MINISTRY OF EDUCATION AND TRAINING
CAN THO UNIVERSITY

School year: 2010-2012

SOKCHEA HUY

EFFECT OF BIOCHAR ON SOIL FERTILITY USING RICE AS INDICATOR PLANT

MASTER OF SCIENCE THESIS IN AGRICULTURAL SCIENCES
ANIMAL HUSBANDRY

Code Number: 02 - 10 - 08

Can Tho City, Viet Nam – 2012

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ANIMAL HUSBANDRY

Code: 60 – 62 - 40

Scientific supervisors:

1- **Dr. Khieu Borin**

2- **Prof. Dr. T R Preston**

AN APPROVAL OF THE SCIENTIFIC EVALUATION COMMITTEE

The thesis with the title: **“***Effect of biochar on soil fertility using rice as indicator plant***”** implemented by Mr. Sokchea Huy was approved by the Scientific Evaluation Committee at the Can Tho University.

Committee member **Secretary**

Opponent number 1 **Opponent number 2**

Can Tho City, March, 2012

Chair person

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Institution awarding degree: Royal University of Agriculture

Country: Cambodia

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Cantho City, *Feb, 2012*

Signature

Sokchea Huy

COMMITMENT

I assure that this thesis is a scientific work which was implemented by myself. All the figures and results presented in the thesis are true and not published in any previous theses.

Author

Sokchea Huy

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Dedication

To

My Parents

Mr. Huy Kimyan and Mrs. An Chhengvun,

My wife and daughter

Mrs. Pech Sina and Ms. Yan Cheanancy,

My brothers

Mr. Sok Poyi and Mr. Sok Kimyen

And

My Sister

Ms. Sok Malen

Effect of biochar on soil fertility using rice as indicator plant

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Abstract

Paper 1

A biotest with maize as indicator plant was used to measure the value as an amender of acid soil (pH 4.6) of biochar derived from gasification of rice husks. The experiment was designed as a 5*2*2 factorial in a completely randomized design (CRD) with 3 replicates. The factors were: source of biochar (from a downdraft gasifier reactor or an updraft gasifier stove), level of biochar (0, 2, 4, 6 or 8% added to the soil), and application of biodigester effluent (0 or 10 g N/m^2). The objective of the experiment was to value the biochar and its interaction with fertilizer on acidic soil and maize biomass improvement.

The biochar from the stove contained more ash (less organic matter) and the pH was higher compared with biochar from the gasifier. The yield of the aerial fraction and of total biomass of maize was 30% higher when the soil (pH 4.6) was amended (at 6 to 8% of the soil) with biochar from an updraft gasiifier stove than from a downdraft gasifier. There was no effect of the level of biochar on maize growth in the absence of biodigester effluent but growth was increased 90% when biochar was incorporated at 6% of the soil and biodigester effluent was applied at 10 g N/m^2 over 30 days. Soil pH was raised from 4.6 to 4.9 and water holding capacity by 50% when 6-8% biochar was added to the soil.

Key words: Biotest, CEC, downdraft, pH, updraft, WHC

Paper 2

Nutrient availability is the main priority in rice productivity in lowland ecosystems. Increasing nutrients in the soil are the key to improve the productivity. However, even though large amount of fertilizer application are applied, large nutrient loss occurs through leaching and evaporation. Biochar is a carbon product resulting from biomass pyrolysis of agricultural residues, can prevent soil nutrient leaching and enhance soil quality or fertility for crop productivity improvement.

The objective of this study was therefore to investigate the effect of biochar on rice grain yield. The experiment was done in the period of 94 days at the ecological farm of the Center for Livestock and Agriculture Development (CelAgrid), located in Phnom Penh city, Cambodia. The experiment was designed as a 2*2*2*2 factorial in a completely randomized block design (CRBD) with 4 replicates and in 64 containers and each size was of 0.042m2 (container capacity volume was 10 liters). The first factor was type of biochar (from a downdraft gasifier or updraft stove); the second factor was type of feedstock (rice husk and bagasse), the third factor was the level of biochar (0 and 5%), the fourth factor was level of fertilizer N from effluent (0 and 100 kg N/ha/crop).

The soil pH and water holding capacity of the soil did increase linearly after biochar application of 5%. On the other hand, biochar gasified by downdraft gasifier and updraft gasifier stove with the feedstock of bagasse and rice husk also upgraded the cation exchange capacity. Rice grain yield was therefore increased by 23% and 41% when the soil was treated with biochar, produced by rice husk and bagasse, respectively. However, there were no differences between biochar from the two types of gasifier (downdraft and updraft) on rice grain yield. It was concluded that biochar application as soil amendment is suitable for small scale and large scale farms to improved soil fertility and productivity of the rice crop..

Key words: *pH, CEC, exchangeable cations, grain, water holding capacity*

Paper 3

The objective of this study was to measure the effect of biochar from rice husk produced by different methods of combustion (drown draft gasifier and paddy rice drying machine) and their interaction with two kinds of fertilizer (biodigester effluent and urea) on soil fertility and paddy rice grain yield.

The experiment was done at the ecological farm of the Center for Livestock and Agriculture Development (CelAgrid), located in Phnom Penh city, Cambodia. The experiment was designed as a 2*2*2 factorial in a completely randomized block design (CRBD) with 4 replicates and in 32 plots each of 20 m^2. The first factor was type of biochar (from a downdraft gasifier or a rice dryer); the second factor was the level of biochar (0 and 3 kg/m^2); the third factor was source of fertilizer N (Biodigester effluent or urea at 100 kg N/ha/crop). The rice husk biochar increased yields of rice grain and straw by 30 and 40%, respectively; but there were no differences between biochar produced in a downdraft gasifier compared with that from a rice dryer, nor between urea and biodigester effluent as N fertilizer. Biodigester effluent increased rice grain yield more than urea in the absence of biochar but there were no differences between the two fertilizers when biochar was applied. Biochar increased soil pH, water holding capacity and cation exchange capacity. These criteria were not affected by the source of N fertilizer, nor by the source of the biochar.

Key words: *pH, CEC, exchangeable cations, grain, straw, water holding capacity*

Abbreviations

ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
CEC	Cation Exchange Capacity
CH_4	Methane
CO_2	Carbon dioxide
DM	Dry matter
FYM	Farm yard manure
IPCC	International Panel on Climate Change
K	Potassium
Mekarn	Mekong basin animal research network
N	Nitrogen
N_2	Nitrous gas
NH_3	Ammonia
NH_4	Ammonium
NO	Nitric oxide
NO2	Nitrite
NO_3	Nitrate
OC	Organic carbon
OM	Organic matter
pH	Power of/potential Hydrogen
P	Phosphorous
Prob/P	Probability
WHC	Water holding capacity
G	Down draft Gasifier
S	Up draft gasifier stove
D	Rice dryer machine
B	Biochar from bagasse
R	Biochar from rice husk
BL	Biochar level

Introduction

From 1960 to 2010, humans have consumed 280 billion tonnes of fossil fuel, and converted it to about 1 trillion tonnes of carbon dioxide (CO_2). Over 40% of that CO_2 has stayed in the atmosphere and about half of the balance has been absorbed into the oceans. Excess CO_2 acts as a greenhouse gas in the atmosphere, trapping infrared radiation, inhibiting the earth from shedding solar heat, and therefore causing the planet to warm. Excess CO_2 in the oceans changes their chemistry, making them more acidic, and threatening their living web. The ultimate outcome of this human-created condition will be determined by the interactions of numerous interconnecting feedbacks (Taylor 2011).

The high population density is the main pressure on excessive non-renewable resources utilization causing the damage to the world environment or leading climate change (Xuan An et al 1999). The pollution particularly was caused by large commercial farms and factories (Preston and Leng 1989). The increased agricultural productivity is also contributing in soil fertility depletion. We use fossil fuel to grow our food, and now there is a headlong push to use food to make our fuel. This shortsighted "solution" is already having negative consequences on food prices and availability, as well as on the environment and species diversity (Taylor 2011).

Climate change and ocean acidification are mainly generated by the human footprint on the planet. 20 global issues were identified that, if not addressed and on the way to resolution by 2020 will have drastic negative effects on the fate of our planet and civilization well into the future. Those issues were divided into three parts such as environmental (such as climate change, soil degradation and loss, and deforestation), social (such as poverty and over population), and regulatory (such as taxation, international labor, and migration) (Rischard 2002).

The better ways to solve the problem is the promotion of integrated farming systems, with minimal external inputs and recycling of all wastes. The most important feature of this approach is the recycling of animal wastes in order to prevent deterioration of soil fertility through loss of nutrients and organic matter, erosion and salinity (Preston and Rodriguez 1996). For instance applying the manure to the soil can reduce environmental pollution and also improve the fertility of the soil through recycling of plant nutrients to the soil.

Moreover, solving climate change and peak oil (declining production with increasing demand), requires us to rapidly install vast new infrastructures for energy supply, housing, transport, and food production and delivery that use less fossil fuel and cause fewer emissions. But building these new infrastructures requires massive quantities of fossil energy and capital and the climate and financial impacts will soon be unaffordable. Wealthy nations resist mitigating past and future greenhouse gas emissions, which cause damaging climate change, but developing and undeveloped nations must sign on (Rischard 2002).

Over the past 20 million years, the Earth’s climate has oscillated between relatively warm and relatively cold conditions called interglacial and glacial period. During interglacial period, atmospheric CO_2 concentrations were relatively high, and during glacial periods, CO_2 concentrations were relatively low. We are currently in an interglacial warm period, because human activities are pushing CO_2 concentrations higher than they were for hundreds of thousands of years. In order to address this issue, the scientific community has formed the Intergovernmental Panel on Climate Change (IPCC), an international, interdisciplinary consortium comprised of thousands of climate experts collaborating to produce consensus reports on climate change science (Harrison 2003).

Hypotheses

The hypotheses to be tested were:

Paper 1

Biochar produced from rice husks and bagasse by updraft gasifier stove and downdraft gasifier will increase maize biomass production.

Paper 2

Biochar from rice husk and bagasse as feedstock with different forms of combustion (downdraft gasifier and updraft gasifier stove), combined with biodigester effluent as organic fertilizer, will improve soil fertility and rice production.

Paper 3

The biochar from rice husk used as feedstock in a downdraft gasifier or in a paddy rice dryer machine, combined with urea and biodigester effluent as main nitrogen sources, will improve soil fertility and rice production.

Literature review

Climate

Cambodia's climate is governed by the monsoon winds, which define two major seasons. From mid-May to early October, the strong prevailing winds of the southwest monsoon bring heavy rains and high humidity. From early November to mid-March, the lighter and drier winds of the northeast monsoon bring variable cloudiness, infrequent precipitation, and lower humidity. Maximum temperatures are high throughout the year, ranging from about 28 °C in January, the coolest month, to about 35 °C in April. Annual precipitation varies considerably throughout the country, from more than 5,000 mm on the seaward slopes of the southwestern highlands to about 1,270–1,400 mm in the central lowland region (David et al 2011).

Gasifier (biochar producer)

At the present, gasifier has been designed and divided into two models which are: down draft and up draft. Normally, down draft gasifer has been operated to produce gas with the gas filters coupled with generators for electricity generation. In contrast, up draft gasifier has been designed to run for cooking, traditionally without gas filters.

However, they have the same four steps in the process of gasification: drying, pyrolysis, combustion and reduction. Through these processes, the main end product is producer gas (20% CO, 20% H_2, 2% CH_4 and 14%CO_2) with temperature of 600 to 1000 ^{0}C and with the yield of biochar from rice husk ranging from 18 to 25%, according to retention time, temperature and feedstock moisture content (Olivier 2010). However, in a downdraft gasifier with feedstock from cassia, cassava, mulberry and coconut the yileds of biochar were 11, 13, 11 and 14%, respectively (Phalla et al 2005). According to Lotchana (2008), biochar from rice husk contains 64% ash and 36% carbon.

Down draft gasifier

The whole system is divided into three main units, i)-gasifier, ii)-filter and iii)-engine. The basic features of the system are (according to the direction of the gas flow):

- **Gasifier** divided into 3 sections: hopper, reaction unit and ash collector. The hopper is to store the feedstock. It consists of drying zone and pyrolysis zone. The reaction zone has a combustion zone and reduction zone. The ash section is the bottom part for storing ash.
- **Venturi scrubber** is a tool for sucking air into gasifier using a current of water driven by a small pump and also for cooling gas.
- **Cyclone separator** is the place for cooling, cleaning and separating the gas from the water
- **Fine filter** is a container, filled with saw dusk for capturing dust and tar.
- **Safety filter** is a container with cloth 1x1 mm mesh sieve. The gas emerging from these filters is extremely pure and clean, suitable for burning in an internal combustible engine.
- **Flare** is a tube in a vertical plane for testing the gas quality by burning before the engine starts

- **Gas control valve** determines the amount of gas going into the engine according to the needs of the engine
- **Air filter** for cleaning air and mixing with the gas prior to entering the ignition zone of the engine
- **Engine** the spark and internal combustion engine are used
- **Exhaust pipe** is for exhausted waste or gases and sometimes can be used for drying wet feedstock as the gas is at a temperature of around 250 ^{0}C.

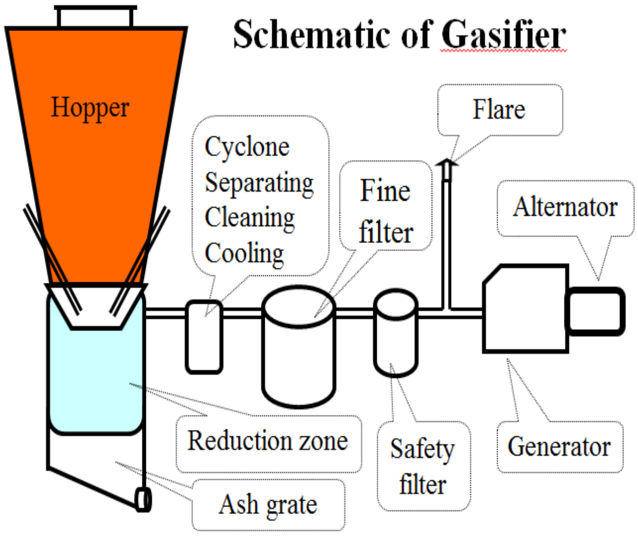

Photo 1: Diagram of downdraft gasifier

Up draft gasifier

This type of gasifier is best described by means of four adjectives: top-lit, forced-air, updraft, and batch.

1. The lighting of the biomass takes place at the top of the reactor (top-lit).
2. Air is forced through the biomass and char within the reactor by means of a fan or blower (forced-air).
3. The air or gases rise within the reactor (updraft).
4. When all of the biomass is gasified, the reactor is emptied of char, and the process is repeated (batch).

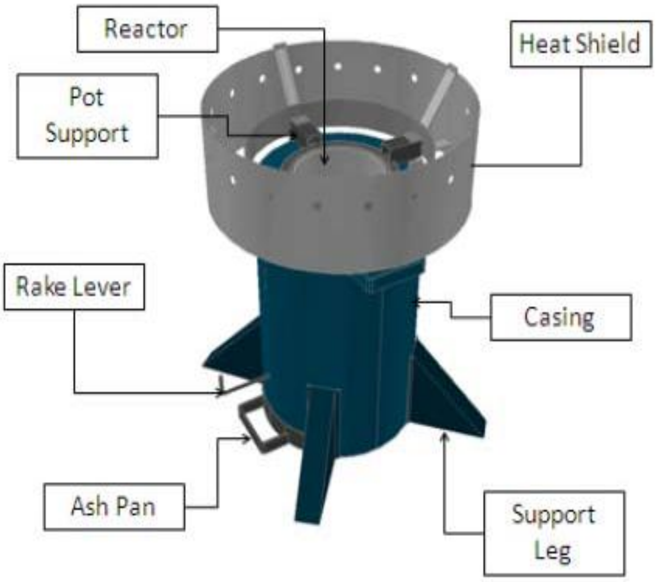

Photo 2: Diagram of updraft gasifier stove

Biochar productivities/application

Biochar is produced from many feedstocks like woody biomass and other agricultural by-products (eg: baggase, rice husk). Biochar is a fine-grained, porous substance and carbon rich product, which in appearance resembles charcoal, it will be produced when biomass is combusted under oxygen limited condition at high temperatures (from 600 to 1000 °C) in either a gasifier or in a gasifier stove. In the Amazon, it has been utilized to improve the fertility of the acid soils (Glaser 2007). It can stay in the soil unchanged for thousands of years and can be an effective medium for long term sequestration of carbon derived originally from the atmosphere through photosynthesis (Lehmann 2009). Biochar offer numerous potential benefits when it was applied to the soil like increasing the capacity for soil to hold nutrients, enhances crop yields, and captures and stores carbon for the long term (Taylor 2011).

Biochar can not only sequester carbon, but also improve soil fertility, and thereby reduce demand for synthetic fertilizers and emissions of the powerful greenhouse gas nitrous oxide (N_2O) , and can conserve and purify water, prevent runoff of chemicals from farm lands, reduce emissions of nitrogen oxide (NOx) and sulfur oxide (SOx) from coal burning power plants, reduce emissions of black carbon from biomass cooking fires, reduce methane emissions from decomposing organic waste piles and more. However, there has been little public awareness or debate over the large-scale application of biochar. Biochar may take 50-100 years for interactions between soil microbes and charcoal to create soils resembling Terra Preta (Ernsting et al 2009).

Biochar is not only a valuable soil amender to increase soil fertility and productivity, but also an appropriate tool for sequestering atmospheric carbon dioxide in soils for the long term in order to mitigate global warming (Lehmann and Joseph 2009). Biochar application to soils is being considered as a means to sequester carbon (C) while concurrently improving soil functions (Verheijen et al 2010).

The use of biochar as a soil additive meets the requirements that the char can be protected from oxidation, and it may be produced from material that would otherwise have degraded to release carbon dioxide into the atmosphere. For biochar to be useful for the sequestering of carbon, it is necessary that it must be long-lived and resistant to chemical processes such as oxidation to carbon dioxide or reduction to methane (Lehmann 2006).

Biodigester

Biodigesters play a crucial role in the conversion of organic matter to methane-rich biogas, with positive impacts on the environment and on human and animal health. Besides biogas production, biodigesters also provide a very good source of organic fertilizer for crops (Preston and Rodriguez 1996). Biogas is used for cooking and lighting to reduce the time and labor for finding fuels. On the other hand, it can also save the costs of buying wood and fertilizer (NRC 1981).

There are many species of biodigesters and models: they can be made from plastic tubes with low pressure and concrete with higher pressure. However, it is the anaerobic digestion, of fermented organic matter (carbohydrate, fat/lipid and protein…) by significant single celled or unicellular microorganisms (fungi, protozoa and bacteria) with four main step: hydrolysis, acidogenesis, acetogenesis and methanogenesis, according to Wikipedia (2011). The conversion efficiency was better for 20 and 30 days retention (550 and 547 litres biogas/kg OM) than for 10 days (376 litres/ kg OM) (Thy et al 2003).

Table 1: Bio gas yield from various substrates

Design Criteria/Substrates	**Dairy per each**	**Beef per each**	**Swine per each**	**Poultry (layer), each**
Animal Weight (lbs)	1400	800	135	4
Total fresh manure (gal/day)	12.5	6.1	1.35	0.032
Solid Content (%)	15	15	10	25
Volatile solids production (lbs/day)	12	5	1	0.038
Retention time (days)	15	13	20	22.5
Biogas yield (ft3/head/day)	46	28	4	0.29
Gross energy content (Btu/head/day)	27 800	16 600	2 300	180
Biogas yield/ton manure (ft3/ton/day)	920	1 148	741	2 266

Source: Barker et al, 2001

Effluent source

Biodigester effluent is potentially superior to raw manure fertilizer because the anaerobic diestion process results in conversion of organic nitrogen in the manure to ionized ammonia (NH_4^+), which can be used directly by plant roots (Forchhammer 1994). According to Thy et al (2003), the proportion of ammonia-N in total N was low in the raw manure, ranged from 0.02 to 0.04 but increased markedly in the effluent from 0.40 to 0.60 with the retention time of 10 to 30 days.

The composition of the effluent for the hydraulic retention times of 10 and 30 days was total N content, 1003 and 1066 mg N/litre, ammonia-N 486 and 636 mg/litre, and ammonia-N to total nitrogen ratio, 0.50 and 0.60 (Thy et al 2003). The effluent from a biodigester charged with cow manure managed with a 20 day retention time, contained 410 mg N/liter (Thu Hang 2003**).**

When digested slurry is used as fertilizer, it will have strong effects on plant tolerance to diseases such as potato wilt, late blight, cauliflower mosaic etc. and thus can be used as bio-chemical pesticide. Karki et al (2005**)** reported that spraying effluent only or in combination with little pesticide could effectively control red spider and aphids attaching vegetables, wheat and cotton. Soaking the seeds with digested slurry can induce the seedlings faster and resist diseases. On the other hand, it can enhance the cation exchange capacity (CEC), improving soil aggregation, increasing water holding capacity of the soils, stabilizing its humid content, and preventing the leaching of nutrients, compared to Farm Yard Manure (FYM).

Bio-slurry has more nutrients, because in FYM, the nutrients are lost by volatilization (especially nitrogen) due to exposure to sun and heat as well as through leaching. It increases agricultural production because of its high content of soil nutrients, and enzymes. However, if only mineral fertilizers are continuously applied to the soil without adding organic manure, the productivity of land will decline.

Table 2: Average constitution of fresh dung, dung slurry and digested slurry

Constituent	**Fresh dung**			**Dung mixing with water**			**Slurry**		
	g/kg	% wet base	% dry base	g/2kg	% wet base	% dry base	g/2kg	% wet base	% dry base
Water	800	80	-	1800	90	-	1820	93	-
Dry matter	200	20	100	200	10	100	140	7	100
Org. matter	150	15	75	150	7.5	75	90	4.5	64
Inorg. matter	50	5	25	50	2.5	25	50	2.5	36
Total N	5	0.50	2.50	5	0.25	2.5	5	0.25	3.60
Mineral N	1	0.10	0.50	1	0.05	0.50	2	0.10	1.40
Organic N	4	0.40	2	4	0.20	2	3	0.15	2.20
Phosphorus	2.50	0.25	1.25	2.50	0.13	1.25	2.5	0.13	1.80
Potassium	5	0.50	2.50	5	0.25	2.50	5	0.25	3.60

Source: Karki et al 2005

Table 3: Nutrients available in composted manure, FYM and digested slurry

Nutrients	**FYM**		**Composted manure**		**Digested slurry**	
	Range (%)	Average (%)	Range (%)	Average (%)	Range (%)	Average (%)
Nitrogen	0.5-1.0	0.8	0.5-1.5	1.0	1.4-1.8	1.60
P2O5	0.5-0.8	0.7	0.4-0.8	0.6	1.1-2.0	1.55
K2O	0.5-0.8	0.7	0.5-1.9	1.2	0.8-1.2	1.00

Source: Karki et al 2005.

Land and Soil condition

Total area of Cambodia is 181 035 Km^2 in which 176 515 Km^2 is land and 4 520 Km^2 is water. 21% of total land is agricultural land but only 7% can access water the whole year. 2.3 million ha is lowland rice, but most of the soils are sandy and poor in nutrients (MAFF 1996).

According to Ministry of Environment (1994), 63 per cent of Cambodia's forests are located in mountainous watershed areas, but most of them have been extensively logged, deforested or degraded. Loss and reduction of the vegetation cover leads to exposure of the soil to sunlight and heavy rainfall, which speeds up the decomposition rate and therefore decreases organic matter in the soil. The process also brings about changes in the physical and chemical soil structure. Consequently, the soil undergoes crusting, and the water filtration, and water and nutrient retention capacity are reduced. The end result is intensive run-off and erosion.

Erosion occurs not only in the upland areas but also in the lowland areas. In practice, water run-off occurs on all land, and the top soil is lost when no protective and conservation measures are in place. In Cambodia, however, few people understand that erosion is a serious problem in the rainfed lowland areas. In addition, population pressure in the rainfed lowlands is triggering a chain of events which will lead to intensive run-off, erosion and a reduction in the groundwater recharge.

Even though, the land is plentiful and in less supply, efficient soil fertility management is the key to sustainable agriculture. Soil fertility and management is the primary concern for the plant nutrient supply. The amount and availability of the nutrients to the crop plants, chemical reactions that they undergo in the soil, loss mechanisms, the processes making the nutrient unavailable or less available to the crops and the ways of replenishing into the soil should be the main objectives to be discussed for sustainable agriculture.

Soil has sustained plants and animals since life began on the planet Earth. Soil is made up of all three physical forms of matter, namely solid, liquid and gas. Nearly one half of the soil is solid while other half is air and water. The amount of air in the soil depends upon its water content; at optimum water content for the growth of most upland plants, water and air may each make up about 30 and 20% of soil volume, respectively. As regards the solid phase, 95% or more of it is mineral (inorganic) in the nature, while the remaining 5% or less is organic in the nature. However, in temperate and cooler regions of the world soil organic matter may be 5 to 10% or even more of the solid phase, while in the warm tropical and subtropical soil organic matter content could be much less than 5%. Thus the proportion of mineral and organic matter differs considerably from soil to soil, depending particularly on the climate of the region (Prasad et al 1936).

Nutrition management and their cycle

There are 16 key elements that are considered as essential for the growth of higher plants like Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S), Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Molybdenum (Mo), Boron (B) and Chlorine (Cl). However, to avoid the symptoms of deficiency is added to the 16 elements listed above such as: sodium (Na), silicon (Si), cobalt (Co) and vanadium (V) (Mengel and Kirkby, 1987).

Nitrogen cycle

Nitrogen is essential for all the living things. Nitrogen atoms are cycled between various forms of life, and between the atmosphere and the soil, by a series of interlinked chemical changes. Animals feed on plants and other animals for their requirement of nitrogen for making proteins. Most plants obtain the nitrogen they require from the soil. In soil, nitrogen is present as nitrates, which are soluble salts of nitric acid. The solubility of nitrates is of great importance. Plants absorb nitrates from aqueous solutions through their roots. Nitrates come to the soil from the atmosphere with rain water. In the atmosphere, at the time of lightning, nitrogen and oxygen combine to form oxides of nitrogen, which, in turn, form nitrates. Nitrates also enter the soil from the decay of dead plants and animals (Harrison 2003).

Nitrogen mineralization

After nitrogen is incorporated into organic matter, it is often converted back into inorganic nitrogen by a process called nitrogen mineralization. When organisms die, decomposers (such as bacteria and fungi) consume the organic matter and lead to the process of decomposition. During this process, a significant amount of the nitrogen contained within the dead organism is converted to ammonium (NH_4^+). Once in the form of ammonium, nitrogen is available for use by plants or for further transformation into nitrate (NO_3^-) through the process called nitrification.

Nitrification

Some of the ammonium produced by decomposition is converted to nitrate via a process called nitrification. The bacteria that carry out this reaction gain energy from it. Nitrification requires the presence of oxygen, so nitrification can happen only in oxygen-rich environments like circulating or flowing waters and the very surface layers of soils and sediments. Ammonium ions are positively charged and therefore stick (are absorbed) to negatively charged clay particles and soil organic matter.

The positive charge prevents ammonium nitrogen from being washed out of the soil (or leached) by rainfall. In contrast, the negatively charged nitrate ion is not held by soil particles and so can be washed down the soil profile, leading to decreased soil fertility and nitrate enrichment of downstream surface and ground waters.

Denitrification

Through denitrification, oxidized forms of nitrogen such as nitrate and nitrite (NO_2^-) are converted to dinitrogen (N_2) and to nitrous oxide gas. Denitrification is an anaerobic process that is carried out by denitrifying bacteria, which convert nitrate to dinitrogen (N_2). Nitric oxide and nitrous oxide are both environmentally important gases. Nitric oxide (NO_2) contributes to smog, and nitrous oxide (N_2O) is an important greenhouse gas, thereby contributing to global climate change.

Once converted to dinitrogen, nitrogen is unlikely to be reconverted to a biologically available form because it is a gas and is rapidly lost to the atmosphere. Denitrification is the only nitrogen transformation that removes nitrogen from ecosystems and it roughly balances the amount of nitrogen fixed by the nitrogen fixers. However, not all of the nitrogen fertilizer applied to agricultural fields stays to nourish crops. Some is washed off of agricultural fields by rain or irrigation water, where it leaches into surface or ground water.

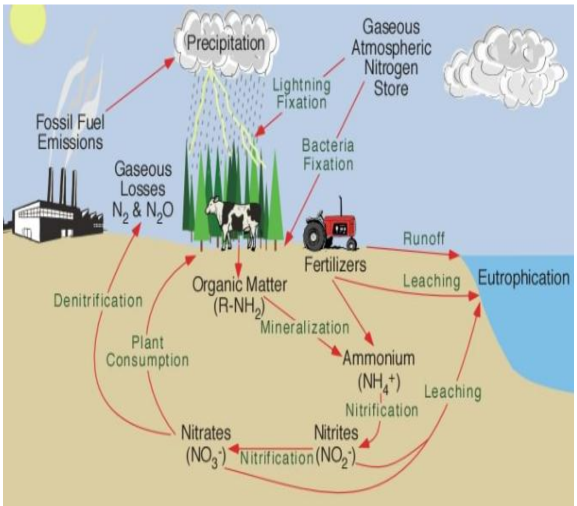

Figure 1: Nitrogen cycle in nature

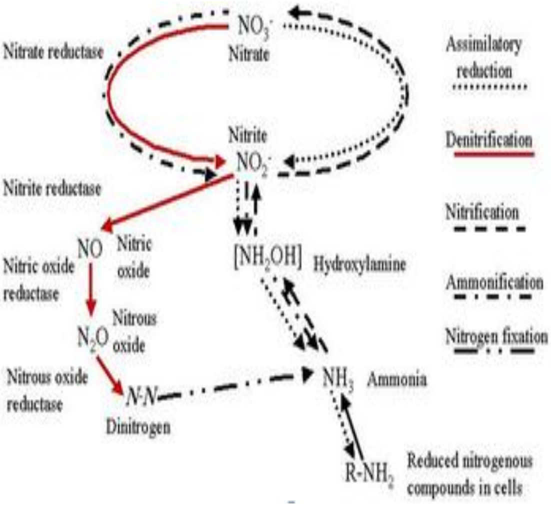

Figure 2: Nitrogen transformation occurring during the nitrogen cycle

Nitrogen fixation

According to Wikipedia (2011), nitrogen-fixing bacteria such as Azotobactor and Rhizobium, living in the soil and root nodule respectively, can convert the nitrogen in air directly in to nitrates which are soluble in the water. However, some plants are also capable of fixing atmospheric nitrogen because their roots have such nodules that contain nitrogen-fixing bacteria. These plants are leguminous, known as legumes. Bean plant is an example of a leguminous plant. The ammonia produced by nitrogen fixing bacteria is usually quickly incorporated into protein and other organic nitrogen compounds, either by a host plant, the bacteria itself, or another soil organism.

Carbon Cycle

The global carbon cycle, one of the major biogeochemical cycles, can be divided into geological and biological components. The geological carbon cycle operates on a time scale of millions of years, whereas the biological carbon cycle operates on a time scale of days to thousands of years (Harrison 2003).

The geological component of the carbon cycle is where it interacts with the rock cycle in the processes of weathering and dissolution, precipitation of minerals, burial and volcanism. Biology plays an important role in the movement of carbon between land, ocean, and atmosphere through the processes of photosynthesis and respiration. Plants take in carbon dioxide (CO_2) from the atmosphere during photosynthesis, and release CO_2 back into the atmosphere during respiration through the following chemical reactions.

Respiration:

$C_6H_{12}O_6$ (organic matter) + $6O_2 \rightarrow 6CO_2 + 6\ H_2O$ + energy

Photosynthesis:

Energy (sunlight) + $6CO_2 + H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

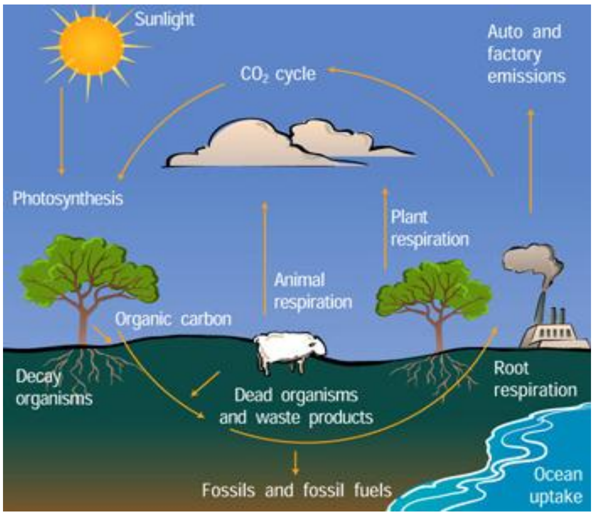

Figure 3: Carbon cycle

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Growth of maize in acid soil amended with biochar, derived from gasifier reactor and gasifier stove, with or without organic fertilizer (biodigester effluent)

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Abstract

A biotest with maize as indicator plant was used to measure the value as an amender of acid soil (pH 4.6) of biochar derived from gasification of rice husks. The experiment was designed as a 5*2*2 factorial in a completely randomized design (CRD) with 3 replicates. The factors were: source of biochar (from a downdraft gasifier reactor or an updraft gasifier stove), level of biochar (0, 2, 4, 6 or 8% added to the soil), and application of biodigester effluent (0 or 10 g N/m^2). The objective of the experiment was to value the biochar and its interaction with fertilizer on acidic soil and maize biomass improvement.

The biochar from the stove contained more ash (less organic matter) and the pH was higher compared with biochar from the gasifier. The yield of the aerial fraction and of total biomass of maize was 30% higher when the soil (pH 4.6) was amended (at 6 to 8% of the soil) with biochar from an updraft gasiifier stove than from a downdraft gasifier reactor. There was no effect of the level of biochar on maize growth in the absence of biodigester effluent but growth was increased 90% when biochar was incorporated at 6% of the soil and biodigester effluent was applied at 10 g N/m^2 over 30 days. Soil pH was raised from 4.6 to 4.9 and water holding capacity by 50% when 6-8% biochar was added to the soil.

Key words: Biotest, CEC, downdraft, pH, updraft, WHC

Introduction

The present world human population of some 6 billion is estimated to at least double in the next 50 years (PRB 2008). The implications for food production are serious especially considered in the light of the probable impacts of climate change in reducing yields of essential cereal grain crops such as rice. At the same time, soil deterioration from depletion of organic matter is an increasingly serious global problem that contributes to hunger and malnutrition. When the soil is intensively cultivated with high levels of chemical fertilization, it is quickly decomposed, leaving the soil compacted and nutrient-poor as well as (Mingxin Guo 2008).

The pH of the soil water is also very important because soil water plays a key role in carrying the nutrients such as nitrogen (N), potassium (K), and phosphorus (P) to support plant growth. Acid soils are common in the tropics. When soil pH is below 4 to 5, growth rates of crops such as maize are reduced. Desirable soil pH values for optimum maize growth are in the range of 6.5 to 7.0 (Nielsen 2005).

Biochar is the by-product from processes such as gasification and pyrolysis where biomass is heated to high temperatures in situations where the supply of oxygen is limited. Biochar is composed of the residual mineral matter from the original biomass and carbon resulting from the incomplete combustion of the biomass. Because of the high temperatures (from 600 to 1000 °C) reached in the gasification and pyrolysis processes, the physical and chemical properties of the carbon-rich residue in biochar are changed.

According to Glaser (2006) the carbon in biochar is intimately associated with "poly-condensed aromatic moieties which are assumed to be responsible for its chemical and biological recalcitrance in the environment". This author also emphasized the importance of the highly porous structure of biochar as responsible for its high capacity to adsorb organic molecules.

As most of the mineral matter in biomass is composed of salts of K, Na and Ca, it has a strong alkaline reaction giving rise to a pH of between 8 and 10 (Rodriguez et al 2009). Thus application of biochar as a soil amender would be especially appropriate in acid soils with a low content of organic matter. Biochar is unlikely to have a major role as a fertilizer but, because of its structure, it can be expected to increase water and air holding capacity, and be a good habitat for some microbes and plant nutrients.

Biochar can be produced in different processes according to the temperature (Table 1).

Table 1: Product yield from pyrolysis (or gasification) of wood (expressed as yield in terms of % dry weight conversion to products) (from IEA 2010)

Mode	Conditions	Liquid	Char	Gas
Fast	Moderate temperature, around 500 ^{0}C, short hot vapor residence time ~1 second.	75%	12%	13%
Intermediate	Moderate temperature, around 500 ^{0}C, moderate hot vapor residence time ~ 10-20 second.	50%	20%	30%
Slow (carbonization)	Low temperature, around 400 ^{0}C, very long solids residence time	30%	35%	35%
Gasification	High temperature, around 800 ^{0}C, long vapor residence time	5%	10%	85%

Much of the discussion on the use of biochar has centered on producing it by pyrolysis. There are few reports on the properties of biochar produced as a byproduct of the processing of fibrous biomass for purposes of production of electricity (Phalla and Preston 2005) or for use in gasifier stoves (Olivier 2010). These two processes differ in the configuration of the reaction and specifically the flow of air. The gasifier described by Phalla and Preston (2005) is a downdraft gasifier whereas the gasifier stove uses the updraft principle. It is possible that the properties of the biochar produced in these two systems will be different.

The object of the present study was therefore to compare the soil amendment properties of biochar produced from rice husks used as the fuel in the two types of gasifier; the updraft (TLUD) gasifier stove designed for cooking (Olivier 2010) compared with the downdraft gasifier to produce a combustible gas as fuel for an internal combustion engine (Phalla and Preston 2005).

Hypotheses

- Biochar produced from rice husks in an updraft gasifier stove will have similar effects on soil fertility as biochar produced from rice husks in a downdraft gasifier

- There will be synergistic effects on yield of maize from both sources of biochar with effluent from a biodigester charged with pig manure.

Materials and methods

The experiment was done in An Giang University of Agriculture, An Giang province, Long Xuyen city, Vietnam. It lasted for 30 days, starting from September 04 to October 04, 2010. The local ambient temperature was about 33-37°C.

Experimental design

The experiment was designed as a 5*2*2 factorial in a completely randomized design (CRD) with 3 replicates. The factors were:

Source of biochar:

- Downdraft gasifier (DDG) versus gasifier stove (GS)
- Level of biochar: 0, 2, 4, 6, and 8%
- Level of biodigester effluent: None or 10 g N/m^2

Source of biochar:

Downdraft gasifier

The gasifier used to produce the biochar is divided into three parts (hopper, reactor and ash collector) with four steps in the process of gasification: Drying, Pyrolysis, Combustion, Reduction (Photos 1 and 2). Through these processes, the main end products are producer gas (CO 20%, H_2 20%, CH_4 3%). When rice husk is the feedstock, the residual biochar is on average about 17% of the dry weight of the feedstock with content of 72% ash and 28% carbon (Sokchea, unpublished data).

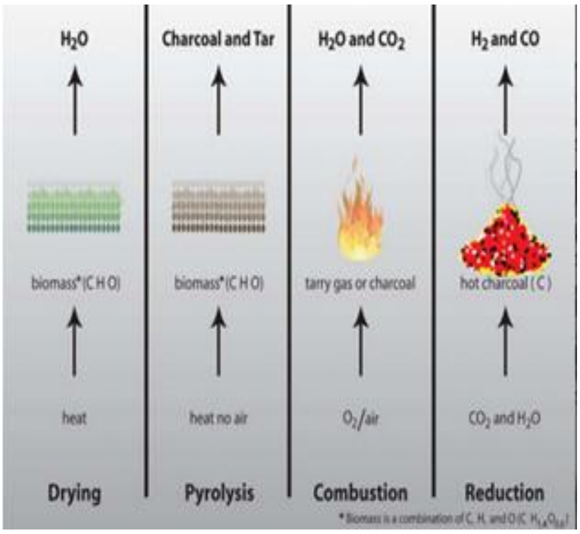

Photo 1: Four processes in gasification for synthesis gas and biochar

Photo 2: Rice husk gasifier at rice milling station

Updraft gasifier stove

This type of gasifier stove has 4 features: top-lit, forced-air, updraft, and batch.

1. The lighting of the biomass takes place at the top of the reactor (top-lit).
2. Air is forced through the biomass and char within the reactor by means of a fan or blower (forced-air).
3. The air or gases rise within the reactor (updraft).
4. When all of the biomass is gasified, the reactor is emptied of char, and the process is repeated (batch).

The gasifier stove (Photos 3 and 4) is divided into three parts (cooker, reactor and ash collector) with 4 steps of gasification: drying, pyrolysis, combustion, reduction. The stove with diameter of 25 cm can burn for around 1 h with 5 kg of rice husk as feedstock. Biochar yield is 25% from rice husk with 35.6% ash and 64.4% carbon. Biomass gasification proceeds from top to bottom at a rate of about 17 mm per minute (Olivier 2010).

Photo 3: Gasifier stove from top view (Olivier 2010)

Photo 4: Gasifier stove, boiling water (Olivier 2010)

Biodigester effluent

The effluent was taken from two “plug-flow” tubular polyethylene (0.5 m^3 liquid volume) biodigester (Photo 5) charged daily with pig manure collected from a nearby pig farm. The daily charge was 5 kg of fresh manure and 20 litres of water with 20 days of retention time. The biodigester effluent was applied every 5 days at the amount of 10g N/m^2 with the duration of 30 days, according to the treatment.

Photo 5: The plug-flow tubular polyethylene biodigesters

Procedure

Maize (*Zea mays*) was chosen as the most suitable indicator plant (Chamnanwit 2001). The soil (pH 4.3) was taken from the campus of An Giang University, located in An Giang province, Long Xuyen city. It was broken down into small pieces and quantities of 1 kg mixed with one of the two kinds of biochar at different levels, according to the treatments. The mixed soil and biochar was put into plastic bags (n=60) of 1.5 liter capacity. Seeds of maize were soaked over-night for better germination before planting three seeds in each bag. Water was sprayed daily on the bags. The biodigester effluent was applied every 5 days in quantities according to the N content to provide the equivalent of 10 g N/m^2 over the 30 day period. After germination, 1 or 2 plants were removed to leave a single plant for the rest of the experiment (Photo 6).

Photo 6. The maize biotest system

At the end of 30 days, the plants were removed from the bags by soaking the contents in water to release the soil. Each component of the plant (Leaves, stems and roots) was weighed separately and samples taken for determination of DM.

Chemical analysis

The soil was analyzed for DM, pH and ash before, and at the end of the experiment. Biochar was analyzed for ash and pH. The DM content was determined using the micro-wave radiation method of Undersander et al (1993). Ash and N were determined following AOAC (1990) procedures. The pH of soil samples was determined using a digital pH meter with glass electrode. The samples were collected and ground to become powder and then, 5 g DM of sample was weighed and put into the sterilized tubes and then, pour 25 ml into each tube, after that shook for 2 hours by machine before centrifugation of 10 minutes and then measured with electronic pH meter and cations exchange capacity (CEC), The biodigester effluent was analysed for nitrogen content (Table 2).

Statistical analysis

The data were analyzed by the GLM option in the ANOVA program of the Minitab software (Minitab 2000). Sources of variation were: biochar source, effluent, biochar level, interactions between biochar*level, biochar*effluent and error.

Results and discussion

Composition of biochar

The biochar from the stove contained more ash (less organic matter) and the pH was higher (Table 2) compared with biochar from the gasifier. The organic matter content was much higher in the biochar derived from rice husks in this study than was reported for biochar derived from gasification of sugar cane bagasse for which the organic matter was 65% (Rodriguez et al 2009). This presumably reflects the much higher content of ash in rice hulls compared with sugar cane bagasse.

Table 2: Chemical composition of soil, biochar and effluent analysis

Composition	DM,%	N, mg/litre	OM,% in DM	pH
Soil	79.5		3.81	4.7
Biochar stove (BS)	94.3		35.6	9.8
Biochar gasifier (BG)	50.7		28.0	9.5
Effluent	nd	320	nd	nd

nd Not determined

Effects of pH

The soil pH increased linearly with increasing level of biochar and was higher for biochar from the stove than that from the gasifier (Figure 1). However, the order of increase was less than that reported by Rodriguez et al (2009). In the study by these authors the soil pH was raised from 4.6 to 6.8 when 5% biochar was added to the soil, an increase of 50% compared with the much smaller increment (from 4.6 to 4.9) observed in the present experiment when the level of gasified rice husk was increased from 0 to 5%.

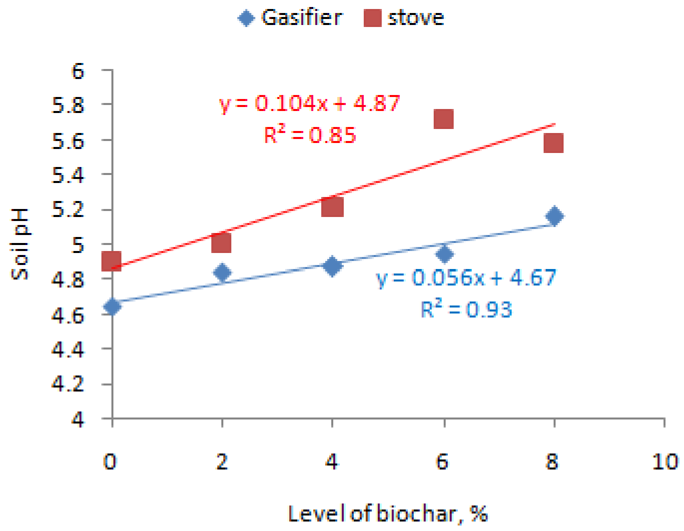

Figure1: Effect of level of different sources of biochar on soil pH

Water holding capacity and cation exchange capacity (CEC)

Water holding capacity was increased by level of biochar with no difference between sources of biochar (Figure 2). By contrast there was no effect of biochar on cation exchange capacity (Figure 3). These results were similar to those reported by Sothavong and Preston (2011) who applied similar treatments to similar samples of the same soil but using rice as the indicator plant. Lehman (2007) emphasized that while cation exchange capacity of soil can be increased by addition of biochar, this depended on the temperature at which the biochar was produced and on the length of time it had been in the soil .

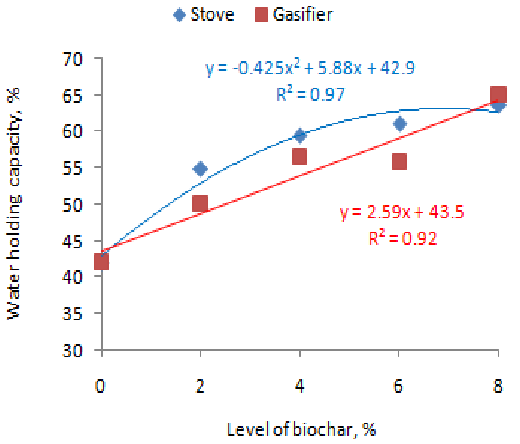

Figure 2: Effect of level and source of biochar on water holding capacity of the soil

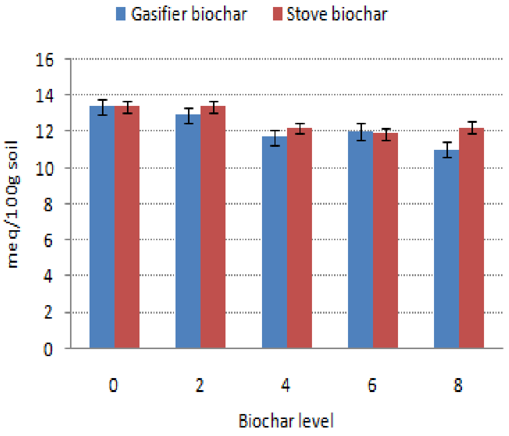

Figure 3: Effect of level and source of biochar on cation exchange capacity (CEC) of the soil

Biomass yield

The yield of the aerial fraction and of total biomass of the maize was higher when the biochar was from the stove than from the gasifier (Table 3), and when effluent was applied. Root yield tended to be increased with the stove biochar (P=0.077) and was increased two-fold when effluent was applied. Level of biochar tended to increase root (P=0.11) and total biomass (P=0.10) There were no interactions among the treatments; however, the pattern of the responses to the level of addition of biochar was quite different (Figures 4-6).

With the addition of biodigester effluent, biomass yields of the three components of the plant were increased as the biochar level was increased reaching a maximum with 8% of biochar added to the soil (equivalent to 80 tonnes biochar/ha, assuming the biochar would be incorporated in the upper 10 cm of the soil profile). By contrast, in the absence of effluent there appeared to be no effect of the biochar. These effects were similar to those reported by Sothavong and Preston (2011) although the optimum level of biochar in presence of effluent tended to be higher in the present study (with 6% biochar) compared with that of Sothavong and Preston (2011) where the maximum response with rice plants was with 4% biochar. Doung Nguyen Khang et al (2010) also found that the optimum maize growth was achieved with 4% biochar (from gasifier stove) in the presence of effluent, with reduced yields at higher levels, while there was no response to biochar when effluent was not applied.

Table 3: Mean values for effects of level of biochar, effluent and biochar type on weights (g/plant) of root, aerial, and total biomass (after 30 days growth)

	Total,	**Aerial**	**Root**
Biochar type			
Gasifier	5.79	3.65	2.14
Stove	7.45	4.78	2.68
SEM	0.52	0.36	0.21
P	0.026	0.029	0.077
Level of biochar, %			
0	5.41	3.54	1.87
2	5.60	3.45	2.14
4	6.47	4.24	2.23
6	7.96	5.12	2.84
8	7.67	4.70	2.96
SEM	0.84	0.58	0.34
P	0.10	0.18	0.11
Effluent			
With	9.36	6.10	3.25
Without	3.88	2.32	1.57
SEM	0.52	0.36	0.21
P	<0.001	<0.001	<0.001

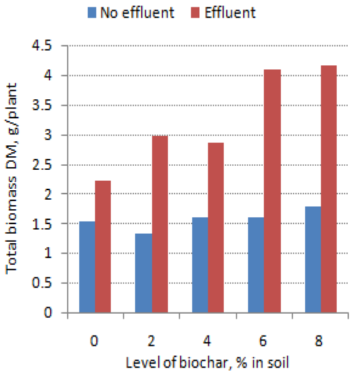

Figure 4: Effect of effluent and level of biochar on root biomass yield of maize

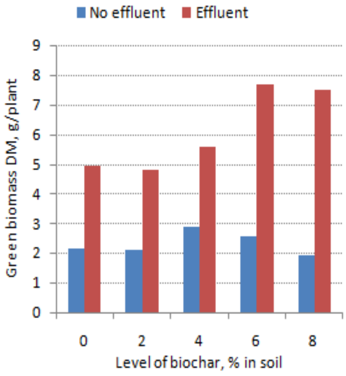

Figure 5: Effect of effluent and level of biochar on green biomass yield of maize

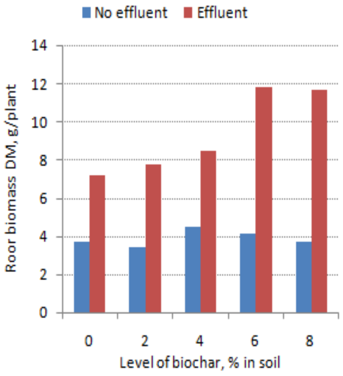

Figure 6: Effect of effluent and level of biochar on total biomass yield of maize

In general the responses to biochar addition to the acid soil (pH 4.6) in the present study were much less pronounced than were reported by Rodriguez et al (2009) where maize yields on a fertile, but acid (pH 4.6) soil were increased three to five-fold with addition of 5% biochar in presence or absence of biodigester effluent. The implication is that the major difference in responses in the two studies reflected differences in the origin of the parent feedstock (sugar cane bagasse in the study of Rodríguez et al [2009] compared with rice husks in the present study). The fact that the soil pH was increased only slightly with biochar from rice husks and that there was no effect on cation exchange capacity lends support to this idea that the nature of the parent feedstock may be a major factor in determining plant growth responses to soil amelioration with biochar. This hypothesis merits future studies to compare widely different sources of feedstock and of sources of biochar with different ratios of ash to organic matter.

Conclusions

- The yield of the aerial fraction and of total biomass of maize in a growth period of 30 days was 30% higher when acid soils (pH 4.6) were amended (at 6 to 8% of the soil) with biochar from an updraft gasifier stove than from a downdraft gasifier reactor.
- There was no effect of the level of biochar on maize growth in the absence of biodigester effluent but growth was increased 90% when biochar was incorporated at 6% of the soil and biodigester effluent was applied at 10g N/m^2 over 50 days.
- Soil pH was raised from 4.6 to 4.9 and water holding capacity by 50% when 6-8% biochar was added to the soil.

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Effect of biochar to amend acid soil and improve cation exchange capacity and to increase rice yield, with interaction between effluent and two kinds of biochar from gasifier and stove

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Abstract

Nutrient availability is the main priority in rice productivity in lowland ecosystems. Increasing nutrients in the soil are the key to improve the productivity. However, even though large amount of fertilizer application are applied, large nutrient loss occurs through leaching and evaporation. Biochar is a carbon product resulting from biomass pyrolysis of agricultural residues, can prevent soil nutrient leaching and enhance soil quality or fertility for crop productivity improvement.

The objective of this study was therefore to investigate the effect of biochar on rice grain yield. The experiment was done in the period of 94 days at the ecological farm of the Center for Livestock and Agriculture Development (CelAgrid), located in Phnom Penh city, Cambodia. The experiment was designed as a 2*2*2*2 factorial in a completely randomized block design (CRBD) with 4 replicates and in 64 containers and each size was of 0.042 m^2 (container capacity volume was 10 liters). The first factor was type of biochar (from a downdraft gasifier or updraft stove), the second factor was type of feedstock (rice husk and bagasse), the third factor was the level of biochar (0 and 5%) and the fourth factor was level of fertilizer N from effluent (0 and 100kg N/ha/crop).

The soil pH and water holding capacity of the soil did increase linearly after biochar application of 5%. On the other hand, biochar gasified by downdraft gasifier and updraft gasifier stove with the feedstock of bagasse and rice husk also upgraded the cation exchange capacity. Rice grain yield was therefore developed up to 23% and 41% while the soil was treated with biochar, produced by rice husk and bagasse, respectively. However, there were no different effects between both types of biochar from both types of combustion (downdraft and updraft) on rice grain yield. It is concluded that biochar application as soil amendment is suitable for small scale and large scale farms to improve soil fertility and productivity of the rice.

Key words: *pH, CEC, exchangeable cations, grain, water holding capacity*

Introduction

Agriculture remains a significant part of the Cambodian economy, with about 80% of Cambodia's population and most of its poor relying on agriculture for their livelihoods, especially rice cultivation. Soil is one of the most important factors in determining crop yields. For agriculture to be sustainable, there is an immediate need to combat the problem of soil erosion and to increase food production.

2.3 million ha is lowland rice in Cambodia but most of soils are sandy and poor in nutrients. Erosion occurs not only in the upland areas but also in the lowland areas. In practice, water run-off occurs on all land, and the top soil is lost when no protective and conservation measures are in place. The most common rain fed lowland soil, are sandy, acidic, extremely infertile and low in organic carbon and cation exchange capacity (Reyes 1995). According to MAFF 1996, there are four important rice agro-ecosystems in Cambodia: rain fed lowland rice, rain fed upland farming, deep-water or floating rice and dry-season (flood recession) rice.

Biochar is a fine-grained, porous substance and carbon rich product, look very much like charcoal produced by natural burning. However, biochar is produced by the combustion of biomass under oxygen limited condition at the high temperatures (from 600 to 1000 °C) in updraft and downdraft gasifier. Through these processes, the main end product are gas production of 40% CO, 40% H_2, CH_4 3%, CO_2 17% and biochar residue (Olivier 2010).

The biochar can remain in the soil unchanged for thousands of years so it can be effective for long term sequestration of carbon (Lehmann et al 2009). It is being considered as a potentially significant means of storing carbon for a long period to mitigate greenhouse gas emissions. Application of biochar as a soil amender will be especially appropriate in acid soils. Biochar is unlikely to have a major role as a fertilizer but, because of its structure, it can be expected to increase water and air holding capacity, and be a good habitat for some microbes and plant nutrients (David et al 2009).

Materials and methods

Duration and location

The experiment was done with scientific concepts and design at the Centre for Livestock and Agriculture Development (CelAgrid, ecological farm) with the period of 94 days, located in Preah Theat village, Rolous commune, Kanal Steung district, Kanal province, approximately 23 km from Phnom Penh city.

Photo 1: Experimental review

Experimental design

The experiment was designed as a 2*2*2*2 factorial in a completely randomized block design (CRBD) with 4 replicates. The first factor was the type of biochar (from downdraft gasifier or updraft gasifier stove), the second factor was feedstock (sugar cane bagasse or rice husk), third factor was level of biochar (0 and 5%) and fourth factor was effluent level (0 and 10 g N/m^2/crop), so there were 64 plots (containers) totally.

Table 1: Layout of the experiment

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
GR0	**GB5**	**SB5**	**GB0**	**GEB5**	**GER5**	**SR5**	**SEB5**	**SER0**	**SB0**	**SER5**	**GER0**	**SR0**	**GEB0**	**SEB0**	**GR5**
17	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
GR5	**SB0**	**GEB0**	**SEB5**	**GER5**	**GB5**	**SEB0**	**GB0**	**SER5**	**GR0**	**SB5**	**GEB5**	**GER0**	**SER0**	**SR5**	**SR0**
33	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
GR0	**GB5**	**SB5**	**SEB0**	**GR5**	**SR0**	**SER0**	**GER5**	**SEB5**	**GEB0**	**GB0**	**GEB5**	**SR5**	**SER5**	**SB0**	**GER0**
49	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**
GB5	**SEB0**	**GER0**	**SB5**	**SEB5**	**GR0**	**SR5**	**GB0**	**SB0**	**SER0**	**SR0**	**GEB5**	**GER5**	**GEB0**	**SER5**	**GR5**

Experimental material

Four types of biochar (rice husk biochar was produced from updraft gasifier stove and from downdraft gasifier and bagasse biochar also from updraft gasifier stove and from downdraft) were selected. All kinds of biochars were mixed with the experimental acidic soil at the amount of 5% in DM before putting into the containers, according to the treatments.

Photo 2 : Rice husk biochar from updraft gasifier stove

Photo 3 : Rice husk biochar from downdraft gasifier

Photo 4 : Bagasse biochar from updraft gasifier stove

Photo 5 : Bagasse biochar from downdraft gasifier

Biochar

The biochar (stove) was obtained from the updraft gasifier used for cooking (Photo 3 and 5). The feedstocks used in the furnace of the stove were rice husk and bagasse. The other source of biochar was a commercial down-draft gasifier (Photo 4 and 6) producing a combustible gas (approximately 20% hydrogen and 20% carbon monoxide) which was used as fuel in an internal combustion gas engine driving an electrical generator to produce electrical power for the rice mill and electricity. The temperature inside the gasifier was around 900 to 1100^{0}C, according to Shackley et al (2010).

Photo 6: Updraft gasifier stove

Photo 7: Downdraft gasifier

Bio-digester effluent

The brick and concrete fixed-dome biodigester had a capacity of 15 m^3. It was charged with manure from pigs fed brewery residues and a commercial concentrate.

Photo 8: Concrete biodigester (high biogas pressure)

Procedures

In this experiment, rice was selected as indicator. Soil was chosen from the rice field with the low pH of 4.5 around the CelAgrid campus. It was broken down into small pieces and quantities of 5 kg mixed with the different biochars at 5 %, according to the treatments. The mixed soil and biochar was put into plastic containers (n=64) of 10 liter capacity. The rice seed was soaked into the water overnight for better germination before planting. Five seeds were grown but after germination in the period of 7 days, only one plant was kept for experiment and the rest were removed completely. Between each container was 30 cm.

Fertilization and watering

The effluent was pumped from the biodigester to PVC drums (Photo 10). The biodigester effluent was applied in three steps: the first time was 20 days after planting, second at 50 days and third at 75 days, with the amount of 100 kg N/ha/crop. From the drums the effluent was applied by hand, according to the treatments.

The water was pumped from a well to PVC drums. The amounts applied were sufficient to maintain the water levels in the each plastic container (Photo 11).

Photo 9: Effluent storage before applied

Photo 10: Water level was kept over the surface

Planted and harvested the rice

After growing in the period of 70 days, the Tillers were counted on the plants in each container (Photo 12). At the time of harvest, the rice plants from each container were soaked into the water to remove the soil (Photo 13) and then, separated into grain and stems + leaves which were weighed separately and also measured the root length.

Photo 11: Counting the tillers

Photo12: Soak into the water to release the soil

Photo13: Rice biomass collected

Analytical procedures

The rice grain, straw (stems + leaves) and root were analysed for DM by the micro-wave radiation method of Undersander et al (1993). Nitrogen was determined following AOAC (1990) procedures. Organic carbon was calculated as OM/1.724 (Walkley et al 1934). Soil samples were analysed for texture, separating the fractions into clay, fine silt, coarse silt, fine sand and coarse sand using the Pipette Method (Day 1965). The cation exchange capacity (CEC) was determined by titrating with 1M Calcium Chloride at pH 7 (Rhoades 1982). The water holding capacity was determined by weighing 15 g of soil into a glass funnel fitted with filter paper and then saturating the soil with water (Photo 15). After 24 the soil was weighed to determine the quantity of water that had been retained.

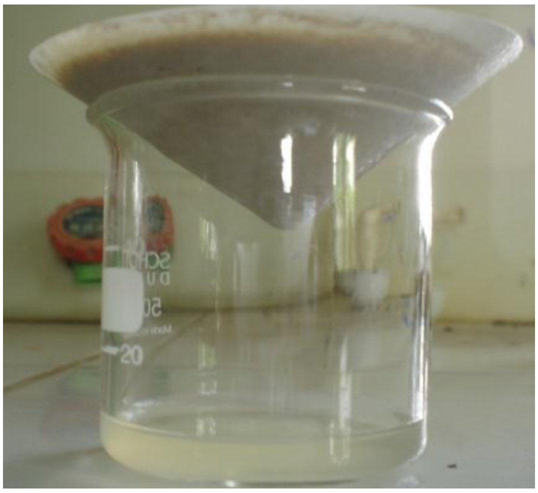

Photo 14: Adding water to saturate the soil then allowing the water to drain for 24 hours to determine water holding capacity

For measurement of the pH, the soil samples were dried in the microwave oven, then ground to a powder. Five gram of the ground sample was put in a beaker and 25 ml of distilled water were added. The suspension was stirred 3 times at 15 minute intervals, and then filtered. The water after filtration was used for determination of pH by using a digital pH meter.

Photo 15: Filter the suspension sample

Photo 16: pH measurement

Statistical analysis

The data were analysed by the General Linear Model of the ANOVA program in the Minitab software (Minitab 2000). Sources of variation were: biochar sources, feed stocks, level of biochar, effluent and interaction between biochar* feed stocks*level of biochar*effluent and error.

Results and discussion

Soil texture, pH, WHC and CEC

According to Turenne (2011), soil texture is determined by the size of the particles: very coarse sand: 2.0-1.0 mm, coarse sand: 1.0-0.5 mm, medium sand: 0.5-0.25 mm, fine sand: 0.25-0.10 mm, very fine sand: 0.10-0.05 mm, silt: 0.05-0.002 mm and clay: < 0.002 mm. There are three elements that define soil type: texture, structure, and porosity. Soil texture is determined by the percentages of sand, clay and silt while soil structure is the way the clay, sand and silt particles join together with organic matter to form aggregates or clusters of particles.

Soil texture, in this experiment was classified as 'silt loam' soil (Table 2). According to ISSS Working Group RB (1998), Soil material that contains 50 to 80 % silt and less than 12 % clay, was recognized as silt loam.

Table 2: Soil texture, using the Pipette Method

Clay	Fine silt	Silt	Fine sand	Sand
7.5	54.8	13.3	18.2	3.5

Table 3: Chemical composition analysis

Sample	Detail	DM%	OM%	OC%	pH	N, mg/ liter	P, %	K,%	CEC, meq/100g
BBS	Baggase biochar from Stove	94.03	12.18	7.06	10.6	N/A	N/A	N/A	201
RBS	Rice husk biochar from stove	93.08	15.10	8.76	10.6	N/A	N/A	N/A	43
RBG	Rice husk biochar from gasifier	67.41	55.17	32.00	9.8	N/A	N/A	N/A	69
BBG	Baggase biochar from Gasifier	91.75	44.27	25.68	10.4	N/A	N/A	N/A	192
Soil		80.56	22.02	N/A	5.0	0.18	N/A	N/A	N/A
Effluent		N/A	N/A	N/A	5.8	0.036	0.14	0.1	N/A

N/A Not analysed

Soil pH was increased by application of biochar (both biochar from rice husk and from bagasse), according to its high pH originally in the range of 9.8 to 10.6, these seem higher than biochar reported by Shackley et al (2010) of 9.63 and by Privadarshini et al 2010, pH of biochar could be from 7.79 to 9.97. On the other hand, biochar produced from cattle dung and coconut shell had alkaline (pH) of 8.9 and 9.9, respectively

(Sukartono et al 2011). However, pH of biochar is affected by feedstock quality, according to Sukartono et al (2011) who also mentioned that different properties of biochars seem to be associated with the nature of the chemical constituents in the feedstock biomass. Biochar was able to reduce soil acidity which decreases liming needs (Lehmann et al 2009). There was no effect on biochar pH between downdraft gasifier and updraft gasifier stove with P-value= 0.826 (table 4).

Water holding capacity (WHC) of the soil became higher after integration with the biochar, compared to the untreated biochar treatments (P=0.001). WHC also depend on variety of feedstock, utilized to produce biochar but was not affected by effluent (Table 4). Biochar properties were varied by kinds of feedstock (Sukartono et al 2011) but the structures of biochar seem closely similar, especially its porous structure and low bulk density which gives higher water and nutrient storages and good habitats of microorganisms (Privadarshini et al 2010).

Agusalim (2010) also reported that water holding capacity was increased from 11.3% for untreated control soil to 15.5% for soil treated with rice husk biochar. Lehmann (2009) suggested that biochar application may enhance the soil moisture retention, while Chan et al (2007) showed that biochar application improved some physical properties of soils, such as increased soil aggregation and water holding capacity. Makoto et al (2007) indicated more concisely that porous structure of biochar was able to retain high water and air holding capacity; also a suitable habitat for some microbes and plant growth, good material for soil amendment and absorption of chemicals and humidity.

Biochar did not accelerate the number of productive tillers at the age of 70 days (P=0.962, Photo 12) but the tillering seems to have been affected by effluent application (P=0.079). It was completely in contrast to Agusalim (2010) who indicated that biochar application was able to increase number of tillers during 45 days, compared to the untreated soil. Moreover, Reddy (2011) also mentioned that rice grew better with more tillers, height, root and finally yield with biochar application. Moreover, transpiration rate of biochar treatment was also increased at the tillering stage and filling stage (Weiming et al 2011).

Table 4: Mean values for number of pH, tillers and water-holding capacity (WHC) of the soil according to source of biochar, feedstock, level of biochar, and effluent level

	Gasifer type		Feedstock		Biochar level (BL)		Effluent (E)			Probabilities			
	Gasifier (G)	Stove (S)	Rice husk (R)	Bagasse (B)	None	5% of soil, DM	None	100kg,N /ha/crop	SEM	G	B	BL	E
pH	5.21	5.19	5.10	5.30	4.94	5.46	5.25	5.16	0.060	0.826	0.022	0.000	0.308
WHC,%	23.50	22.01	21.71	23.80	20.64	24.87	22.51	23.00	0.869	0.228	0.095	0.001	0.696
Tillers/plant	5.97	5.49	5.45	6.00	5.74	5.72	5.44	6.0	0.912	0.139	0.960	0.962	0.079

By addition of biochar as soil amendment, cation exchange capacity was increased, compared to the untreated control at the beginning and the end of experiment. However, soil CEC after harvesting seemed to be less than at the beginning (Table 5a and 5b). However, according to James et al (2010), biochar increased the CEC of the soil. CEC was increased up to 40% by initial addition of biochar, reported by Topoliantz (2002). Moreover, many authors (Liang et al 2006; Yamato et al 2006; Priyadarshini et al 2010; Agusalim 2010 and Gregory 2009) also reported increases of soil CEC through application of biochar.

Biochar retains nutrients in soil directly through the negative charge that develops on its surfaces, and this negative charge can buffer acidity in the soil, as does organic matter in general (Lehmann et al 2009). Asahina et al (2009) indicated that total nitrogen of the soil was higher in the biochar treatment and biochar also improved nitrogen holding capacity of the soil. Tom (2007) showed that biochar also gave an increase in the level of exchangeable K and Mg including P. Jessica et al (2011) found that biochar could improve agriculturally significant soil parameters such as soil pH, cation exchange capacity and soil water holding capacity. It was able to increase those performance parameters such as improved nitrogen use efficiency and therefore crop productivity. Further, biochar has the potential to reduce greenhouse gas emissions through carbon sequestration, as well as potentially decreasing methane and nitrous oxide emissions from the soil.

Cation exchange capacity (CEC) is the capacity of a soil for ion exchange of cations between the soil and the soil water. CEC is used as a measure of nutrient retention capacity. It is expressed as milli-ion equivalent per 100 g, or more commonly as milliequivalent (meq) per 100 g or cmol/kg. For agricultural soils, CEC is ideally between 10 and 30 meq/100 g (Wikipedia 2010).

Table 5a: Effect of different type of biochar on cation exchange capacity of the soil at the beginning

	Downdraft gasifier (G)				**Updraft stove (S)**			
	Rich husk (R)		**Bagasse (B)**		**Rich husk (R)**		**Bagasse (B)**	
	0%	5%	0%	5%	0%	5%	0%	5%
Without the effluent								
CEC	8.5	13	15.5	25	11.5	13.5	10.5	20.5
With the effluent								
CEC	14.5	16	11.5	25.5	9	16	9.5	22.5

Table 5b: Effect of different type of biochar on cation exchange capacity of the soil after harvested

	Downdraft gasifier (G)				**Updraft stove**			
	Rich husk (R)		**Bagasse (B)**		**Rich husk (R)**		**Bagasse (B)**	
	0%	5%	0%	5%	0%	5%	0%	5%
Without the effluent								
CEC	9	11	8.5	10.5	9	10.5	10	11.5
With the effluent								
CEC	9.5	12	11.3	13	12	18.5	11	11.5

Grain and straw yield

Biochar application as the soil amendment was able to increase paddy rice yield (P=0.055). On the other hand, bagasse biochar gave higher paddy grain yield than rice husk biochar (P=0.016). However, there was no difference between both types of combustion (downdraft gasifier and updraft gasifier stove) (Table 4). Reddy (2011) also mentioned that in the paddy fields with applied biochar there was an improvement of soil fertility with more tillers, greater plant height, better roots and finally more yield of paddy. The rice net photosynthetic rates of biochar treatments were higher than in control treatments. Rice yield for biochar treatments were higher than for the control according to Weiming et al (2011).

Table 6: Mean values for root length, root biomass, Leave+stem biomass, grain yield and total biomass ,according to source of biochar, feedstock, level of biochar, and effluent level

	Gasifer type		Feedstock		Biochar level		Effluent			Probabilities			
	Gasifier	Stove	Rice husk	Bagasse	None	5% of soil, DM	None	100kg,N /ha/crop	SEM	G	B	BL	E
Root, length	37.66	34.31	34.97	37.00	34.88	37.09	35.34	37.09	1.260	0.066	0.26	0.219	0.475
Root, DM,g	19.14	20.85	18.58	21.40	17.92	22.06	19.33	20.65	2.443	0.623	0.418	0.236	0.704
Stem+leaves	48.68	50.94	48.86	50.31	47.31	52.31	47.10	52.52	2.268	0.485	0.556	0.125	0.097
Grain, DM,g	28.44	27.93	27.06	29.31	27.30	29.07	24.40	31.96	0.640	0.576	0.016	0.055	0.000
Total, DM,g	96.26	99.72	94.50	101.47	97.53	98.44	90.84	105.14	4.291	0.571	0.255	0.881	0.002

Bounsuy (2010) in Cambodia recorded that the rice yield was enhanced up to 3.76 tonnes/ha with application of 40 tonnes/ha of biochar compared with 1.82 tonnes/ha with 20 tonnes/ha of biochar. According to Afeng et al (2010), biochar amendment at

10 and 40 tonnes/ha increased the rice yield by 12% and 14% in unfertilized soils and by 8.8% and 12.1% in the soil with N fertilization. However, Singhal et al (2011) showed that application of 2 tonnes rice-husk-biochar per ha increased the grain yield from less than 4 tonnes per ha for the control treatment to more than 5 tonnes/ha for the biochar treatment. The fertilizer application increased the yield by about 10%, and the fertilizer plus biochar application increased the yield by up to 25 % according to Asahina et al (2009). Tom (2007) showed that application of rice husk charcoal at the recommended rate (10-20 mt/ha) gave a yield increase of 10 - 40%.

Soil pH was higher with bagasse biochar, compared to rice husk (Figure 1) but both biochars were able to improve soil pH. There were interactions between the effect of different biochars, by using effluent as organic fertilizer on yield of grain (Table 7 and Figure 2). The rice grain yield was increased more by incorporating bagasse biochar as soil amendment, compared to rice husk biochar but there were no differences between both combustion types (downdraft gasifier and updraft gasifier stove) (Figure 3).

Table 7: Effect of biochar on pH, WHC, Tillers, rice grain yield, root length and biomass, Stem+leaves and total biomass (interaction)

Interaction between gasifier/stove and biochar

	GB	GR	SB	SR	SEM	P
pH	5.26	5.16	5.34	5.04	0.085	0.244
WHC,%	23.49	23.52	24.11	19.9	1.229	0.090
Tillers/plant	6.63	5.31	5.38	5.59	1.289	0.021
Grain,DM	29.64	27.24	28.98	26.87	0.905	0.875
Root length	37.69	37.62	36.31	32.31	1.782	0.274
Root biomass	24.86	12.41	17.94	23.75	3.45	0.016
Stem+leave	53.88	43.49	47.64	54.24	3.207	0.011
Total	108.38	84.13	94.57	104.86	6.069	0.006

Interaction between Gasifier/stove and biochar level

	GB		SB			
	0%	5%	0%	5%	SEM	P
pH	4.92	5.51	4.97	5.42	0.085	0.422
WHC,%	22.51	24.49	18.77	25.24	1.228	0.073
Tillers/plant	6.09	5.84	5.38	5.59	1.289	0.470
Grain,DM	25.72	31.16	26.98	28.87	0.905	0.000
Root length	35	40.31	34.75	33.87	1.782	0.088
Root biomass	20.75	17.52	15.09	26.6	3.455	0.038
Stem+leave	50.62	46.75	54.01	47.87	3.207	0.725
Total	97.08	95.43	97.97	101.46	6.068	0.673

Interaction between Gasifier/stove and effluent

	GB		SB			
	None	Effluent	None	Effluent	SEM	P
pH	5.18	5.24	5.31	5.07	0.085	0.083
WHC,%	23.64	23.37	21.39	22.63	1.228	0.541
Tillers/plant	5.69	6.25	5.19	5.78	1.289	0.962

Grain,DM	25.21	31.66	23.6	32.26	0.905	0.228
Root length	37.19	38.13	33.5	35.13	1.782	0.848
Root biomass	17.44	20.83	21.22	20.47	3.455	0.552
Stem+leave	44.9	52.47	49.3	52.58	3.207	0.505
Total	87.55	104.96	94.12	105.31	6.069	0.61

Interaction between biochar and level

	Bagasse (B)		Rice husk (R)			
	0%	5%	0%	5%	SEM	P
pH	4.89	5.71	4.99	5.21	0.085	0.001
WHC,%	21.73	25.87	19.55	23.87	1.228	0.939
Tillers/plant	6.25	5.75	5.22	5.69	1.289	0.139
Grain,DM	27.32	31.29	27.27	26.84	0.905	0.018
Root length	36.12	37.87	33.62	36.31	1.782	0.794
Root biomass	21.18	21.63	14.66	22.5	3.455	0.29
Stem+leave	53.19	48.33	51.43	46.29	3.207	0.965
Total	101.69	101.25	93.36	95.63	6.068	0.825

Interaction between biochar and Effluent

	Bagasse (B)		Rice husk (R)			
	None	Effluent	None	Effluent	SEM	P
pH	5.42	5.19	5.07	5.13	0.084	0.096
WHC,%	23.52	24.08	21.5	21.92	1.228	0.956
Tillers/plant	5.75	6.25	5.125	5.78	1.289	0.809
Grain,DM	26.32	32.3	22.49	31.62	0.905	0.087
Root length	34.56	39.44	36.12	33.81	1.782	0.049
Root biomass	20.52	22.28	18.14	19.02	3.455	0.9
Stem+leave	46.53	54.99	47.67	50.06	3.207	0.348
Total	93.38	109.57	88.29	100.7	6.068	0.756

Interaction between biochar level and effluent

	No biochar		5% biochar			
	None	Effluent	None	Effluent	SEM	P
pH	4.94	4.94	5.55	5.37	0.084	0.308
WHC,%	21.09	20.19	23.94	25.8	1.228	0.266
Tillers/plant	4.13	4.83	5.54	5.50	3.455	0.664
Grain,DM	23.21	31.38	25.6	32.54	0.904	0.498
Root length	33.31	36.44	37.37	36.81	1.782	0.306
Root biomass	16.52	19.32	22.15	21.98	3.455	0.669
Stem+leave	50	54.62	44.2	50.43	3.207	0.803
Total	89.73	105.33	91.94	104.94	6.068	0.831

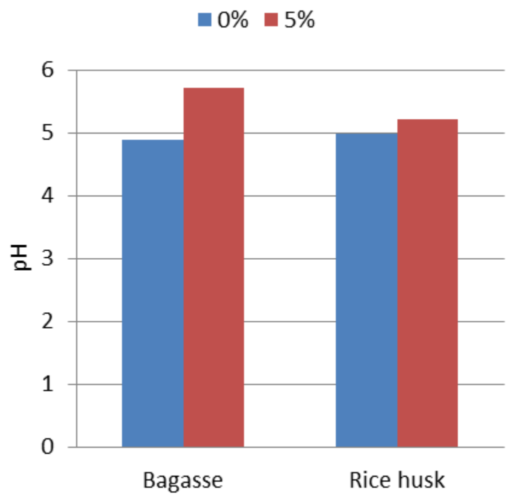

Figure1: The difference between both biochars with their level on soil pH (interaction)

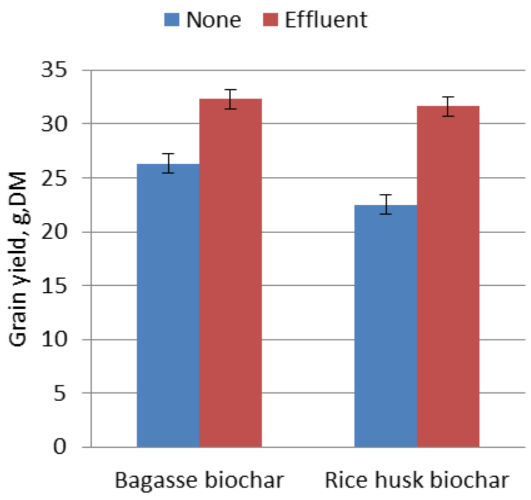

Figure2: The interaction between biochar and effluent on rice grain yield

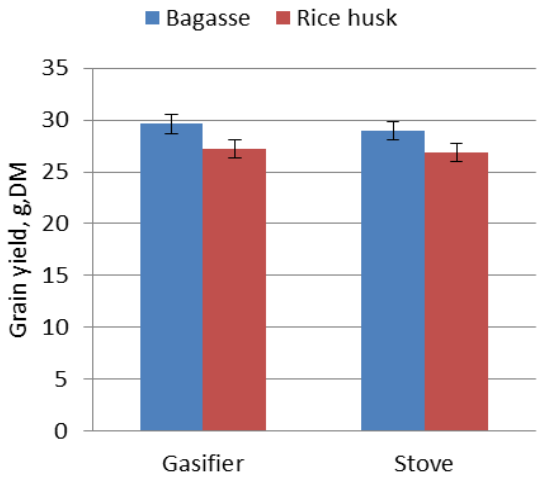

Figure3: Effect of different combustion of bagasse and rice husk on rice yield (interaction)

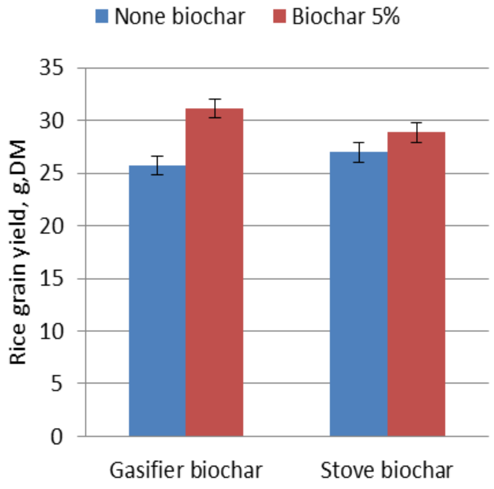

Figure4: The difference between gasifier biochar and stove biochar with their level on yield (interaction)

Conclusions

- Biochar application as soil amendment increased soil pH, water holding capacity and cation exchange capacity in the soils.
- Incorporating 5% of biochar (5 kg, DM of biochar/100 kg, DM of soil) increased yields of rice grain of 23% to 41%. However, bagasse biochar was able to increase rice yield higher than rice husk biochar with effluent applied at 100 kg N /ha/crop.
- There were no different effects between both systems of combustion (downdraft gasifier and updraft gasifier stove) on rice grain yield.

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Effect of biochar from rice husks (combusted in a downdraft gasifier or a paddy rice dryer) on production of rice fertilized with biodigester effluent or urea

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Abstract

The objective of this study was to measure the effect of biochar of rice husk produced by different types of combustion (drowndraft gasifier and paddy rice drying machine) and their interaction between two kinds of fertilizer (effluent and urea) on soil fertility and paddy rice grain yield. The experiment was done at the ecological farm of the Center for Livestock and Agriculture Development (CelAgrid), located in Phnom Penh city, Cambodia. The experiment was designed as a 2*2*2 factorial in a completely randomized block design (CRBD) with 4 replicates and in 32 plots each of 20 m^2. The first factor was type of biochar (from a downdraft gasifier or a rice dryer); the second factor was the level of biochar (0 and 3 kg/m^2); the third factor was source of fertilizer N (Biodigester effluent or urea at 100 kg N/ha/crop).

The rice husk biochar increased yields of rice grain and straw by 30 and 40%, respectively; but there were no differences between biochar produced in a downdraft gasifier compared with that from a rice dryer, nor between urea and biodigester effluent as N fertilizer. Biodigester effluent increased rice grain yield more than urea in the absence of biochar but there were no differences between the two fertilizers when biochar was applied. Biochar increased soil pH, water holding capacity and cation exchange capacity. These criteria were not affected by the source of N fertilizer, nor by the source of the biochar.

Key words: *pH, CEC, exchangeable cations, grain, straw, water holding capacity*

Introduction

The population of Cambodia was almost 15.1 million in 2010, and will increase to 23.8 million in 2050 but with 40 percent still being under the poverty line (PRB 2010). Poverty, population growth and environmental degradation (air, soil and water pollution) are increasingly being considered as major subjects for research and development. Agriculture is very important in Cambodia with around 37.1% of GDP generated from agricultural productivities (FAO 2003). Soil is one of the most important factors in determining crop yields. For agriculture to be sustainable there is an immediate need to combat the problem of soil erosion and to increase food production.

According to MAFF (1996), soil fertility depends on the agro-ecosystem. There are four important rice agro-ecosystems in Cambodia: rain fed lowland rice, rain fed upland rice, deep-water or floating rice, and dry-season (flood recession) rice. There are 2.3 million ha in lowland rice in Cambodia but most of the soils are sandy and poor in nutrients. Erosion occurs not only in the upland areas but also in the lowland areas. In practice, water run-off occurs on all land, and the top soil is lost when no protective and conservation measures are in place. The most common rain-fed lowland soils are sandy, acidic, extremely infertile and low in organic carbon and cation exchange capacity.

Global climate change raises major questions about management of fibrous residues from rice growing – straw and rice husks. Decomposition of organic matter in flooded rice gives rise to emissions of methane, which is about 22 times more climate forcing than CO_2. Rice-based systems are estimated to contribute from 9 to 19% of global methane emissions. An opportunity to address these issues in a completely new way arises from research on anthropogenic soils in Brazil, called terra preta. These soils are characterized by high content of black carbon (carbonized organic matter or biochar) most probably due to the application of charcoal, according to Sombroek (1966).

Agricultural fires were found to account for 8-11% of the annual global fire activity. Burning crop residue before and/or after harvest is a common farming practice. About 30% more GHG emissions can be reduced when the biochar is applied to soil. The biochar option can address issues emerging from soil organic carbon depletion and carbon sequestered in soil actually removes CO_2 from the atmosphere. Biochar formation decelerates the carbon cycle with important implications for carbon management. Terra Preta may be the best proof that soil organic carbon (SOC) enrichment is possible if done with a form of carbon such as biochar. Terra Preta soils show not only a doubling in the organic carbon content but also a higher cation exchange capacity (CEC) (Jonah et al. 2010).

Materials and methods

Location and duration

The experiment was conducted for 110 days at the Centre for Livestock and Agriculture Development (CelAgrid) (Photo 1).

Experimental design

The experiment was arranged as a 2*2*2 factorial in completely randomized block design (CRBD) with plot size 20 m^{2} (4*5m) and 4 replicates. The first factor was type of biochar (gasifier and paddy rice dryer machine), the second factor was fertilizer (Biodigester effluent and Urea) and the third factor was level of biochar (0 and 3 kg/m^{2}). There were 32 plots in total with the overall area of 640 m^{2} (Photo 2).

Table 1: Layout of the experiment

1	2	3	4	5	6	7	8
GUB3	**SUB3**	**GEB3**	**SUB0**	**SEB3**	**GUB0**	**GEB0**	**SEB0**
9	10	11	12	13	14	15	16
SUB0	**GUB0**	**SEB0**	**SEB3**	**GUB3**	**GEB3**	**SEB0**	**GEB0**
17	18	19	20	21	22	23	24
GEB0	**GUB3**	**GUB0**	**SEB0**	**GEB3**	**SEB3**	**SUB3**	**SUB0**
25	26	27	28	29	30	31	32
SUB3	**GUB0**	**SEB3**	**GEB0**	**GEB3**	**SUB3**	**GUB3**	**SUB0**

Experimental materials

The rice seeds were bought from DomnukTeuk group, Phnom Penh, Cambodia. The urea was bought from the local market while the effluent was produced by a concrete dome biodigester, charged with pig manure. The biochar (dryer) was collected from the rice grain dryer in CelAgrid farm the biochar (gasifier) was bought from the local rice milling station.

Photo 1: Biochar from rice dryer

Photo 2: Biochar from downdraft gasifier

Biochar

The biochar (dryer) was obtained from a machine used to dry paddy rice (Photo 3). The feedstock used in the furnace of the dryer was rice husk. The temperature in the furnace was around 500 ^{0}C. The other source of biochar was a commercial down-draft gasifier (Photo 4) producing a combustible gas (approximately 20% hydrogen and 20% carbon monoxide) which was used as fuel in an internal combustion gas engine driving an electrical generator to produce electrical power for the rice mill. The temperature inside the gasifier was around 600^{0}C.

Photo 3: Dryer machine utilizing rice husk as feedstock

Photo 4: Downdraft gasifier, designed for rice husk feedstock

The biochar was sprayed on the flooded soil surface (Photo 7), and immediately afterwards the plots were ploughed to break down the large particles of soil and to ensure the texture was suitable to transplant the germinated rice.

Photo 5: The biochar was broadcast on the flooded soil surface

Bio-digester effluent

The brick and concrete fixed-dome biodigester (Photo 8) had a capacity of 15 m^3. It was charged with manure from pigs fed brewery residues and a commercial concentrate.

Photo 6: Concrete biodigester

Fertilization and irrigation

The biodigester effluent and the urea were applied in three steps: the first time was 25 days after transplanting the rice, and then after two successive intervals of 20 days. The total quantity was the equivalent of 100 kg N/ha. The effluent was pumped from the biodigester to PVC drums situated in each block (Photo 9). From the drums the effluent was applied by hand. Urea was broadcast by hand.

The plots were irrigated with water from a well. The amounts applied were sufficient to maintain the water levels in the plots (Photo 10).

Photo 7: Effluent flow system to its treatment

Photo 8: Water supply from the well

Planting and harvesting of the rice

The rice seed variety name is Phka Romdoul and it was sown in a nursery for germination. After 20 days, it was transplanted in the experimental plots. Two plants were planted in each hole which was at 30 cm distances.

Midway through the growing season (50 days) the tillers were counted on 16 randomly selected plants in each plot (Photo 11).

At the time of harvest (Photo 12), the rice plants from each plot were gathered (Photo 13) and separated into grain and stems + leaves which were weighed separately.


Photo 9: Counting the tillers


Photo10: Harvesting the rice plants


Photo11: Collecting the rice biomass

Analytical procedures

The rice grain and straw (stems + leaves) were analysed for DM by the micro-wave radiation method of Undersander et al (1993). Nitrogen and ash were determined following AOAC (1990) procedures. Organic carbon was calculated as OM/1.724 (Walkley et al 1934). Soil samples were analysed for texture, separating the fractions into clay, fine silt, coarse silt, fine sand and coarse sand using the Pipette Method (Day 1965). The cation exchange capacity (CEC) was determined by titrating with 1M Calcium Chloride at pH 7 (Rhoades 1982). The water holding capacity was determined by weighing 15 g of soil into a glass funnel fitted with filter paper and then saturating the soil with water (Photo 14). After 24 h the soil was weighed to determine the quantity of water that had been retained.

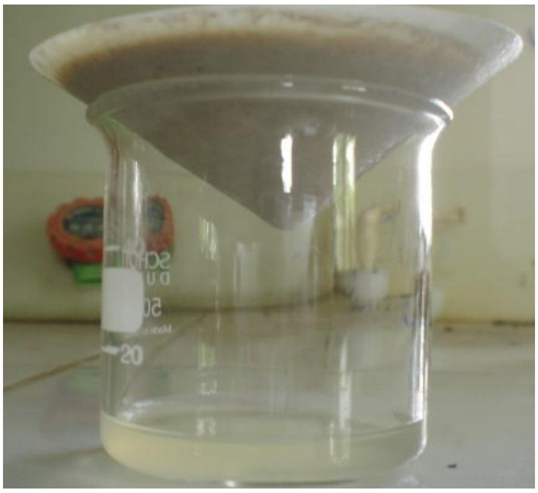
Photo 12: Adding water to saturate the soil then allowing the water to drain for 24 hours to determine water holding capacity

For measurement of the pH, the soil samples were dried in the microwave oven, then ground to a powder. Five grams of the ground sample was put in a beaker and 25 ml of distilled water were added. The suspension was stirred 3 times at 15 minute intervals, and then filtered. pH was measured on the filtrate using a digital pH meter.

Statistical analysis

The data were analyzed by the General Linear Model of the ANOVA program in the Minitab software (Minitab 2000). Sources of variation were: Biochar source, fertilizer source, biochar level and interaction biochar source*fertilizer source*biochar level and error.

Results and discussion

Soil texture, pH, WHC and CEC

According to Turenne (2011), soil texture is determined by the size of the particles: very coarse sand: 2.0-1.0 mm, coarse sand: 1.0-0.5 mm, medium sand: 0.5-0.25 mm, fine sand: 0.25-0.10 mm, very fine sand: 0.10-0.05 mm, silt: 0.05-0.002 mm and clay: < 0.002 mm. There are three elements that define soil type: texture, structure, and porosity. Soil texture is determined by the percentages of sand, clay and silt while soil structure is the way the clay, sand and silt particles join together with organic matter to form aggregates or clusters of particles.

The data in Table 2 indicate that the soil in the experimental area would be classified as "loam" soil (Berry et al 2007).

Table 2: Soil texture, using the Pipette Method

Clay	Fine silt	Silt	Fine sand	Sand
8.6	53.2	12.6	18.5	6.3

Table 3: Chemical composition of biochar, biodigester effluent and soils (soil samples were taken at the beginning of the experiment after application of biochar and fertilizer)

	OM, %	OC, %	DM, %	pH	N, mg/liter	P, %	K, %	CEC, meq/100g
Gasifier biochar (GB)	53.9	31.2	61.9	9.8	N/A	N/A	N/A	69
Dryer biochar (DB)	10.3	5.99	91.7	10.7	N/A	N/A	N/A	78
Effluent	N/A	N/A	N/A	5.8	400	0.12	0.10	N/A
Soil	14.6	N/A	88.9	5.5	0.15	N/A	N/A	N/A

N/A= Not analyzed

Soil pH was increased by application of biochar (Table 4) as was tillering capacity. Agusalim (2010) also showed that the application of rice husk biochar as a soil amendment could increase the number of rice tillers, compared to untreated soil.

The water holding capacity of the soil was increased by application of biochar but there were no differences between the sources of biochar nor between urea and biodigester effluent fertilizers (Table 4). These results are similar to those reported by Agusalim (2010) where water holding capacity was increased from 11.3% for untreated control soil to 15.5% for soil treated with rice husk biochar. Sokchea et al (2011) and Sisomphone et al (2011) reported increases in WHC of soil from 43 to 53% and 40 to

50%, respectively, as a result of biochar application. The higher values in these latter reports probably reflected differences in soil characteristics between the different experiments. Lehmann et al (2009) suggested that biochar application may enhance the water holding capacity of the soil, and Chan et al (2007) also showed that biochar application in the soil was improved some physical properties of soils, such as increased soil aggregation and water holding capacity.

Table 4: Mean values for number of tillers, and pH and water-holding capacity (WHC) of the soil according to source of biochar, level of biochar, and source of fertilizer (measurement of tillers was done midway through the experiment; measuurements on soils were taken at the beginning of the experiment after application of biochar and fertilizer)

	Biochar source (BS)		**Biochar level (BL)**		**N source (N)**			**Probability**		
	Dryer (D)	**Gasifier (G)**	**None**	**3 kg/m^2**	**Effluent (E)**	**Urea**	**SEM**	**BS**	**BL**	**N**
Tillers/plant	14.70	15.45	13.10	17.08	14.65	15.53	2.229	0.353	0.000	0.288
Soil pH	5.80	5.72	5.49	6.03	5.81	5.71	0.090	0.528	0.000	0.770
WHC, %	15.2	14.7	12.1	17.8	14.5	15.4	1.264	0.770	0.004	0.585

At the beginning of the experiment and after application of biochar, the cation exchange capacity (CEC) was increased by both kinds of biochar (Table 5a; Figure 1a). Content of calcium, sodium and magnesium were not affected by biochar addition but content of potassium was increased two-fold. However, in the samples taken after harvest (Table 5b; Figure 1b) there appeared to be no effect of the biochar on the CEC, while the content of the calcium, sodium and magnesium were increased, while that of potassium had decreased. As in the samples taken at the beginning of the experiment, availability of potassium was increased by bochar with no effect on the other elements. We have no explanation for the changes in cation status which appeared to have occurred in the soils after harvest.

According to Lehmann (2003) the availability of potassium, phosphorus and zinc are upgraded when biochar is applied but calcium and copper less so Increase in CEC of up to 40% over initial CEC by addition of biochar was reported by Topoliantz (2002). James et al (2010) also showed that biochar increased the CEC of the soil, and that this was associated with soil fertility improvement and decreased fertilizer runoff. Many authors (Liang et al 2006; Yamato et al 2006; Priyadarshini et al 2010 and Agusalim (2010) have reported increases of CEC in soils through application of biochar).

Table 5a: Exchangeable cation content and cation exchange capacity (meq/100g soil) on soils after treatment without(B_0) or with 3% biochar (B_0) (from gasifier or dryer) and fertilized with biodigester effluent or urea at the beginning of the experiment

	Effluent				**Urea**			
	Gasifier (G)		**Rice dryer (D)**		**Gasifier (G)**		**Rice dryer (D)**	
	B_0	**B_3**	**B_0**	**B_3**	**B_0**	**B_3**	**B_0**	**B_3**
Ca	3	4	3.4	3.4	3.6	3.6	3	3.2
Mg	2.4	2	2.6	2.2	2	3.4	2	2
Na	2.17	3.7	2.17	2.83	2.17	3.26	2.17	2.83
K	1.25	3.59	1.28	3.21	1.03	3.46	0.9	2.69
CEC	8	17.5	10.5	15.5	10.5	17.5	7.5	14.5

Table 5b: Exchangeable cation content and cation exchange capacity (meq/100g soil) on soils after harvest

	Effluent				Urea			
	Gasifier (G)		Rice dryer (D)		Gasifier (G)		Rice dryer (D)	
Biochar,	B_0	B_3	B_0	B_3	B_0	B_3	B_0	B_3
Ca	3.4	3.8	4.2	4.4	3	3.8	3.6	4
Mg	3.4	3.4	1.8	3.6	2.6	3.6	3.4	3.2
Na	4.13	4.78	3.48	4.35	3.48	4.35	3.7	4.35
K	1.41	2.56	1.41	2.69	0.64	1.67	0.64	2.05
CEC	10.5	11	13	12.5	11	11	12	12

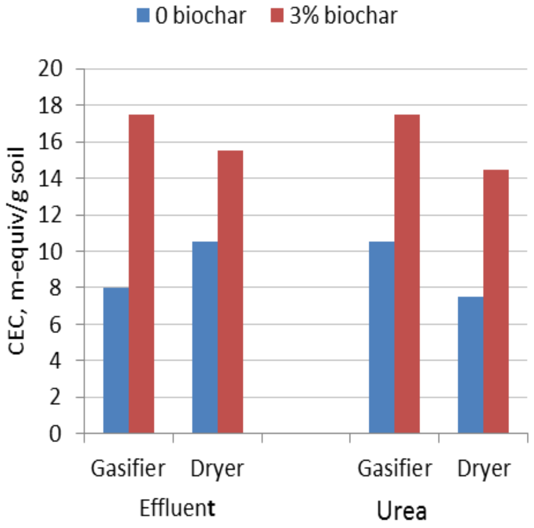

Figure 1a: Effect of biochar on cation exchange capacity of soil samples taken after application of biochar at the beginning of the experiment

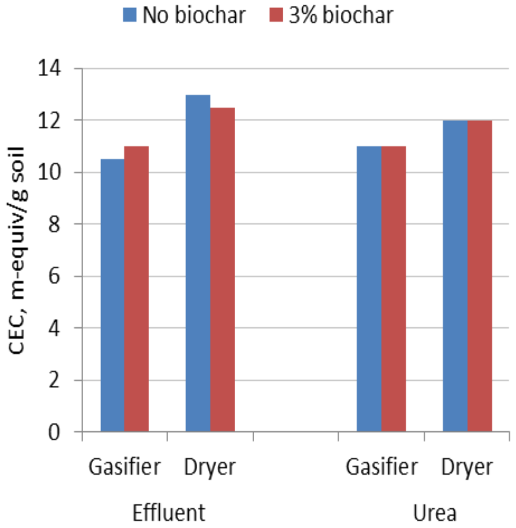

Figure 1b: Effect of biochar on cation exchange capacity of soil samples taken after harvesting the rice

Grain and straw yield

Incorporating biochar in the soil increased yields of grain and straw by 30 and 40%, respectively (Table 6; Figures 2 and 3); but there were no differences between the two sources of biochar, nor between urea and biodigester effluent as fertilizer.

Table 6: Mean values for yield of grain and straw (kg DM/ha) according to source of biochar, level of biochar, and source of fertilizer

	Biochar source (BS)		Biochar level (BL)		N source (N)			Probability		
	Dryer (D)	Gasifier (G)	None	3 kg/m^2	Effluent	Urea	SEM	G	BL	N
Stem+Leaves	3063	3006	2603	3466	3075	2993	199.390	0.841	0.005	0.772
Rice grain	2797	2959	2395	3361	2965	2792	166.559	0.499	0.000	0.470

Total	5861	5966	4999	6828	5868	5958	334.462	0.827	0.001	0.850

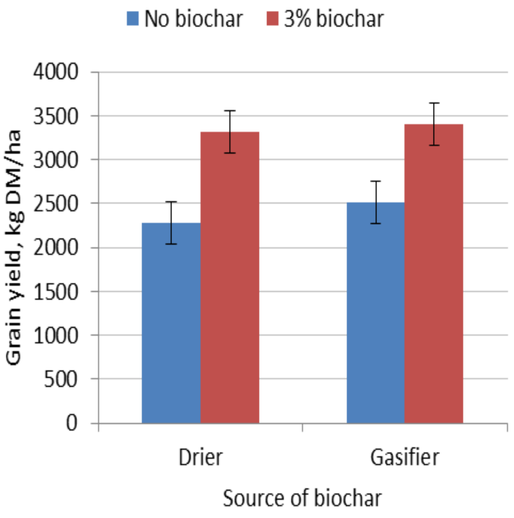

Figure 2. Effect of source and level of biochar on rice grain yield

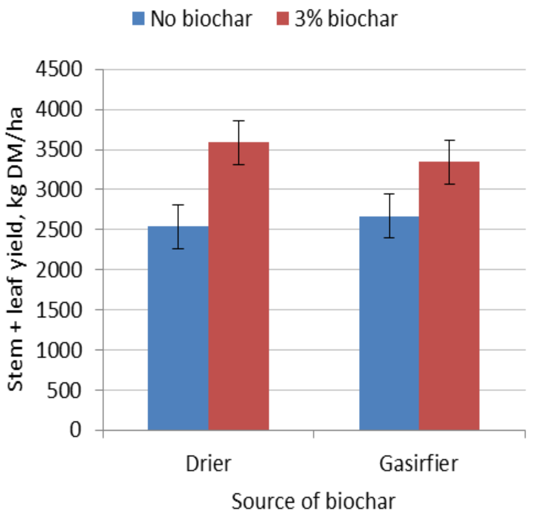

Figure 3. Effect of source and level of biochar on rice straw (stem + leaf) yield

Increases in rice yield from application of biochar were reported by Bounsuy (2010) in Cambodia. They recorded yields of 3.76 tonnes/ha with application of 40 tonnes/ha of biochar compared with 1.82 tonnes/ha with 20 tonnes/ha of biochar. Priyadarshini et al (2010) described linear increases in rice yield from application of biochar. According to Afeng et al (2010), biochar amendment at 10 and 40 tonnes/ha increased the rice yield by 12% and 14% in unfertilized soils and by 8.8% and 12.1% in the soil with N fertilization. However, Singhal et al (2011) showed that application of 2 tonnes rice-husk-biochar per ha increased the grain yield from less than 4 tonnes per ha for the control treatment to more than 5 tonnes/ha for the biochar treatment.

There were no interactions between the effects of level of biochar and source of fertilizer on tillering rates of the rice plants and soil pH (Table 7; Figures 4 and 5). Tillering was increased by effluent compared with urea when no biochar was applied but there were no differences between the two fertilizers in the presence of biochar. In the absence of biochar, grain yield was higher with effluent but the contrary was the case when biochar was applied. Soil pH showed the same trends as grain yield. It was to be expected that grain yield would be higher with effluent as, besides nitrogen, this fertilizer also contained a range of other plant nutrients.

Table 7: Mean values for numbers of tillers, soil pH (at beginning after application of biochar and fertilizer) and rice yield, according to application of biochar and source of fertilizer (Interaction effects)

	No biochar		**3 kg biochar/m^2**			
	Effluent	**Urea**	**Effluent**	**Urea**	**SEM**	**P**
Tillers/plant	13.1	13	17.8	16.3	0.81	0.36
Rice grain	2744	2046	3185	3538	236	0.035
Soil pH	5.68	5.31	5.93	6.13	0.126	0.036

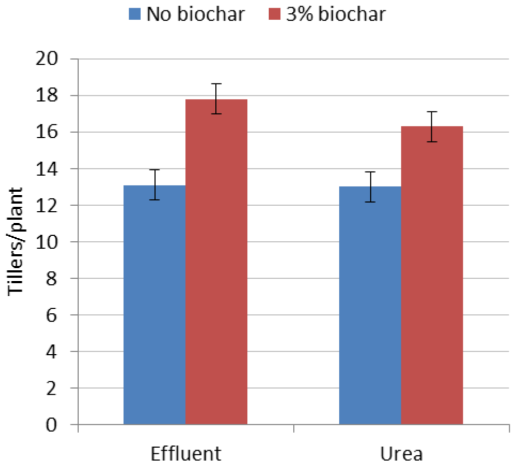

Figure 4: Effect of biochar and nitrogen sources on rice tillering

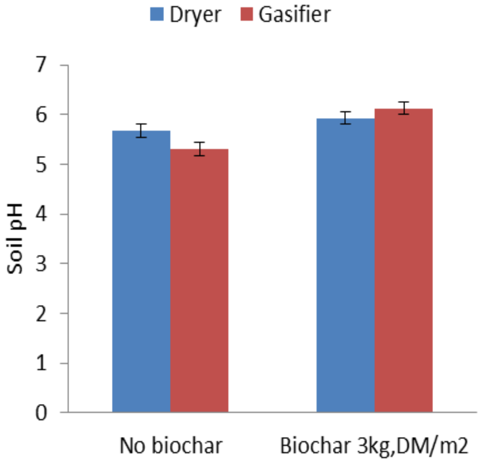

Figure 5: Effect of two kinds of biochar on soil pH amendment

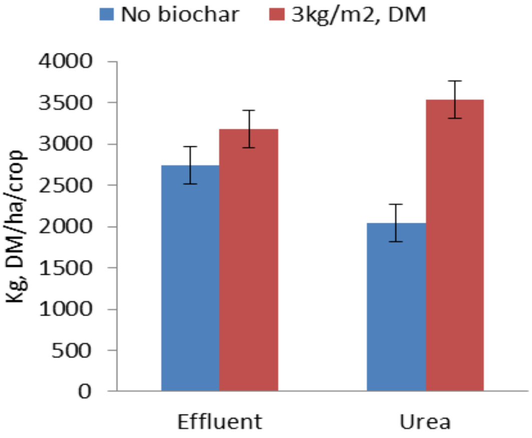

Figure 6: The interaction between nitrogen source and biochar level on rice grain yield

Conclusions

- Incorporating 3 kg/m^2 of rice husk biochar in a loam soil (pH 5.5) increased yields of rice grain and straw by 30 and 40%, respectively. However, there were no differences between biochar produced in a downdraft gasifier compared with that from a rice dryer, nor between urea and biodigester effluent applied at 100 kg N/ha.
- Biodigester effluent increased rice grain yield more than urea in the absence of biochar but there were no differences between the two fertilizers when biochar was applied.

- Biochar increased soil pH, water holding capacity and cation exchange capacity in the soils at the beginning of the experiment, but had no effect in the samples taken after harvest. These criteria were not affected by the source of N fertilizer.

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