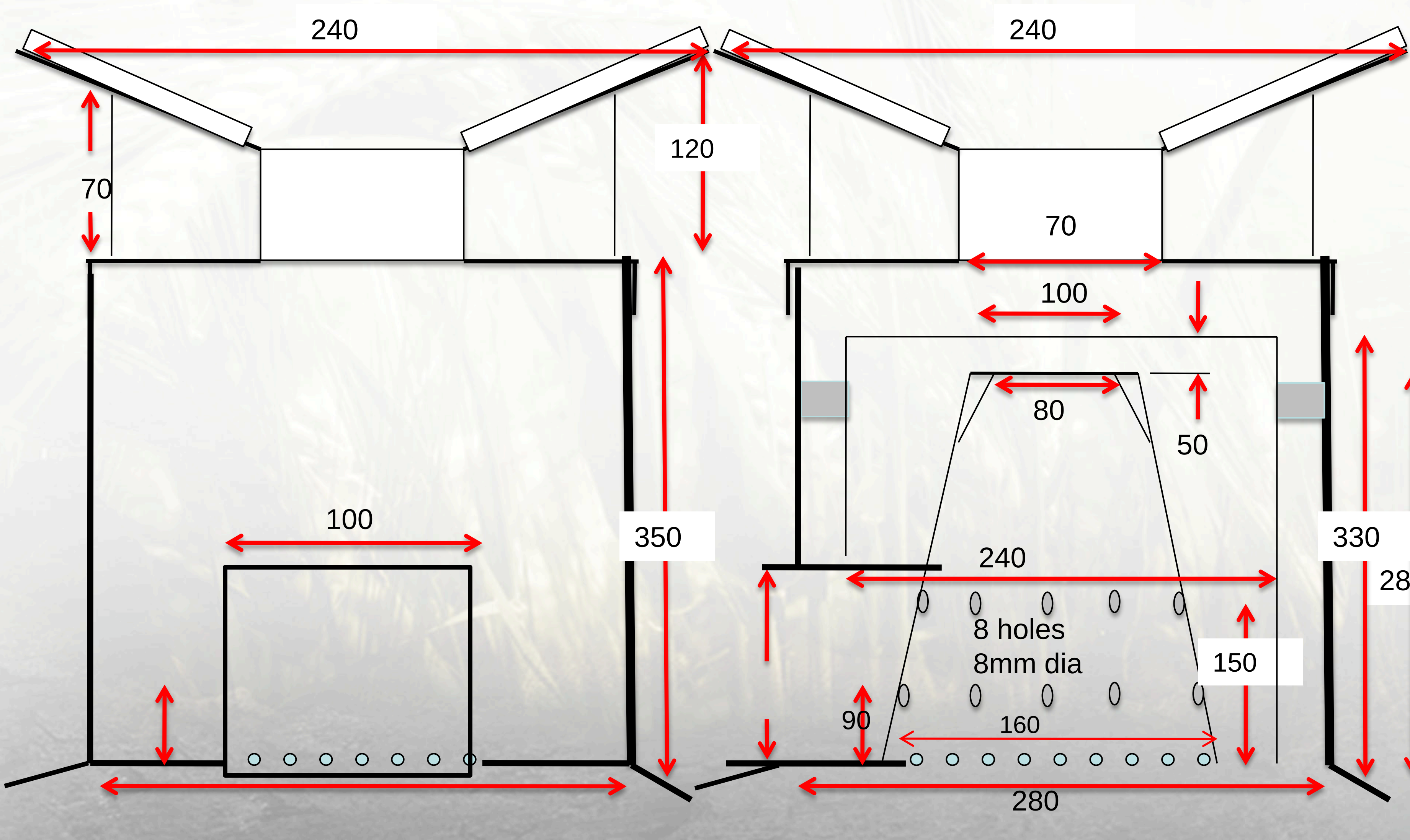
1) After discussion it was agreed to reduce the dimensions of the new stove and bring the cone underneath the top of the lid as per the design recommended in the previous report (see next slide for dimensions).

1) The number of holes in the inner cone were increased to 2 rows of 16 with a diameter of approximately 8mm

1) It was decided not to have an inner lid, thus there was both liberation of pyrolysis gases from the top of the pyrolysis chamber as well as through the holes.

1) This new stove was completed the day before village testing late at night.

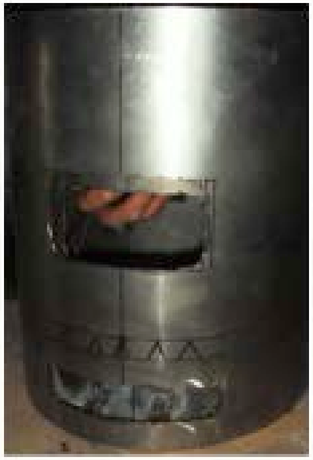
DK-B1



240
70
120
100
350
240
70
100
80
50
330
280
240
8 holes
8mm dia
150
90
160
280

Building the New Stove

Inner and middle Chambers for biomass



Outer Casing

Pot Holder

Lugs to position pyrolysis chamber

Top of pyrolysis chamber

Controlled Cooking Tests Binh Thanh Commune

Gas Analysis

- Three stoves were tested. The version made during the last trip DK-B3, the first of the modified stoves DK-B2 and the last version DK-B1.
- Method was a modified version of controlled cooking test.
- Three dishes were cooked by 3 women, 1) rice 2) pork 3) green vegetable. All women used the same amount of food and water
- Cooks were rotated after each dish so they cooked on all stoves
- Each women had the same weight of a mixture of bamboo, wood and rice husk.
- Time to ignite the fire, bring water to boil, and cook food was recorded.
- Weight of wood used, food cooked and biochar produced was recorded
- Emissions of CO and NOx measured for the three stoves for part of the test.

Controlled Cooking Tests Results

	DK-B3	DK-B2	DK-B1	open fire
The amount of used wood (gram)	1235	970	955	2000
The amount of used biomass (gram)	600	960	965	730
The biochar (gram)	105	185	190	315
Total weight wood - 1.5x total weight biochar	1078	693	670	1528
Total weight of food (gram)	1850	1850	1850	1850
Total weight food/total weight wood	1.50	1.91	1.94	0.93
Total time for cooking rice to simmer(minutes)	30.00	34.00	29.00	32.00

Controlled Cooking Tests Results
Comparison with Rocket Stove in Kenya

Reduction in fuel consumption is similar to that reported for Rocket stove in Kenya

	Open Fire Kenya	Rocket Stove Kenya	DK-B1	open fire Vietnam
Total weight of food (gram)	1850	1850	1850	1850
Total weight food/total weight wood	1.4	2.061	1.94	0.93

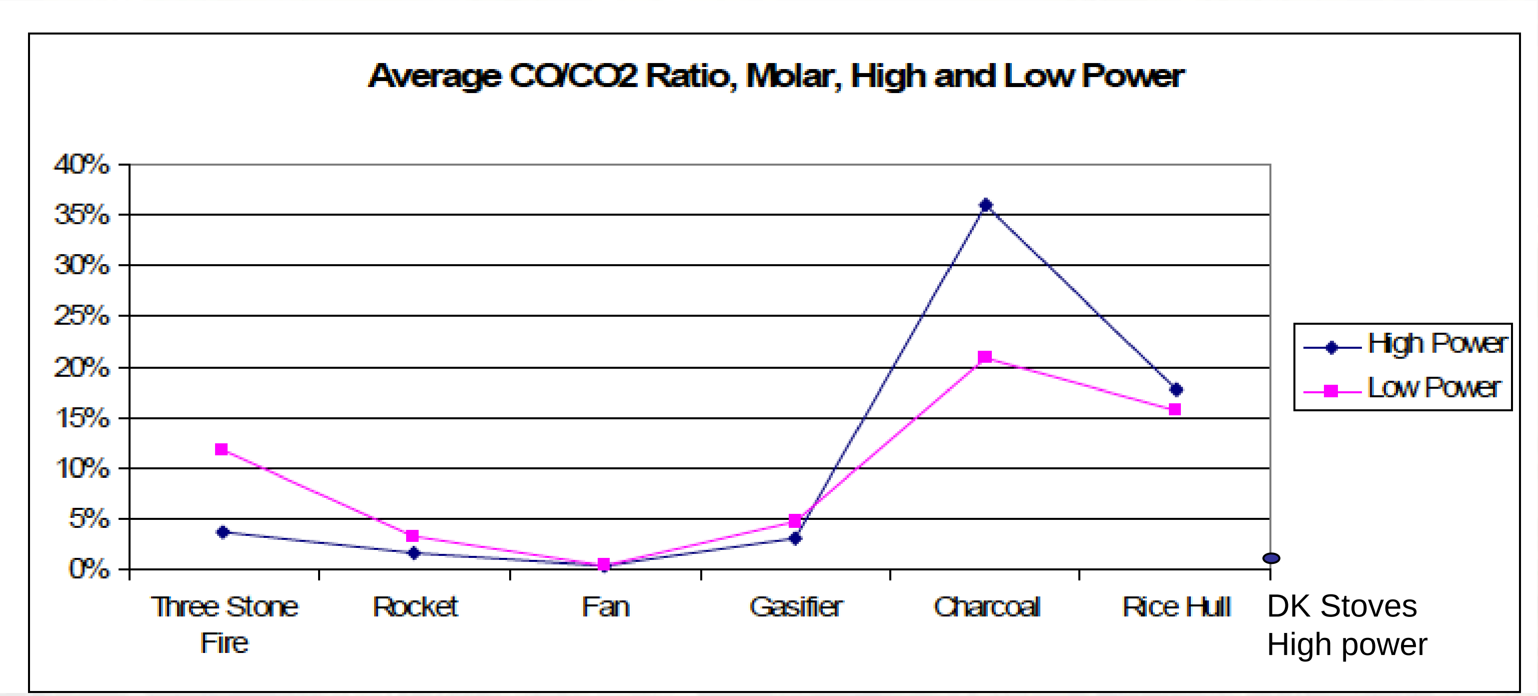
Food cooked in Kenya includes rice and beans and beef which is similar to the dishes cooked in Vietnam (Aitkens et al (2010) Energy for Sustainable Development 14, pp 186-193)

Controlled Cooking Tests Results

% Gas Composition			
	DK-B3	DK-B2	DK-B1
CO	0.15	0.10	0.10
NOx	0.014	0.0087	0.0092
O2	12	15	15
CO2	8.7	5.8	5.8
%CO/CO2	1.7	1.7	1.7
%NOx/CO2	.17	.15	.15

Emissions are approximate and are taken for a short period of time (3-5 minutes) during the high power phase. These stoves need to be tested with more sophisticated equipment using a hood as per the US EPA method developed by Dr Jetter.

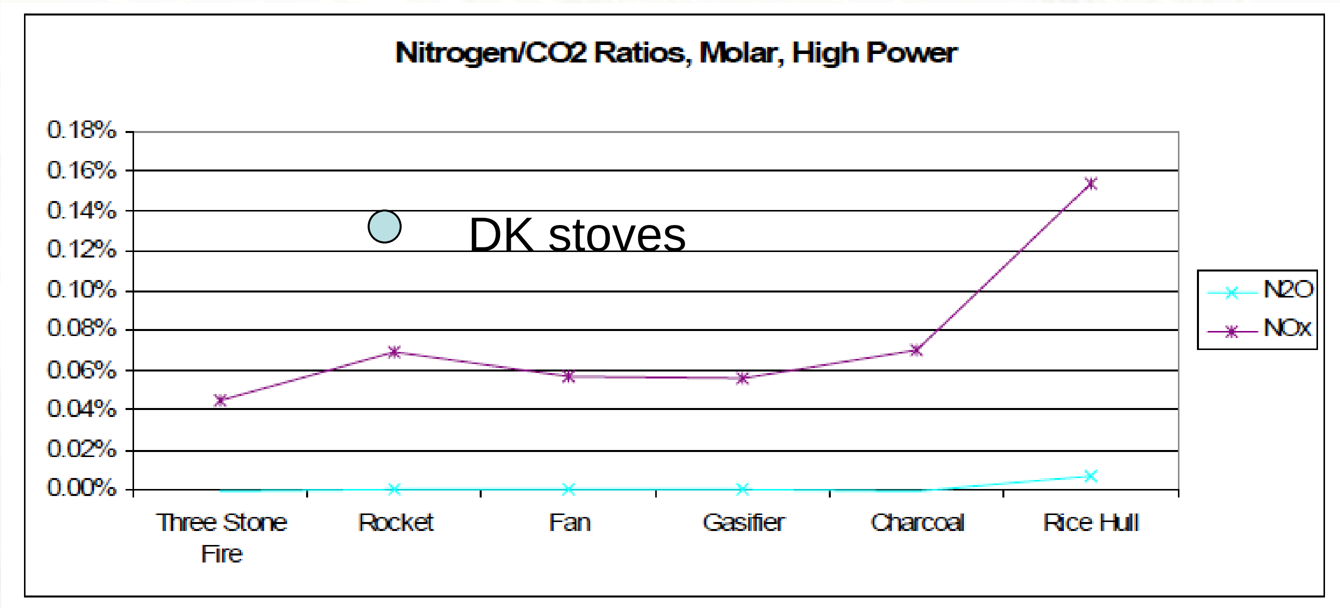
Controlled Cooking Tests Results



CO emissions from new stove in high power phase probably similar to Rocket stove.

Source: **Laboratory Comparison of the Global-Warming Potential of Six Categories of Biomass Cooking Stoves.** Nordica MacCarty, Damon Ogle, Dean Still, Dr. Tami Bond, Christoph Roden, Dr. Bryan Willson. September 2007. Aprovecho research Laboratory

Controlled Cooking Tests Results



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NO emissions from new stove in high power phase probably slightly higher than than those reported by Aprovecho. Changes to the design should reduce the NOx levels to those reported for Rocket and three stones fire.

Source: **Laboratory Comparison of the Global-Warming Potential of Six Categories of Biomass Cooking Stoves.** Nordica MacCarty, Damon Ogle, Dean Still, Dr. Tami Bond, Christoph Roden, Dr. Bryan Willson. September 2007. Aprovecho research Laboratory

Feedback On Stoves

Participants	DK-B3	DK-B2	DK-B1 (newest version)	Traditional stove	Note
Tran Thi Bang	"My stove is easy to use. But i dont like its shape so much".				This first stove was not starting quickly and significantly, but during cooking testing time, it showed the highest efficiency and the lest of smoke.
Tran Thi Chung		"My stove has big flame. My dishes have the best quality"			The rice dish which Mrs Chung cooked had an overcooked layer at the bottom of the pot indicating higher temperatures during the low power phase. Mrs Chung seems confident using this stove.
Nguyen Thi Vi			"I like this stove most"		This is the youngest women in the testing.
Ma Thi Dung				"Traditional stove can not be as good as those."	After the first dish was finished, Mrs Dung took some bricks to reduce wind effects. She also run out of wood at the end of cooking.

Feedback On Stoves

Participants	DK-B3	DK-B2	DK-B1 (newest version)	Traditional stove	Note
Women's dscussion about the stoves after the tests	- Advantage: It concentrate and keep the heat. - Limitation: look unwiedly.	- Advantage: It concentrate and keep the heat. - Limitation:	- Advantage: small and neat . The flame was quite big and attractive. This is the chosen one by women. It concentrate and keep the heat. - Limitation: It was smoky due to the use of straw and the need to stop fire for steaming of rice.	- Advantage: Using easily and quickly. Many type and size of wood can be used. - Limitation: Smoke. Not safe, high fuel consumption. Effect to health.	There was an outside woman talking about the cooking: She made the comment that the reason why the all of the new stoves had smoke emissions was due to poor operating procedure such the wood was not added when needed to keep a flame in the firebox People's practice is cooking rice before other dishes. But with these stoves, it is supposed to cook others before rice is better.

Conclusions From Stove Testing

It appears that the women on the whole are satisfied with the new design of stove (DK-B1)

It is the most efficient in terms of the weight of food cooked per kilogram of food, however the design built during the last trip is faster (DK-B3).

Training is required to ensure optimal use of the stove

Emissions are approximate and are taken for a short period of time (3-5 minutes). From the author’s experience with more accurate equipment and long term trials emissions during the flaming phase are probably similar to other improved stoves.

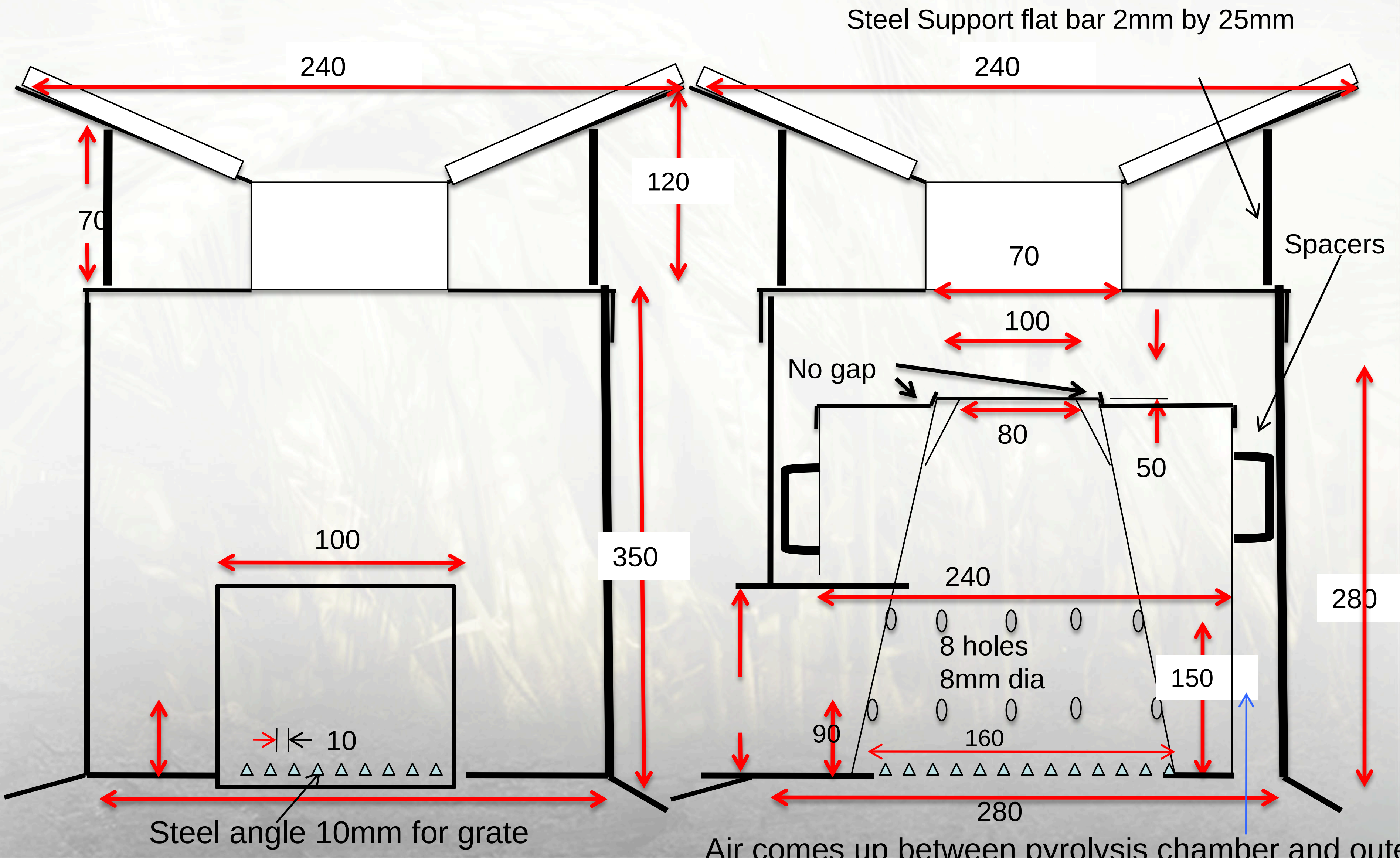
There needs to be rigorous testing and optimisation to further reduce emissions especially during the low power simmering phase.

It is recommended that there be money allocated to purchase emissions testing equipment from Aprovecho in the USA

Further Work to be Undertaken

- Purchase equipment so that the components for the new stove have accurate dimensions and the pyrolysis chamber can be properly sealed at the top.
- Redesign the pyrolysis chamber so that the rate of charring of the biomass is slower and matches cooking practice.
- To do this experiment with a sealed top on the pyrolysis chamber and a ceramic insert in the combustion chamber.
- If a ceramic insert cannot be manufactured with the existing time frame and budget then ensure thicker steel is used for the combustion chamber casing to ensure adequate lifetime (.1 year).
- Develop a Monitoring and Evaluation program
- Develop training program for users and ensure that all users receive training before they acquire a stove
- Monitor stove usage after 1 week in selected households and if women have problems with the stoves then either change the design or type of training that has been provided.
- Evaluation of the first 100 households after 3 months and make necessary changes to the design before introducing the other 350 stoves.

Stove dimensions for Final Metal Design for Field Testing



Further Work Undertaken; Ceramic Inner Chamber Option

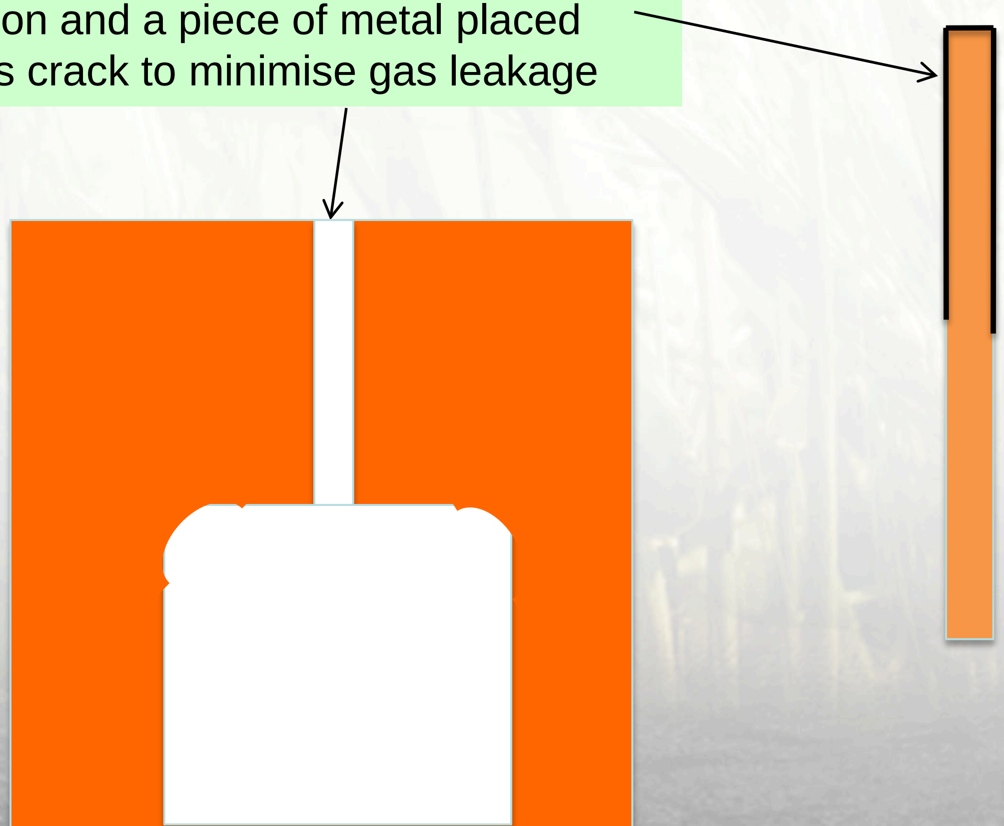
Lid fits over the ceramic inner chamber and the second chamber

This design will be refined and tested in a small number of households

Ceramic Inner Chamber Option; Dealing with Expansion Cracking

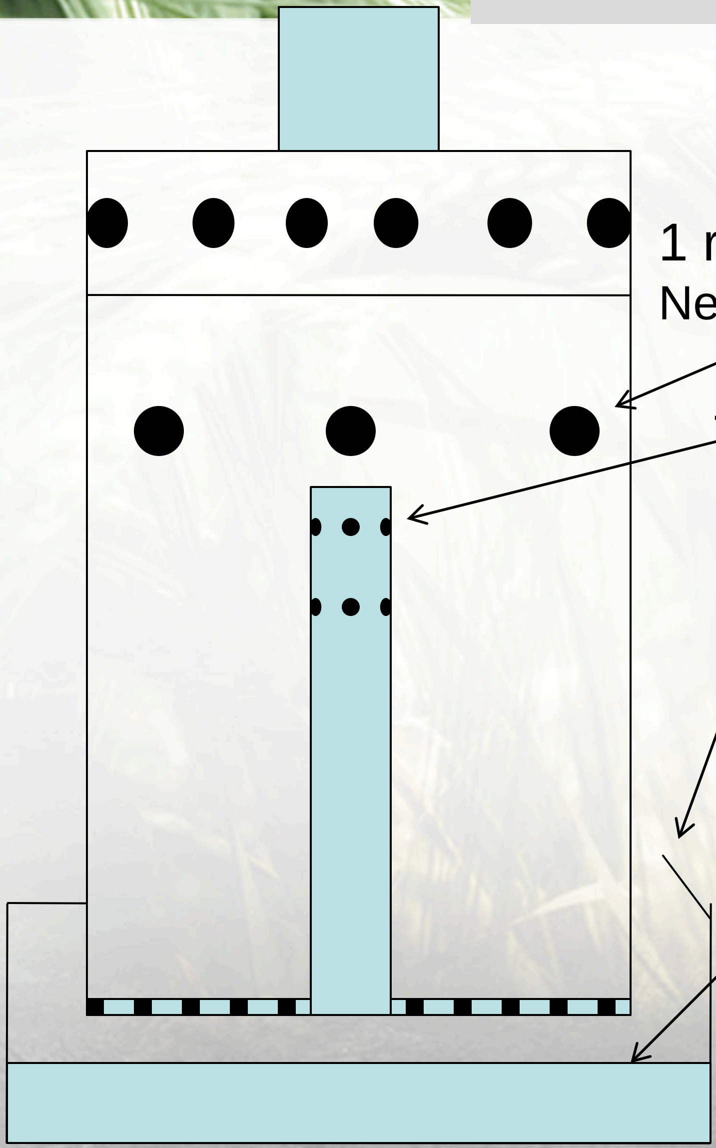
Problems were experienced with cracking in the middle of the door way so it has been recommended to add a crack to allow for expension

A 5mm crack is left in the ceramic for expansion and a piece of metal placed over this crack to minimise gas leakage



Test TLUD Straw Pyrolysis Unit

The following changes were made to the drum



1 row holes 8x50mm

Needs to be able to close off to determine if necessary

Two rows of holes 6x10mm

Door to regulate the air coming into the bottom of the unit

Water to moderate the temperature of the bottom of the reactor. As the water heats up steam is produced and flows through the pyrolysing straw improving gas quality and possibly activating surface.

At end of the run fill drum up with water to cool biochar and prevent air coming in

Test Run With Emissions Testing

- Oven sits in drum with water
- 10% mixture of clay and lime added to straw and then layers of rice husks and straw (10kg?)
- 10kg of wood and bamboo.
- Start fire and when wood is fully light partially quench flame with water to reduce temperature.
- When volume of straw and wood is reduced by 50% close doors to minimise air input.
- When flame subsides fill drum with water to just above its bottom.
- Open drum after 90 minutes

Further Experimental Program For Straw TLUD

1. Yield of biochar was approximately 20-23%
2. Appeared that the water under the drum was not needed and the temperature could be controlled by spraying water on the flaming biomass and adding a small amount of clay to the straw.
3. After flaming pyrolysis finished the air can be shut off at the bottom of the drum and pyrolysis could be completed within 90 minutes.

Further Experimental Program For Straw TLUD

1. Average gas composition during the flaming phase

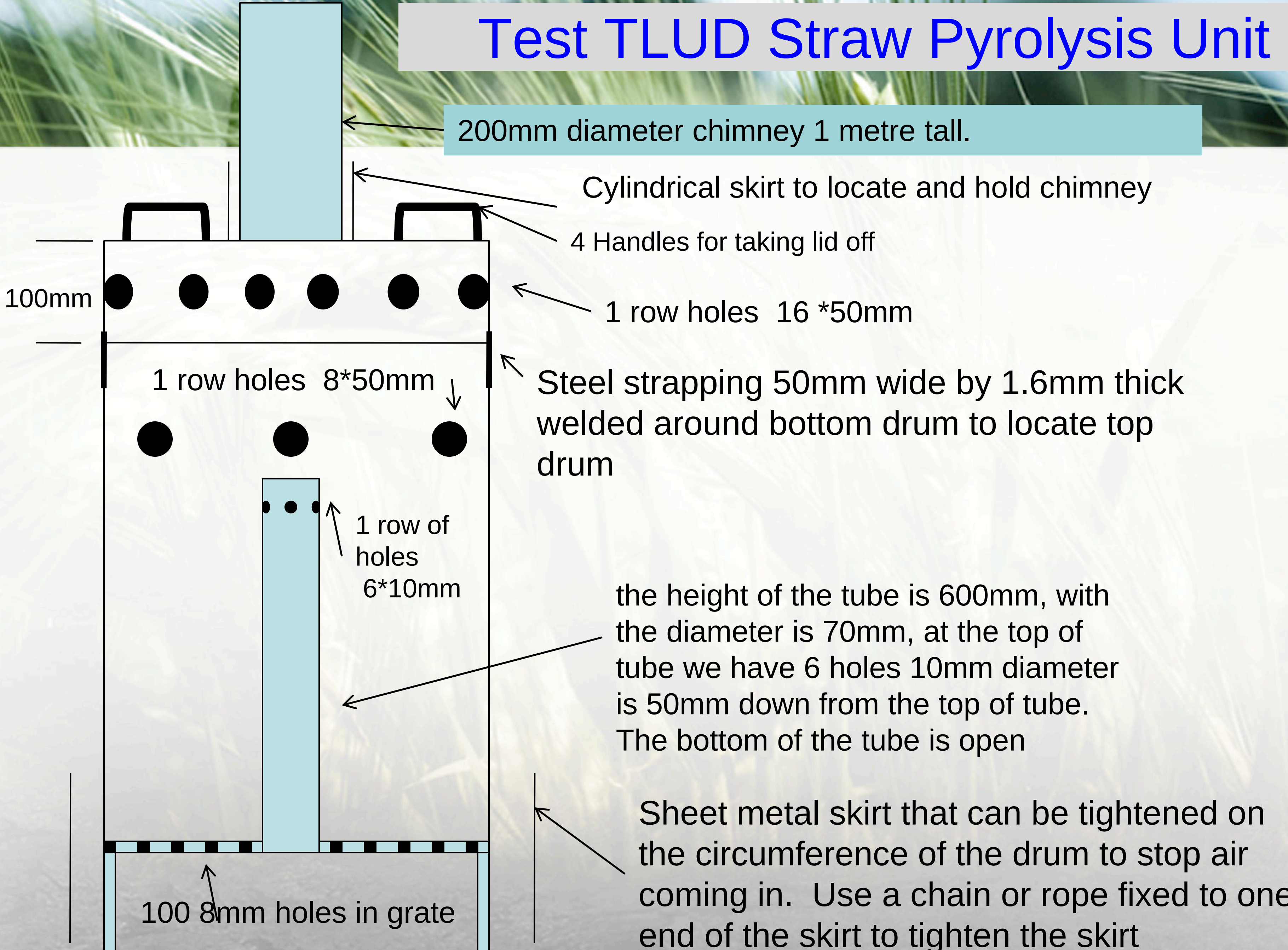
% Gas Composition	Time (minutes)						
	3'	5'	6'	9'	10'	14'	15'
CO	0.05	0.03	0.03	0.10	0.06	0.15	>1500ppm
NOx	0.02	0.03	0.03	0.02	0.02	0.02	0.01
O2	15	11.4	12.6	13.2	15.4	16.3	15.4
CO2	5.8	9.4	8.2	7.6	5.4	4.4	
%CO/CO2	0. 86	0.319	0.37	1.31	1.11	3.4	>2%

CO Emissions low compared to Field and forest burning

	Comments	$\Delta CO/\Delta CO_2$ %
Darley, 1966	Agricultural waste	5.4 (3–16)
Boubel, 1969	Stubble fields, Straw	6.6 (3–16)
Crutzen et al., 1979	Forest fires	12.4 (11–14)
		19.9 (16–25)
Greenberg et al., 1984	Cerrado (grassland),	11.9

R. Koppmann1, K. von Czapiewski, and J. S. Reid A review of biomass burning emissions, part I: gaseous emissions of carbon monoxide, methane, volatile organic compounds, and nitrogen containing compounds Atmos. Chem. Phys. Discuss., 5, 10455–10516, 2005www.atmos-chem-phys.org/acpd/5/10455/ SRef-ID: 1680-7375/acpd/2005-5-10455 European Geosciences Union

Test TLUD Straw Pyrolysis Unit



Demonstration of TLUD Oven at Binh Thanh Commune

Prepare the feedstock
Put a thin layer of slurry of clay and lime on the straw. Cut wood and Bamboo to fit across the drum

Place straw, then rice husks, then bamboo/wood in layers about 20cm high

Make sure steel skirt around bottom of drum is open to allow air to come in.
Light fire.

Demonstration of TLUD Oven at Binh Thanh Commune

Putting lid on

Reducing Air

Cutting air off

Reducing Temperature to about 450-550C with spray water

Testing Quality of Char

Dry Biomass In = 23kg
Dry Biochar Out= 8.6kg
Yield = 37%

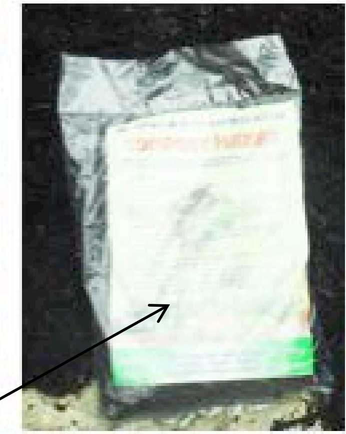
High yield due to high ash content of the rice husk and aged bamboo and wood

Conclusions and Recommendations from Field Trial of the TLUD Drum Oven

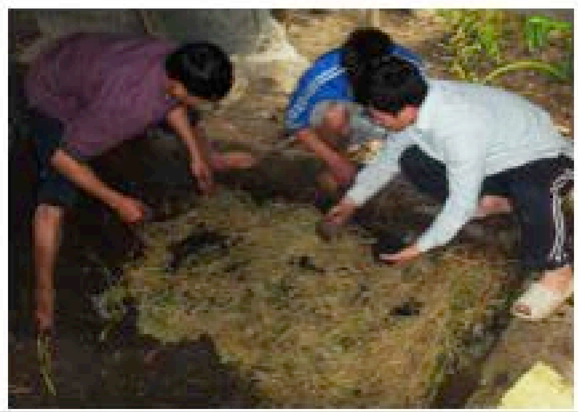
1. The present drum pyrolyser is working well with acceptable emissions compared with open field burning.
2. The women did not see a problem with either the preparation of the feedstock and mixing with a small amount of clay and lime.
3. The women did not see any difficulty operating the kiln
4. Given that biochar from open burning is already used in gardens, the women understood the advantages of using a drum to make high quality biochar.
5. There is scope for a range of different formulations including adding cow dung and phosphate to the feedstock. A comprehensive research program should be undertaken to determine optimal feedstock combinations for different crops.
6. It would appear that the use of aged wood and bamboo could result in a more effective biochar due to the higher mineral content on the surface.
7. Detailed analysis of the biochars needs to be carried out.

Women Making Biochar and Biochar Composts For Field Trials

Another 4 drums were made and women made enough biochar to carry out field trials in rice paddies after Tet. Some of the biochar was used to make compost



Adding microbes to biochar to help composting



Mixing local plant that assists with composting of manure and straw

Covering with plastic for anaerobic composting