MINISTRY OF EDUCATION AND TRAINING

CAN THO UNIVERSITY

School year: 2010-2012

SISOMPHONE SOUTHAVONG

EFFECT OF SOIL AMENDER (BIOCHAR OR CHARCOAL) AND BIODIGESTER EFFLUENT ON GROWTH AND YIELD OF WATER SPINACH, RICE AND ON SOIL FERTILITY

MASTER OF SCIENCE THESIS IN AGRICULTURAL SCIENCES
ANIMAL HUSBANDRY

Code: 60 – 62 - 40

Scientific supervisors:

1- **Dr. Ngo Van Man**

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

AN APPROVAL OF THE SCIENTIFIC EVALUATION COMMITTEE

The thesis with the title: "*Effect of soil amender (biochar or charcoal) and biodigester effluent on growth and yield of water spinach, rice and on soil fertility"* implemented by Mr. Sisomphone Southavong 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

CURRICULUM VITAE

I. BIO-DATA

Full name: Sisomphone Southavong Gender: Male
Date of birth: 26 April 1983 Place of birth *(ward/commune, district, city/province, country):* Thahinnue village, Pakse district, Champasack province
Father's birthplace: Thahinnue village, Pakse district, Champasack province; Nationality: Laotian
Position *(before participating MSc program): Lecturer*
Workplace (*current or before participating MSc program): Champasack University*
Residence address *(house number, district, ward/district, city/province): Chatsanh village, Pakse district, Champasack province, Lao PDR*
Mailing address:
Tel: +856 20 2224 3429 Fax: +856 31 260 158
E-mail:spdeuk@yahoo.com or sisomphone.stv@gmail.com

II. EDUCATIONAL BACKGROUND

1. Undergraduate education

Type of training (*Permanent or impermanent)*: *Permanent*
Institution awarding degree: National University of Laos
Major: Plant science
Year earned: 2005
Country: Lao PDR
Institution awarding degree: National University of Laos
Country: Lao PDR
Name of the thesis: Study on ground-water surface-water interactions within a small headwater catchment: possible consequences for soil loss and the physico-chemistry of the stream
Name of supervisor: Mr. Inthong Somphou and Dr. Olivier RIBOLZI

2- Master of Sciences

Type of training (*Permanent or un-permanent)*: Permanent
Institution awarding degree: Can Tho University
Major: Agricultural science
Year earned: 2012
Country: Vietnam
Institution awarding degree: Can Tho University
Country: Vietnam
Name of the thesis: "*Effect of soil amender (biochar or charcoal) and biodigester effluent on growth and yield of water spinach, rice and on soil fertility"*
Name of supervisor: Dr. Ngo Van Man; Prof. Dr. Thomas R Preston

3. Foreign languages

1. English — Level of proficiency (IELTS): 5.5
2. Vietnamese — Level of proficiency: Good

4. BSc Degree awarding:

- Major: Plant science

- Degree number: 2484, date/month/year: 01/04/2006 at National University of Laos, country: Lao PDR

Cantho City, *02 Feb, 2012*

Signature

Sisomphone Southavong

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

Sisomphone Southavong

ACKNOWLEDGEMENT

The studies in this thesis were carried out at the Integrated Farming Demonstration Centre, Champasack University, Pakse, Champasack province, Lao PDR. The author gratefully acknowledges to the MEKARN project, financed by Sida-SAREC, for supporting the research.

I would like to express my best gratitude to:

Can Tho University, Faculty of Agriculture and Applied Biology on implementing this MSc program and An Giang University.

Dr. Ngo Van Man, Mekarn Regional co-ordinator, my supervisor, for all your support, advice and explanations throughout the research, also for your reading and correcting my thesis papers.

Prof. Dr. Thomas Reg Preston, my teacher and adviser, for all your valuable guidance and support during the study and correction of the thesis.

I would also like to extend sincere thanks to Assoc. Prof. Dr. Duong Nguyen Khang, Co-ordinator of the SAREC-MEKARN Project, Prof. Nguyen Van Thu and the staff of CTU, especially Dr. Nguyen Minh Thong, for need help, best preparation for accommodation, transportation and study facilities. Responsible facilitators: Dr. Ho Quang Do, Assoc. Prof. Dr Bui Xuan Men and Dr. Nguyen Thi Kim Dong and all Professors, lecturers and assistant lecturers in MEKARN courses, for giving me care and useful knowledge.

My special thanks to my colleagues in Scientific Research and Academic Service Office, Integrated Farming Demonstration Centre and Faculty of Agriculture and Forestry, Champasack University for provision of research facilities. Mr. Vilaphon Phothisalath, Mr. Athit Masouvanh, Mr. Vanhyuly Souvanamethy and Mr. Thongxay Keochantheung my students for their great help in data collection and laboratory analysis during my study.

Warm thanks are extended to my family for their great help, encouragement and support during the period of my study.

I would like to warmly thank all of my friends in the CTU-MSc course 2010-2012 from the three countries: Vietnam, Laos and Cambodia, for sharing the culture, friendship and creating a warm atmosphere throughout the time of the course.

I would like to thank all the people who contributed to this study.

Dedication

To

My wife Khamphisay Khammingsavath
My son Xaysomphone Southavong

My families

And

My country.

Table of contents

Abstract

A series of experiments was carried out to determine the effect of: (i) biochar from different sources and effluent from a biodigester (charged with pig manure) on growth of rice in acid soils; (ii) biochar and charcoal as soil amenders in combination with effluent from a biodigester charged with pig manure on growth of water spinach and to test the long-term effect of biochar application to soil in improving soil and crop production; (iii) soil amender (biochar or charcoal) in combination with biodigester effluent in a staggered (increasing) application on growth of water spinach; and (iv) biochar and biodigester effluent on growth and yield of water spinach under field conditions.

Paper 1

The trial was carried out at the experimental farm of An Giang University to measure changes in soil fertility as a function of the growth of rice plants (bio-test) cover a period of 30 days. The experiment was arranged in a completely randomized design with 3 replications of the treatments applied to samples of soil held in one and half litre capacity plastic bags and compared in a 5*2*2 factorial arrangement. The factors were: five levels of biochar (0, 2, 4, 6 and 8%); two types of biochar (Downdraft Gasifier or Updraft Gasifier Stove); and with or without biodigester effluent at 100 kg N/ha.

The biomass growth of rice (over 30 day period from planting) showed a curvilinear increase as the level of biochar was raised from 0 to 2-4%, followed by a slight decline with higher levels. There were no differences due to source of biochar (gasifier or Top Lit Updraft [TLUD] stove). Application of biodigester effluent at 100 kg N/ha increased biomass growth five-fold with no interaction due to type or level of biochar. Biochar raised soil pH from 4.5 to 5.13 and 5.40 with the higher value for stove biochar. There were no effects of treatment on cation exchange capacity of the soil but water holding capacity was increased from 38 to 59% with no differences due to source or level of biochar.

Key words: *CEC, nitrogen, pyrolysis, soil pH, Terra Preta, water holding capacity*

Paper 2

A biotest was carried out at the research centre of Champasack University, Lao PDR to determine the effect of biochar, charcoal and biodigester effluent on growth of water spinach. The fifteen treatments in a completely randomized 3*5 factorial arrangement with 3 replications were: soil amender (biochar or charcoal or none) at 40 tonnes/ha and level of effluent (0, 25, 50, 75 or 100 kg N/ha) applied to samples of soil held in fifteen litre capacity plastic baskets. Sixty seeds of water spinach were planted in each basket. After germination, some seedlings were removed to balance the number in each basket (40 seedlings) for the rest of the experiment. The plants were irrigated every morning and evening. Measurements were made of height, number of leaves, and weight of above-ground biomass after 35 days and again (re-growth) after a further 35 days.

Both soil amenders (biochar and charcoal) gave similar improvements in water holding capacity, from 27.4% to 39.0 and 37.6, respectively. Soil pH was increased from 4.7 to 6.6 due to addition of biochar and to 6.3 with charcoal. Biochar increased foliage yield of the water spinach in both the first and second harvests, but there was no apparent effect on foliage growth from application of charcoal. In the first harvest, there were curvilinear responses to biodigester effluent for biochar and charcoal amenders, with the peak occurring at between 50 and 75 kg N/ha. For the un-amended soil the response was linear with the highest yield at 100 kg N/ha. In the second harvest, the response to effluent for the biochar amender was again curvilinear with the peak at 50-75 kg N/ha; by contrast the response to effluent with the charcoal amender was linear with maximum yield requiring 100 kg N/ha. On the un-amended soil there was no relationship between effluent level and biomass yield.

Key words: *biotest, rice husk, soil pH, TLUP gasifier stove, water holding capacity*

Paper 3

The hypothesis that was tested in the present study was that there would be a synergistic response in growth of water spinach when biodigester effluent with staggered application was combined with biochar derived from combustion of rice husk in an updraft TLUD stove. The experiment was carried out at the research centre of Champasack University, Lao PDR to measure changes in soil fertility as a function of the growth of water spinach plants over a 28 day period following seeding. A completely randomized design was used with 3 replications of fifteen treatments in a 3*5 factorial arrangement. The factors were: soil amender (biochar or charcoal or none) at 40 tonnes/ha and level of effluent (0, 25, 50, 75 or 100 kg N/ha). The treatments were applied to samples of soil held in fifteen litre capacity plastic baskets. Effluent was applied at 7 day intervals (total 4 times) and the application was staggered with 10, 20, 30 and 40% respectively at each successive application.

Biomass DM yield of the water spinach was increased by biochar but not by charcoal. The application of biodigester effluent increased linearly the yield of the water spinach. Soil pH and water-holding capacity were increased by biochar but were not affected by level of effluent.

Key words: *biotest, rice husk, soil pH, TLUP gasifier stove, water holding capacity*

Paper 4

The experiment was conducted at the Integrated Farming Demonstration Centre, Champasack University, Lao PDR to investigate the effect of biochar and biodigester effluent on biomass yield of water spinach and on soil fertility. The treatments were arranged in a randomized complete block design (RCBD) as a 3*2 factorial with 4 replications. The factors were application of biochar to soil at 40 tonnes/ha or none and three levels of biodigester effluent at 0, 50 or 100 kg, N/ha. Twenty four plots were prepared with a total area of 96 m^2. Each plot had an area of 4 m^2 (1*4m). Spacing between plots was 80 cm and between replications was 120 cm. Biochar was applied to the soil at 16 kg/4m^2 or 40 tonnes/ha. Water spinach was established from seed with spacing between rows of 20 cm and between seeds 2-3 cm.

The water holding capacity of the soil was increased by application of biochar but there were no differences due to the level of biodigester effluent. Soil pH was increased by application of biochar from 4.68 to 6.22. There was no apparent effect of level of effluent on soil pH. The biomass yield of water spinach in both first and second harvests was increased due to the application of biochar.

Key words: *rice husk, soil pH, soil texture, TLUP gasifier stove, water holding capacity*

Abbreviations

ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
CEC	Cation Exchange Capacity
CRD	Completely Randomized Design
DM	Dry Matter
FFTC	Food and Fertilizer Technology Centre
K	Potassium
Mekarn	Mekong Basin Animal Research Network
N	Nitrogen
OM	Organic Matter
P	Phosphorus
pH	Potential of Hydrogen Ion Concentration
RCBD	Randomised Complete Block Design
SEM	Standard error of the mean
Sida/SAREC	Swedish International Development Agency-Department for Research Cooperation
TLUD	Top Lit Up Draft
WHC	Water Holding Capacity
WS	Water spinach

Contents of the theses

This thesis is based on the following papers, which are referred to by the numbers 1, 2, 3 and 4.

1. **Southavong S and Preston T R 2011** Growth of rice in acid soils amended with biochar from gasifier or TLUD stove, derived from rice husks, with or without biodigester effluent. Livestock Research for Rural Development. Volume 23, Article #32. http://www.lrrd.org/lrrd23/2/siso23032.htm
2. **Sisomphone Southavong, Preston T R and Ngo Van Man 2012** Effect of soil amender (biochar or charcoal) and biodigester effluent on growth of water spinach. *Livestock Research for Rural Development. Volume 24, Article #026,* http://www.lrrd.org/lrrd24/2/siso24026.htm
3. **Sisomphone Southavong, Preston T R and Ngo Van Man 2012** Effect of biochar and charcoal with staggered application of biodigester effluent on growth of water spinach. Livestock Research for Rural Development. Volume 24, Article #039, http://www.lrrd.org/lrrd24/2/siso24039.htm
4. **Sisomphone Southavong, Preston T R and Ngo Van Man 2012** Effect of Biochar and Biodigester Effluent on Growth of Water Spinach (*Ipomoea aquatic*) and Soil Fertility. Livestock Research for Rural Development. Volume 24, Article #034, http://www.lrrd.org/lrrd24/2/siso24034.htm

Introduction

An increasing number of global threats such as climate change, poverty, declining agricultural production, scarcity of water, fertilizer shortage and the resulting social and political unrest seem overwhelming (Lehmann and Joseph 2009). The urgency to address these threats creates an ever increasing demand for solutions that can be implemented now or at least in the near future. These solutions need to be widely implemented both locally by individuals and through large programmes in order to produce effects on a global scale. This is a daunting and urgent task that cannot be achieved by any single technology, but requires many different approaches (Lehmann and Joseph 2009).

The soil is a very crucial factor in food production. Negative impacts on soil can result in food crises. The most important problem of tropical agriculture is the inability of the land to sustain annual food crop for more than a few years at a time. Since animals, in turn, depend on plants, it becomes obvious that all agricultural activities directly or indirectly depend on the soil (Akinrinde 2006). The fertility of soils is important in agriculture particularly in making decisions on planting of crops.

There has been much recent interest in biochar as a way of stabilising photosynthetic carbon, usually with associated energy by-products (syngas, bio-liquids and/or heat) (Lehmann and Joseph 2009; Shackley and Sohi 2010; Sohi et al 2010; Verheijen et al 2010). Biochar has been defined as 'the porous carbonaceous solid produced by thermochemical conversion of organic materials in an oxygen depleted atmosphere which has physiochemical properties suitable for the safe and long-term storage of carbon in the environment and, potentially, soil improvement' (Shackley and Sohi 2010).

The application of biochar (charcoal or biomass-derived black carbon ([BC]) to soil is proposed as a novel approach to establish a significant, long-term, sink for atmospheric carbon dioxide in terrestrial ecosystems. Apart from positive effects in both reducing emissions and increasing the sequestration of greenhouse gases, the production of biochar and its application to soil will deliver immediate benefits through improved soil fertility and increased crop production (Lehman et al 2006). Moreover, some researchers claim that biochar may be an immediate solution to reducing the global impact of farming (and in reducing the impact from burning of agricultural waste). It has been shown that biochar has multiple uses. When added to soil it can significantly improve soil fertility and also act as a sink for carbon (Lehmann 2007; Lehmann and Joseph 2009). In this way, the carbon is removed from the atmosphere in a process called sequestration (Zwietenoe 2006; Davies 2007).

Increases in crop yield with biochar application has been reported for crops such as cowpea (Yamato et al 2006), soybean (Tagoe et al 2008), maize (Yamato et al 2006; Rodríguez et al 2009), upland rice (Asai et al 2009), paddy rice (Shackley et al 2011; Sokchea et al 2012) and water spinach (Sisomphone et al 2012a; Sisomphone et al 2012b; Sisomphone et al 2012c). Haefele (2007) and Haefele et al (2008) discussed the possibility of biochar applications for rice-based cropping systems. Reichenauer et al (2009) applied biochar in tsunami-affected paddy fields in Sri Lanka, and the experimental results showed that the 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 per ha for the biochar treatment. Boun Suy Tan (unpublished data) has also indicated that applying biochar (from a downdraft gasifier) to the soil at 40 tonnes/ha in combination with compost could triple the yield of rice from 1.25 to 3.76 tonnes/ha.

It is believed that biochar acts as a soil conditioner enhancing plant growth by retaining nutrients and by providing other services such as improving soil physical and biological properties (Glaser et al 2002; Lehmann and Glaser 2003; Lehmann and Rondon 2005).

Water spinach (*Ipomoea aquatica*) is a vegetable that is consumed by people and animals; it has a short growth period, is resistant to common insect pests and can be cultivated either in dry or flooded soils. Moreover, it has been found that water spinach has a high potential to convert nitrogen from biodigester effluent into edible biomass with high protein content (Kean Sophea and Preston 2001). Hongthong Phinmasan et al (2004) reported that water spinach as the only source of feed for growing rabbits appears to support acceptable growth rates of close to 20 g/day with a DM feed conversion of 2.7. This simple feeding system may be attractive for small-holder farmers in the tropics, due to the possibility to raise rabbits with a local resource (water spinach) that is easy to grow and needs no processing.

The pH of biochar produced by gasification of bagasse and rice husks is 9.5 (Kong Saroeun and Preston 2008) and biochar produced from rice husk by gasifier stove is 9.8 (Southavong and Preston 2011). As these soil conditioners have high pH value, they should be used in the low pH soil (acid soil) because they can increase the pH of the soil (Southavong and Preston 2011; Sokchea and Preston 2011; Zhang et al 2012) and thus increase the yield of acid sensitive crops (Lickacz 2002; FFTC 2008). Positive results from application of biochar to acid (pH 4.5) soils in Colombia were reported by Rodríguez et al (2009). Of special importance in this study was the apparent interaction between biodigester effluent and biochar especially in very poor soil.

Effluent is the liquid waste from anaerobic biodigesters (Bui Xuan An et al 1997). When applied to vegetables and plants, it can lead to increases in biomass yield and a higher content of crude protein. Examples of these effects were observed in Chinese cabbage (San Thy and Pheng Buntha 2005), water spinach (Kean Sophea and Preston 2001; Ho Bunyeth and Preston 2004; Nguyen Van Hiep and Preston 2006), mulberry (Phiny et al 2009), cassava (Le Ha Chau 1998), maize (Rodríguez et al 2009; Sokchea and Preston 2011) and rice biomass (Southavong and Preston 2011).

Charcoal is a black substance that resembles coal and generally is made from wood that has been burned, or charred, in a reduced flow of oxygen so that what is left is an impure carbon residue. Charcoal is reported to have beneficial effects in soil by helping to clean the soil of pollutants; it also acts as a soil conditioner http://www.wisegeek.com/what-is-charcoal.htm. It is used as a top dressing for gardens, bowling greens and lawns, and as a substitute for lime in soil additives because of the potash content (http://www.buyactivatedcharcoal.com/natural_fertilizer). Ogawa (1987) reported that charcoal applied to the soil could stimulate the activity of soil microorganisms and promote the formation of root nodules and vesicular-arbuscular mycorrhizae in soybean roots.

Hypotheses

The hypotheses to be tested were:

Paper 1

- On the acid soils in Vietnam it is expected there will be positive effects on plant growth from application of biochar in combination with biodigester effluent.
- The biochar from an updraft (TLUD) gasifier stove will have similar properties in stimulating plant growth as biochar from a downdraft gasifier.

Paper 2

- There would be a synergistic response in growth and yield of water spinach when biodigester effluent is combined with biochar.

Paper 3

- In this study, it was hypothesized that adding biochar and applying biodigester effluent in a staggered (increasing) pattern would enhance the impact of both the biochar and the effluent on plant growth.

Paper 4

- It was hypothesized that adding biochar and applying biodigester effluent to larger plots in a field trial would increase biomass yield of water spinach.

Literature review

Biochar

Terra Preta ("black earth") was discovered by Dutch soil scientist Wim Sombroek in the 1950's, when he discovered pockets of rich, fertile soil in the Amazon rainforest (otherwise known for its poor, thin soils). Carbon dating has shown them to date back between 1,800 and 2,300 years (Glaser et al 2002). Biochar is a form of charcoal produced from biomass, by a process known as pyrolysis. Pyrolysis means heating in the absence of oxygen, which prevents complete burning of the organic biomass (which happens in open fires) (Sohi et al 2009). It is rich in a stable form of carbon which is not oxidised by soil micro-organisms.

Biochar has unique properties that make it not only a valuable soil amendment to sustainably increase soil health and productivity, but also an appropriate tool for sequestering atmospheric carbon dioxide in soils for the long term in an attempt 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 term 'biochar' is a relatively recent development, emerging in conjunction with soil management and C sequestration issues (Lehmann et al 2006). It has previously been used in connection with charcoal production (e.g., Karaosmanoglu et al 2000; Demirbas 2004). The rationale for avoiding the term 'charcoal' when discussing fuel may stem from the intent to distinguish it from coal.

Biochar properties

Biochar is an organic material produced via the pyrolysis of C-based feedstocks (biomass) and is best described as a 'soil conditioner'. Despite many different materials having been proposed as biomass feedstock for biochar (including wood, crop residues and manures), the suitability of each feedstock for such an application is dependent on a number of chemical, physical, environmental, as well as economic and logistical factors (Verheijen et al 2010).

Stability

Biochar has long been used to date archaeological deposits by quantifying its carbon-14 decay (Arnold and Libby 1951), since biochar and other, more aromatic black carbons persist in the environment longer than any other form of organic carbon. Finely divided biochar has even remained in soils in humid tropical climates, such as the Amazon, for thousands of years (Sombroek et al 2003), resisting the rapid rates of mineralization common to organic matter in these environments and producing a distinct black colour. Such biochar is typically older than any other form of carbon in soils (Pessenda et al 2001).

Despite this high level of resistance, we know that biochar will ultimately be mineralized to CO_2; otherwise, soil organic matter would be dominated by biochar accumulated over geological time scales (Goldberg 1985).

Nutrient retention

Nutrients are retained in soil and remain available to plants mainly by adsorption to minerals and organic matter. While we are usually unable to change the mineralogy of a given soil, we can change the amount of soil organic matter. Typically, the ability of soils to retain cations in an exchangeable form available to plants (cation exchange capacity [CEC]) increases in proportion to the amount of soil organic matter, and this holds for biochar as well. However, biochar has an even greater ability than other soil organic matter to adsorb cations per unit carbon (Sombroek et al. 2003), due to its greater surface area, greater negative surface charge, and greater charge density (Liang et al 2006). In contrast to other organic matter in soil, biochar also appears to be able to strongly adsorb phosphate, even though it is an anion

Biochar application

The application of bio-char (charcoal or biomass-derived black carbon [C]) to soil is proposed as a novel approach to establish a significant, long-term, sink for atmospheric carbon dioxide in terrestrial ecosystems. Apart from positive effects in both reducing emissions and increasing the sequestration of greenhouse gases, the production of bio-char and its application to soil will deliver immediate benefits through improved soil fertility and increased crop production (Lehman et al 2006). Moreover, some researchers claim that biochar may be an immediate solution to reducing the global impact of farming (and in reducing the impact from all agricultural waste). It has been shown that biochar has multiple uses. When added to soil it can significantly improve soil fertility and also act as a sink for carbon (Lehmann 2007). In this way, the carbon is removed from the atmosphere in a process called sequestration (Zwietenoe 2006; Davies 2007).

Improving soil

Any bio-energy production will lead to a maximum removal of biomass from land. This highly extractive procedure potentially leads to widespread soil degradation, with negative effects on soil productivity, habitats, and off-site pollution. Pyrolysis, coupled with an organic matter return through biochar applications, addresses this dilemma, because about half of the original carbon can be returned. In addition, the biochar is extremely effective in restoring soil fertility. Several overviews have presented evidence for the improvement of soil productivity by biochar (see Glaser et al. [2002] and Lehmann and Rondon [2006]). The extraordinary persistence of biochar makes it possible to extend its application beyond the area from which the biomass was obtained to generate the bio-energy. Once applied to a certain location, additions do not need to be repeated annually, as exemplified by the persistently high fertility of Amazonian Dark Earths over several hundred to thousands of years, as well as by remnants of historic charcoal production (Glaser et al 2002; Lehmann and Rondon 2006). This allows application to areas which were not harvested for bio-energy production, but which would benefit from improved soil fertility or reduced pollution by agro-chemicals.

Effect on soil pH

Anions are bound very poorly by soils under neutral or basic pH conditions. This is one of the reasons why crops need fertilising, as anionic nutrients (e.g. phosphates) are leached or flushed from the soil into ground/surface waters (eutrophication) (Verheijen et al 2010). Cheng et al (2007) found that biochar exhibited an anion exchange capacity (at pH 3.5) which decreased to zero as it aged in soil (over 70 years). Whether biochar can play a role in anion exchange capacity of soils remains an unanswered question and a research effort is required into the mechanisms to establish under what conditions (e.g. more neutral pH) anions may be retained (Verheijen et al 2010).

As previously discussed, biochar pH is mostly neutral to basic. The liming effect has been discussed in the literature as one of the most likely mechanisms behind increases in plant productivity after biochar applications (Verheijen et al 2010). Lower pH values in soils (greater acidity) often reduce the CEC and thereby the nutrient availability. In addition, for many of the tropical soils studied, reduced aluminium toxicity by reducing the acidity is proposed as the most likely chemical mechanism behind plant productivity increases (Verheijen et al 2010)..

Other global warming impacts of 'biochar'

Airborne black carbon, or soot, is the second greatest contributor to global warming after carbon dioxide, according to Hansen (2007). It is emitted from burning of fossil fuel and biomass. 'Biochar' proponents claim that charcoal-making stoves can play a major role in reducing black soot emissions which is also true for many different types of 'clean' biomass stoves. A review by Woolf (2008) warns that, if the charcoal is not transported, stored and added to the soil with care, the black carbon content could become airborne and thus contribute to global warming. This raises the question of how biochar is to be integrated into soils. To avoid the problem of airborne black carbon, it will likely be essential that biochar be tilled deep into soils, a disruptive process which also results in carbon emissions from soil (Almuth and Rachel 2009).

Reducing pollution of waterways

When applied to soil, biochar may reduce off-site pollution in two ways: first, by retaining nutrients such as nitrogen and phosphorus in the soil, and lowering the amount of soil nutrients leached into groundwater or eroded into surface waters. Secondly, biochar would reduce pollution by improving nutrient retention in the topsoil, thereby reducing the amount of fertilizer needed to grow a crop. Reduced leaching has been demonstrated in greenhouse studies (Lehmann et al 2003) and can be expected from adsorption behaviour (Figure 1). The reductions in erosion have not been tested; erosion reductions based on the movement of nutrients adsorbed to sediments are debatable, whereas reductions in soluble nutrients can be expected.

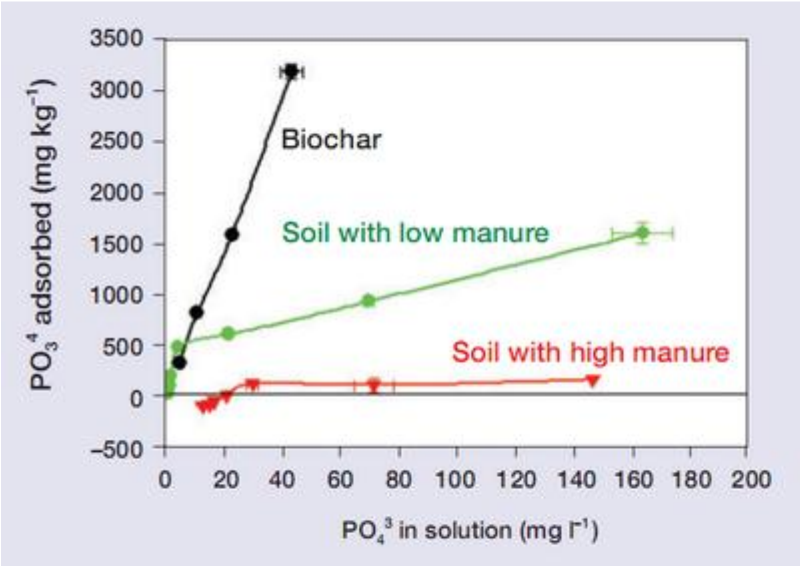

Figure 1: Adsorption of phosphate to biochar (produced from Robinia pseudoacacia L at 350˚C for 16 hours; Cheng et al. 2006) in comparison to soil after short- and long-term application of animal manure (phosphate adsorption to soil from Lehmann et al. [2005]). Means and standard errors are shown; n = 3.

Water spinach (*Ipomoea aquatica*)

Water spinach (WS) has been considered native to Africa, Asia, and the south-western Pacific Islands. The herbs have been a medicinal vegetable in southern Asia since at least A.D. 300, and perhaps since 200 B.C. People still gather plants from the wild and cultivate them (Austin 2007).

Human and animal food

Throughout much of tropical Asia this is a common food eaten by all social groups (Burkill 1966, Roxburgh 1824). This pot herb is popular across an array of countries as an addition to other foods at mealtime; some eat water spinach two or three times a week (Cornelius et al. 1985). There are several ways people consume these herbs, although the most frequent is a cooked vegetable. A common method is to lightly fry the young tips, including stems and leaves (Westphal 1993). However, tips are also eaten boiled, steamed, or added to soups, stews, curries, sambals. Often the branch tips are cooked with onions and chilies, or with garlic, ginger, other spices, shrimp paste, and cuttlefish. Several dishes are regional favourites, such as Cantonese furu (wéng cài 蕹 菜 with bean-curd), and with bean paste and shallots in Hakka cuisine (Fujian, Guangdong, Jiangxi,). Thais stir-fry pak bung with oyster sauce and shrimp paste. In Vietnam giau muông is used as a garnish and eaten with noodles. The dishes adobong kangkong (spicy pork or chicken) and sinigang (kangkong, sour fish, and meat stews) are popular in the Philippines.

Water spinach is a vegetable that is consumed by people and animals; it has a short growth period, is resistant to common insect pests and can be cultivated easily either in dry or flooded soils. *Ipomoea aquatica* is also fodder for animals, in limited quantity as it is somewhat laxative. These herbs are often grown in fish ponds by Chinese, particularly as food for their pigs (Ly et al 2002, Westphal 1993), although they are also fed to cattle and fish (Edie and Ho 1969). In Vietnam, WS is fed to chickens, ducks, and pigs (Ogle et al 2003). Moreover, it has been found that WS has a high potential to convert nitrogen from biodigester effluent into edible biomass with high protein content (Kean Sophea and Preston 2001). The biomass yield was higher when water spinach was grown in soil rather than in water according to Ly Thi Luyen and Preston (2003). Le Thi Men and Preston (2005) have suggested that small-holder farmers should cultivate vegetables as supplements for pigs, using animal's excreta effectively. San Thy and Preston (2001) also reported that the effluent from biodigester loaded with pig manure was a good fertilizer for water spinach production, and improved soil productivity. Earthworm compost was superior to urea in promoting biomass growth and crude protein content of water spinach (Tran Hong Chat et al 2005). Hongthong Phinmasan et al (2004) reported that water spinach as the only source of feed for growing rabbits appears to support acceptable growth rates of close to 20 g/day with a DM feed conversion of 2.7. This simple feeding system may be attractive for small-holder farmers in the tropics, due to the possibility to raise rabbits with a local resource (water spinach) that is easy to grow and needs no processing.

Charcoal

Charcoal is a black substance that resembles coal and generally is made from wood that has been burned, or charred, in a reduced flow of oxygen so that what is left is an impure carbon residue. Charcoal is reported to have beneficial effects in soil by helping to clean the soil of pollutants; it also acts as a soil conditioner http://www.wisegeek.com/what-is-charcoal.htm. It is used as a top dressing for gardens, bowling greens and lawns, and as a substitute for lime in soil additives because of the potash content (http://www.buyactivatedcharcoal.com/natural_fertilizer). Ogawa (1987) reported that charcoal applied to the soil could stimulate the activity of soil microorganisms and promote the formation of root nodules and vesicular-arbuscular mycorrhizae in soybean roots.

Biodigester effluent

The polyethylene tubular biodigester technology is a cheap and simple way to produce gas for small-scale farms. It is appealing to rural people because of the low investment, fast payback, simple technology, positive effects on the environment and women' lives in rural areas (Bui Xuan An et al 1997).

The use of farm yard manure and biodigester effluent is one option to be investigated, in order to develop better plant growing practices. 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. Soeurn Than (1994**)** demonstrated that plastic tube biodigesters can be a low-cost source of energy and partly reduce the problem of severe energy shortage for households in rural areas of Vietnam and Cambodia**.** The advantages of passing manure through a biodigester are many and include gas production for cooking, improved health through elimination of pathogens and no loss of plant nutrients in the process (Bui Xuan An et al 1997). Besides environmental preservation, Preston and Rodriguez (1996) showed that biodigesters provide a very good source of fertilizer for crops on land and water. Many reports have shown clearly the improvement on vegetable and crops yields and a higher content of crude protein by application of biodigester effluent. Examples of these effects were observed in Chinese cabbage (San Thy and Pheng Buntha 2005), water spinach (Kean Sophea and Preston 2001; Ho Bunyeth and Preston 2004; Nguyen Van Hiep and Preston 2006) and cassava (Le Ha Chau 1998; Phiny et al 2009).

References

Akinrinde A E 2006 Soils: Nature, Fertility Conservation and Management, Agronomy Department, University of Ibadan, Ibadan, Nigeria. pp. 1.

Almuth Ernsting and Rachel Smolker 2009 Biochar for Climate Change Mitigation: Fact or Fiction? http://www.biofuelwatch.org.uk/docs/biocharbriefing.pdf

Arnold J R and Libby W F 1951 Radiocarbon dates. Science 113: 111-20.

Asai H, Samson B K, Stephan H M, Songyikhangsuthor K, Homma K, Kiyono Y, Inoue Y, Shiraiwa T and Horie T 2009 Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield. Field Crops Research, 111, 81–84.

Austin F D 2007 Water Spinach (Ipomoea aquatica, Convolvulaceae) A food gone wild. Ethnobotany Research & Applications. A Journal of Plants, People, and Applied Research. Ethnobotany Research and Applications 5:123-146 (2007). http://scholarspace.manoa.hawaii.edu/bitstream/handle/10125/226/I1547-3465-05-123.pdf;jsessionid=7B6E71C75151243EDC741033BD43BFBD?sequence=6

Bui Xuan An, Preston T R and Dolberg F 1997 The introduction of low-cost polyethylene tube biodigesters on small scale farms in Vietnam. Livestock Research for Rural Development (9) 2:27-35. http://lrrd.org/lrrd9/2/an92.htm

Burkill I H 1966 A Dictionary of the Economic Products of the Malay Peninsula. Ministry of Agriculture and Cooperatives, Kuala Lumpur.

Cheng C H, Lehmann J, Thies J E, et al 2006 Oxidation of black carbon by biotic and abiotic processes. Org Geochem 3 37 7: 1477–88.

Cornelius J, Nugteren J A and Westphal E 1985 Kang-kong (*Ipomoea aquatica Forssk.*): An important leaf vegetable in Southeastern Asia. Abstracts on Tropical Agriculture 10(4): 9-21.

Davies R 2007 Biochar/Agri-char /Terra Preta: Its potential use for carbon sequestration, improve soil fertility and sustainable (carbon-negative) energy production and poverty reduction.

Demirbas A 2004 Determination of calorific values of bio-chars and pyro-oils from pyrolysis of beech trunkbarks, Journal of Analytical and Applied Pyrolysis, vol. 72, pp. 215–219.

Edie E E and B W C Ho. 1969 Ipomoea aquatica as a vegetable crop in Hong Kong. Economic Botany 23:32-36.

FFTC (Food & Fertilizer Technology Center) 2008 Application of Rice Husk Charcoal. 5F.14 Wenchow St., Taipei 10616 Taiwan R.O.C. Tel: (886-2) 2362-6239 Fax: (886-2) 2362-0478 Email: info@fftc.sagnet.org http://www.agnet.org/

Glaser B, Lehmann J and Zech W 2002 'Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – A review' *Biology and Fertility of Soils* 35, 219–230.

Goldberg E D 1985 Black carbon in the environment. New York, NY: John Wiley and sons.

Haefele S M 2007 Black soil green rice. Rice Today, 6, 26–27.

Haefele S M, Knoblauch C, Gummert M, Konboon Y and Koyama S 2008 Black carbon (biochar) in rice-based systems: Characteristics and opportunities. In: Woods W I, Teixeira W G, Lehmann J, Steiner C, Prins A W and Rebellatods L (Eds.). Amazon dark earths: Wim Soembrok's vision (pp 445-463. Amsterdam: Springer.

Hansen J, Sato M, Kharecha P, Russell G, Lea D W and Siddall M 2007 'Climate change and trace gases', Philosophical Transactions of the Royal Society A, 365, pp. 1925–54.

Ho Bunyeth and Preston T R 2004 Biodigester effluent as fertilizer for water spinach established from seed or from cuttings. Livestock Research for Rural Development. Vol. 16, Art. No. 79. http://www.lrrd.org/lrrd16/10/buny16079.htm

Hongthong Phimmmasan, Siton Kongvongxay, Chhay Ty and Preston T R 2004: Water spinach (Ipomoea aquatica) and Stylo 184 (Stylosanthes guianensis CIAT 184) as basal diets for growing rabbits. Livestock Research for Rural Development. Vol. 16, Art. No. 34. http://www.lrrd.org/lrrd16/5/hong16034.htm

Karaosmanoglu F, Isigigur-Ergundenler A and Sever A 2000 'Biochar from the straw-stalk of rapeseed plant', Energy and Fuels, vol. 14, pp. 336–339

Kean Sophea and Preston T R 2001 Comparison of biodigester effluent and urea as fertilizer for water spinach vegetable. Livestock Research for Rural Development, Volume 13, Number 6, December 2001. http://www.lrrd.org/lrrd13/6/kean136.htm

Kong Saroeun and Preston T R 2008 Effect of effluent and biochar on the growth of water spinach. MSc 2008-10 miniproject. http://www.mekarn.org/msc2008-10/miniprojects/minpro/saroeun.htm

Le Ha Chau 1998 Biodigester effluent versus manure from pigs or cattle as fertilizer for production of cassava foliage (*Manihot esculenta*). Livestock Research for Rural Development, Volume 10, Number 13, 1998. http://www.lrrd.org/lrrd10/3/chau2.htm

Lehmann J, da Silva Jr J P, Steiner C, Nehls T, Zech W and Glaser B 2003 Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. Plant Soil 2 24 49 9: 343–357.

Lehmann J and Glaser B 2003 'Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments', Plant and Soil 249, 343–357.

Lehmann J, Lan Z, Hyland C, et al. 2005 Long-term dynamics of phosphorus forms and retention in manure-amended soils. Environ Sci Technol 3 39 9: 6672–80.

Lehmann J and Rondon M 2005 'Bio-char soil management on highly-weathered soils in the humid tropics', in N. Uphoff (ed.), Biological Approaches to Sustainable Soil Systems, Boca Raton, CRC Press, in press. http://www.biochar.info/52/downloads/Lehmann_et_al_2006_Bio-char_soil_management.pdf

Lehmann J and Rondon M. 2006. Biochar soil management on highly weathered soils in the humid tropics. In: Uphoff N (Ed). Biological approaches to sustainable soil systems. Boca Raton, FL: CRC Press.

Lehmann J, Gaunt J and Rondon M 2006 Bio-char Sequestration in Terrestrial in Ecosystem – A Review. Mitigation and Adaptation Strategies for Global Change (2006) 11: 403–427. Springer 2006.

Lehmann J 2007 Bio-energy in the black. Concepts and Questions. Front Ecol Environ 2007; 5(7): 381–387. http://www.css.cornell.edu/faculty/lehmann/publ/FrontiersEcolEnv%205,%20381-387,%202007%20Lehmann.pdf

Lehmann J 2007 A handful of carbon. *Nature* 447 143-144 http://www.css.cornell.edu/faculty/lehmann/publ/Nature%20447,%20143-144,%202007%20Lehmann.pdf

Lehmann J and Joseph S (Eds) 2009 Biochar for Environmental Management: Science and Technology. Earthscan, London, UK.

Leng R A 2009 Peak Oil, resource depletion, global warming, financial stress and future world food and feed production. (Editors: Reg Preston and Brian Ogle) International Conference on Livestock, Climate Change and the Environment**,** An Giang University, Vietnam, 16-18 October 2009. httm://www.mekarn.org/workshops/environ/proenv/lengnew.htm

Le Thi Men, Ogle Brian and Vo Van Son 2000 Evaluation of water spinach as a protein source for BaXuyen and Large White sows, from: http://www.mekarn.org/sarpro/lemen.htm

Liang B, Lehmann J, Solomon D, et al. 2006 Black carbon increases cation exchange capacity in soils. Soil Sci Soc Am J 7 70 0: 1719–30.

Lickacz J 2002 Wood Ash - An Alternative Liming Material for Agricultural Soils. Pulse and Oilseed Unit, Alberta Agriculture, Food and Rural Development. http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agdex3435

Ly J, P Samkol and T R Preston. 2002 Nutritional evaluation of aquatic plants for pigs: pepsin/pancreatin digestibility of six plant species. Livestock Research for Rural Development 14(1). www.cipav.org.co/lrrd/lrrd14/1/ly141a.htm.

Ly Thi Luyen and Preston T R 2003 Effect of the urea level on biomass production of water spinach *(Ipomoea aquatica)* grown in soil and water. Livestock Research for Rural Development (16) 10, from: http://www.lrrd.org/lrrd16/10/luye16081.htm

Nguyen Van Hiep and Preston T R 2006 Effect of cattle manure and biodigester effluent levels on growth and composition of water spinach. Livestock Research for Rural Development. Volume 18, Article No. 48. http://www.lrrd.org/lrrd18/4/hiep18048.htm

Ogawa M 1987 Mutualistic microorganisms at the plant-soil interface. Rural Culture Association. (In Japanese).

Ogle B, Ogle M, Ho T T, Hoang N D, Nguyen N X D 2003 Food, feed or medicine: The multiple functions of edible wild plants in Vietnam. Economic Botany 57:103–117.

Pessenda L C R, Gouveia S E M, and Aravena R 2001 Radiocabon dating of total soil organic matter and humin fraction and its comparison with ^{14}C ages of fossil charcoal. Radiocarbon 43: 595-601.

Phiny C, Borin K, Preston T R and Ty C 2009 Effect of level of effluent from biodigesters loaded with pig manure on the growth of mulberry (Morus alba) trees. Livestock Research for Rural Development. Volume 21, Article #114. http://www.lrrd.org/lrrd21/7/phin21114.htm

Reichenauer T G, Panamulla S, Subasinghe S and Wimmer B 2009 Soil amendments and cultivar selection can improve rice yield in salt-influenced (tsunami-affected) paddy fields in Sri Lanka. Environ. Geochem. Health, 31, 573–579**.**

Rodríguez L and Preston T R 1996 Use of effluent from low-cost plastic biodigesters as fertilizer for duck weed ponds. Livestock Research for Rural Development. Volume 8, Article #19. http://www.lrrd.org/lrrd8/2/lylian2.htm

Rodríguez L, Salazar P and Preston T R 2009 Effect of biochar and biodigester effluent on growth of maize in acid soils. Livestock Research for Rural Development. Volume 21, Article #110. http://www.lrrd.org/lrrd21/7/rodr21110.htm

Roxburgh W 1824 Flora Indica or descriptions of Indian Plants. Volume 2. Edited by W. Carey & N. Wallich. Oriole Editions reprint, 1975, New York.

San Thy and Preston T R 2001 Evaluation of the effluent from different retention times as fertilizer for growing water spinach (*Ipomoea aquatica*), from: http://www.mekarn.org/msc2001-03/theses03/santexp2.htm

San Thy and Pheng Buntha 2005 Evaluation of fertilizer of fresh solid manure, composted manure or biodigester effluent for growing Chinese cabbage (Brassica pekinensis). Livestock Research for Rural Development. Vol. 17, Art. No. 26. http://www.lrrd.org/lrrd17/3/sant17026.htm

Shackley S and Sohi S 2010 Benefits and Issues Associated with the Application of Biochar to Soil. Department for Environment, Food and Rural Affairs, UK Government, London.

Shackley S, Carter S, Knowles T, Middelink E, Haefele S and Haszeldine S 2011 Sustainable gasification-biochar systems? A case-study of rice-husk gasification in Cambodia, Part II: Field trial results, carbon abatement, economic assessment and conclusions. Energy Policy doi:10.1016/j.enpol.2011.11.023.

Sohi S, Loez-Capel E, Krull E and Bol R 2009 Biochar's roles in soil and climate change: A review of research needs. CSIRO Land and Water Science Report 05/09, series ISSN: 1834-6618. 64 pp.

Sohi S, Krull E, Lopez-Capel E and Bol R 2010 A review of biochar and its use and function in soil. Advances in Agronomy 105, 47–82.

Sokchea H and Preston T R 2011 Growth of maize in acid soil amended with biochar, derived from gasifier reactor and gasifier stove, with or without organic fertilizer (biodigester effluent). Livestock Research for Rural Development. Volume 23, Article #69. http://www.lrrd.org/lrrd23/4/sokc23069.htm

Sokchea Huy, Khieu Borin and T R Preston 2012 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. Livestock Research for Rural Development. Volume 24, Article #012, http://www.lrrd.org/lrrd24/1/sokc24012.htm

Sisomphone Southavong, Preston T R and Ngo Van Man 2012a Effect of soil amender (biochar or charcoal) and biodigester effluent on growth of water spinach. Livestock Research for Rural Development. Volume 24, Article #026, http://www.lrrd.org/lrrd24/2/siso24026.htm

Sisomphone Southavong, Preston T R and Ngo Van Man 2012b Effect of biochar and charcoal with staggered application of biodigester effluent on growth of water spinach. Livestock Research for Rural Development. Volume 24, Article #039, http://www.lrrd.org/lrrd24/2/siso24039.htm

Sisomphone Southavong, Preston T R and Ngo Van Man 2012c Effect of Biochar and Biodigester Effluent on Growth of Water Spinach and Soil Fertility. Livestock Research for Rural Development. Volume 24, Article #040, http://www.lrrd.org/lrrd24/2/siso24040.htm

Sombroek W, Ruivo M L, Fearnside P M et al 2003 Amazonian Dark Earths as carbon stores and sinks. In: Lehmann J, Kern D C, Glaser B, and Woods W I (Eds). Amazonian Dark Earths: origin, properties, management. Dordrecht, Netherlands: Kluwer Academic Publishers.

Southavong S and Preston T R 2011 Growth of rice in acid soils amended with biochar from gasifier or TLUD stove, derived from rice husks, with or without biodigester effluent. Livestock Research for Rural Development. Volume 23, Article #32. http://www.lrrd.org/lrrd23/2/siso23032.htm

Tagoe S O, Takatsugu Horiuchi T and Matsui T 2008 Effects of carbonized and dried chicken manures on the growth, yield, and N content of soybean. Plant Soil, 306, 211–220.

Tran Hong Chat, Ngo Tien Dung, Dinh Van Binh and Preston T R 2005 Effect on yield and composition of water spinach (Ipomoea aquatica), and on soil fertility, of fertilization with worm compost or urea, from: http://www.mekarn.org/proctu/chat47.htm

Verheijen F, Jeffery S, Bastos A C, van der Velde M and Diafas I 2010 Biochar Application to Soils. A Critical Scientific Review of Effects on Soil Properties, Processes and Functions. JRC Scientific and Technical Report. http://eusoils.jrc.ec.europa.eu/esdb_archive/eusoils_docs/other/EUR24099.pdf

Westphal E 1993 *Ipomoea aquatica* Forskal. In: Plant Resources of South-East Asia. Vol. 8, Vegetables, Siemonsma, J. S. and K. Piluek (eds.), Pudoc Scientific Publishers, Wagenington, The Netherlands, pp. 181-184.

Woolf D 2008 Biochar as a soil amendment: A review of the environmental implications. http://www.google.com/url?sa=t&rct=j&q=dominic%20woolf%202008%20.pdf&source=web&cd=1&ved=0CCIQFjAA&url=http%3A%2F%2Forgprints.org%2F13268%2F1%2FBiochar_as_a_soil_amendment_-_a_review.pdf&ei=sIceT5aAKoyXiQeR-OntDQ&usg=AFQjCNEeEJUlq5h3YZto83FrZNyPcJ45VQ&cad=rja

Yamato M, Okimori Y, Wibowo I F, Anshori S and Ogawa M 2006 Effects of the application of charred bark of Acacia mangium on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. Journal Soil Science and Plant Nutrition, 52, 489–495.

Zhang A, Bian R, Pan G, Cui L, Hussain Q, Li L, Zheng J, Zheng J, Zhang X, Han X and Yu X 2012 Effects of biochar amendment on soil quality, crop yield and greenhouse gas emission in a Chinese rice paddy: A field study of 2 consecutive rice growing cycles. Field Crops Research 127, 153-160.

Zwietenoe Lukas Van 2006 Magic biochar Recycles, fertilizes and sequesters. http://www.dpi.nsw.gov.au/archive/agriculture-today-stories/september-2006/magic-biochar

Growth of rice in acid soils amended with biochar from gasifier or TLUD stove, derived from rice husks, with or without biodigester effluent

Sisomphone Southavong and T R Preston*

Champasack University
Champasack province, Lao PDR
spdeuk@yahoo.com
**Finca Ecológica, TOSOLY, UTA (Colombia)*
AA #48, Socorro, Santander, Colombia

Abstract

The trial was carried out at the experimental farm of An Giang University to measure changes in soil fertility as a function of the growth of rice plants (bio-test) cover a period of 30 days. The experiment was arranged in a completely randomized design with 3 replications of the treatments applied to samples of soil held in one and half litre capacity plastic bags and compared in a 5*2*2 factorial arrangement. The factors were: five levels of biochar (0, 2, 4, 6 and 8%); two types of biochar (Downdraft Gasifier or Updraft Gasifier Stove); and with or without biodigester effluent at 100 kg N/ha.

The biomass growth of rice (over 30 day period from planting) showed a curvilinear increase as the level of biochar was raised from 0 to 2-4%, followed by a slight decline with higher levels. There were no differences due to source of biochar (gasifier or TLUD stove). Application of biodigester effluent at 100 kg N/ha increased biomass growth five-fold with no interaction due to type or level of biochar. Biochar raised soil pH from 4.5 to 5.13 and 5.40 with the higher value for stove biochar. There were no effects of treatment on cation exchange capacity of the soil but water holding capacity was increased from 38 to 59% with no differences due to source or level of biochar.

Key words: *CEC, nitrogen, pyrolysis, soil pH, Terra Preta, water holding capacity*

Introduction

Viet Nam has approximately two million hectares (ha) of acid sulphate soils, a large proportion of which are in the Red River Delta in the north and the Mekong Delta in the south. These soils need to be reclaimed for agricultural production, since toxic elements such as aluminium and iron accumulate in crop roots, harming growth and ultimately yield (http://ssc.undp.org/uploads/media/Acid.pdf).

Rice occupies a position of overwhelming importance in the global food system. Over a third of the world's population, predominantly in Asia, depends on rice as a primary dietary staple. Many of these people live in densely populated countries on an average annual income of less than $US 100, of which a third or more is typically spent on rice (Barker et al 1985). Lack of food security is especially common in sub Saharan Africa and South Asia, with malnutrition in 32 and 22 per cent of the total population, respectively (FAO 2006).

Soil improvement is not a luxury but a necessity in many regions of the world. Conventional ways of improving soil fertility are by addition of chemical fertilizer (NPK) and/or organic matter. A recent development, based on observations of methods used by indigenous peoples in

Amazonia (Lehmann 2007), is the application of biochar, which is a form of charcoal derived by pyrolysis. Pyrolysis is the process of heating fibrous biomass in a restricted supply of oxygen, which prevents complete combustion of the biomass (which happens in open fires). According to Lehmann and Joseph (2009), biochar is the carbon-rich product obtained when biomass, such as wood, manure or leaves, is heated in a closed container with little or no available air. In more technical terms, biochar is produced by thermal decomposition of organic material under a limited supply of oxygen and at temperatures of around 700°C.

Gasification is a process for deriving a combustible gas by burning fibrous biomass in a restricted current of air; most of the gasifiers developed for this process are of the "down-draft" type (Figure 1). The process is a combination of partial oxidation of the biomass with the production of carbon which at a high temperature (600-800°C) acts as a reducing agent to break down water and carbon dioxide (from the air) to hydrogen and carbon monoxide, both of which are combustible gases (Figure 2). Biochar is the solid residue from the process.

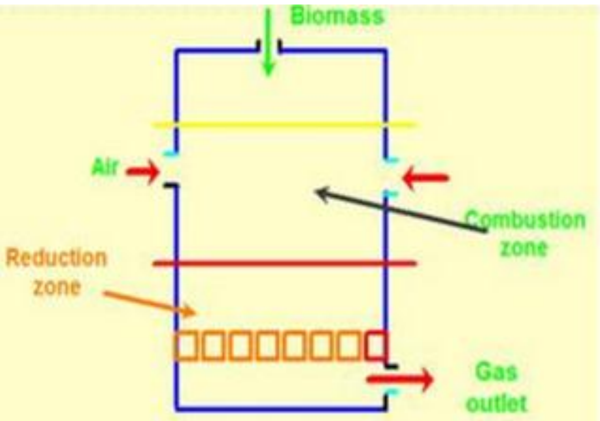

Figure 1: Principles of biomass gasification

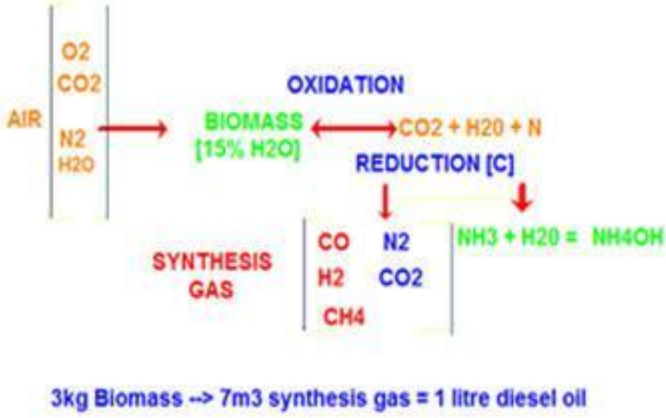

Figure 2: Chemical reactions in the gasifier

Biochar is also produced in gasifier stoves designed for cooking. The design is different from the downdraft gasifier in that the flow of air is upwards so as to produce a flame for cooking, as seen in this recent version of a "TLUD" gasifier stove being constructed in Vietnam (Photos 1-3).

Photos 1-3: The TLUD gasifier stove developed in Vietnam (Olivier 2010)

Application of biochar to soils may be a partial solution to reducing the negative impact of farming on global warming. It has been shown that biochar has multiple uses. When added to the soil it can significantly improve soil fertility (Rodriguez et al 2009) and also act as a sink for carbon (Lehmann 2007). In this way, the carbon is removed from the atmosphere in a process called sequestration (Zwietenoe 2006). Besides that, biochar can act as a soil conditioner, enhancing plant growth by supplying and, more importantly, retaining nutrients by providing other services such as improving the physical and biological properties of soils (Glaser et al 2002; Lehmann and Glaser 2003; Lehmann and Rondon 2005).

The pH of biochar produced by gasification of sugar cane bagasse and rice husks is about 9 (Rodriguez et al 2009; Kong Saroeun and Preston 2008). Application of biochar has been shown to increase the pH of acid soils (Rodriguez et al 2009), thus it could be used to increase the yield of acid-sensitive crops (FFTC 2008; Lickacz 2002).

Animal manure is a potential replacement for chemical fertilizer and is traditionally used by poor farmers. However, in most cases it is not properly managed so that the efficiency of utilization of the manure is very low. The introduction of low-cost biodigesters in Southeast Asia (Bui Xuan An et al 1997) has made it possible for small-scale farmers to convert manure into biogas and a nutrient rich effluent. When applied to vegetables and plants, it can lead to increases in biomass yield and a higher content of crude protein. Examples of these effects were observed in Chinese cabbage (San Thy and Pheng Buntha 2005), water spinach (Kean Sophea and Preston 2001; Ho Bunyeth and Preston 2004) and cassava (Le Ha Chau 1998).

Hypotheses

- On the acid soils in Vietnam it is expected there will be positive effects on plant growth from application of biochar in combination with biodigester effluent.
- The biochar from an updraft (TLUD) gasifier stove will have similar properties in stimulating plant growth as biochar from a downdraft gasifier.

Objectives

- To determine effect of biochar from different sources and effluent from the biodigester (charged with pig manure) on growth of rice in acid soils.

Materials and methods

Location and duration

The experiment was conducted at the experimental farm of An Giang University, Long Xuyen City, An Giang, southern Vietnam. The trial was over a period of 40 days from 1 September to 10 October 2010.

Experimental design

The experiment was arranged in a completely randomised design (CRD) as a 5*2*2 factorial with 3 replications.

The factors were:

- Biochar from rice husks used as fuel in a downdraft gasifier (Photo 6) or in an updraft (TLUD) gasifier stove (Photo 7).

- Level of biochar added to soil: 0, 2, 4, 6 and 8%
- Fertilizer: Biodigester effluent (10 g N/m^2) or none

Procedure

One kg of acid soil (DM basis) with or without biochar was put in plastic bags of 1.5 litre capacity (Photo 4). Five seeds of rice (a local variety purchased from the market) were planted in each bag. Water was applied uniformly to all bags every morning and evening. Biochar (gasifier) derived from rice husks was brought from Celagrid, Cambodia (Photos 6 and 9). Biochar (stove) was made locally by burning rice husks in a "gasifier stove" (Photos 7 and 10).

The effluent was taken from a "plug-flow" tubular polyethylene (0.5 m^3 liquid volume) biodigester (Photo 5) charged daily with pig manure collected from the farmer's farm (daily charge was 5 kg of fresh manure and 20 litres of water) with 20 days of retention time. The N content of the effluent was 600 mg/litre with 535 mg/litre as NH_4-N. It was applied 5 days after seed germination and then every 5 days for 30 days (total of 5 times). The quantities were calculated according to the N content of the effluent to give the equivalent of 100 kg N/ha (10 g N/m^2).

Photo 4: General view of the experimental layout

Photo 5: The plug-flow tubular polyethylene biodigester

Photo 6: Biochar produced from gasifier

Photo 7: Biochar produced from stove

Photo 8: Experimental soil

Photo 9: The 9 KW downdraft gasifier (Ankur Technologies) gasifier installed in CelAgrid, Cambodia

Photo 10: The updraft gasifier stove

Data collection

Observations were made of germination and growth of the rice plants. When the seeds were germinated, 2 to 4 plants were removed to leave only one seedling in each bag. The height of the plants was measured at day 5, 10, 15, 20 25 and 30 (total period of 30 days). In addition, the colour of the plant, germination and growth of plants were observed every day. At the end of the trial, the plants and roots were removed from the bags, washed free of soil, and weighed for fresh biomass. The root length was measured. The green parts (leaves and stems) and the roots were separated and analyzed immediately for DM content. Samples of soil and biochar were analysed at the beginning and end of the trial for pH, ash and CEC (Cation Exchange Capacity). Water holding capacity was also recorded.

Chemical analysis

The DM content of the rice plant (leaf, root and stem) and the soil was determined using the micro-wave relation method of Undersander et al (1993). Soil samples were analyzed for organic matter (OM) by AOAC (1990) method. Biodigester effluent was analyzed for nitrogen (N) content according to AOAC (1990) method. The pH of soil samples was determined using microprocesser pH meter (5 g soil samples were mixed with 25 ml of water and agitated in a mechanical shaker for two hours then centrifuged for 10 minutes before measuring). Cation Exchange Capacity of the soil was analysed according to Houba et al (1988). Water holding capacity was determined by saturating the soil with water and then leaving it in a funnel lined with filter paper during 24 hours.

Statistical analysis

The data were analyzed according to the General Linear Model option in the ANOVA programme of the Minitab (2000) software. Sources of variation were level of biochar, effluent, biochar type, interactions biochar level*effluent, biochar level*biochar type, effluent*biochar type and error.

Results and discussion

Chemical composition of experimental materials

The OM content was higher for biochar derived from the gasifier stove than from the updraft gasifier (Table 1). Both values were considerably lower than was reported for biochar obtained from an updraft gasifier in Colombia charged with sugar cane bagasse (65% OM; Rodríguez et al 2009). The difference can probably be explained by the much higher content of ash in rice husks (about 20%) compared with sugar cane bagasse (2 to 5%).

Table 1: Chemical composition of experimental materials

Composition	DM, %	N, mg/liter	OM, % in DM	pH
Soil	79.5	-	3.23	4.5
Biochar stove	94.3	-	35.6	9.8
Biochar gasifier	50.7	-	27.9	9.5
Effluent	NA	600	NA	NA

NA: Not analysed

Water holding capacity

The biochar from both sources increased the water holding capacity of the soil with a curvilinear trend according to the level of biochar in the soil (Table 2 and Figures 3 and 4).

Table 2: Effect of biochar on soil water holding capacity, %

Biochar type	Biochar level, %				
	0	2	4	6	8
Gasifier biochar	37.9	50.0	54.1	55.6	58.5
Stove biochar	37.9	45.4	51.8	51.2	59.6

There was no difference between the two sources of biochar. The results are similar to those reported by Glaser et al (2002) where water retention capacity was 18% higher in adjacent soils one of which had been amended by charcoal.

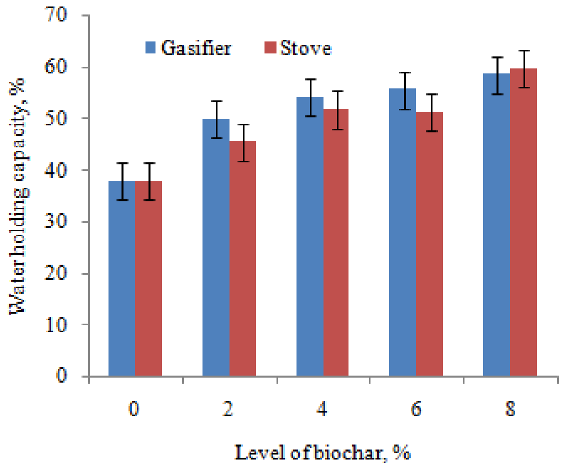

Figure 3: Effect of biochar type and level of biochar on water holding capacity of soil

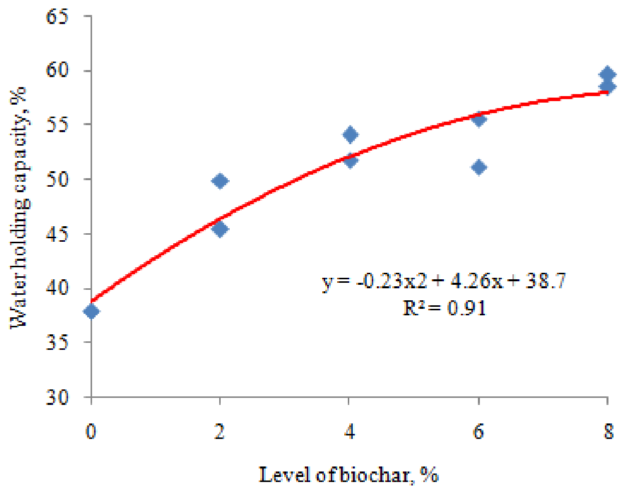

Figure 4: Relationship between level of biochar and water holding capacity of soil

Effect of biochar and effluent on rice biomass yield

The source of biochar had no effect on yield of rice biomass, both aerial part and root; however, soil pH was higher with biochar from the stove (Table 3). Rice biomass yield was increased from 3 to 5 times by application of biodigester effluent. The response to level of biochar was curvilinear (Figures 5 and 6) with increases in yield as the biochar was increased from 0 to 2-4%, followed by a decline with higher levels.

Table 3: Mean values for effects of level of biochar, effluent and biochar type on height and weights of aerial part, root of rice and on soil pH (after 30 days growth)

	Height, cm	Aerial part, g DM	Root weight, g DM	Soil pH
Biochar type				
Gasifier	40.4	1.64	0.64	5.13
Stove	40.9	1.73	0.65	5.40
P	0.61	0.54	0.93	0.001
Level of biochar, %				
0	39.4	1.70	0.57	4.95
2	41.0	2.04	0.80	5.09
4	41.5	1.80	0.77	5.17
6	40.2	1.44	0.57	5.54
8	41.0	1.44	0.52	5.53
P	0.69	0.05	0.08	0.001
Effluent				
With	36.1	0.63	0.97	5.44
Without	45.2	2.74	0.32	5.09
P	0.001	0.001	0.001	0.001
P (interactions)				
B*E	0.92	0.33	0.24	0.001
B*L	0.07	0.07	0.25	0.001
E*L	0.52	0.90	0.67	0.28

B: Biochar type, E: Effluent, L: Level of biochar

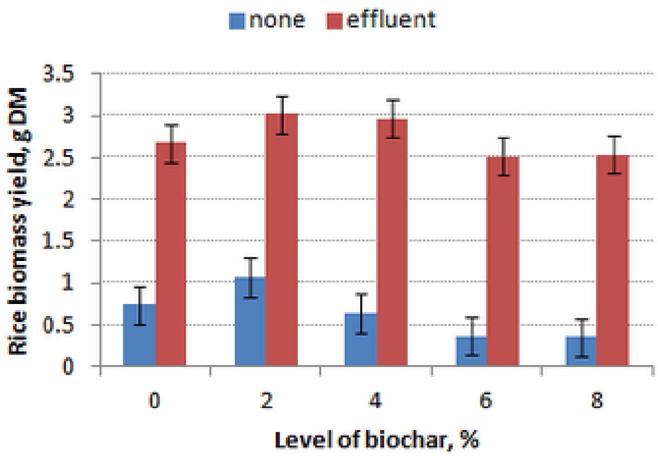

Figure 5: Relationship between level of biochar and aerial biomass, in presence or absence of effluent

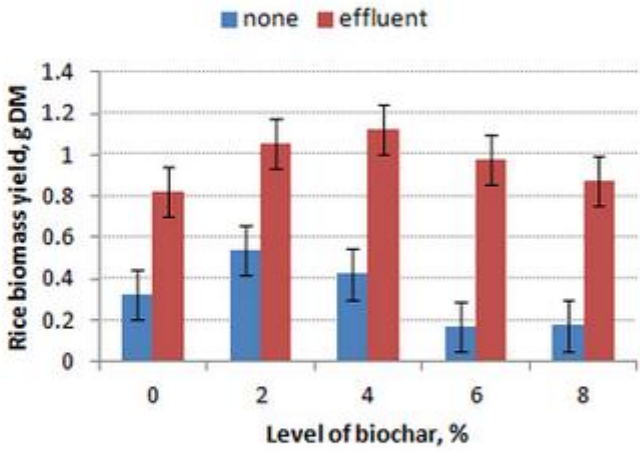

Figure 6: Relationship between level of biochar and root weight in presence or absence of effluent

The increase in growth of the rice brought about by moderate levels of biochar (2-4%) is in agreement with the preliminary report of Boun Suy Tan (2010) in which application of 40 tonnes/ha (about 4% of the soil assuming a cultivation depth of 10cm) of biochar (from rice husk gasifier) doubled the yield of rice grain (from 1.5 to 3.7 tonnes/ha). The slight depression in yield with higher levels of biochar is similar to results of Duong Nguyen Khang et al (2010) with maize as the indicator plant.

Many researchers have emphasized the importance of nutrient supply, especially nitrogen, as a determinant of plant growth response to soil amendment with biochar (see review by Sohi et al 2009). Similar synergistic effects on plant growth by combining charcoal with chicken manure were observed by Steiner et al (2007).

Effect of biochar and effluent on soil pH

The pH of the soil increased linearly with level of biochar addition and was higher for stove than for gasifier biochar (Figure 7) in absence of effluent and the converse when effluent was applied (Figure 8). A positive effect of biochar in improving soil pH was observed by Rodríguez et al (2009), where the pH of an acid soil increased from 4.6 to 6.3 with addition of 5% biochar to the soil. In a very acid soil, Agusalim Masulili et al (2010) reported that application of biochar from rice husk at 10 tonnes/ha increased soil pH from 3.75 to 4.40.

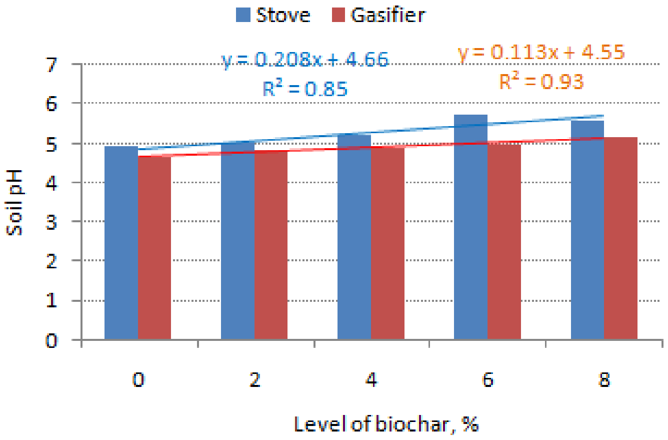

Figure 7: Effect of biochar type on soil pH in absence of effluent

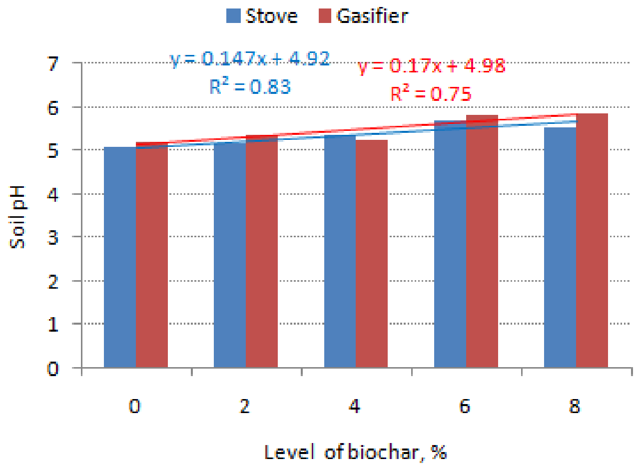

Figure 8: Effect of biochar type on soil pH in presence of effluent

Cation exchange capacity (CEC)

Surprisingly, the biochar produced from rice husk derived from both gasifier and TLUD stove had no effect on cation exchange capacity (Figure 9). This is in contrast to reports by Bot and Benites (2005) and Agusalim Masulili (2010).

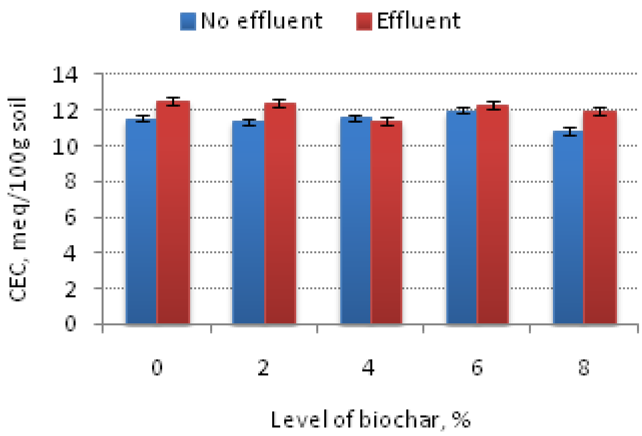

Figure 9: Mean values for cation exchange capacity (CEC) in soil amended with different levels of biochar and application of biodigester effluent

Conclusions and recommendations

- The biomass growth of rice (over 30 day period from planting) showed a curvilinear increase as the level of biochar was raised from 0 to 2-4%, followed by a slight decline with higher levels. There were no differences due to source of biochar (gasifier or TLUD stove).
- Application of biodigester effluent at 100 kg N/ha increased biomass growth five-fold with no interaction due to type or level of biochar.

- Biochar raised soil pH from 4.5 to 5.13 and 5.40 with the higher value for stove biochar.
- There were no effects of treatment on cation exchange capacity of the soil but water holding capacity was increased from 38 to 59% with no differences due to source or level of biochar.

Acknowledgement

The authors would like to express their appreciation to the MEKARN program funded by SIDA-SAREC project, Can Tho University and An Giang University for providing the opportunity and budget to carry out the study. We gratefully thank Ms. Dao Thi My Tien, Ms. Bui Phan Thu Hang, Mr. Nguyen Ba Trung and Ms. Nguyen Huu Yen Nhi for their help in facilitating the execution of the experiment.

References

Agusalim Masulili, Wani Hadi Utomo and Syechfani M S 2010 Rice Husk Biochar for Rice Based Cropping System in Acid Soil. The Characteristics of Rice Husk Biochar and Its Influence on the Properties of Acid Sulfate Soils and Rice Growth in West Kalimantan, Indonesia. Journal of Agricultural Sciences. Vol 2, No. 1. March 2010.

AOAC 1990 Official methods of analysis. Association of Official Analytical Chemists, Arlington, Virginia, 15th edition, 1298 pp.

Barker R, Herdt R W and Rose B 1985 The Rice Economy of Asia. Resources for the Future/Washington, D.C. In Cooperation with the International Rice Research Institute/Manila. Published by Resources for the Future, Inc., 1616 P Street, N.W., Washington, D.C. 20036.

Bot A and Benites J 2005 The importance of soil organic matter: Key to drought-resistant soil and sustained food production. FAO soil Bull. 2005. No. 80. Rome: FAO.

Boun Suy Tan 2010 Preliminary results from biochar rice trials. http://biocharinnovation.wordpress.com/workshop-cambodia/.

Bui Xuan An, Preston T R and Dolberg F 1997 The introduction of low-cost polyethylene tube biodigesters on small scale farms in Vietnam. Livestock Research for Rural Development (9) 2:27-35. http://lrrd.org/lrrd9/2/an92.htm

Doerr S H, Shakesby R A and Walsh R P D 2000 "Soil water repellency: its causes, characteristics and hydro-geomorphological significance". Earth-Science Reviews 51, no. 1-4 (August): 33-65.

FAO (United Nations Food and Agriculture Organization) 2006 The State of Food Insecurity in the World, FAO, Rome, www.fao.org/docrep/009/a0750e/a0750e00.htm, accessed 7 August 2008

FFTC (Food & Fertilizer Technology Center) 2008 Application of Rice Husk Charcoal. 5F.14 Wenchow St., Taipei 10616 Taiwan R.O.C. Tel: (886-2) 2362-6239 Fax: (886-2) 2362-0478 Email: info@fftc.agnet.org http://www.agnet.org/

Glaser B, Haumaier L, Guggenberger G and Zech W 2001 "The 'Terra Preta' phenomenon: a model for sustainable agriculture in the humid tropics", Naturwissenschaften 88: 1

Glaser B, Lehmann J and Zech W 2002 'Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal –Are view' *Biology and Fertility of Soils* 35, 219–230.

Ho Bunyeth and Preston T R 2004 Biodigester effluent as fertilizer for water spinach established from seed or from cuttings. Livestock Research for Rural Development. Vol. 16, Art. No. 79. http://www.lrrd.org/lrrd16/10/buny16079.htm

Houba V J C, Lee J J Van der, Novozamsky and Walinga 1988 Soil and Plant Analysis. Department of Soil Science and Plant Nutrition, Wageningen Agricultural University. De Dreyen 3 Wageningen. The Netherland. http://ssc.undp.org/uploads/media/Acid.pdf

Kean Sophea and Preston T R 2001 Comparison of biodigester effluent and urea as fertilizer for water spinach vegetable. Livestock Research for Rural Development, Volume 13, Number 6, December 2001. http://www.lrrd.org/lrrd13/6/kean136.htm

Kong Saroeun and Preston T R 2008 Effect of effluent and biochar on the growth of water spinach. MSc 2008-10 miniproject.

Le Ha Chau 1998 Biodigester effluent versus manure from pigs or cattle as fertilizer for production of cassava foliage (*Manihot esculenta*). Livestock Research for Rural Development, Volume 10, Number 13, 1998. http://www.lrrd.org/lrrd10/3/chau2.htm

Lehmann J 2007 A handful of carbon. *Nature* 447 143-144 http://www.css.cornell.edu/faculty/lehmann/publ/Nature%20447,%20143-144,%202007%20Lehmann.pdf

Lehmann J and Glaser B 2003 'Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments', Plant and Soil 249, 343–357.

Lehmann J, da Silva Jr J P, Steiner C, Nehls T, Zech W and Glaser B 2003 Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. Plant and Soil, 249, 343-357.

Lehmann J and Joseph S 2009 Biochar for Environmental Management, Science and Technology, Earthscan, UK. p. 1.

Lehmann J and Rondon M 2005 'Bio-char soil management on highly-weathered soils in the humid tropics', in N. Uphoff (ed.), Biological Approaches to Sustainable Soil Systems, Boca Raton, CRC Press, . http://www.biochar.info/52/downloads/Lehmann_et_al_2006_Bio-char_soil_management.pdf

Lickacz J 2002 Wood Ash - An Alternative Liming Material for Agricultural Soils. Pulse and Oilseed Unit, Alberta Agriculture, Food and Rural Development. http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agdex3435

Olivier P 2010 The Small-Scale Production of Food, Fuel, Feed and Fertilizer; a Strategy for the Sustainable Management of Biodegradable Waste. 27c Pham Hong Thai Street, Dalat, Vietnam. www.mekarn.org/workshops/pakse/html/olivier.docx

Rondon M, Ramirez J A and Lehmann J 2005 "Charcoal additions reduce net emissions of greenhouse gases to the atmosphere", in Proceedings of the 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration, Baltimore, USA, March 21–24 2005, p. 208.

Rondon M A, Lehmann J, Ramírez J and Hurtado M 2007 Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with bio-char additions'. Biology and Fertility of Soils. Volume 43, No 6. http://www.css.cornell.edu/faculty/lehmann/publ/BiolFertSoils%202006,%20online%20first,%20Rondon.pdf

Rodríguez L, Salazar P and Preston T R 2009 Effect of biochar and biodigester effluent on growth of maize in acid soils. Livestock Research for Rural Development. Volume 21, Article #110. http://www.lrrd.org/lrrd21/7/rodr21110.htm

Sohi S, Lopez-Capel Elisa, Krull Evelyn and Bol R 2009 Biochar, climate change and soil: A review to guide future research CSIRO Land and Water Science Report 05/09.

San Thy and Pheng Buntha 2005 Evaluation of fertilizer of fresh solid manure, composted manure or biodigester effluent for growing Chinese cabbage (Brassica pekinensis). Livestock Research for Rural Development. Vol. 17, Art. No. 26. http://www.lrrd.org/lrrd17/3/sant17026.htm

Sohi S, Loez-Capel E, Krull E and Bol R 2009 Biochar's roles in soil and climate change: A review of research needs.CSIRO Land and Water Science Report 05/09, 64 pp.

Steiner C, Teixeira W, Lehmann J, Nehls T, Vasconcelos de Macêdo J, Blum W and Zech W 2007 "Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil", Plant and Soil 291:1-2. http://www.css.cornell.edu/faculty/lehmann/publ/PlantSoil,%20online,%202007,%20Steiner.pdf

Undersander D, Mertens D R and Theix N 1993 Forage analysis procedures. National Forage Testing Association. Omaha pp 154.

Zwietenoe Lukas Van 2006 Magic biochar Recycles, fertilizes and sequesters. http://www.dpi.nsw.gov.au/archive/agriculture-today-stories/september-2006/magic-biochar

Received 11 January 2011; Accepted 14 January 2011; Published 1 February 2011

Effect of soil amender (biochar or charcoal) and biodigester effluent on growth of water spinach (*Ipomoea aquatica*)

Sisomphone Southavong, T R Preston* and Ngo Van Man**

Champasack University
Champasack province, Lao PDR
spdeuk@yahoo.com
**Finca Ecológica, TOSOLY, UTA (Colombia)*
AA #48, Socorro, Santander, Colombia
***Nong Lam University, Ho Chi Minh city, Vietnam*

Abstract

A biotest was carried out at the research centre of Champasack University, Lao PDR to determine the effect of biochar, charcoal and biodigester effluent on growth of water spinach. The fifteen treatments in a completely randomized 3*5 factorial arrangement with 3 replications were: soil amender (biochar or charcoal or none) at 40 tonnes/ha and level of effluent (0, 25, 50, 75 or 100 kg N/ha) applied to samples of soil held in fifteen litre capacity plastic baskets. Sixty seeds of water spinach were planted in each basket. After germination, some seedlings were removed to balance the number in each basket (40 seedlings) for the rest of the experiment. The plants were irrigated every morning and evening. Measurements were made of height, number of leaves, and weight of above-ground biomass after 28 days and again (re-growth) after a further 28 days.

Both soil amenders (biochar and charcoal) gave similar improvements in water holding capacity, from 27.4% to 39.0 and 37.6, respectively. Soil pH was increased from 4.7 to 6.6 due to addition of biochar and to 6.3 with charcoal. Biochar increased foliage yield of the water spinach in both the first and second harvests, but there was no apparent effect on foliage growth from application of charcoal. In the first harvest, there were curvilinear responses to biodigester effluent for biochar and charcoal amenders, with the peak occurring at between 50 and 75 kg N/ha. For the un-amended soil the response was linear with the highest yield at 100 kg N/ha. In the second harvest, the response to effluent for the biochar amender was again curvilinear with the peak at 50-75 kg N/ha; by contrast the response to effluent with the charcoal amender was linear with maximum yield requiring 100 kg N/ha. On the un-amended soil there was no relationship between effluent level and biomass yield.

Key words: *biotest, rice husk, soil pH, TLUP gasifier stove, water holding capacity*

Introduction

The world is faced with major perturbations, a financial crisis precipitated by simultaneous and interrelated/interactive events including Peak Oil (the end of inexpensive energy), other global resource depletion and climate change all of which are undermining world food economy. There is an urgent need to respond to these challenges in order to produce and deliver food to maintain the present world population, let alone the increased population predicted by 2030 of 8-10 billion people (Leng 2009).

The fertility of soils is important in agriculture particularly in making decisions on planting of crops. *Terra Preta* ("black earth") was discovered by Dutch soil scientist Wim Sombroek in the 1950's, when he discovered pockets of rich, fertile soil in the Amazon rainforest (otherwise known for its poor, thin soils). Carbon dating has shown them to date back between 1,800 and 2,300 years (Glaser et al 2002). Biochar is a form of charcoal produced from biomass, by a process known as pyrolysis. Pyrolysis means heating in the absence of oxygen, which prevents complete burning of the organic biomass (which happens in open fires). It is rich in a stable form of carbon which is not oxidised by soil micro-organisms.

The application of biochar (charcoal or biomass-derived black carbon [BC]) to soil is proposed as a novel approach to establish a significant, long-term, sink for atmospheric carbon dioxide in terrestrial ecosystems. Apart from positive effects in both reducing emissions and increasing the sequestration of greenhouse gases, the production of biochar and its application to soil will deliver immediate benefits through improved soil fertility and increased crop production (Lehman et al 2006). Moreover, some researchers claim that biochar may be an immediate solution to reducing the global impact of farming (and in reducing the impact from burning of agricultural waste). It has been shown that biochar has multiple uses, when added to soil it can significantly improve soil fertility and also act as a sink for carbon (Lehmann 2007). In this way, the carbon is removed from the atmosphere in a process called sequestration (Zwietenoe 2006; Davies 2007).

The increase in crop yield with biochar application has been reported elsewhere for crops such as cowpea (Yamato et al 2006), soybean (Tagoe et al 2008), maize (Yamato et al 2006; Rodríguez et al 2009), and upland rice (Asai et al 2009). Haefele (2007) and Haefele et al (2008) discussed the possibility of biochar applications for rice-based cropping systems. Reichenauer et al (2009) applied biochar in tsunami-affected paddy fields in Sri Lanka, and the experimental results showed that the 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 per ha for the biochar treatment. Boun Suy Tan (unpublished data) has also indicated that applying biochar (from a downdraft gasifier) to the soil at 40 tonnes/ha in combination with compost could triple the yield of rice from 1.25 to 3.76 tonnes/ha. It is believed that biochar acts as a soil conditioner enhancing plant growth by retaining nutrients and by providing other services such as improving soil physical and biological properties (Glaser et al 2002; Lehmann and Glaser 2003; Lehmann and Rondon 2005).

Water spinach (*Ipomoea aquatica*) is a vegetable that is consumed by people and animals; it has a short growth period, is resistant to common insect pests and can be cultivated either in dry or flooded soils. Moreover, it has been found that water spinach has a high potential to convert nitrogen from biodigester effluent into edible biomass with high protein content (Kean Sophea and Preston 2001). Hongthong Phinmasan et al (2004) reported that water spinach as the only source of feed for growing rabbits appears to support acceptable growth rates of close to 20 g/day with a DM feed conversion of 2.7. This simple feeding system may be attractive for small-holder farmers in the tropics, due to the possibility to raise rabbits with a local resource (water spinach) that is easy to grow and needs no processing.

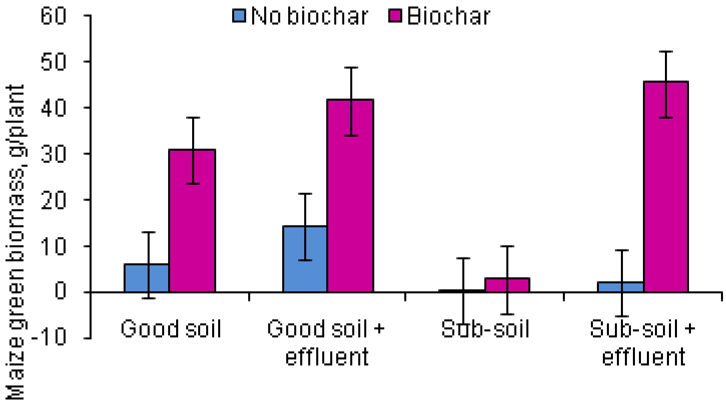

Figure 1: Effect of biochar and effluent added to fertile soil and sub-soil on fresh weight of aerial part of maize (40 days of growth) (from Rodriguez et al 2009)

The pH of biochar produced by gasification of bagasse and rice husks is 9.5 (Kong Saroeun and Preston 2008) and biochar produced from rice husk by gasifier stove is 9.8 (Southavong and Preston 2011). As these soil conditioners have high pH value, they should be used in the low pH soil (acid soil) because they can increase the pH of the soil and thus increase the yield of acid sensitive crops (Lickacz 2002; FFTC 2008). Positive results from application of biochar to acid (pH 4.5) soils in Colombia were reported by Rodríguez et al (2009). Of special importance in this study was the apparent interaction between biodigester effluent and biochar especially in very poor soil (Figure 1).

Effluent is the liquid waste from anaerobic biodigesters (Bui Xuan An et al 1997). When applied to vegetables and plants, it can lead to increases in biomass yield and a higher content of crude protein. Examples of these effects were observed in Chinese cabbage (San Thy and Pheng Buntha 2005), water spinach (Kean Sophea and Preston 2001; Ho Bunyeth and Preston 2004; Nguyen Van Hiep and Preston 2006), mulberry (Phiny et al 2009), cassava (Le Ha Chau 1998), maize (Rodríguez et al 2009; Sokchea and Preston 2011) and rice biomass (Southavong and Preston 2011).

Charcoal is a black substance that resembles coal and generally is made from wood that has been burned, or charred, in a reduced flow of oxygen so that what is left is an impure carbon residue. Charcoal is reported to have beneficial effects in soil by helping to clean the soil of pollutants; it also acts as a soil conditioner http://www.wisegeek.com/what-is-charcoal.htm. It is used as a top dressing for gardens, bowling greens and lawns, and as a substitute for lime in soil additives because of the potash content (http://www.buyactivatedcharcoal.com/natural_fertilizer). Ogawa (1987) reported that charcoal applied to the soil could stimulate the activity of soil microorganisms and promote the formation of root nodules and vesicular-arbuscular mycorrhizae in soybean roots.

The objectives of the present study were:

- To evaluate the effect on growth of water spinach of biochar and charcoal as soil amenders in combination with effluent from a biodigester charged with pig manure.
- To test the long-term effect of biochar application to soil in improving soil and crop production.

Materials and Methods

Location, duration and climate of the study area

The experiment was conducted at the research centre of Champasack University, about 13 km from Pakse City, Champasack province, southern Laos. The trial covered the period of March to May 2011. The climate in this area is tropical monsoon with a rainy season between May and October and a dry season from November to April. The mean air temperature is 28.2°C. Average annual rainfall is 2,000mm/year.

Experimental design

The experiment was arranged in a completely randomized design (CRD) as a 5*3 factorial with 3 replications (Tables 1 and 2 and Photo 1).

The factors were:

- Level of biodigester effluent equivalent to: 0, 25, 50, 75 or 100 kg N/ha
- Soil amender: biochar, charcoal (both at 4kg/m^2) or none

Table 1. Experimental treatments

Effluent levels, kg N/ha	**Soil amenders**		
	Biochar	**Charcoal**	**None**
0	BE0	CE0	SE0
25	BE25	CE25	SE25
50	BE50	CE50	SE50
75	BE75	CE75	SE75
100	BE100	CE100	SE100

B: Biochar; C: Charcoal; S: Soil; E: Effluent

Table 2. Experimental layout

1	2	3	4	5	6	7	8	9
BE0	BE50	BE100	CE100	CE25	CE100	CE50	BE25	CE0
10	11	12	13	14	15	16	17	18
CE100	SE75	BE0	CE25	BE50	SE25	SE100	CE75	SE25
19	20	21	22	23	24	25	26	27
SE25	BE0	BE75	CE0	CE25	SE50	CE50	SE100	BE100
28	29	30	31	32	33	34	35	36
BE100	BE25	SE0	SE50	SE100	BE75	CE75	BE75	CE0
37	38	39	40	41	42	43	44	45
SE75	SE0	BE50	CE75	BE25	SE75	SE0	CE50	CE50

Photo 1: Experimental view

Photo 2: Biochar from updraft gasifier stove

Photo 3: Charcoal powder

Materials

The biochar (Photo 2) was produced locally by burning rice husks in an updraft (TLUD) gasifier stove (Olivier 2010) (Photo 4). Charcoal was bought locally from a farmer nearby the University campus. The effluent were taken from a "plug-flow" biodigester (5 m^3 liquid volume) made from tubular polyethylene with UV filter (Photo 5) and charged daily with washing (1 m^3) from pig pens holding on average 21 pigs of 50 kg mean live weight. Water spinach seeds were bought locally from the market.

Photo 4: The updraft TLUD gasifier stove

Photo 5: Effluent from the plug-flow tubular polyethylene biodigester

Procedure and data collection

Fifteen kg of acid soil (pH 4.68) with or without soil amender (biochar or charcoal) were put into plastic baskets (35*48cm) according to the experimental layout in Table 2. Water spinach seeds (dry-land species) were soaked in water over-night (for better germination) before planting. Sixty seeds were planted in each basket. After germination, some seedlings were removed to balance the number in each basket (40 seedlings) for the rest of the experiment. The distance between rows was 8cm with 2-3cm between seeds. The baskets were lined with a plastic net so that excess water could drain away easily (Photo 6). Water was applied uniformly to all baskets every morning and evening. On rainy days no additional water was applied. The colour, germination and growth of the plants were observed every day.

Photo 6: Experimental basket

The heights of the plants and number of leaves were measured every 7 days over a total period of 28 days. At the end of the trial, the green biomass (leaf + stem) was harvested and weighed and allowed to re-grow for a further 28 days. Samples of the foliages were analysed for dry matter

(DM) content. Samples of soil were analysed at the beginning and end of the trial for pH, OM, water holding capacity and N. Biochar and charcoal were analysed for DM, pH and ash content.

Fertilizing

The fertilizer (biodigester effluent) was applied at the beginning and at 7-day intervals interval (total of 4 times) during the growing period. The quantities were calculated according to the N content of the effluent based on the treatments (25% at each application). For the re-growth period, there was no further addition of effluent.

Chemical analysis

The DM content of the water spinach and soil samples was determined using the micro-wave radiation method of Undersander et al (1993). Organic matter (OM) and N of soil and effluent were determined by AOAC (1990) methods. The pH of soil was determined using a digital pH meter.

Statistical analysis

The data were analyzed according to the General Linear Model option in the ANOVA programme of the Minitab (2000) software. Sources of variation were effluent, soil amender, interaction effluent*soil amender and error. The Tukey test in the Minitab software was used to separate mean values that differed when the F-test was significant at $P<0.05$.

Results and discussion

Chemical composition of experimental materials

The pH content of the biochar was much higher than of charcoal (Table 3), a result similar to that reported by Southavong and Preston (2011). The OM content was much higher for charcoal than for biochar (Table 3). The N content of the effluent was much lower compared to reports by Rodríguez et al (2009); Southavong and Preston (2011) and Sokchea and Preston (2011). The reason for this may have been the more dilute influent to the biodigester as a result of washing the pens frequently.

Table 3: Chemical composition of experimental materials

Composition	DM, %	N, mg/liter	OM, % in DM	pH
Soil	96.9	320	9.34	4.68
Biochar	71.1	-	11.3	10.0
Charcoal	95.7	-	66.3	6.96
Effluent	NA	370	NA	6.81

NA: Not analysed

Water holding capacity

Both soil amenders (biochar and charcoal) gave similar improvements (about 50%) in water holding capacity (Table 4). The value was considerably lower than was reported for biochar obtained from an updraft gasifier in Colombia charged with sugar cane bagasse and biochar derived from a TLUD gasifier stove (Southavong and Preston 2011). These authors compared two types of biochar and 5 different levels ranging from 0 to 8%. The increase in water holding capacity was from 37.9 to 59.6% (an increase of over 50%). The difference can probably be explained by the soil properties in the two studies. Sokchea and Preston (2011) experimented with similar soil to that used by Southavong and Preston (2011), and reported an increase from 43 to 62% in water holding capacity when biochar was added.

Table 4: Effect of biochar and charcoal on soil water holding capacity

Soil amender	Water holding capacity, %
Biochar	38.7
Charcoal	38.2
None	27.4

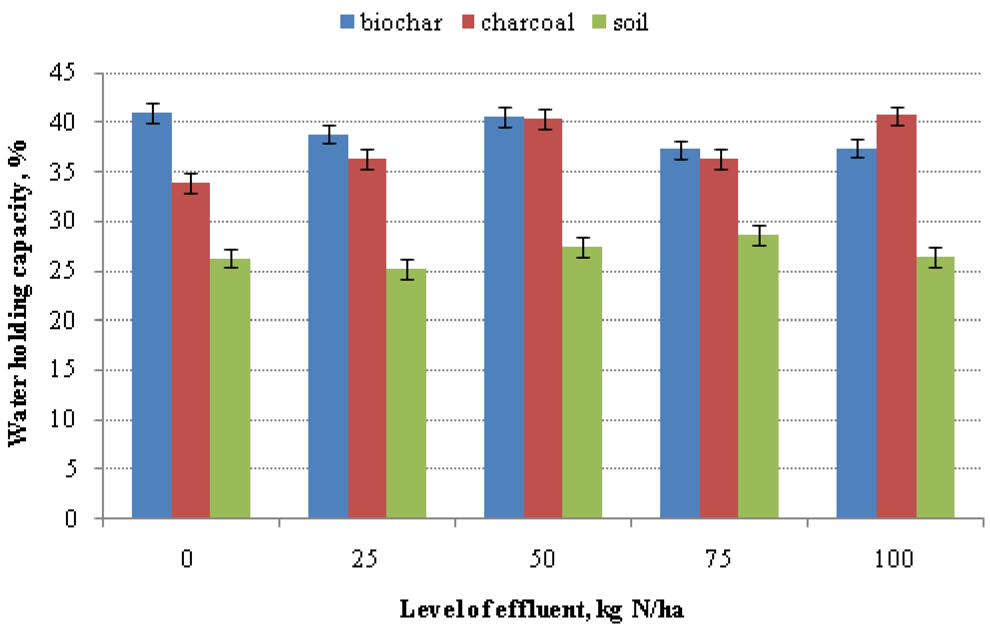

Figure 2: Effect of biochar, charcoal and biodigester effluent on soil water holding capacity after first harvest

Effect of biochar and effluent on water spinach biomass yield

Table 5: Mean values for effects of soil amender and level of effluent on height and green biomass weights of water spinach (after 28 days growth)

	Height, cm	No. of leaves	Width of leaf, cm	Biomass yield 1st harvest, g/0.168m² in DM			kg/ha	Biomass yield 2nd harvest in DM	
				Leaf	Stem	Total		Total, g	kg/ha
Soil amender									
Biochar	37.3[a]	23.4[a]	28.7[a]	240[a]	244[a]	67.0[a]	3,989[a]	67.2[a]	4,000[a]
Charcoal	36.7[ab]	20.5[b]	28.3[a]	208[ab]	214[ab]	58.4[ab]	3,476[ab]	44.5[ab]	2,650[ab]
None	35.3[b]	18.5[c]	25.8[b]	169[b]	160[b]	46.0[b]	2,740[b]	33.1[b]	1,967[b]
Prob.	0.008	0.001	0.001	0.04	0.01	0.02	0.02	0.03	0.03
SEM	0.46	0.48	0.55	3.28	2.07	4.98	296	8.29	493
Level of effluent, kg N/ha									
0	31.7[c]	18.3[b]	23.9[c]	165	135[b]	42.8	2,545	39.1	2,327
25	35.4[b]	18.9[b]	26.2[bc]	176	186[ab]	50.1	2,980	42.7	2,541
50	39.1[a]	22.2[a]	30.0[a]	235	242[a]	66.0	3,929	55.9	3,326
75	37.3[ab]	22.0[a]	28.0[ab]	211	234[ab]	61.1	3,636	49.8	2,961
100	38.8[a]	22.6[a]	29.8[a]	241	230[ab]	65.8	3,919	53.9	3,206
Prob.	0.001	0.001	0.001	0.12	0.03	0.058	0.058	0.77	0.77
SEM	0.59	0.62	0.71	4.24	2.67	6.43	383	10.7	637
Prob. (interactions)									
S*E	0.001	0.002	0.059	0.44	0.89	0.70	0.70	0.98	0.98
SEM	10.3	1.08	1.24	7.33	4.62	11.1	663	18.5	1,103

B: Soil amender, E: Effluent level, Prob: Probability

The superscript [abc] in the same column is significantly different ($P<0.05$)

Biochar increased foliage yield of the water spinach in both the first and second harvests, but there was no apparent effect on foliage growth from application of charcoal. In the first harvest (Figure 3; Table 5, there were curvilinear responses to biodigester effluent for biochar and charcoal amenders, with the peak occurring at between 50 and 75 kg N/ha. For the un-amended soil the response was linear with the highest yield at 100 kg N/ha. In the second harvest (Figure 4; Table 5), the response to effluent for the biochar amender was again curvilinear with the peak at 50-75 kg N/ha. The biochar showed the long term effect in improving the biomass yield of WS in agreement with Sombroek et al (2003). Glaser et al (2002), Lehmann and Glaser (2003) and Lehmann and Rondon (2005) reported that when biochar is applied to soil it helps to retain the nutrients which remain available to plants thus increasing the plant growth and yield; by contrast the response to effluent with the charcoal amender was linear with maximum yield requiring 100 kg N/ha. On the un-amended soil there was no relationship between effluent level and biomass yield.

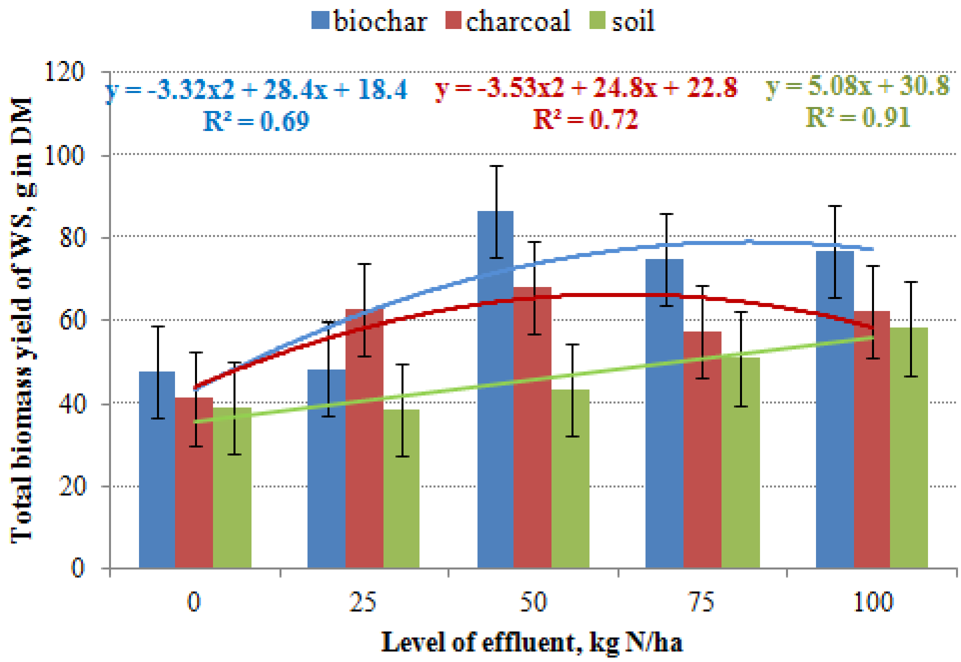

Figure 3: Effect of biochar, charcoal and biodigester effluent on biomass yield in the first harvest

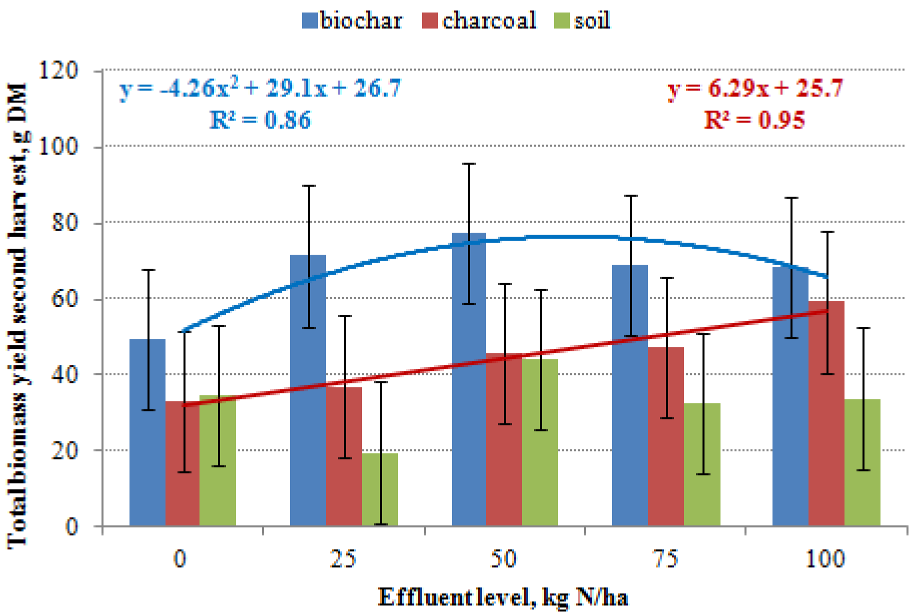

Figure 4: Effect of biochar, charcoal and biodigester effluent on biomass yield in the second harvest

Effect of soil amender on soil pH

The pH of the soil was significantly increased when biochar was applied. There were no effects on soil pH due to level of effluent (Table 6; Figures 6). In the research reported by Rondon et al (2007) the biochar was made by pyrolysis of eucalyptus logs and contained only 0.3% of ash. Their data showed an increase in soil pH from 5.0 to 5.4 after applying 40g biochar per 1 kg of soil, much less than the increase from 4.7 to 6.6 in our experiment.

Table 6: Mean values for effects of soil amender and level of effluent on soil pH and water holding capacity (after 28 days growth)

	Soil pH	WHC, %
Soil amender		
Biochar	6.60[a]	39.0[a]
Charcoal	6.33[b]	37.6[b]
Soil	5.72[c]	26.8[c]
Prob.	0.001	0.001
SEM	0.01	0.55
Effluent level		
0	6.25[ab]	33.8[b]
25	6.10[c]	33.5[b]
50	6.22[a]	36.2[a]
75	6.19[a]	34.1[b]
100	6.31[b]	34.9[b]
Prob.	0.001	0.01
SEM	0.01	0.42
Prob. (interactions)		
S*E	0.001	0.001
SEM	0.01	0.95

B: Soil amender, E: Effluent level, Prob: Probability

The superscript [abc] in the same column is significantly different ($P<0.05$)

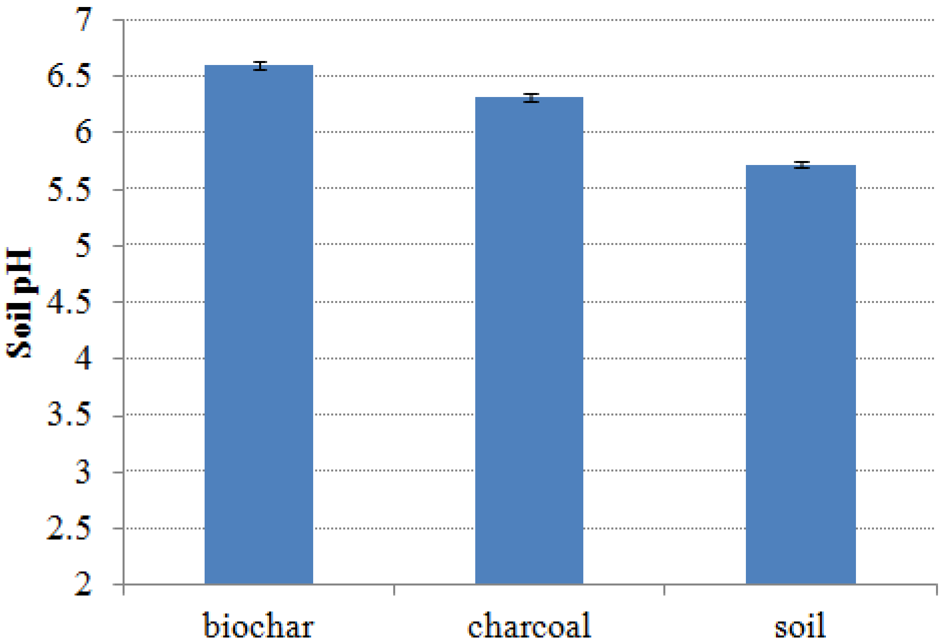

Figure 5: Effect of soil amender application on soil pH after first harvest

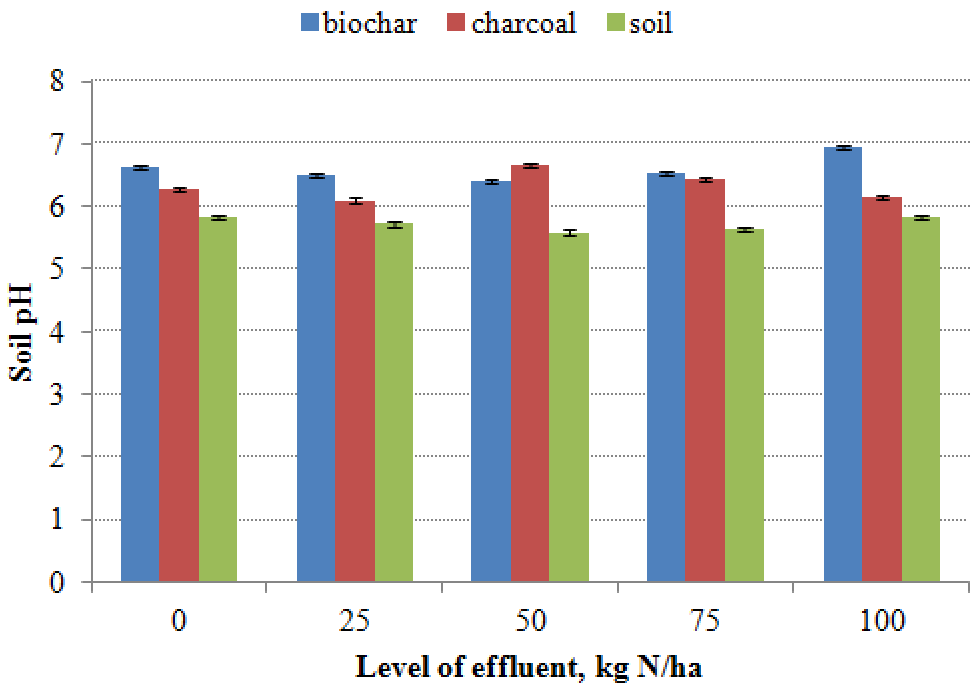

Figure 6: Effect of biochar, charcoal and biodigester effluent on soil pH

Conclusions and recommendations

- Biochar increased foliage yield of water spinach in both first and second harvests but there was no apparent effect on foliage growth from application of charcoal.
- Soil pH was increased from 4.7 to 6.6 due to addition of biochar.
- Both soil amenders (biochar and charcoal) gave similar improvements in water holding capacity.

Acknowledgement

The authors would like to express their sincere thanks to Sida MEKARN program funded by sida SAREC project for financial support as part of the requirements for the MSc degree at Cantho University in "Animal Production; Specialized in Response to Climate Change and Depletion of Non-renewable resources", special thanks to Dr. Phetsamay Vyraphet for useful and valuable advice, students of Faculty of Agriculture and Forestry and Champasack University for providing the study site to carry out this trial.

References

Asai H, Samson B K, Stephan H M, Songyikhangsuthor K, Homma K, Kiyono Y, Inoue Y, Shiraiwa T and Horie T 2009 Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield. Field Crops Research, 111, 81–84.

AOAC 1990 Official methods of analysis. Association of Official Analytical Chemists, Arlington, Virginia, 15th edition, 1298 pp.

Davies R 2007 Biochar/Agri-char /Terra Preta: Its potential use for carbon sequestration, improve soil fertility and sustainable (carbon-negative) energy production and poverty reduction.

FFTC (Food & Fertilizer Technology Center) 2008 Application of Rice Husk Charcoal. 5F.14 Wenchow St., Taipei 10616 Taiwan R.O.C. Tel: (886-2) 2362-6239 Fax: (886-2) 2362-0478
Email: info@fftc.agnet.org http://www.agnet.org/

Glaser B, Lehmann J and Zech W 2002 'Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal –Are view' *Biology and Fertility of Soils* 35, 219–230.

Haefele S M 2007 Black soil green rice. Rice Today, 6, 26–27.

Haefele S M, Knoblauch C, Gummert M, Konboon Y and Koyama S 2008 Black carbon (biochar) in rice-based systems: Characteristics and opportunities. In: Woods W I, Teixeira W G, Lehmann J, Steiner C, Prins A W and Rebellatods L (Eds.). Amazon dark earths: Wim Soembrok's vision (pp 445-463. Amsterdam: Springer.

Ho Bunyeth and Preston T R 2004 Biodigester effluent as fertilizer for water spinach established from seed or from cuttings. Livestock Research for Rural Development. Vol. 16, Art. No. 79.
http://www.lrrd.org/lrrd16/10/buny16079.htm

Hongthong Phimmmasan, Siton Kongvongxay, Chhay Ty and Preston T R 2004 Water spinach (Ipomoea aquatica) and Stylo 184 (Stylosanthes guianensis CIAT 184) as basal diets for growing rabbits. Livestock Research for Rural Development. Vol. 16, Art. No. 34. http://www.lrrd.org/lrrd16/5/hong16034.htm

Kean Sophea and Preston T R 2001 Comparison of biodigester effluent and urea as fertilizer for water spinach vegetable. Livestock Research for Rural Development, Volume 13, Number 6, December 2001.
http://www.lrrd.org/lrrd13/6/kean136.htm

Kong Saroeun and Preston T R 2008 Effect of effluent and biochar on the growth of water spinach. Msc 2008-10 miniproject. http://www.mekarn.org/msc2008-10/miniprojects/minpro/saroeun.htm

Le Ha Chau 1998 Biodigester effluent versus manure from pigs or cattle as fertilizer for production of cassava foliage (*Manihot esculenta*). Livestock Research for Rural Development, Volume 10, Number 13, 1998.
http://www.lrrd.org/lrrd10/3/chau1.htm

Lehmann J and Glaser B 2003 'Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments', Plant and Soil 249, 343–357.

Lehmann J and Rondon M 2005 'Bio-char soil management on highly-weathered soils in the humid tropics', in N. Uphoff (ed.), Biological Approaches to Sustainable Soil Systems, Boca Raton, CRC Press, in press.

Lehmann J, Gaunt J and Rondon M 2006 Bio-char Sequestration in Terrestrial in Ecosystem – A Review. Mitigation and Adaptation Strategies for Global Change (2006) 11: 403–427. Springer 2006

Lehmann J 2007 A handful of carbon. *Nature* 447 143-144
http://www.css.cornell.edu/faculty/lehmann/publ/Nature%20447,%20143-144,%202007%20Lehmann.pdf

Leng R A 2009 Peak Oil, resource depletion, global warming, financial stress and future world food and feed production. (Editors: Reg Preston and Brian Ogle) International Conference on Livestock, Climate Change and the Environment**,** An Giang University, Vietnam, 16-18 October 2009.
httm://www.mekarn.org/workshops/environ/proenv/lengnew.htm

Lickacz J 2002 Wood Ash - An Alternative Liming Material for Agricultural Soils. Pulse and Oilseed Unit, Alberta Agriculture, Food and Rural Development. http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agdex3435

Minitab 2000 Minitab Release 13.31 for windows, Windows* 95/98/2000/xp. Minitab Inc., State College Pennsylvania, USA.

Nguyen Van Hiep and Preston T R 2006 Effect of cattle manure and biodigester effluent levels on growth and composition of water spinach. Livestock Research for Rural Development. Volume 18, Article No. 48.
http://www.lrrd.org/lrrd18/4/hiep18048.htm

Ogawa M 1987 Mutualistic microorganisms at the plant-soil interface. Rural Culture Association. (In Japanese).

Olivier P 2010 The Small-Scale Production of Food, Fuel, Feed and Fertilizer; a Strategy for the Sustainable Management of Biodegradable Waste. http://www.mekarn.org/workshops/pakse/html/olivier.docx

Phiny C, Borin K, Preston T R and Ty C 2009 Effect of level of effluent from biodigesters loaded with pig manure on the growth of mulberry (Morus alba) trees. Livestock Research for Rural Development. Volume 21, Article #114. http://www.lrrd.org/lrrd21/7/phin21114.htm

Reichenauer T G, Panamulla S, Subasinghe S and Wimmer B 2009 Soil amendments and cultivar selection can improve rice yield in salt-influenced (tsunami-affected) paddy fields in Sri Lanka. Environ. Geochem. Health, 31, 573–579**.**

Rodríguez L, Salazar P and Preston T R 2009 Effect of biochar and biodigester effluent on growth of maize in acid soils. Livestock Research for Rural Development. Volume 21, Article #110. http://www.lrrd.org/lrrd21/7/rodr21110.htm

San Thy and Pheng Buntha 2005 Evaluation of fertilizer of fresh solid manure, composted manure or biodigester effluent for growing Chinese cabbage (Brassica pekinensis). Livestock Research for Rural Development. Vol. 17, Art. No. 26. http://www.lrrd.org/lrrd17/3/sant17026.htm

Sokchea H and Preston T R 2011: Growth of maize in acid soil amended with biochar, derived from gasifier reactor and gasifier stove, with or without organic fertilizer (biodigester effluent). Livestock Research for Rural Development. Volume 23, Article #69. http://www.lrrd.org/lrrd23/4/sokc23069.htm

Sombroek W, Ruivo M L, Fearnside P M et al 2003 Amazonian Dark Earths as carbon stores and sinks. In: Lehmann J, Kern D C, Glaser B, and Woods W I (Eds). Amazonian Dark Earths: origin, properties, management. Dordrecht, Netherlands: Kluwer Academic Publishers.

Southavong S and Preston T R 2011 Growth of rice in acid soils amended with biochar from gasifier or TLUD stove, derived from rice husks, with or without biodigester effluent. Livestock Research for Rural Development. Volume 23, Article #32. http://www.lrrd.org/lrrd23/2/siso23032.htm

Tagoe S O, Takatsugu Horiuchi T and Matsui T 2008 Effects of carbonized and dried chicken manures on the growth, yield, and N content of soybean. Plant Soil, 306, 211–220.

Undersander D, Mertens D R and Theix N 1993 Forage analysis procedures. National Forage Testing Association. Omaha pp 154.

Yamato M, Okimori Y, Wibowo I F, Anshori S and Ogawa M 2006 Effects of the application of charred bark of Acacia mangium on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. Journal Soil Science and Plant Nutrition, 52, 489–495.

Zwietenoe Lukas Van 2006 Magic biochar recycles, fertilizes and sequesters. http://www.dpi.nsw.gov.au/archive/agriculture-today-stories/september-2006/magic-biochar

Received 24 July 2011; Accepted 27 January 2012; Published 7 February 2012

Effect of biochar and charcoal with staggered application of biodigester effluent on growth of water spinach (*Ipomoea aquatica*)

Sisomphone Southavong, T R Preston* and Ngo Van Man**

Champasack University
Champasack province, Lao PDR
spdeuk@yahoo.com
Finca Ecológica, TOSOLY, UTA (Colombia)
AA #48, Socorro, Santander, Colombia
***Nong Lam University, Ho Chi Minh City, Vietnam*

Abstract

The hypothesis that was tested in the present study was that there would be a synergistic response in growth of water spinach when biodigester effluent with staggered application was combined with biochar derived from rice husk in an updraft TLUD stove. The experiment was carried out at the research centre of Champasack University, Lao PDR to measure changes in soil fertility as a function of the growth of water spinach plants over a 28 day period following seeding. A completely randomized design was used with 3 replications of fifteen treatments in a 3*5 factorial arrangement. The factors were: soil amender (biochar or charcoal or none) at 40 tonnes/ha and level of effluent (0, 25, 50, 75 or 100 kg N/ha). The treatments were applied to samples of soil held in fifteen litre capacity plastic baskets. Effluent was applied at 7 day intervals (total 4 times) and the application was staggered with 10, 20, 30 and 40% respectively at each successive application.

Green biomass yield of the water spinach was increased by biochar but not by charcoal. The application of biodigester effluent increased linearly the green biomass yield of the water spinach. Soil pH and water-holding capacity was increased by biochar but was not affected by level of effluent.

Key words: *biotest, rice husk, soil pH, TLUP gasifier stove, water holding capacity*

Introduction

Soils are one of the Earth's essential natural resources, yet they are often taken for granted. They are the medium in which plants grow to feed and clothe the world. Soils and the functions they play within an ecosystem vary greatly from one location to another as a result of many factors, including differences in climate, the animal and plant life living on them, soil's parent material, the position of the soil on the landscape, and the age of soil. To understand soil fertility is to understand a basic need of agricultural production (Jhonson 2009; Glendinning 2000).

Biochar, a charcoal-like substance made from biomass and used as a soil amendment, has been credited with multiple benefits, including the ability to improve soil fertility, protect water quality, and generate carbon neutral energy (Brick 2010).

In recent years, producing and using biochar as a soil amender and climate mitigation strategy has generated considerable interest (Lehmann et al 2006; Lehmann 2007). It is believed that biochar acts as a soil conditioner enhancing plant growth by retaining nutrients and by providing other services such as improving soil physical and biological properties (Glaser et al 2002; Lehmann and Glaser 2003; Lehmann and Rondon 2005). Many researches have been done and reported on the use of biochar in combination with biodigester effluent for improving plant growth and yield as well as physical properties of the soil (Southavong and Preston 2011; Sokchea and Preston 2011; Rodríguez et al 2011; Sisomphone et al 2012). Moreover, Rodríguez et al (2009) showed that there were synergistic effects on growth of maize from combining biochar (the residue from the gasification of sugar cane bagasse) with biodigester effluent, as additives to an acid sub-soil (pH 4.5). In a previous study in our laboratory (Sisomphone et al 2012), the biodigester effluent was applied in equal amounts at 7 day intervals in the growth of the plant. In the present study, it was hypothesized that adding biochar and applying biodigester effluent in a staggered (increasing) pattern would enhance the impact of both the biochar and the effluent on plant growth.

Materials and methods

Location

The study was conducted between June and Aug 2010 in the integrated farming demonstration center of Champasack University, located in the village of Huay Leusy, about 13 km from Pakse district, Champasack province, Lao PDR (15° N, 105° 2' E, 175 m above sea level). The mean air temperature in the region is 28.2°C and average annual rainfall 2000mm.

Treatments and design

A completely randomized design was used with 3 replications of the treatments applied to samples of soil held in fifteen litre capacity plastic baskets. Fifteen treatments were compared in a 3*5 factorial arrangement. The trial covered a period of 28 days from 06 May to 03 Jun 2011.

The factors were:

- Soil amender: biochar, charcoal at 40 tonnes/ha or none
- Biodigester effluent: 0, 25, 50, 75 and 100 kg N/ha with staggered (increasing) rates of application over 28 days

The layout of the experiment is shown in Tables 1 and 2 and Photo 1.

Table 1: Experimental treatments

Effluent, kg N/ha	Soil amenders		
	Biochar	**Charcoal**	**None**
0	BE0	CE0	SE0
25	BE25	CE25	SE25
50	BE50	CE50	SE50
75	BE75	CE75	SE75
100	BE100	CE100	SE100

B: Biochar; C: Charcoal; S: Soil; E: Effluent

Table 2: Experimental layout

1	2	3	4	5	6	7	8	9
BE0	CE100	SE50	SE75	BE50	BE75	BE0	SE75	CE0
10	11	12	13	14	15	16	17	18
BE100	SE25	SE100	CE50	SE100	CE75	SE0	CE0	BE50
19	20	21	22	23	24	25	26	27
CE100	BE100	CE75	CE50	CE25	SE50	BE0	SE100	BE25
28	29	30	31	32	33	34	35	36
CE50	BE75	BE25	CE75	CE25	BE100	CE0	BE50	SE0
37	38	39	40	41	42	43	44	45
SE0	SE50	CE25	SE25	BE75	CE100	SE25	SE75	BE25

Photo 1: View of the experimental layout

Photo 2: Biochar from updraft gasifier stove

Photo 3: Charcoal powder

Materials

The biochar was derived from rice husk (Photo 2), produced locally in an updraft (TLUD) gasifier stove (Olivier 2010; Photo 4). Charcoal was bought locally from an adjacent farmer. The effluent was taken from a “plug-flow” biodigester made of tubular polyethylene with UV filter of 5 m^3 liquid volume (Photo 5) charged daily with washings (1 m^3) from pig pens holding on average 21 pigs of 50 kg mean live weight. Water spinach seeds were bought locally from the market.

Photo 4: The updraft TLUD gasifier stove

Photo 5: Effluent from the plug-flow tubular polyethylene biodigester

Procedure and data collection

Plastic baskets (35*48cm; capacity 20 kg) were filled with 15 kg of acid soil (pH 4.86) to which had been added 4% (by weight) of biochar (Photo 6). Seeds of dry-land species of water spinach (n=60) were planted in each basket. After germination some plants were eliminated leaving only 40 plants as the experimental unit. The distance between rows was 8 cm and 2-3 cm between seeds. The baskets were lined with a plastic net so that the excess water could drain away easily (Photo 6). The water was applied uniformly to all baskets every morning and evening. In raining day additional water will not be applied.

Photo 6: Experimental basket with soil

The height of the plants was measured every 7 days over a total period of 28 days. At the end of the trial, the green biomass (leaf + stem) was harvested and weighed, then analysed for dry matter (DM) content. Samples of soil were analysed at the beginning and end of the trial for pH, OM, water holding capacity, and N. Biochar and charcoal were analysed for DM, pH and ash content.

Fertilizing

The fertilizer (biodigester effluent) was applied at the beginning and then 7 day interval (total of 4 times) during the growing period. The quantities were calculated according to the N content of the effluent based on the experimental layout (Table 2). The staggered application was 10, 20, 30 and 40% of the total specified quantity applied at days 1, 7, 14, and 21 respectively (Table 3).

Table 3: Quantities of effluent applied in each basket

Days	Level of N kg/ha	mg N/litre	Staggered rate, %	N needed/plot, g	Effluent applied/plot, ml
1	25	446	10	0.042	94
1	50	446	10	0.084	188
1	75	446	10	0.126	283
1	100	446	10	0.168	377
7	25	447	20	0.084	188
7	50	447	20	0.168	376
7	75	447	20	0.252	564
7	100	447	20	0.336	752
14	25	251	30	0.126	502
14	50	251	30	0.252	1,004
14	75	251	30	0.378	1,506
14	100	251	30	0.504	2,008
21	25	275	40	0.168	611
21	50	275	40	0.336	1,222
21	75	275	40	0.504	1,833
21	100	275	40	0.672	2,444

Chemical analysis

The DM content of the water spinach, biochar, charcoal and soil samples was determined using the micro-wave radiation method of Undersander et al (1993). Organic matter (OM) of soil and N effluent were determined by AOAC (1990) methods. The pH of soil, biochar, charcoal and effluent was determined using a digital pH meter. For measurement of the pH of the solid samples, 5g of grounded samples (DM basis) were put in a beaker and 25 ml of distilled water were added. The suspension was stirred and kept over night. In the next morning before measuring the pH the sample was stirred again for 5- 10 minutes, then kept for another 5 - 10 minutes to let the solid part sink down and then the measurement was taken in the liquid part by using a digital pH meter.

Statistical analysis

The data were analyzed according to the General Linear Model option in the ANOVA programme of the Minitab (2000) software. Sources of variation were effluent, soil amender, interaction effluent*soil amender and error. The Tukey test in the Minitab software was used to separate mean values that differed when the F-test was significant at $P<0.05$.

Results and discussion

Chemical composition of experimental materials

The biochar contained more ash [less organic matter] and the pH was higher (Table 3) in this study than was reported for biochar derived from gasification of sugar cane bagasse for which the organic matter was 65% and pH was 9.0 (Rodriguez et al 2009). This presumably reflects the much higher content of ash in rice husk compared with sugar cane bagasse. The N content of the biodigester effluent was much lower compared to the value reported by Rodriguez et al (2009) which was 700 mg N/litre. This was probably due to the newly installed biodigester and the feed of the pigs which was only taro silage and rice bran.

Table 4: Chemical composition of experimental materials

Composition	DM, %	N, mg/litre	OM, % in DM	pH
Soil	85.7	NA	25.4	4.86
Biochar	83.5	-	22.9	9.75
Charcoal	79.3	-	36.5	7.56
Effluent	NA	324	NA	6.66

NA: Not analysed

Water-holding capacity and pH of the soil

Biochar improved the soil water holding capacity by 50% (Table 5 and Figure 1), with charcoal having a smaller effect. The level of improvement with biochar was similar to the value reported by Sisomphone et al (2012) when 4% (by weight) biochar was added to the soil. Soil pH was increased by biochar but not by charcoal (Figure 2). There was no apparent effect of level of effluent on soil pH. A positive effect of biochar in improving soil pH was observed by Rodríguez et al (2009), where the pH of an acid soil increased from 4.6 to 6.3 with addition of 5% biochar to the soil and Southavong and Preston (2011) where the soil pH increased from 4.5 to 5.13 and 5.40 when biochar was added to soil at 2 to 8% with the higher value for biochar from the stove than from the down draft gasifier. Agusalim Masulili et al (2010) also reported that application of biochar from rice husk at 10 tonnes/ha in a very acid soil increased pH from 3.75 to 4.40.

Table 5: Mean values for effects of soil amender and level of effluent on soil pH and water holding capacity (after 28 days growth)

	Soil pH	WHC, %
Soil amender		
Biochar	6.17[a]	38.6[a]
Charcoal	5.79[b]	32.6[ab]
Soil	5.76[b]	25.9[b]
Prob.	0.001	0.004
SEM	0.06	2.42
Effluent level	0.14	
0	5.91	31.2
25	5.81	34.4
50	5.93	30.1
75	5.89	32.5
100	5.99	33.6
Prob.	0.69	0.86
SEM	0.08	3.13
Prob. (interactions)		
S*E	0.75	0.93
SEM	0.14	5.42

B: Soil amender, E: Effluent level, Prob: Probability
The superscript [abc] in the same column is significantly different (P<0.05)

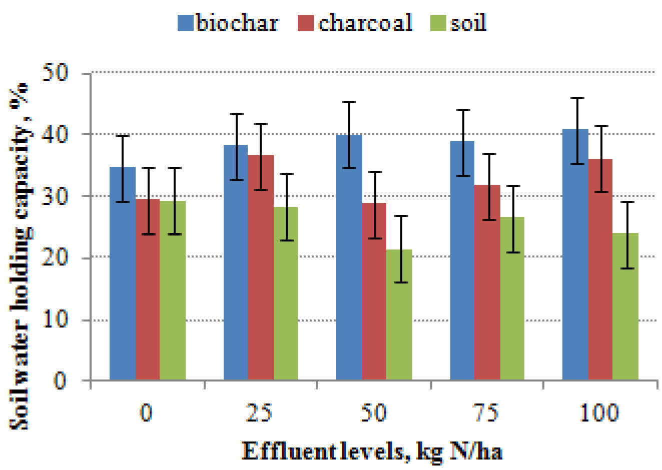

Figure 1: Effect of biochar, charcoal and biodigester effluent on soil WHC

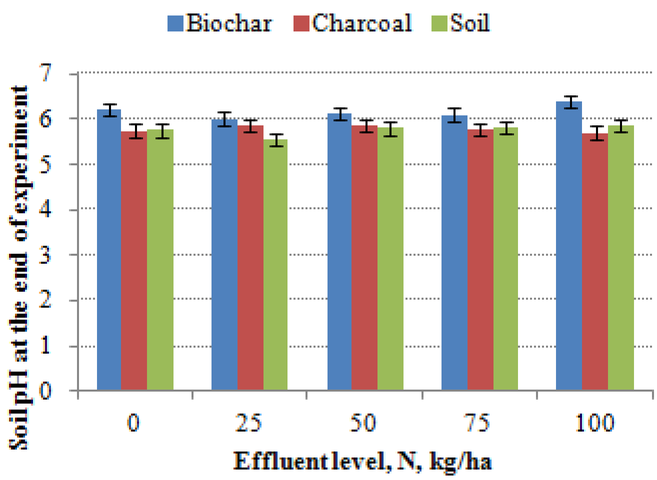

Figure 2: Effect of soil amender on soil pH after 28 days growth

Effect of biochar and effluent on water spinach biomass yield

The increase in growth of the water spinach brought about by the biochar (Table 6; Figures 3 and 4) is in agreement with the majority of reports in the literature (rice [Sisomphone Southavong and Preston 2011]; maize [Rodriguez et al 2009; Sokchea and Preston 2011]; water spinach [Sisomphone et al 2012]). The staggered application of biodigester effluent resulted in a linear increase in height and green biomass yield of the water spinach. This response (equivalent to 18.3 tonnes/ha) is similar to the 20.7 tonnes/ha yield of water spinach reported in Cambodia by Kean Sophea and Preston (2001) with the same application of 100 kg N/ha of biodigester effluent.

Table 6: Mean values for effects of soil amender and level of effluent on height, number of leaf, wideness, weights of water spinach and on soil pH (after 28 days growth)

	Height, cm	**No. of leaves**	**Width, cm**	**Biomass yield, g/0.168m^2 DM**			**Kg/ha, DM**
				Leaf	**Stem**	**Total**	
Soil amender							
Biochar	39.6^{a}	20.3^{a}	27.7^{a}	18.0^{a}	13.7^{a}	31.7^{a}	$1,887^{a}$
Charcoal	36.5^{b}	16.8^{b}	24.2^{b}	14.1^{b}	11.5^{ab}	25.6^{ab}	$1,524^{ab}$
Soil	34.0^{c}	15.0^{b}	23.0^{b}	10.9^{b}	9.81^{b}	20.7^{b}	$1,232^{b}$
Prob.	0.001	0.001	0.001	0.001	0.02	0.001	0.001
SEM	0.58	0.91	0.66	18.8	1.07	19.1	123
Level of effluent, kg N/ha							
0	30.1^{a}	16.0^{a}	19.1^{a}	8.01^{c}	6.32^{c}	14.3^{c}	851^{c}
25	35.4^{b}	16.6^{a}	24.5^{b}	11.7^{bc}	8.95^{c}	20.6^{c}	$1,226^{c}$
50	35.2^{b}	15.8^{a}	23.0^{b}	13.2^{bc}	9.98^{bc}	23.2^{bc}	$1,381^{bc}$
75	39.3^{c}	18.2^{ab}	27.6^{c}	17.0^{ab}	14.6^{ab}	31.6^{ab}	$1,881^{ab}$
100	43.5^{d}	20.1^{b}	30.4^{c}	21.8^{a}	18.5^{a}	40.2^{a}	$2,393^{a}$
Prob.	0.001	0.05	0.001	0.001	0.001	0.001	0.001
SEM	0.75	1.17	0.86	1.39	1.19	2.47	89
Prob. (interactions)							
S*E	0.01	0.35	0.01	0.39	0.16	0.28	0.28
SEM	1.30	2.03	1.49	2.06	2.41	4.27	4.27

S: Soil amender, E: Effluent level, Prob: Probability

[abc] *Means in the same column without common superscript are different at $P<0.05$*

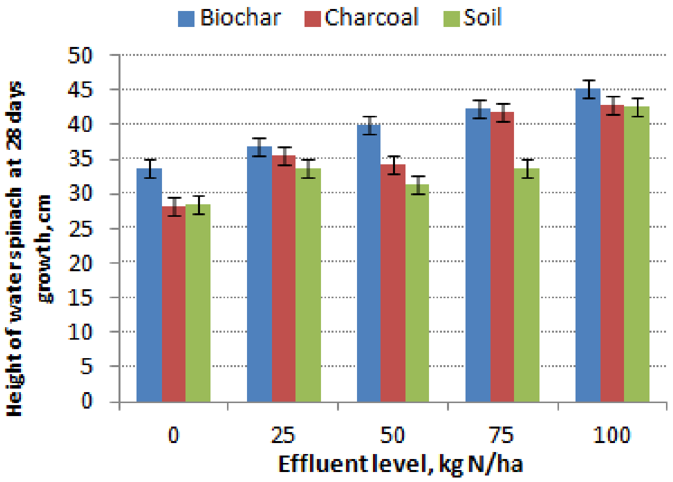

Figure 3: Effect of biochar, charcoal and biodigester effluent on height of water spinach

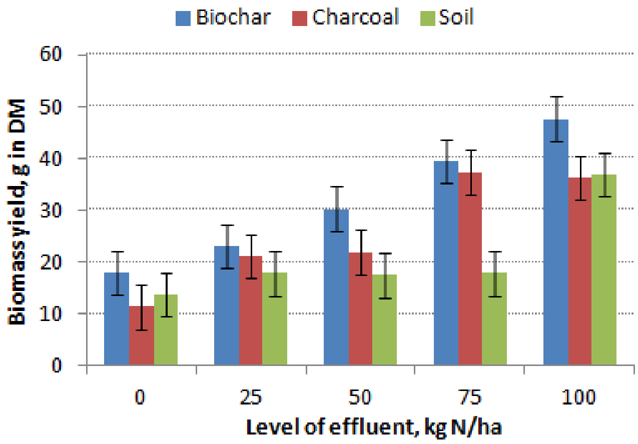

Figure 4: Effect of biochar, charcoal and biodigester effluent on biomass yield of water spinach (per plot of 0.168m^2), DM basis

Conclusions

- Biochar increased foliage yield of water spinach but there was no apparent effect on foliage growth from application of charcoal.
- Soil pH was increased from 4.86 to 6.17, and water holding capacity from 25.9 to 38.6%, due to addition of biochar.

- The staggered application of effluent gave a linear increase in biomass yield with the increasing level of effluent up to 100 kg N/ha.

Acknowledgement

This paper is part of the requirements by the Senior Author for the MSc degree at Cantho University in "Animal Production; Specialized in Response to Climate Change and Depletion of Non-renewable resources". The authors are grateful to the MEKARN program funded by sida SAREC project for financial support, and staff and students from Champasack University for their help with the experiment. Special thanks to Dr. Phetsamay Vyraphet for useful advice during the experiment.

References

Agusalim Masulili, Wani Hadi Utomo and Syechfani M S 2010 Rice Husk Biochar for Rice Based Cropping System in Acid Soil. The Characteristics of Rice Husk Biochar and Its Influence on the Properties of Acid Sulfate Soils and Rice Growth in West Kalimantan, Indonesia. Journal of Agricultural Sciences. Vol 2, No. 1. March 2010.

AOAC 1990 Official methods of analysis. Association of Official Analytical Chemists, Arlington, Virginia, 15th edition, 1298 pp.

Brick S 2010 Biochar assessing the promise and risks to guide U.S policy. Natural Resources Defense Council (NRDC). pp. 1.

Glaser B, Lehmann J and Zech W 2002 'Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal –Are view' *Biology and Fertility of Soils* 35, 219–230.

Glendinning J S 2000 Soil fertility. Australian manual. Fertilizer Industry of Australia, Inc. Revised edition. National Library of Australia Cataloguing in Publication entry. pp. 1.

Jhonson C 2009 Biology of soil science. Oxford Book Company. Jaipur, India. Printed at Rajdhani Printers, Delhi. pp. 1.

Kean Sophea and Preston T R 2001 Comparison of biodigester effluent and urea as fertilizer for water spinach vegetable. Livestock Research for Rural Development. Volume 13, Article #59 http://www.lrrd.org/lrrd13/6/kean136.htm

Lehmann J and Glaser B 2003 'Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments', Plant and Soil 249, 343–357.

Lehmann J, Gaunt J and Rondon M 2006 Bio-char Sequestration in Terrestrial in Ecosystem – A Review. Mitigation and Adaptation Strategies for Global Change (2006) 11: 403–427. Springer 2006. http://www.css.cornell.edu/faculty/lehmann/publ/MitAdaptStratGlobChange%2011,%20403-427,%20Lehmann,%202006.pdf

Lehmann J and Rondon M 2005 'Bio-char soil management on highly-weathered soils in the humid tropics', in N. Uphoff (ed.), Biological Approaches to Sustainable Soil Systems, Boca Raton, CRC Press, in press.

Lehmann J 2007 A handful of carbon. *Nature* 447 143-144 http://www.css.cornell.edu/faculty/lehmann/publ/Nature%20447,%20143-144,%202007%20Lehmann.pdf

Minitab 2000 Minitab Release 13.31 for windows, Windows* 95/98/2000/xp. Minitab Inc., State College Pennsylvania, USA.

Olivier P 2010 The Small-Scale Production of Food, Fuel, Feed and Fertilizer; a Strategy for the Sustainable Management of Biodegradable Waste. http://www.mekarn.org/workshops/pakse/html/olivier.docx

Rodríguez L, Salazar P and Preston T R 2009 Effect of biochar and biodigester effluent on growth of maize in acid soils. Livestock Research for Rural Development. Volume 21, Article #110. http://www.lrrd.org/lrrd21/7/rodr21110.htm

Rodríguez L, Salazar P and Preston T R 2011 Effect of a culture of "native" micro-organisms, biochar and biodigester effluent on the growth of maize in acid soils. Livestock Research for Rural Development. Volume 23, Article #223. http://www.lrrd.org/lrrd23/10/rodr23223.htm

Sisomphone Southavong, Preston T R and Ngo Van Man 2012 Effect of soil amender (biochar or charcoal) and biodigester effluent on growth of water spinach. *Livestock Research for Rural Development. Volume 24, Article #026,* http://www.lrrd.org/lrrd24/2/siso24026.htm

Sokchea H and Preston T R 2011: Growth of maize in acid soil amended with biochar, derived from gasifier reactor and gasifier stove, with or without organic fertilizer (biodigester effluent). Livestock Research for Rural Development. Volume 23, Article #69. http://www.lrrd.org/lrrd23/4/sokc23069.htm

Southavong S and Preston T R 2011 Growth of rice in acid soils amended with biochar from gasifier or TLUD stove, derived from rice husks, with or without biodigester effluent. Livestock Research for Rural Development. Volume 23, Article #32. http://www.lrrd.org/lrrd23/2/siso23032.htm

Undersander D, Mertens D R and Theix N 1993 Forage analysis procedures. National Forage Testing Association. Omaha pp 154.

Received 24 December 2011; Accepted 29 January 2012; Published 7 February 2012

Effect of Biochar and Biodigester Effluent on Growth of Water Spinach (*Ipomoea aquatic*) and Soil Fertility

Sisomphone Southavong, T R Preston* and Ngo Van Man**

Champasack University
Champasack province, Lao PDR
spdeuk@yahoo.com
Finca Ecológica, TOSOLY, UTA (Colombia)
AA #48, Socorro, Santander, Colombia
***Nong Lam University, Ho Chi Minh city, Vietnam*

Abstract

The experiment was conducted at the Integrated Farming Demonstration Centre, Champasack University, Lao PDR to investigate the effect of biochar and biodigester effluent on biomass yield of water spinach and on soil fertility. The treatments were arranged in a randomized complete block design (RCBD) as a 3*2 factorial with 4 replications. The factors were application of biochar to soil at 40 tonnes/ha or none and three levels of biodigester effluent at 0, 50 or 100 kg, N/ha. Twenty four plots were prepared with a total area of 96 m^2. Each plot had an area of 4 m^2 (1*4m). Spacing between plots was 80cm and between replications was 120cm. Biochar was applied to the soil at 16kg/4m^2 or 40 tonnes/ha. Water spinach was established from seed with spacing between rows of 20 cm and between seeds 2-3 cm.

The water holding capacity of the soil was increased by application of biochar but there were no differences due to the level of biodigester effluent. Soil pH was increased by application of biochar from 4.68 to 6.22. There was no apparent effect of level of effluent on soil pH. The biomass yield of water spinach in both first and second harvestswas increased due to the application of biochar.

Key words: *rice husk, soil pH, soil texture, TLUP gasifier stove, water holding capacity*

Introduction

The soil is a very crucial factor in food production. The most important problem of tropical agriculture is the inability of the land to sustain annual food crop for more than a few years at a time. Since animals, in turn, depend on plants, it becomes obvious that all agricultural activities directly or indirectly depend on the soil (Akinrinde 2006).

An increasing number of global threats such as climate change, poverty, declining agricultural production, scarcity of water, fertilizer shortage and the resulting social and political unrest seem overwhelming (Lehmann and Joseph 2009). The urgency to address these threats creates an ever increasing demand for solutions that can be implemented now or at least in the near future. These solutions need to be widely implemented both locally by individuals and through large programmes in order to produce effects on a global scale. This is a daunting and urgent task that cannot be achieved by any single technology, but requires many different approaches (Lehmann and Joseph 2009).

At best, common renewable energy strategies can only offset fossil fuel emissions of CO_2 – they cannot reverse climate change. One promising approach to lowering CO_2 in the atmosphere, while producing energy and biochar, is by pyrolysis and gasification of biomass (Lehmann

2007). This technology relies on capturing the off-gases from thermal decomposition of wood or grasses to produce heat, electricity, or biofuels. Biochar is a major by-product of this pyrolysis, and has remarkable environmental properties (Lehmann 2007). Biochar is produced by so-called thermal decomposition of organic material under limited supply of oxygen (O2), and at relatively low temperatures (<700°C). This process often mirrors the production of charcoal, which is one of the most ancient industrial technologies developed by mankind – if not the oldest (Harris, 1999). In soil, biochar was shown to persist longer and to retain cations better than other forms of soil organic matter. Furthermore, the cation retention of fresh biochar is relatively low compared to aged biochar in soil, and it is not clear under what conditions, and over what period of time, biochar develops its adsorbing properties (Lehmann 2007).

Previous biotest experiments conducted in our laboratory (Sisomphone et al 2012a; Sisomphone et al 2012b) showed that there were effects on growth of water spinach from combining biochar (the residue from the gasification of rice husks) with biodigester effluent, as additives to an acid soil (pH 4.6). It was therefore hypothesized that applying similar method in a field trial would also increase biomass yield of water spinach.

Materials and methods

Location

The experiment was carried out in the integrated farming demonstration center of Champasack University located in the Huay Leusy village, about 13 km from Pakse district, Champasack province, Lao PDR between May and Sep 2010, the mean air temperature of 28.2°C and average annual rainfall of 2000mm/year.

Experimental design

Six treatments were arranged in a randomized complete block design (RCBD) as a 3*2 factorial with 4 replications.

The factors were:

- Addition of biochar: with or without at 40 tonnes/ha
- Application of biodigester effluent: 0, 50 or 100 kg N/ha

Table 1: Experimental treatments

Effluent, kg N/ha	Soil amenders	
	Biochar	**None**
0	B4E0	B0E0
50	B4E50	B0E50
100	B4E100	B0E100

B: Biochar; E: Effluent

Table 2: Experimental layout

Rep I	B4E0	B0E50	B4E100	B4E50	B0E100	B0E0
Rep II	B0E0	B4E0	B0E50	B4E50	B0E100	B4E100
Rep III	B4E0	B0E0	B0E100	B4E50	B0E50	B4E100
Rep IV	B0E100	B4E100	B0E50	B0E0	B4E50	B4E0

Photo 1: Experimental view

Materials

The biochar (Photo 2) was derived from rice husk (Photo 3), produced locally in an updraft (TLUD) gasifier stove (Olivier 2010; Photo 4). The effluent used in the experiment was taken from a "plug-flow" biodigester made of tubular polyethylene with UV filter of 5 m^3 liquid volume (Photo 5) charged daily with washings (1 m^3) from pig pens holding on average 21 pigs of 50 kg mean live weight fed rice bran and taro silage. Water spinach seeds (dry land species) were bought locally from the market.

Photo 2: Biochar

Photo 3: Rice husk

Photo 4: The updraft gasifier stove

Photo 5: Plug-flow biodigester

Land preparation, plot size and planting

Land was ploughed by using a two-wheel tractor. Then twenty four plots were prepared with a total area of 96 m^2. Each plot had an area of 4 m^2 (1*4m); spacing between plots was 80cm and between replications was 120cm. Biochar was applied to the soil at 16kg/4m^2 or 40 tonnes/ha (Photo 6). Water spinach seeds were soaked overnight in warm water before planting in the next day for better germination. The spacing between rows was 20 cm and between seeds 2-3 cm (Photo 7).

Photo 6: Applying biochar to soil

Photo 7: Planting of water spinach

Fertilizing and irrigation

Samples of the effluent were analyzed for N before applying to the water spinach plots. Effluent from the biodigester was applied to the treatments at the beginning of planting and then at 7 day interval (total 4 times). The quantities were calculated according to the N content of the effluent to give the equivalent of 50 or 100 kg N/ha. Water was applied uniformly to all plots every morning and evening. On rainy days no additional water was applied.

Measurements

The heights of the plants and number of leaves were measured every 7 days over a total period of 28 days by selecting 10 representative plants in each plot. At the end of the trial, the green biomass (leaf + stem) was harvested by using the frame (0.8*3m) and weighed and allowed to re-grow for a further 28 days. Samples of the foliages were analysed for dry matter (DM) content. Samples of soil were analysed at the beginning and end of the trial for pH, OM, water holding capacity and N. Biochar was analysed for DM, pH and ash content.

Chemical analysis

The DM content of the water spinach, biochar and soil samples was determined using the micro-wave radiation method of Undersander et al (1993). Organic matter (OM) of biochar and soil and N content of effluent were determined by AOAC (1990) methods. The pH of soil was determined using digital pH meter by adding 5g of ground sample (DM basis) into a beaker with 25 ml of distilled water. The suspension was stirred and kept over-night. In the next morning before measuring the pH the sample was stirred again for 5- 10 minutes, then kept for another 5 - 10 minutes to let the solid part sink down and then the measurement was taken in the liquid part. Soil samples were analysed for texture, separating the fractions into clay, fine silt, coarse silt,

fine sand and coarse sand using the Pipette Method
http://www.geology.iupui.edu/research/SoilsLab/procedures/psd/index.htm
The cation exchange capacity (CEC) was determined by titrating with 1M Calcium Chloride at pH 7. Water holding capacity was measured by weighing 5 g of soil (DM basis) into a glass funnel fitted with filter paper and then saturating the soil with water. After 24 h the soil was weighed to determine the quantity of water that had been retained.

Statistical analysis

The data were analyzed according to the General Linear Model option in the ANOVA programme of the Minitab (2000) software. Sources of variation were effluent, biochar, interaction effluent*biochar, block and error. Tukey test in the Minitab software was used to separate mean values that differed when the F-test was significant at P<0.05.

Results and discussion

Soil characteristics

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 (Turenne 2011). 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 3 indicate that the soil in the experimental area would be classified as "clay" soil (Foth 1990; Berry et al 2007).

Table 3: Soil texture, using the Pipette Method

Soil particle size, %				Texture class
Coarse	**Fine**	**Clay**	**Silt**	
2.02	10.9	75.1	11.9	C

Chemical composition of experimental materials

Table 4: Chemical composition of experimental materials before starting the experiment

	DM, %	OM, % in DM	pH	N, mg/ liter	P_2O_5, %	K_2O, %	Exchangeable cation (meq/100g)			
							Ca^{2+}	Mg^{2+}	K^+	Na^+
Soil	96.9	9.34	4.68	105#	0.121	0.005	2.2	4.6	0.1	0.2
Biochar	82.2	20.2	10.1	NA	NA	NA	4.0	13.2	0.7	0.6
Soil + biochar	NA	NA	NA	NA	NA	NA	2.6	5.4	0.4	0.3
Effluent	NA	NA	6.81	443	NA	NA	NA	NA	NA	NA

NA: Not analysed
 # N, mg/kg soil

Water-holding capacity and pH of the soil

Biochar has high total porosity, and it can both retain water in small pores and thus increase WHC and let the water flow through the larger pores after heavy rain from topsoil to deeper soil layers (Asai et al 2009). The water holding capacity of the soil was increased by application of biochar but there were no differences with level of biodigester effluent (Table 6, Figure 2). The level of improvement with biochar was similar to the value reported by Sisomphone et al (2012a) and Sisomphone et al (2012b) when 4% (by weight) biochar was added to the soil. 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 lower values in this present report probably reflected differences in soil characteristics between the different experiments. 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. A positive improvement of WHC was also reported by (Karhu et al 2011). Soil pH was increased by application of biochar from 4.68 to 6.22 (Figure 2); there was no apparent effect of level of effluent on soil pH. A positive effect of biochar in improving soil pH was observed by Rodríguez et al (2009), where the pH of an acid soil increased from 4.6 to 6.3 with addition of 5% biochar to the soil and Southavong and Preston (2011) where the soil pH increased from 4.5 to 5.13 and 5.40 when biochar was added to soil at 2 to 8% with the higher value for biochar from the stove than from the down draft gasifier. Agusalim Masulili et al (2010) also reported that application of biochar from rice husk at 10 tonnes/ha in a very acid soil increased pH from 3.75 to 4.40 and in the study by Zhang et al (2012) there was also a positive effect due to biochar.

Table 5: Water holding capacity of the soil before planting

Soil amender	Water holding capacity, %
Biochar	34.6
None	26.3

Table 6: Mean values for effects of biochar and level of effluent on soil pH and water holding capacity (after 28 days growth)

	Soil pH	WHC, %
Soil amender		
Biochar	6.22[a]	39.7[a]
Soil	5.86[b]	33.2[b]
Prob.	0.02	0.004
SEM	0.10	1.41
Effluent level		
0	5.97	34.7
50	6.01	36.5
100	6.15	38.1
Prob.	0.55	0.33
SEM	0.12	1.73
Prob. (interactions)		
B*E	0.99	0.94

B: Biochar, E: Effluent level, Prob: Probability

The superscript [ab] in the same column is significantly different ($P<0.05$)

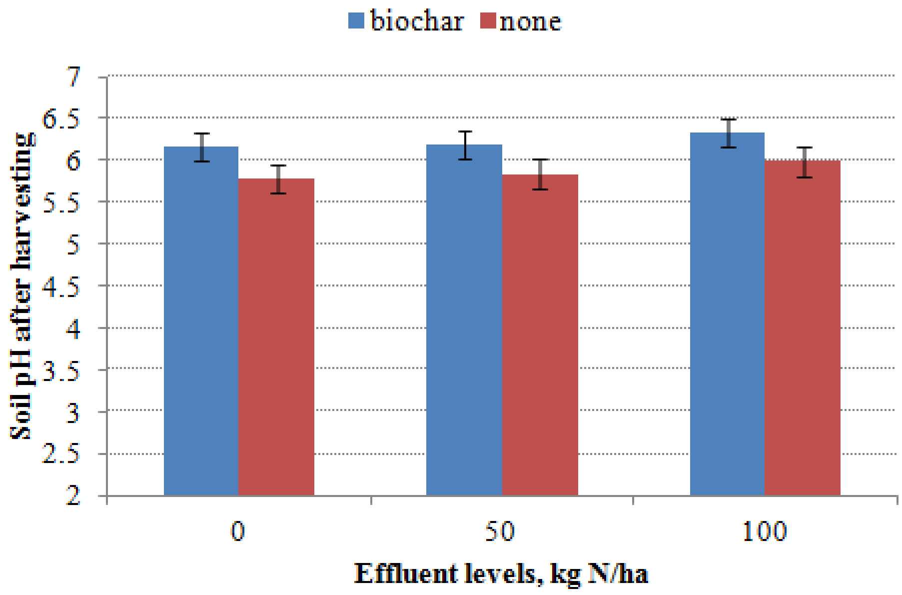

Figure 1: Effect of biochar and biodigester effluent on soil pH

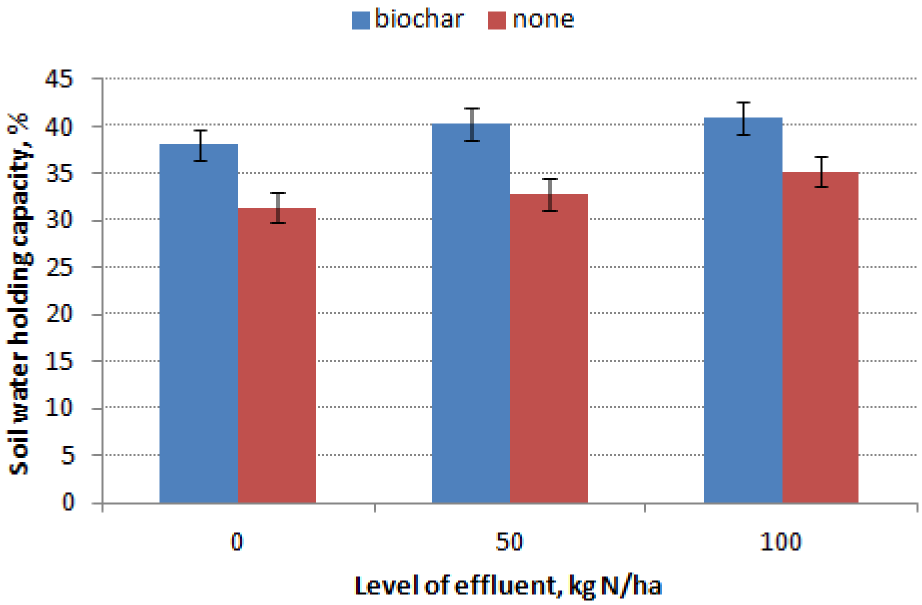

Figure 2: Effect of biochar and biodigester effluent on water holding capacity

Effect of biochar and effluent on water spinach biomass yield

Biochar increased foliage yield of the water spinach in both the first and second harvests. The long-term effect of biochar to enhance the fertility of the soil was observed by Sisomphone et al (2012a) and it is in agreement with the majority of reports in the literature (rice biomass [Sisomphone and Preston 2011], rice gain yield [Zhang et al 2010; Zhang et al 2012]; maize [Rodriguez et al 2009; Sokchea and Preston 2011]; water spinach [Sisomphone et al 2012b]). This response (equivalent to 18.1 tonnes/ha) is similar to the 18.3 tonnes/ha yield of water spinach reported by (Sisomphone et al 2012b). Lehmann (2007) stressed that nutrients of the soil are retained and remain available to plant due to application of biochar hence it increased crop yield. It has been well documented that biochar amendment to crop lands enhances crop productivity through improving soil quality (Asai et al 2009; Major et al 2010; Sohi et al 2010; Zwieten et al 2010; Gaskin et al 2010; Haefele et al 2011).

Table 7: Mean values for effects of soil amender and level of effluent on height and green biomass weights of water spinach (after 28 days growth)

	Height, cm	No. of leaves	Width of leaf, cm	Biomass yield 1st harvest, kg/4m² DM			kg/ha, DM	Biomass yield 2nd harvest, DM	
				Leaf	Stem	Total		Total, kg	kg/ha
Soil amender									
Biochar	46.1[a]	13.8[a]	31.8[a]	0.19[a]	0.46[a]	0.65[a]	1,618[a]	0.55	1,379
None	37.9[b]	12.4[b]	25.2[b]	0.14[b]	0.33[b]	0.46[b]	1,153[b]	0.35	792
Prob.	0.001	0.001	0.001	0.04	0.05	0.03	0.03	0.02	0.02
SEM	0.78	0.12	0.56	0.01	0.04	0.05	142	0.06	163
Level of effluent, kg N/ha									
0	39.0[b]	12.9	27.2[b]	0.16	0.33	0.49	1,213	0.34	847
50	42.6[a]	13.1	28.6[ab]	0.16	0.43	0.59	1,477	0.50	1,247
100	44.5[a]	13.3	29.7[a]	0.17	0.41	0.59	1,466	0.47	1,163
Prob.	0.001	0.09	0.03	0.85	0.38	0.49	0.49	0.35	0.36
SEM	0.96	0.15	0.69	0.02	0.05	0.07	174	0.08	200
Prob. (interactions)									
S*E	0.07	0.83	0.23	0.68	0.73	0.78	0.78	0.75	0.75

B: Soil amender, E: Effluent level, Prob: Probability

The superscript [ab] in the same column is significantly different (P<0.05)

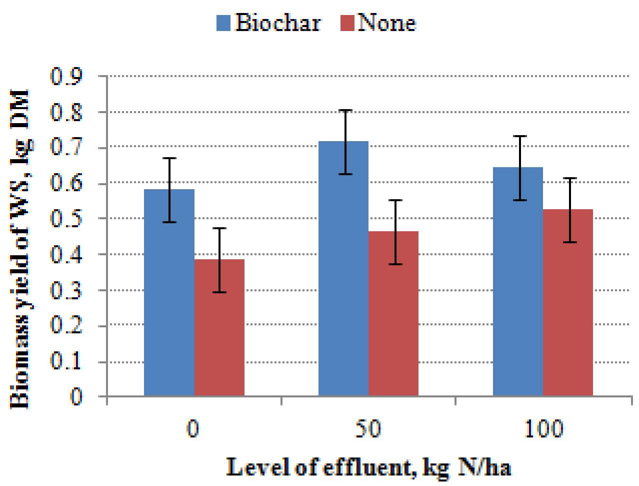

Figure 3: Effect of biochar on total biomass yield first harvest, kg/4m² DM basis

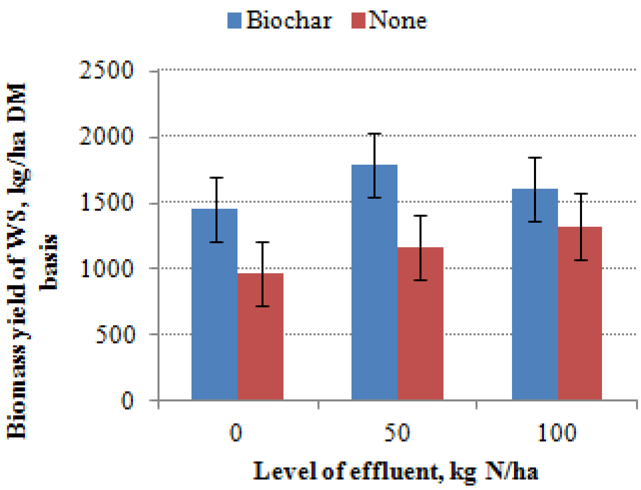

Figure 4: Effect of biochar on total biomass yield first harvest, kg/ha DM basis

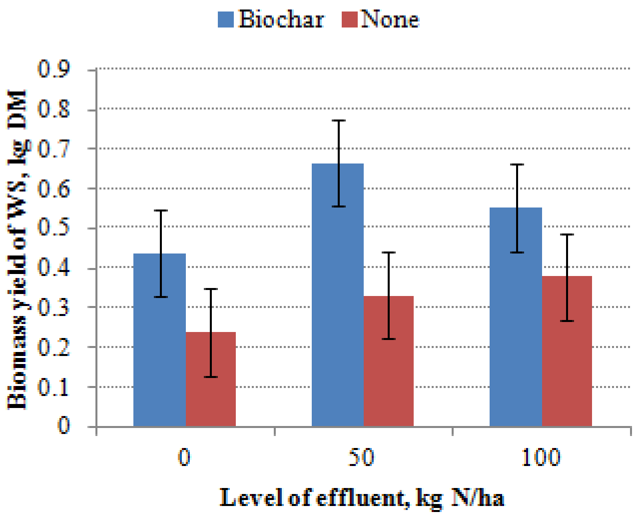

Figure 5: Effect of biochar on total biomass yield second harvest, kg/4m^2 DM basis

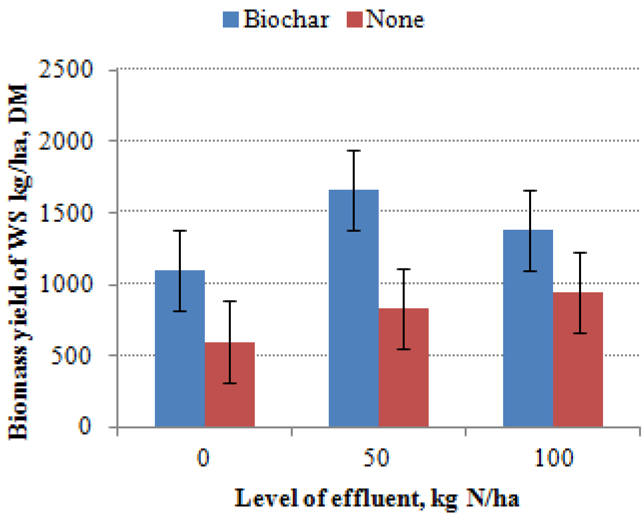

Figure 6: Effect of biochar on total biomass yield second harvest, kg/ha DM basis

Conclusions and recommendations

- Biochar increased foliage yield of water spinach in both first and second harvests but there was no apparent effect on foliage growth from application of level of effluent.
- Soil pH was increased from 4.68 to 6.22 due to addition of biochar.
- Water holding capacity of the soil was increased by application of biochar.

Acknowledgement

The authors are very grateful to the Sida MEKARN program funded by sida SAREC project, Sweden, for the support for this research as part of the requirements for the MSc degree at Cantho University in "Animal Production; Specialized in Response to Climate Change and Depletion of Non-renewable resources". Dr. Phetsamay Vyraphet, Dean Faculty of Agriculture and Forestry for his patient and valuable guidance and advice during my experiment. Champasack University is also acknowledged for provision of research facilities.

References

Akinrinde A E 2006 Soils: Nature, Fertility Conservation and Management, Agronomy Department, University of Ibadan, Ibadan, Nigeria. pp. 1.

Asai H, Samson B K, Stephan H M, Songyikhangsuthor K, Homma K, Kiyono Y, Inoue Y, Shiraiwa T and Horie T 2009 Biochar amendment techniques for upland rice production in Northern Laos: 1. Soil physical properties, leaf SPAD and grain yield. Field Crops Research 111, 81-84.

AOAC 1990 Official methods of analysis. Association of Official Analytical Chemists, Arlington, Virginia, 15th edition, 1298 pp.

Berry W, Ketterings Q, Antes S, Page S, Russell-Anelli J, Rao R and De Gloria S 2007 Nutrient Management Spear Program. http://nmsp.css.cornell.edu

Foth H D 1990 Fundamentals of Soil Science. Michigan State University. JOHN WILEY & SONS. Printed in the United States of America. pp. 22-25.

Gaskin J W, Speir R A, Harris K, Das K C, Lee R D and Morris L A 2010 Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrient status, and yield. Agron. J. 102, 623–633.

Haefele M S, Konboon Y, Wongboon W, Amarante S, Maarifat A A, Pfeiffer M E and Knoblauch C 2011 Effects and fate of biochar from rice residues in rice-based systems. Field Crops Research. 121, 430–440.

Harris P 1999 'On charcoal', Interdisciplinary Science Reviews, vol. 24, pp. 301–306.

Karhu K, Mattila T, Bergström I and Regina K 2011 Biochar addition to agricultural soil increased CH_4 uptake and water holding capacity - Results from a short-term pilot field study. Agriculture, Ecosystems and Environment. 140, 309-313.

Lehmann J 2007 Bio-energy in the black. Concepts and Questions. Front Ecol Environ 2007; 5(7): 381–387. http://www.css.cornell.edu/faculty/lehmann/publ/FrontiersEcolEnv%205,%20381-387,%202007%20Lehmann.pdf

Lehmann J and Joseph S 2009 Biochar for Environmental Management Science and Technology. First published by Earthscan in the UK and USA in 2009. pp.

Major J, Rondon M, Molina D, Riha S J and Johannes L 2010 Maize yield and nutrition after 4 years of doing biochar application to a Colombian savanna oxisol. Plant and Soil 333, 117–128.

Minitab 2000 Minitab Release 13.31 for windows, Windows* 95/98/2000/xp. Minitab Inc., State College Pennsylvania, USA.

Olivier P 2010 The Small-Scale Production of Food, Fuel, Feed and Fertilizer; a Strategy for the Sustainable Management of Biodegradable Waste. http://www.mekarn.org/workshops/pakse/html/olivier.docx

Rodríguez L, Salazar P and Preston T R 2009 Effect of biochar and biodigester effluent on growth of maize in acid soils. Livestock Research for Rural Development. Volume 21, Article #110. http://www.lrrd.org/lrrd21/7/rodr21110.htm

Sisomphone Southavong, Preston T R and Ngo Van Man 2012a Effect of soil amender (biochar or charcoal) and biodigester effluent on growth of water spinach. Livestock Research for Rural Development. Volume 24, Article #026. Retrieved, from http://www.lrrd.org/lrrd24/02/siso24026.htm

Sisomphone Southavong, Preston T R and Ngo Van Man 2012b Effect of biochar and charcoal with staggered application of biodigester effluent on growth of water spinach. *Livestock Research for Rural Development. Volume 24, Article #039,* http://www.lrrd.org/lrrd24/2/siso24039.htm

Sohi S, Krull E, Lopez-Capel E and Bol R 2010 A review of biochar and its use and function in soil. Advances in Agronomy 105, 47–82.

Sokchea H and Preston T R 2011 Growth of maize in acid soil amended with biochar, derived from gasifier reactor and gasifier stove, with or without organic fertilizer (biodigester effluent). Livestock Research for Rural Development. Volume 23, Article #69. http://www.lrrd.org/lrrd23/4/sokc23069.htm

Southavong S and Preston T R 2011 Growth of rice in acid soils amended with biochar from gasifier or TLUD stove, derived from rice husks, with or without biodigester effluent. Livestock Research for Rural Development. Volume 23, Article #32. http://www.lrrd.org/lrrd23/2/siso23032.htm

Turenne J 2011 Soil Properties and Texture (a Basic Power Point presentation) http://nesoil.com/properties/texture/index.htm

Undersander D, Mertens D R and Theix N 1993 Forage analysis procedures. National Forage Testing Association. Omaha pp 154.

Zhang A, Cui L, Pan G, Li L, Hussain Q, Zhang X, Zheng J and Crowley D 2010 Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. Agriculture, Ecosystems and Environment 139, 469-475.

Zhang A, Bian R, Pan G, Cui L, Hussain Q, Li L, Zheng J, Zheng J, Zhang X, Han X and Yu X 2012 Effects of biochar amendment on soil quality, crop yield and greenhouse gas emission in a Chinese rice paddy: A field study of 2 consecutive rice growing cycles. Field Crops Research 127, 153-160.

Zwieten V L, Kimber S, Morris S, Chan K Y, Downie A, Rust J, Joseph S and Cowie A 2010 Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant and Soil 327, 235-246.

Received 29 December 2011; Accepted 29 January 2012; Published 7 February 2012

General conclusion and recommendations

Application of biochar at 40 tonnes/ha improved:

- Biomass yield of rice and water spinach
- Soil physical properties (increase in pH and in water holding capacity)
- Use of fertilizer nutrients (eg: carryover effects in 2^{nd} harvest with no fertilizer).

The results of the experiments described in this thesis suggest that application of biochar has the potential to improve productivity of rice and water spinach in Laos, but that the effect of biochar application is highly dependent on soil fertility and fertilizer management. The improvement in soil water holding capacity by biochar would be one opportunity to be applied in the drought areas. The long-term effect of biochar on the carryover of soil nutrients would be a means by which rural poor farmers could reduce their investment in fertilizers.