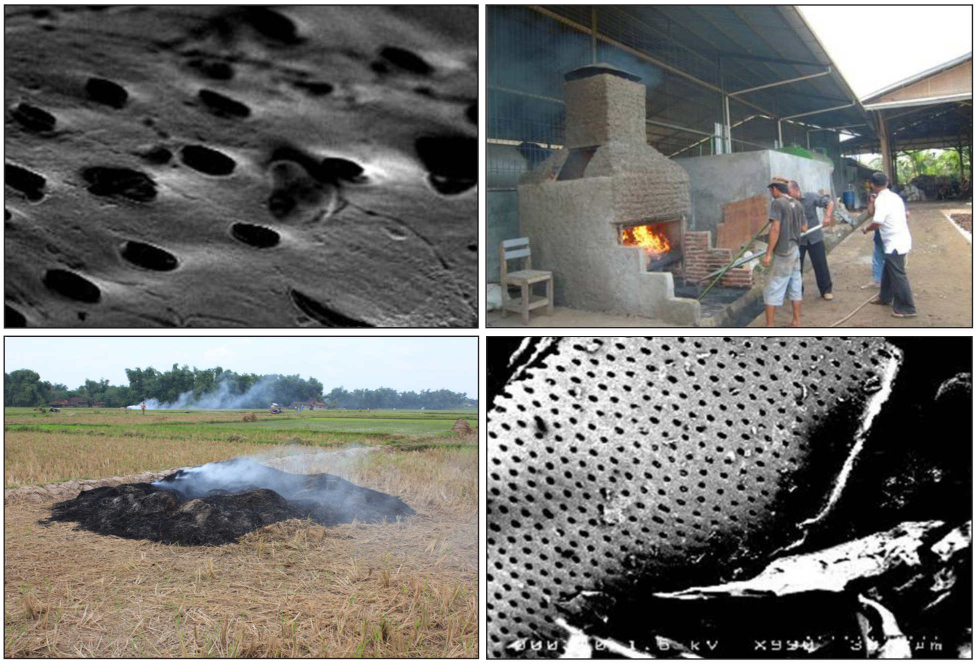
Limited Proceedings

2014 No.18

Biochar for future food security: learning from experiences and identifying research priorities

Edited by
Keiichi Hayashi



The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today, IRRI is one of the 15 nonprofit international research centers supported by the Consultative Group on International Agricultural Research (www.cgiar.org).

IRRI receives support from the following CGIAR members: Asian Development Bank, Australia, Bangladesh, Canada, China, European Commission, Food and Agriculture Organization, France, Germany, India, International Fund for Agricultural Development, Iran, Japan, Korea, Norway, Philippines, Portugal, Rockefeller Foundation, Sweden, Switzerland, Syngenta Foundation for Sustainable Agriculture, Thailand, Turkey, UK, USA, and the World Bank.

In 2009, IRRI also received support from 5 PRIME, Bayer CropScience, Bill & Melinda Gates Foundation, Bioversity International, CARE, Challenge Programs (Generation, HarvestPlus, and Water & Food), Eiselen Foundation, FOSS, Gatsby Foundation, Global Crop Diversity Trust, Grand Challenges in Global Health project, International Atomic Energy Association, International Fertilizer Industry Association, International Plant Nutrition Institute, International Potash Institute, International Fund for Agricultural Research, Kellogg Company, Malaysian Agricultural Research and Development Institute, Nunhems B.V., Pioneer Overseas Corporation, Plan International Cambodia, and World Vision, among others.

IRRI Limited Proceedings Series
The series allows IRRI scientists and partners to quickly share information with specialized institutions and individuals. It consists of proceedings from conferences, meetings, and workshops. To permit rapid publication, the review and editing may not be as rigorous as with formal proceedings.

Mailing address: DAPO Box 7777, Metro Manila, Philippines
Phone: +63 (2) 580-5600
Fax: +63 (2) 580-5699
Email: irri@cgiar.org
Home page: www.cgiar.org.irri
Rice Knowledge Bank: www.knowledgebank.irri.org
Courier address: Suite 1009, Pacific Bank Building
6776 Ayala Avenue, Makati City, Philippines
Tel. +63 (2) 891-1236, 891-1174, 891-1258, 891-1303

Suggested citation:
Hayashi K, editor. 2014. Biochar for future food security: learning from experiences and identifying research priorities. IRRI Limited Proceedings No. 18. Los Baños (Philippines): International Rice Research Institute. 78 p.

Cover photo:
Gustan Pari
Center for Research and Development on Forestry Engineering and Forest Products Processing
Ministry of Forestry, Indonesia

ISSN 1607-7776

Biochar for future food security: learning from experiences and identifying research priorities

Edited by
Keiichi Hayashi

JIRCAS
JAPAN

IRRI

Contents

The role of biochar and prospects for its use in rice production in Southeast Asia 1
Keiichi Hayashi

Biochar for forestry and agricultural production 5
Gustan Pari, Han Roliadi, and Sri Komarayati

Application of biochar produces changes in some soil properties 11
Ainin Niswati

Changes in water retention, water use efficiency, and aggregate stability of sandy soils following biochar application 17
Sukartono, W.H.Utomo, W.H. Nugroho, and Suwardji

Evaluating the effects of biochar on N absorption and N use efficiency in maize 25
Widowati, W.H. Utomo, B. Guritno, and L.A. Soehono

Nitrogen fertilizer requirement of maize (*Zea mays* L.) on biochar-treated soil 32
Wani Hadi Utomo and Titiek Islami

Use of biochar to improve soil characteristics and increase rice yield in swamplands 37
D. Nursyamsi, E. Maftuah, I. Khairullah, and Mukhlis

Gas emissions from the production and use of biochar in the peatland of Kalimantan 47
Abdul Hadi, Abdul Ghofur, Annisa Farida, Triharyo Subekti, and Dedi Nursyamsi

Evaluation of the effects of activated carbon on POP insecticide residues in mustard in Central Java, Indonesia 54
Elisabeth Srihayu Harsanti, Asep Nugraha Ardiwinata, Sri Wahyuni, and Dedi Nursyamsi

The role and use of activated carbon in the agriculture sector to control insecticide residues 60
Asep Nugraha Ardiwinata and Elisabeth Srihayu Harsanti

Economic analysis of biochar application in agroforestry systems 70
Rachman Effendi

FOREWORD

Biochar research started almost 20 years ago and there are already accumulated research outputs from various research groups from many areas, including improving soil health and plant productivity and reducing greenhouse gas emissions. However, there are limited studies on the application of biochar in agriculture. Thus, there is a need to identify research gaps on technology development to maximize the potential of this promising agricultural material.

Along this line, the national workshop on Biochar for Food Security: Learning from Experiences and Identifying Research Priorities was held in Bogor, West Java, Indonesia on February 4 and 5, 2013. In this workshop, there were 15 presentations made of studies carried out from various fields from different organizations and 11 papers are published through this limited proceedings.

The first paper provides a summary of biochar research in the world, including its history and findings on various functions of biochar. The next paper focuses on the constraints to biochar production and presents a method of converting smoke into wood vinegar, which has a significant role in crop protection. There are two papers on the function of biochar and its effect on the physical and chemical properties of the soil and three more papers that show that the yield of some crops like maize and rice were improved by biochar. There are also three more papers that focus on the environmental benefits of biochar application such as mitigation of greenhouse gas emissions and remediation of polluted soils caused by chemical compounds from pesticides. The last paper presents an economic evaluation of biochar application in the agroforestry-agriculture combined system and shows that biochar application improved farmers' income despite the cost increase.

The papers presented in this document cover a wide range of biochar research areas in Indonesia, which shows promising prospects for sustainable agricultural production and better livelihood. It is hoped that this limited proceedings will contribute to future agricultural research on technology development in Indonesia.

Keiichi Hayashi
Project Coordinator/Soil Scientist
IRRI-Japan Collaborative Research Project on
Climate Change Adaptation in Rainfed Rice Areas (CCARA)
IRRI

Martin Gummert
Senior Scientist, Postharvest Development
IRRI

Dr. Zulkifli Zaini
IRRI Representative and Liaison Scientist
IRRI-Indonesia Office

The role of biochar and prospects for its use in rice production in Southeast Asia

Keiichi Hayashi

Rice is the most important food crop in the developing world and the staple food of more than half of the world's population. In developing countries alone, more than 3.3 billion people depend on rice for more than 20% of their calorie need. Worldwide, there are about 150 million ha of harvested rice land. Annual production of rice is about 650 million t, of which 90% is produced and consumed in Asia. On top of actual rice production, another 116 million t of rice is projected to be needed by 2035 compared with the rice demand in 2010. Thus, rice supply should be enhanced either by ensuring an increase of 8 million t each year in the next decade, developing 160-165 million ha of land for rice production, and/or increasing rice yield by 0.6 t ha^{-1} for the next 10 years.

There are three possible ways to make these happen 1) expansion of existing land and greater intensification efforts 2) reducing losses and waste, and/or 3) improving production efficiency. The first two approaches require a strong government commitment in terms of investment on infrastructure such as irrigation systems and agricultural inputs such as chemical fertilizers. Considering financial capacity, one question remains — Is this feasible for rice-producing countries that are mostly still developing? The third way seems to be more feasible in terms of implementation. Nutrient and water are the most essential elements for rice growth and efficiency in their use is one of the fundamental pathways to improve productivity. Therefore, nutrient use efficiency and water use efficiency are critical to achieving better crop production. In general, most of the small farmers in Southeast Asia apply chemical fertilizers only once at the early growth stage of rice. Thus, the rice plant cannot use the applied nutrients throughout the growing season. The recommended fertilizer application dramatically demonstrates the increase in physiological nutrient use efficiency through topdressing at the panicle initiation stage.

Also, a water-saving technology developed by the International Rice Research Institute has shown improvement of water use in irrigated rice. The alternate wetting and drying technology allows farmers to save up to 15-30% of water use without any yield penalty. These technologies are mostly applied to irrigated rice production. Worldwide, 150 million ha of land is used in rice production; 100 million ha is devoted to irrigated rice and 50 million ha is set aside for rainfed rice. Considering future rice demand, it is imperative that both irrigated and rainfed areas enhance their productivity. Technology development should also focus on improving rice production in rainfed areas.

In irrigated areas, water is available for rice production throughout the cropping season, with irrigation canals or water pumps/wells as the main sources of water supply. Local farmers can control the supply and ensure rice growth without water stress. This enables matching of fertilizer application with crop growth, eventually resulting in high yield because of better nutrient use efficiency.

On the other hand, the rainfed environment is where water supply depends mainly on rainfall and no water control can thus be expected due to the unpredictability of the weather. In this environment, farmers are not able to identify the appropriate time for fertilizer application; eventually, nutrient use efficiency cannot go as high as that in irrigated areas and rainfed rice production remains low. This main constraint necessitates appropriate steps to improve the current situation and enhance future production.

The application of organic matter is one possible way to remedy the situation because it involves a relatively slow nutrient release, through decomposition, in the soil. However, organic matter should be applied every year due to high turnover rate under high temperature in aerobic condition. This increases labor demand. On top of this, direct application of organic matter such as rice straw increases methane emission from rice fields, considered a costly trade-off in terms of sustainability.

Recently, many scientific groups from different fields became interested in biochar because of its promising characteristics. However, available information is becoming too diversified for practical use. In this paper, we put a particular focus on rice production and examine how biochar can enhance rice production and what needs to be done to apply research findings on biochar to facilitate future research efforts.

Biochar and the beginning of biochar research

Biochar is a residue from incomplete biomass combustion at 400-500 °C and it has been well known among people for centuries since fire had come into our life. However, research on biochar started only in the mid-1990s, with almost half of the research papers being published only in the last 6 years (Marris 2006). This implies that utilization of this material in agriculture is still being developed for the current agricultural production system. Nevertheless, we can see the effects of this material through past studies carried out in the Amazon. Starting in 1879, Amazonian dark soils (*terra preta de Indio*) were characterized and their effects on agricultural production documented by recent studies (Sombroek 1992, Lehmann et al 2003). Much attention was put on terra preta at the World Congress of Soil Science when many scientists from various fields discussed how to take this soil into the actual world of carbon sequestration and biofuels.

Role of biochar in soil improvement

Various studies related to the basics of biochar use in agriculture have been published. The recent ones showed that silt loam with and without biochar resulted in a water-holding capacity of 0.485 and 0.540 g H_2O dry soil ($p=0.028$), respectively (Karhu et al 2011), implying the positive effect of biochar on soil physical property. Another study showed that cumulative leaching from Ferralsols was suppressed when organic matter was added and that biochar caused a pronounced reduction in leaching (Lehmann et al 2003). These soil improvements are attributed to the physical property of biochar. Liang et al (2006) described the physical property of biochar in their study of Anthrosols in the Amazon. Cation exchange capacity (CEC) of Anthrosols was shown to be higher, within the range of 7.3-30.7 $\text{cmol}_c\ \text{kg}^{-1}$, than that of adjacent soils Oxisols and Spodosols. This high CEC is derived from the chemical structure of biochar, which is composed of aromatic carbon such as humic and fluvic acid and carboxyl groups. The results of Nakamura et al (2007) showed terra preta having two times higher content of $Na_4P_2O_7$ extracted humic acid compared with the adjacent soil of yellow Latosols. The chemical and physical properties of biochar contributed to a significant increase in shoots and roots of cowpea as dosage increased (Lehmann et al 2003). Asai et al (2009) also found a positive effect of biochar on rice production, emphasizing that this highly depends on soil fertility and fertilizer management.

Role of biochar in greenhouse gas emission

Recent studies reveal that the presence of biochar can reduce greenhouse gas (GHG) emission during the cropping season, whereas rice straw application aggravates emission to a greater degree compared with control (Feng et al 2012). They found that the population of methanogenic archaeal was unchanged in both soils with or without biochar, but that methane emission was significantly reduced in soil with char than in soil without char. The study revealed that the population of methanotrophic proteobacteria was increased by biochar addition and methane from methanogenic archaeal was consumed by methanotrophic proteobacteria. Conventionally, many studies recommend the application of organic matter to the soil, but not many discussions have been made to define the type of organic matter to be applied. Organic matter such as cow manure or compost showed a high correlation with CEC, the level of correlation was much higher than that of a 1:1 clay such as kaolinite. However, the application of organic matter is required every year because of high turnover rate, but this is not always a feasible option among local farmers. On top of this, application of rice residue enhances GHG emission.

Application of biochar to rice production

A review of the literature points to the potential role of biochar in rice production. Some of its important characteristics hold promise. However, there are some constraints that need to be overcome. The most crucial is the fact that applied biochar cannot stay on the soil surface or near the plants because it floats on account of its light specific gravity. Eventually, applied biochar is washed out from the rice field after heavy or continuous rainfall. The Indonesian Agricultural and Environmental Research Institute has initiated work on this problem by using char as a coating material of chemical fertilizer and they have established a technology to make activated carbon-coated urea (ACU), which is made of locally available materials, mostly agricultural wastes. With biochar used as a coating material, the granular ACU is easily applied and easily stabilized on the soil surface, even in the presence of ponding water. Terra preta contains 25 t ha^{-1} of biochar; 8 t biochar ha^{-1} is at least required for good agronomic results (Haefele 2007). ACU contains only 15% of biochar on top of the 90-120 kg urea N ha^{-1}. Thus, a large amount of biochar application is not achievable through ACU. Nevertheless, IRRI pot experiment results during the 2012 dry season looked promising. The biochar given through fertilizer application was only 18 kg ha^{-1} but there was a significant increase in grain yield compared with the control and no significant yield difference compared with sulfur-coated urea.

Direction of biochar research and development

Biochar research is a relatively new field, but several studies in different fields have been made and certain information is already available for agricultural use. However, research outputs come mainly from short-term experiments in the laboratory or research station. There is a need for application studies to confirm the effects of biochar on actual rice production and this could form the basis for developing/implementing an appropriate technology. Research on these topics may be done—dynamics of biochar and its contribution to plant growth in the rhizosphere; long-term effects of biochar on GHG mitigation; effects of biochar from rice straw on soil fertility and rice production; quality improvement of ACU and development of slow-release fertilizers; and life-cycle assessment of biochar production from agricultural waste and its application.

References

Asai H, Samson SK, Haefele SM, Songyikhangsuthor K, Homma K, Inoue Y, Shiraiwa T. Horie T. 2009. Biochar amendment techniques for upland rice production in northern Laos: 1. Soil physical properties, leaf SPAD and grain yield. Field Crops Res. 111 (1-2): 81-84.

Feng Y, Xu, Y, Yu Y, Xie Z, Lin X. 2012. Mechanisms of biochar decreasing methane emission from Chinese paddy soils. Soil Biol. Biochem. 46: 80-88.

Haefele SM. 2007. Black soil, green rice. Rice Today :26-27

Karhu K, Mattila T, Bergström I, Regina K. 2011. Biochar addition to agricultural soil increased CH_4 uptake and water holding capacity – results from a short-term pilot field study. Agric. Ecosyst. Environ. 140 (1-2): 309-313.

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

Liang B, Lehmann L, Solomon D, Kinyangi J, Grossman J, O'Neill B, Skjemstad JO, Thies J, Luizao, FJ, Petersen J, Neves EG. 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J. 70: 1719-1730.

Marris E. 2006. Black is the new green. Nature 422: 624-626.

Nakamura S. Hiraoka M, Matsumoto E, Tamura K, Higashi T. 2007. Humus composition of Amazonian dark earths in the Middle Amazon, Brazil. Sci. Plant Nutr. 53: 229-235.

Sombroek WG, Nachtergaele FO, Hebel A. 1993. Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. Ambio 22: 417-426.

Vasilyeva NA, Abiven S, Milanovskiy EY, Hilf M, Rizhkov OV, Schmidt MWI. 2011. Pyrogenic carbon quantity and quality unchanged after 55 years of organic matter depletion in a Chernozem. Soil Biol. Biochem. 43: 1985-1988.

Notes

Author's address: Crop and Environmental Sciences Division, International Rice Research Institute, Los Baños, Philippines, and Crop, Livestock and Environment Division, Japan International Research Center for Agricultural Sciences, Tsukuba, Japan.

Biochar for forestry and agricultural production

Gustan Pari, Han Roliadi, and Sri Komarayati

Charcoal has long been known for its use either as energy source or as an important material for agriculture/forestry-related purposes. The role of charcoal in improving soil fertility and enhancing productivity of agricultural and forestry land has attracted remarkable attention. The raw material for charcoal can be wood or other ligno-cellulosic materials. The technology commonly employed by the community to manufacture charcoal involves the use of kiln systems. Such manufacturing technologies are simple enough to carbonize ligno-cellulosic feedstock in the kiln. The charcoal yield of these kilns usually ranges from 20 to 25% (w/w), meaning that, as much as 75 to 80% of the materials are lost through gases in smoke that further escape into the atmosphere. Environmental concerns have been raised since such air pollutants are increasing and they contribute to global warming. Counter measures are urgently needed to reduce the amount of these pollutants. Indonesia's Center for Research and Development on Forestry Engineering and Forest Products Processing has developed a technology by cooling the smoke during the carbonization of the ligno-cellulosic materials, thereby transforming it into a liquid state (popularly known as wood vinegar). Intensive and rigorous research revealed that wood vinegar is an effective biopesticide and biofertilizer. On top of this, charcoal showed promise in its application to wood plant species, improving their biomass weight, stem height, and diameter. Furthermore, a combination of charcoal and compost (organic fertilizers obtained from bio-conversion of organic materials) was able to enhance vegetable production, two to three times higher than the control (no charcoal with compost). Scientific evaluations have shown that these so-called biochar technologies, charcoal and wood vinegar manufacture, add value to less beneficial biomass in a more productive and environment-friendly manner.

Keywords: biochar technology, ligno-cellulosic materials, charcoal, wood vinegar

Charcoal refers to a product that has a predominant carbon (C) content. It results from the carbonization of C-containing materials, particularly ligno-cellulosic biomass. Such biomass also contains elements other than C; these are hydrogen (H), oxygen (O), sulfur (S), phosphorus (P), and inorganic constituents (ash). Carbonization of ligno-cellulosic biomass proceeds at elevated temperatures (400-800 ^{o}C) without oxygen or under limited oxygen, yielding the ultimate solid product, charcoal. This product finds its main use as energy source. It is also used as raw material in the manufacture of activated charcoal, compost charcoal, nano-carbon, lithium battery, and silicon carbide and it takes a remarkable role in C sequestration. Such charcoal uses depend on C content and processing method.

Indonesia has long been known as a charcoal-producing country. Most of the charcoal is exported to the world market. The country is one of the top five charcoal-exporting countries (China, Malaysia, South Africa, and Argentina). In 2008, Indonesia exported 29,867,000 kg of charcoal. This consisted of coconut-shell charcoal (15.96%), mangrove-wood charcoal (22.31%), and other-wood charcoal (61.73%) (Statistics Agency for Indonesia, 2009).

Charcoal production in Indonesia usually employs the traditional method, the heaping-kiln system, so called as some amount of ligno-cellulosic materials (LCM) are heaped on the ground. In Indonesia, more than 10,000 kilns are in operation. In Mataram, charcoal manufacture with this heaping system has proceeded for more than four successive generations. Wood wastes such as slabs and small woody pieces generated by the community-owned sawmills can be carbonized into charcoal. The heaping-kiln system uses a dome-shaped kiln (constructed with reddish bricks) because biomass materials are scarce. Various types of waste commonly used for charcoal manufacture include wood sawdust, wood slabs, woody end cuts, stumps, corn cobs, coconut, kemiri (*Aleuritus molucana*) nuts, coconut shells, oil palm shells, coffee-seed shells, etc. These materials, so far, have not been used judiciously.

Charcoal manufacturing in the community and in industry has 20-25% yield, which means that 70-85% of the carbonized LCM is lost as condensable gases/vapors (e.g., acetic acid, methanol, ketone, and phenol) and incondensable gases (e.g., CO_2, CO, H_2, and CH_4). These condensable and incondensable gases that escape or are released into the air become atmosphere pollutants and aggravate global warming. To minimize gas emission, research is conducted to produce wood vinegar out of these condensable gases which would be beneficial to the community. This effective and environment-friendly technology should be properly disseminated, along with a package of appropriate charcoal production practices and wood vinegar applications. Furthermore, this will be a good model to achieve a win-win situation: the ecosystem benefits through reduced waste, reduced gas emission, and enhanced environmental conditions.

The technology behind charcoal manufacture

Traditional kilns

Various LCMs such as wood slabs, woody end cuts, twigs or branches (from wood processing), coconut shells, kemiri nuts, and oil palm shells are used. Traditional kilns such as the heaping kilns are common in many communities because they are cheap and simple to operate. They replaced the pit-type kilns where LCMs are placed in pits dug in the soil. Heaping kilns give an average of 20% charcoal yield with moisture content at 4.7%; ash content, 2.3%; volatile matter, 17.6%; and fixed C, 80.0%.

Modified drum kilns

Drum kilns are modern kilns that have undergone various modification processes to produce charcoal from LCMs. A drum kiln consists of four main parts 1) a drum with one end open 2) the cover of the drum 3) a smoke chimney, and 4) air holes at the bottom of the drum that facilitate the initial burning of LCM (Fig. 1).

Using a drum kiln, carbonization is done within 6-8 h. The exothermic course that occurs during this process is detected through a thin bluish smoke that comes out of the chimney. The drum kiln can further be equipped with a cooling device made of bamboo or a continuous cooler made of stainless steel pipe to change the evolving condensable smoke into wood vinegar. The incondensable gases that evolve, such as CO_2 and CO, can be also reduced to a significant amount through a device instead of being released into the air. Other evolving gases/vapors such as H_2 and H_2O can also be transformed into liquid condensates (e.g., methanol and acetic acid).

The charcoal yield obtained by the drum kiln method can reach 24%; it would have a moisture content of 5.5%, an ash content of 2.4%, volatile matter content of 11.6%, and fixed carbon content of 85.9%. The yield of wood vinegar concurrently obtained varies between 5 and 30%, depending on the cooling system and LCM characteristics.

Charcoal from rice husks using semi-continuous kilns

The drum kiln is very useful for carbonizing LCMs such as rice husks into charcoal. The semi-continuous kiln can be built as a permanent structure using reddish bricks or as a mobile one with thin zinc metal. In principle, carbonization takes place by heating the rice husks, which is set in advance at the bottom of a preheated kiln. Afterward, the carbonized rice husks are extinguished by pouring water or by putting them into a chest filled with water

Fig. 1. A modified drum kiln with major parts—drum, cover, smoke chimney, and bamboo cooling device.

placed in front of the kiln. In a day (9 h), this type of kiln is able to process 150-299 kg of rice husks, and the charcoal yield is 20-24%. Rice husk charcoal has 3.49% moisture content, 5.19% ash, 28.93% volatile matter, and 65.88% fixed carbon.

Carbonizing sawdust using semi-continuous kilns

Carbonization procedures for wood sawdust are almost similar to those followed for rice husks. Twigs are placed at the bottom of the preheated kiln and sawdust is added on top of these twigs during the carbonizing process. Sawdust should be added little by little or layer by layer while checking the previously put sawdust in the kiln. The progress of carbonization can be measured by monitoring the surface of the sawdust and the smoke coming out from of the chimney. Charcoal yield from wood sawdust using this kiln can reach 14%, on average. The charcoal properties are as follows: 3.2% moisture content, 4.8% ash, 23.12% volatile matter, and 72.1% fixed carbon.

Charcoal manufacture using shaped kilns

A dome-shaped kiln is suitable for coarse LCMs with 8 cm diameter and it can take wood logs. The carbonization process for charcoal manufacture using this kiln does not differ much from that of the drum kiln. The difference lies with capacity, size of raw material, and duration of carbonization. This type of kiln is constructed using red bricks layered with clay soil. The average charcoal yield is as much as 23%, with moisture content at 4.9%; ash content, 2.3%; volatile matter, 17.2%; and fixed carbon, 80.4%. As in the modified drum kiln, a cooling device may also be attached to this kiln. A charcoal yield of 20-30% implies that 70-80% of LCM escapes to the air as smoke, which further brings about an environmental impact. With the cooling technology, a significant part of the smoke can be condensed into wood vinegar, which is useful as bio-pesticide repellent and soil activator. Research has shown that agricultural crops and forestry plants treated with wood vinegar exhibit greater resistance to biotic stresses. Furthermore, biomass production is enhanced remarkably. Several countries such as Malaysia, Thailand, Japan, and Brazil have been engaged in wood vinegar production at a commercial scale. The charcoal as produced simultaneously becomes a byproduct.

Application of charcoal to forestry

Morphologically, charcoal has a lot of micropores that increase the effective surface area and this is the main reason for the highly adsorptive and absorptive capabilities that improve soil fertility. Therefore, the application of charcoal, combined with compost in infertile or nutrient-poor land, can expectedly improve soil fertility, regulate soil pH, enhance soil aeration, stimulate the formation of endo- and ectomycorrhiza spores, and absorb the excess CO_2 in the soil. This way, productivity of land and forest plantation area can be considerably increased.

Research has shown that an enhanced plant medium contributed to the growth of *Eucalyptus urophylla* at the seedling stage when bamboo charcoal and activated bamboo charcoal were mixed in it. Addition of sawdust charcoal and vegetation-litter charcoal to the growth media of *Acacia mangium* and *Eucalyptus citriodora* brought about a 30% increase in the growth of their seedlings compared with control (without charcoal addition). Similar results were seen when charcoal was added: the diameter of *E. urophylla* stem increased. In another occasion, incorporation of bamboo charcoal and rice-husk charcoal (5% and 10%, respectively) in the growth media increased the height of red pepper by 11% compared with control. The effect was enhanced when charcoal was combined with compost. For example, the addition of wood-sawdust charcoal and sawdust compost to the plant growth media resulted in an increase in diameter (by 8 cm) in some tree species as compared with control (Gusmailina et al 1999).

Research conducted by Komarayati (1996) showed that bioconversion of tusam-wood (*Pinus merkusii*) sawdust and rubber-wood (*Hevea brasiliensis*) sawdust with the aid of microorganisms such as EM4 and animal manure brought about an 85% yield increase. The 4-day process also improved the C-N ratio (19:94).

Komarayati et al (2011) also reported that 10-30% addition of charcoal to the compost made the diameter of some tree species 1.0-1.2 times larger than that of the control (untreated plants). Incorporation of 1-4% wood vinegar into the compost also increased tree height, 1.4-1.7 times higher than control. Application of 2% wood vinegar adequately supported the growth and production of particular plants (Nurhayati 2007, Komarayati and Santoso 2011).

However, the effect on some tree species such as jabon and sengon was not significant when wood vinegar was applied separately. This is because wood vinegar, which results from the condensation of the smoke that comes from carbonization of LCM, contains particular organic compounds that might be essential to improve soil quality as well as to enable the plant to grow better and stronger.

The addition of charcoal to the soil improves soil organic carbon content and this effect can be optimized 6 mo after application. The increase in soil organic-carbon content varies from 2.46-2.54% to 2.95-3.10%. Soil with wood vinegar revealed corresponding increases of 1.98-2.32% and 2.71-3.20%. The addition of charcoal and/or wood vinegar to the soil did not show any changes in total nitrogen (N) and total phosphorus (P). Potassium (K) content in the soil changed from 0.82-0.96 $\text{cmol}_c\ \text{kg}^{-1}$ to 1.15-2.54 $\text{cmol}_c\ \text{kg}^{-1}$ when charcoal was added. Adding wood vinegar to the soil did not change its K content. It seems that elements such as K in the original LCM (e.g., wood) remain intact after carbonization. Wood vinegar does not include K because this element is not volatilized through carbonization.The addition of wood vinegar brought about a significant increase in the diameter of jabon plants. The increase was greater through wood vinegar addition than through charcoal and the growth response of jabon plants (in terms of diameter increase) was higher than that of sengon plants. Although sengon and jabon plants are both fast-growing, their responses to wood vinegar differed. Wood vinegar contains organic compounds that remarkably improve soil quality and this results in healthier and stronger plants compared with those to which charcoal was added (Anonymous 2010). Results of analysis on macro and micro elements in liquid fertilizer derived from wood vinegar showed inorganic elements such as sodium (Na), P, K, calcium (Ca), magnesium (Mg), manganese (Mn), zinc (Zn) (Table 1), and others such as phenol and acetic acid (Table 2) that could serve as natural pesticides.

Activated charcoal manufactured from kemiri (*Aleurites molucana*) nut shells is also a good medium on which seedlings can be grown. When mixed with animal manure, gmelina plant species increased its height and stem diameter, which resulted in an increase of biomass such as root, total number of microbes, and total inorganic material. Five percent,

Table 1. Inorganic elements from wood vinegar.

Element	Concentration (ppm)
Phosphorus	0.72
Potassium	6.28
Sodium	0.07
Calcium	9.66
Magnesium	2.68
Iron	22.34
Manganese	0.37
Copper	0.37
Zinc	0.60

Source: Pari (2009)

10%, and 15% application of activated charcoal improved significantly the diameter and root development. Gmelina plants had an 8.2% increase in stem height, 46% increase in stem diameter, and 5.8% increase in biomass when 15% activated charcoal was added (Lempang, 2009).

To hasten the maturity of compost as well as to meet Indonesian quality standards, these mixtures are used: compost charcoal that results from the composting of market organic garbage through biodecomposer EM4; a mixture of organic decomposer (orgadec), EM4, and wood vinegar; or a mixture of orgadec, EM4, charcoal, and wood vinegar. The use of compost made from market organic garbage on dewa plant species could significantly increase stem height, number of leaves, number of sprouts, and weight of biomass. There were significant increases when activated charcoal was added to the compost, especially activated charcoal made by using superheated water vapor activation and wood vinegar after fractionation using methanol (Gani 2007). Research on the application of compost charcoal in agroforestry showed that tusam (*Pinus merkusii*) tree stands as the core plant species and caisin and pakchoy vegetables as intercrops improved soil pH from 3.5 to 6.0, yielding an amount two to three times higher than untreated vegetable plots. These effects were still observed, even after 10 years.

Tabel 2. Chemical compounds in wood vinegar, derived from lignin and cellulose in ligno-cellulosic materials through pyrolysis.

Compound indicatively derived from lignin (%)		Compound indicatively derived from cellulose (%)	
Formic acid	10.04	Acetone	8.98
Acetic acid	23.11	Acetic acid	27.83
Acetaldehyde	0.33	Propanone	15.75
Propanoic acid	1.66	Propionic acid	2.33
Isopropyl alcohol	l0.31	Propane	1.09
Vinyl ester	0.39	Oxirane	0.21
Propanol	0.42	Hexane	0.97
Butanoic acid	0.49	Butanoic acid	1.15
Pyridine	0.16	Isobutane	0.25
Furan methanol	l0.43	Oxirane	0.12
Butyrolactone	0.86	Hydroperoxide	0.18
Cyclopentene	0.17	Furfuraldehyde	3.55
Phenol	2.85	Furan	0.95
Glycidol	0.09	Butanedione	0.25
Furfurylalcohol	l0.55	Hexene	0.40
Guaiacol	5.71	Cyclopentene	0.39
Cresol	0.76	Furan carboxaldehyde	0.59
-	-	Furfural	0.77
-	-	Propanediamine	0.39
-	-	Phenol	1.58
Octene	0.44		
-	-	Glycidol	0.12
-	-	Butanal	0.88
Propanal	0.34		
-	-	Ethanone	0.35
-	-	Pyrrole	0.52
-	-	Butyl phenol	0.06
Methoxy phenol	0.04		
-	-	Crotonic acid	3.16
-	-	Pyrocatechol	0.27

Source: Pari (2004).

Concluding remarks

With the introduction of applied technology, it is evident that particular materials (byproducts or waste materials) can be processed into value-added products. The extent of their usefulness depends on the level, advancement, and compatibility of technologies that are applied. In this regard, charcoal and wood vinegar are also considered bio-materials (e.g., ligno-cellulosic biomass). Application of charcoal as well as wood vinegar showed positive results in all respects, be it on seedling medium, a cultivation field, or agroforestry area. Soil pH was higher and there was better plant growth in terms of increased diameter, height, and total biomass, including root development. Charcoal remains as a solid product after pyrolysis of LCMs (particularly wood) in carbonization kilns; some portion of the stuff is lost as smoke, which escapes into the air. By installing a condensing device, a large portion of the smoke can be converted into liquid form (popularly called wood vinegar). Environmental pollution is mitigated through the production of wood vinegar, which is found to be a useful bio-fertilizer and bio-pesticide.

The charcoal-manufacturing process and the wood vinegar-collecting system are the main elements of biochar technology. This technology converts ligno-cellulosic stuff (biomass) into useful products (charcoal and wood vinegar), which, in turn, enhance the growth of forest and agricultural plants.

References

Anonymous. 2010. Wood vinegar as conditioner and for stronger plantation. Tabloid Sinar Tani. www.tabloidsinartani.com Accessed 29/11/2010

Gani A. 2007. Bioconversion of market organic garbage into komarasca and its application on leaves of dewa plants [in Indonesian; with English abstract]. Dissertation, Post Graduate School, Bogor Agriculture University, Bogor, Indonesia.

Gusmailina, Pari G, Komarayati S. 1999. Technology of charcoal and activated charcoal usage as soil conditioner at forestry plants [in Indonesian]. Forest Products Research and Development, Bogor, Indonesia.

Gusmailina, Pari G, Komarayati S. 2002. Report of cooperative research. Center for Research and Development on Forest Products (CRDFP, Indonesia) and Japan International Forestry Promotion and Cooperation Center (JIFPRO). CRDFP and JIFPRO, Bogor, Indonesia.

Gusmailina, Pari G, Komarayati S, Nurhayati T. 1990. Utilization of residual solid from the fermentation, as the compost to enhance the growth of sprouts of *Eucalyptus urophylla*, J. For. Prod. Res. (4): 157-163.

Komarayati S. 1996. Utilization of sawdust waste from wood industries as compost. Bull. For. Prod. Res. 14(9): 337-343.

Komarayati S, Gusmailina, Pari G. 2011. Charcoal and wood vinegar: non-wood forest product items to enhance the growth of plants and for carbon store [in Indonesian]. Center for Research and Development on Forest Products, Bogor, Indonesia.

Komarayati S, Santoso E. 2011. The influence of charcoal compost, wood vinegar, and mycorrhyza as mengkudu (*Morinda citrifolia*) on seedling growth. J. For. Prod. Res. 29(2): 155-178.

Lempang M. 2009. Properties of activated charcoal from kemiri (*Aleurites molucana*) nut shells, and its application as growth media for Melina plant species [in Indonesian]. Thesis, Post Graduate School, Bogor Agriculture University, Bogor, Indonesia.

Nurhayati T. 2007. Integrated production of charcoal with wood vinegar and utilization of wood vinegar at agriculture plants [in Indonesian]. Paper presented at the training program for integrated production of charcoal and its derivative products, 17-26 July 2007, Forestry Service of Bulungan Regency, East Kalimantan, Indonesia.

Pari G. 2004. Scrutiny of structure of activated charcoal from wood sawdust as adsorption for formaldehyde emission from plywood [in Indonesian; with English abstract]. Dissertation, Bogor Agriculture University, Bogor, Indonesia.

Pari G, Nurhayati. 2009. Wood vinegar from tusam and sawmill wood waste for medicine and plantation health. Forest Products Research and Development Center, Bogor, Indonesia.

Statistics Agency for Indonesia. 2009. Statistics of domestic and overseas trade [in Indonesian and English]. Statistics Agency, Jakarta, Indonesia.

Notes

Authors' address: Gustan Pari, Han Roliadi, and
Sri Komarayati, Center for Research and Development on
Forestry Engineering and Forest Products Processing
Ministry of Forestry, Indonesia.

Application of biochar produces changes in some soil properties

Ainin Niswati

The purpose of this review is to explore and study the feasibility of amending the soil with biochar and to assess impact on its chemical, physical, and biological properties. Soil pH, organic carbon, total N, K, Ca, Mg, and cation exchange capacity increased by applying biochar at an increasing rate. Bulk density, porosity, and water-holding capacity of the soil amended by biochar significantly changed, with better quality for crop production. The effects of biochar addition on soil biota vary, depending on the kind of biota existing in the environment.

Keywords: biochar, soil physics, soil biology, soil chemistry

Biochar has gotten the attention of researchers because of its capacity to improve the soil (Lehmann and Joseph 2009). Most research is related to the rehabilitation of degraded land and carbon sequestration, which holds promise for the improvement of soil chemical, physical, and biological properties.

In wet tropical regions such as Indonesia (especially in Sumatra where there is a wide coverage of acidic tropical soils), relatively high rainfall and temperature result in rapid loss of soil organic carbon. The recalcitrant fraction of biochar, which persists in the soil over the long term, is expected to increase soil fertility or rehabilitate degraded/poor soils.

Lampung has several large estates where land management is intensive and soils become rapidly degraded. One of the large estates is PT Gunung Madu Plantation, which was opened in 1975 through the conversion of secondary forest into commercial plantations (PT GMP 2009). The soil productivity of these plantations should be maintained for sustainable production. Application of biochar is one of the technologies that can improve soil productivity in degraded land or poor soil. PT Great Giant Pineapple is another agricultural venture in Indonesia where acid soil is used for pineapple production, which enhances nutrient depletion in the land. Likewise, rice, maize, cassava, and oil palm are major commodities that need to be maintained and whose productivity need to be improved.

Residues from various agricultural products are available in Lampung Province—oil palm empty fruit bunches, cassava skin, cacao skin, rice husks, rice straw, maize cobs, bagasse, etc. Since there is no way to use these materials, they remain as waste. Utilizing these materials as feedstock for biochar production is one of the better ways to get rid of the waste problem while enhancing soil productivity at the same time. Appropriate technology should be disseminated to local farmers to enable them to produce biochar from agricultural wastes.

In terms of using biochar as a soil amendment, the most frequently asked questions have to do with its effect on plant growth, what type of biochar will perform better, what is the lifetime of biochar in the soil, what is the optimal amount and mode of application, etc. There is much scope for scientific research in this realm. When applied to the soil, biochar may improve the nutrient supply to the plants, as well as the physical and biological properties of the soil. In view of all these, this review aims to explore and study the feasibility of amending soil with biochar and to determine its impact on the soil’s chemical, physical, and biological properties. It summarizes existing data pertaining to changes in soil properties in any region.

Changes in soil properties

Biochar application to the soils is considered a soil amelioration technique, enhancing plant growth by supplying more nutrients and providing other functions such as improving the physical and biological properties of the soil.

Soil chemical properties

A number of studies have shown that biochar can increase soil pH, cation exchange capacity (CEC), total N, available P, exchangeable Ca, magnesium, etc. and can reduce Al availability (Table 1). Widowati et al (2012) reported that biochar application decreased N fertilizer requirement. They also found that organic carbon was increased by biochar application. Similar results were seen with different types of biochar and soil in various regions (Rondon et al 2007, Novak et al 2009, Cui et al 2011, Masulili et al 2010, Laird et al 2010). The increase in soil carbon through biochar application is attributed to the stability of biochar in the soil, which persists despite microbial action. By using isotopes, Steinbeiss et al (2009) reported that the mean residence time of biochar in the soil varied between 4 and 29 years, depending on soil type and quality of biochar. In soils regularly managed by biochar amendments, the increasing aromatic carbon content is likely to affect soil properties (Knicker et al 2013). This phenomenon needs further investigation.

The application of paper mill waste biochar, combined with inorganic fertilizer, showed higher soybean and radish biomass compared with sole application of inorganic fertilizer (van Zwieten et al 2010). Application of chicken manure and city waste biochar increased maize biomass (Widowati et al 2012). This higher biomass production is attributed to biochar increasing the soil pH. According to Chu et al (2011), biochar amendment significantly increases soil pH by 0.18–0.36 unit. Novak et al (2009) stated that, after 67 days and two leaching events, biochar addition to the Ultisols of Norfolk soil increased soil pH. The findings of van Zwieten et al (2010) suggest that while biochar may not provide a significant source of plant nutrients, it can improve the nutrient assimilation capability of the crop by positively influencing the soil environment. Sukartono et al (2011) reported that application of biochar improved soil fertility status, especially soil organic C, CEC, available P, exchangeable K, Ca, and Mg of the sandy soils in Lombok, Indonesia. Since biochar is highly porous and has a large specific surface area, its impact on soil CEC and other nutrients that have correlation with CEC is very important.

Besides the direct/indirect effect of biochar on soil fertility characteristics, application of biochar contributes to the interaction of soil with microelements such as lead and cadmium. Jiang et al (2012) reported that incorporation of biochar increased Pb(II) adsorption by variably charged soils. Biochar amendment significantly decreased extracted Cd in the soil by 17-47%. Some types of biochar also appear to reduce the mobility of heavy metals such as Cu and Zn (Hua et al 2009). Novak et al (2009) reported that most soil micronutrient concentrations were not influenced by biochar addition; however, biochar application decreased exchangeable acidity, S, and Zn.

Soil physical properties

Studies on the effect of biochar on soil physical properties are limited. However, some studies showed effects on parameters such as bulk density, porosity, water-holding capacity, and aggregate stability (Table 2). Most research findings point to the improvement of soil bulk density with biochar application (Karhu et al 2011, Haryani and Gunito 2012, Masulili et al 2010); water-holding capacity also increased (Karhu et al 2011). Biochar has high porosity, which allows high water-holding capacity. However, it is hydrophobic as it is dry due to its high porosity and light bulk density. Adding biochar to the soil also improves soil physical property, water permeability, and aggregate stability (Table 2). Peng et al (2011) reported that, compared with chemical fertilizer application, biochar amendment to a typical Ultisol resulted in better crop growth.

Table 1. Changes in chemical properties of the soil as affected by application of biochar in several experiments.[a]

Treatment	Location/soil type	Biochar origin	Soil pH (H_2O)	Available Al (mg kg^{-1})	Organic C (%)	Total N (%)	Available P Bray I (ppm)	Exchangeable K (cmol kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	CEC (cmol kg^{-1})	Information source
Control	Malang, Indonesia				1.20 a	0.09 a	19.45 a	0.69 a			13.22 a	Widowati et al (2012)
N (145 kg ha^{-1})	Malang, Indonesia				1.15 a	0.17 ab	23.54 ab	0.47 ab			14.18 a	
N (145 kg ha^{-1}) + biochar (30 t ha^{-1})	Malang, Indonesia	Chicken manure			3.14 c	0.39 c	29.45 b	2.18 c			19.27 b	
N (145 kg ha^{-1}) + biochar (30 t ha^{-1})	Malang, Indonesia	City waste			3.18 c	0.31 c	30.04 b	2.14 b			18.34 b	
Control	Fixing bean, Typic Haplustox, Columbia	Logs of *Eucalyptus deglupta*	5.04 e	173.3	1.23 a	0.08 a	5.17 a	0.94 d	1012	28 de	10.82	Rondon et al (2007)
Biochar (30 g kg^{-1})			5.08 de	140.2	2.12 b	0.09 b	4.62 ab	2.19 c	370	44c	11.85	
Biochar (60 g kg^{-1})			5.24 c	120.8	2.70 c	0.10 c	4.34 ab	3.21 b	453	54 bc	13.17	
Biochar (90 g kg^{-1})			5.41 b	97.2	3.80 d	0.11 c	4.42 ab	4.51 a	667	86 a	13.15	
Control	Non-fixing bean, Typic Haplustox, Columbia		5.13 cde	139.5	1.14 a	0.07 a	4.47 ab	1.06 d	714	25 e	10.25	
Biochar (30 g kg^{-1})			5.17 cd	114.5	1.84 b	0.0867 b	4.39 ab	2.16 c	508	43 cd	10.34	
Biochar (60 g kg^{-1})			5.34 bc	110.8	2.25 c	0.0893 bc	2.01 c	3.11 b	697	62 b	11.70	
Biochar (90 g kg^{-1})			5.62 a	82.3	4.16 d	0.0951 c	3.58 b	4.89 a	653	83 a	12.90	
Control	Rice farm, Jiangsu, China	Wheat straw	5.89		2.16							Cui et al (2011)
Biochar (10 g kg^{-1})			6.13		2.37							
Biochar (20 g kg^{-1})			6.24		2.90							
Biochar (40 g kg^{-1})			6.27		3.38							

Table 1 continued...

Treatment	Location/soil type	Biochar origin	Soil pH (H_2O)	Available Al (mg kg^{-1})	Organic C (%)	Total N (%)	Available P Bray I (ppm)	Exchangeable K (cmol kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	CEC (cmol kg^{-1})	Information source
Control	Ustipssamment Lombok, Indonesia, rainy season		6.29		0.87	0.11	23.59	0.70			13.34	Sukartono et al (2011)
Biochar (15 t ha^{-1})		Coconut shell	6.49		1.15	0.12	26.48	0.75			15.04	
Biochar (15 t ha^{-1})		Cattle dung	6.45		1.14	0.16	26.24	0.89			15.10	
Control	Acid sulfate soil of West Kalimantan, Indonesia		3.36		0.54			0.20	0.24	3.55	6.64	Masulili et al (2010)
Biochar (15 t ha^{-1})		Rice husk	4.40		4.09			0.51	0.44	3.57	8.03	
Control	Ultisols, Norfolk soil, Florence, SC		5.2		1.74						5.2	Novak et al (2009)
Biochar (0.5%)		Pecan shells	5.6		1.83						5.4	
Biochar (1.0%)			5.9		2.19						5.6	
Biochar (2%)			6.4		2.92						5.9	

[a]Means followed by the same letter in the same column are not significantly different (p=0.05).

Soil biological properties

Many complex organisms live in soils, which are continually changing in response to varying soil characteristics, climate, and land management through application of organic matter (Thies and Rillig 2009). The addition of biochar to the soil is likely to have different effects on the soil biota. The soil biota is vital to the functioning of the soils, providing many essential ecosystem services. Little is known on the effect of biochar on soil biota, however. Some studies have mostly focused on bacteria, mycorrhiza, and earthworms. Quilliam et al (2012) reported the activity of soil microorganisms by soil respiration, saying that reapplication of biochar significantly increased the level of basal soil respiration with the highest rate in the 50 t ha^{-1} soil application at the beginning and 50 t ha^{-1} soil reapplication 13 days after sowing. In long-term plots, however, application rate of biochar had no significant influence on basal respiration rates compared with the control. It is hypothesized that the very porous biochar provides the surfaces on which soil microbes colonize and grow. Graber et al (2010) have found that, with increasing rate of biochar application, there were more culturable colonies of general bacteria, *Bacillus* spp., yeasts, and *Trichoderma* spp. but decreasing culturable filamentous fungi *Pseudomonas* spp. and *Actinomycetes* spp. Root-associated yeast and *Trichoderma* spp., which were non-measurable in the control treatment, increased by 3 and 2 log units in the biochar treatments, respectively. Significantly, a greater number of general bacteria, *Pseudomonas* spp., and fungi were also observed; bulk microbial abundance, diversity, and activity were strongly

Table 2. Physical properties of the soil as affected by application of biochar in several experiments.[a]

Treatment	Location/soil type	Biochar origin	Bulk density (g cm^{-3})	Porosity (%)	Water-holding capacity (g H_2O g^{-1} dry soil)	Aggregate stability index	Permeability (cm h^{-1})	Information source
Control	Silt loam, southern Finland		1.30	50.9	0.485 ± 0.014			Karhu et al (2011)
Biochar (9 t ha^{-1})		Charcoal	1.25	52.8	0.540 ± 0.019			
Control	Ultisols/Gunung Madu, Lampung		1.11 b	43.19 a		0.67 a	4.24 b	Haryani and Gunito (2012)
Biochar (10 t ha^{-1})		Bagasse	1.07 a	45.07 b		0.79 b	2.83 a	
Control	Acid sulfate soil of West Kalimantan		1.24	44.43				Masulili et al (2010)
Biochar (15 t ha^{-1})		Rice husk	1.17	53.16				

[a]Means followed by the same letter in the same column are not significantly different (p=0.05).

influenced by soil pH. The buffering capacity imparted by the CEC of biochar may help maintain the appropriate pH conditions and minimize pH fluctuations in the microhabitats within the biochar particles.

Rondon et al (2007) stated that biochar application has the potential to improve N availability in agroecosystems by means of biological N_2 fixation (BNF). They reported that the proportion of fixed N_2 increased from 50% without biochar addition to 72% with 90 g kg^{-1} biochar. Total N derived from the atmosphere significantly increased by 49 and 78% with 30 and 60 g kg^{-1} biochar added to the soil, respectively. The higher BNF is perhaps caused by some nutrients such as Mo, P, Ca, and Mg, which were high in biochar-amended soils.

Warnock et al (2007) reviewed several research publications about the direct and indirect influence of biochar on arbuscular mycorrhizal fungi (AMF) colonization in plant roots and found that biochar increased the ability of AMF to assist their host in resisting infection by plant pathogens. Some studies have reported possible mechanisms: (1) biochar changes soil nutrient availability, (2) biochar alters the activity of other microorganisms that have effects on the mycorrhizae, (3) biochar alters the plant-mycorrhizal fungi signaling processes or detoxifies allelochemicals, leading to altered root colonization by mycorrhizal fungi, and (4) biochar serves as a refuge for the colonizing fungi and bacteria.

A limited number of studies have examined the impact of biochar addition to the soil on population density and biomass of earthworms. Weyers and Spokas (2011) reviewed some research on the addition of biochar and other black carbon substances, including slash-and-burn charcoal and wood ash, to earthworms. They identified a range, from short-term negative impacts to long-term null effects on earthworm population density and total biomass. They hypothesized that these are related to soil pH or to the fact that biochar is premoistened. Feeding behavior may be affected or there are unknown factors involved.

Conclusions

The of literature showed that biochar has high potential in improving soil physical, chemical, and biological properties. However, it is not widely applied in Indonesia, partly due to the lack of awareness among the local producers. In an agroindusrial land where most of the people work as farmers, there are sufficient amounts and kinds of biomass materials for biochar production. The application of biochar to agricultural land seems suitable. This necessitates further studies to ensure the wide use of this important resource in Indonesia.

References

Cui L, Li L, Zhang A, Pan G, Bao D, Chang A. 2011. Biochar amendment greatly reduced rice Cd uptake in a contaminated paddy soil: two-year field experiment. BioResources 6: 2605-2618.

Graber ER, Harel YM, Kolton M, Cytryn E, Silber A, David DR, Tsechansky L, Borenshtein M, Elad Y. 2010. Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. Plant Soil 337: 481-496.

Haryani S, Gunito H. 2012. Abu ketel dan arang bagas sebagai bahan pembenah tanah untuk perbaikan sifat fisik tanah dan keragaan tanaman tebu di tanah ultisol. Disampaikan pada Seminar & Expo Nasional 2012 Hiti Komda Jawa Timur Ilmu Tanah untuk Mendukung Pembangunan Nasional Berwawasan Lingkungan, Surabaya, 29 November 2012. 9 p.

Hua L, Wu W, Liu Y, McBride MB, Chen Y. 2009. Reduction of nitrogen loss and Cu and Zn mobility during sludge composting with bamboo charcoal amendment. Environ. Sci. Pollut. Res. 16: 1-9.

Jiang TY, Jiang J, Xu RK, Li Z. 2012. Adsorption of Pb(II) on variable charge soils amended with rice-straw derived biochar. Chemosphere 89: 249-256.

Knicker H, González-Villa FJ, González-Vázquez R. 2013. Biodegradability of organic matter in fire-affected mineral soils of southern Spain. Soil Biol. Biochem. 56: 31-39.

Laird D, Fleming P, Wang BQ, Horton R, Karlen D. 2010. Biochar impact on nutrient leaching from a midwestern agricultural soil. Geoderma 158: 436-442.

Lehmann J, Joseph S. 2009. Biochar for environmental management: an introduction. In: Lehmann J, Joseph S, eds. Biochar Environmental Management–Science and Technology. Earthscan Publishing for a Sustainable Future, Londong-Sterling VA. p 1-12.

Masulili A, Utomo WH, Syechfani MS. 2010. Rice husk biochar for rice-based cropping system in acid soil. 1. The characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia. J. Agric. Sci. 2: 39-47.

Novak JM, Busscher WJ, Laild DL, Ahmedna M, Watts DW, Niandou MAS. 2009. Impact of biochar amendment on fertility of a southeastern coastal plain soil. Soil Sci. 174: 105-112.

Peng X, Ye LL, Wang CH, Zhou H, Sun B. 2011. Temperature- and duration-dependent rice straw-derived biochar: characteristics and its effects on soil properties of an Ultisol in southern China. Soil Till. Res. 112: 159-166.

PT GMP [PT Gunung Madu Plantation]. 2009. PT Gunung Madu Plantation: integrity, professionalism, productivity and efficiency sustainability. Gunung Batin, Lampung Tengah. 30 p.

Quilliam RS, Marsden KA, Gertler C, Rousk J, DeLuca TH, Jones DL. 2012. Nutrient dynamics, microbial growth and weed emergence in biochar-amended soil are influenced by time since application and reapplication rate. Agric. Ecosyst. Environ. 158: 192-199.

Rondon MA, Lehmann J, Ramírez J, Hurtado M. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with biochar addition. Biol. Fertil. Soils 43: 699-708.

Steinbeiss S, Gleixner G, Antonietti M. 2009. Effect of biochar amendment on soil carbon balance and soil microbial activity. Soil Biol. Biochem. 41: 1301-1310.

Sukartono, Utomo WH Kusuma Z, Nugroho WH. 2011. Soil fertility status, nutrient uptake, and maize (*Zea mays* L.) yield following biochar and cattle manure application on sandy soils of Lombok, Indonesia. J. Trop. Agric. 49: 47-52.

Thies JE, Rillig MC. 2009. Characteristics of biochar - biological properties. In: Lehmann J, Joseph S, eds. Biochar Environmental Management-Science and Technology. Earthscan Publishing for a Sustainable Future, Londong-Sterling VA. p 85-105.

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

Warnock DD, Lehmann J, Kuyper TW, Rillig MC. 2007. Mycorrhizal responses to biochar in soil–concepts and mechanisms. Plant Soil 300: 9-20.

Weyers SL, Spokas KA. 2011. Impact of biochar on earthworm populations: a review. Appl. Environ. Soil Sci. Article ID:541592.

Notes

Author's address: Soil Science Division, Department of Agrotechnology, Faculty of Agriculture, University of Lampung. Jl. Sumantri Brojonegoro No. 1 Bandarlampung 35145, Indonesia.

Changes in water retention, water use efficiency, and aggregate stability of sandy soils following biochar application

Sukartono, W.H.Utomo, W.H. Nugroho, and Suwardji

The sandy soils in northern Lombok, eastern Indonesia, with inherently low soil organic carbon and fertility may benefit from the addition of biochar. A field study evaluated the effect of biochar on water retention, crop water use efficiency (WUE), and aggregate stability under three consecutive seasons of maize cropping from December 2010 to October 2011 in sandy loam soils of northern Lombok, Indonesia. The treatments were coconut shell biochar (CSB), cattle dung biochar (CDB), cattle manure applied during the early first crop only (CM1), cattle manure applied every growing season (CM2), and no organic amendment (control, C). An evaluation conducted after the end of the third maize crop showed that application of organic amendments (biochar and cattle manure) slightly altered soil pore size distribution, resulting in changes in water retention as well as available water capacity (AWC). The AWC of the biochar-treated soil (0.206 cm^3 cm^{-3}) was comparable with that of soil treated with cattle manure applied every planting time (0.220 cm^3 cm^{-3}). The WUE of biochar-treated soils, CSB and CDB, were 9.44 kg mm^{-1} and 9.24 kg mm^{-1}, respectively, whereas that of CM1, CM2, and C were 8.54, 9.97, and 8.08 kg mm^{-1}, respectively. Biochars and cattle manure applied every growing season improved WUE by 16.83% and 23.39%, respectively. As in CM2, after a year, the application of biochar increased soil aggregate stability. The stability of aggregates were 66.62%, 61.37%, 61.18%, 58.44%, and 57.11% for CM2, CSB, CDB, CM1, and C, respectively. Overall results showed that biochar and cattle manure are both valuable amendments that can improve WUE and sustain maize production in sandy loam soils in tropical semiarid areas of northern Lombok, Indonesia.

Keywords: biochar, cattle manure, water retention, maize yield

Sandy soils are generally characterized by low water-holding capacity, leading to the plants' poor water use efficiency (WUE) and fertilizer use efficiency. This is the type of soil on which staple crops such as maize (*Zea mays* L.) are grown in the semiarid tropics of north Lombok, eastern Indonesia. The soil has low clay content (<10%) and poor soil organic C (SOC, 0.89%) (Sukartono et al 2011). Poor soil structure, along with low SOC caused by the rapid turnover of soil organic matter under high temperature and aeration (Fearnside 2000), also accounts for low available water capacity of sandy soils in tropical regions (Glaser et al 2002). In addition, plant growth efficiency and yield are low on this soil type due to the crop's low WUE. To alleviate these problems, soil management options to increase SOC and improve the crop's WUE (Lehman et al 2003) are promising.

The positive impact of applying manure to improve soil fertility has been widely reported elsewhere (Diels et al 2004). As a practical option, application of fresh organic matter such as manure has also been traditionally done by local farmers in northern Lombok. However, the effects do not last long under the current cropping system. For this reason, manure has to be applied in very huge amounts, often more than 50 t ha^{-1} every year, to sustain soil productivity. Local farmers cannot afford this. In addition, Diels et al (2004) mentioned the small amount of organic substances left in the soil due to very rapid mineralization under tropical conditions. An alternative to using ordinary fresh organic manure is applications of more stable organic compounds such as biochar (Glaser et al 2002).

Currently, biochar has been attracting attention as a sustainable technology to increase soil C sequestration while improving soil fertility other than using fresh organic matter on tropical agricultural soils (Steiner et al 2007). Biochar is a C-rich material obtained from heating organic biomass under limited oxygen conditions (Lehmann 2007). Soil with biochar may change not only its chemical (Lehmann et al 2003, Liang et al 2006) but also its physical properties (Glaser et al 2002, Chan et al 2008, Karhu et al 2011). Nevertheless, there is limited research on the improvement of soil physical properties, particularly water retention and aggregate stability. This study aimed to show that adding biochar to the soil could give effects similar to what cattle manure brings in terms of improving water-holding capacity, WUE, and aggregate stability as well as sustaining SOC under a maize cropping system in the sandy soils of north Lombok, eastern Indonesia.

Materials and methods

Biochar preparation

The biochars used in the study were produced from cattle dung and coconut shell. The cattle dung biochar (CDB) was simply made by heating cattle dung (15% water content) in a cylinder (56 cm diameter, 42 cm high) at 254 °C for 10 h to complete the charring process. On the other hand, the coconut shell biochar (CSB) was prepared through auto thermal combustion of coconut shell in a pit (1.0 m deep, 1.0 m wide, and 1.5 m long) for 9 to 10 h at a mean temperature of 240 °C. Both biochars were subjected to crushing to enable them to pass through 1.0-mm sieves.

The characteristics of the biochars (water content, bulk density, pH, electrical conductivity, ash, organic C, N, P, K, Ca, Na, Mg, and cation exchange capacity) and the cattle manure used in the study are presented in Table 1. Biochar water content (%w/w) was measured by oven-drying a 10-g portion of biochar for 24 h at 80 °C. Bulk density was calculated from biochar weight at 15 °C, which covers a volume of 10 cm^3 (Özçimen and Karaosmanoglu, 2004). Biochar pH was measured according to the method of Ahmedna et al (1977): here, 1% (w/w) of biochar suspension was prepared by diluting the biochar particles with deionized water. The suspension was heated to 90 °C and stirred for 20 min to allow dissolution of the soluble biochar components. pH was measured using a pH meter (Jenway 3305) after cooling the biochar suspension to room temperature. Ash content was determined according to Novak et al (2009) with dry combustion using muffle furnace at 760 °C for 6 h. Total C was analyzed by a method described by Masulili et al (2010). Total P was read with a spectrophotometer and K, Ca, Mg, and Na were measured using an atomic absorption spectrometer (Shimatzu).

Table 1. Characteristics of biochar and cattle manure used in the field experiment.

Characteristic	Cattle dung biochar	Coconut shell biochar	Cattle manure
Water content (% w/w)	8.20	5.56	10.10
Bulk density (g cm^{-3})	0.67	0.71	-
pH-H_2O	8.90	9.90	6.87
C (%)	23.53	80.59	10.24
N (%)	0.73	0.34	0.94
P (%)	0.57	0.10	0.62
K (%)	0.69	0.84	0.53
Ca (%)	0.51	0.40	0.65
Na (%)	0.15	0.12	0.35
Mg (%)	0.44	0.06	0.40
Potential CEC (cmol kg^{-1})	16.79	11.78	-
Ash (%)	75.34	7.36	-

Experimental site and soil conditions

The field experiment was located at the dryland experimental farm of Mataram University in Bayan District of north Lombok, Indonesia (08° 25′ S, 116° 23′ E) at an altitude of 20.5 m above sea level. Under a semiarid tropical climate, the local area has a mean annual temperature of 31 °C, an annual rainfall of less than 1,300 mm, and atmospheric humidity ranging from 80 to 85%. The rainfall recorded in 2011 was 1,234.2 mm, distributed from December/January to April/May. The soil was Ustipssamment (USDA 1998) derived from volcanic ash containing pumice stone materials that came from Mt. Rinjani. The surface soil (0-20 cm) has a sandy loam texture (55% sand and 10% clay) with a pH of 5.97, low SOC (0.89 %), and low nutrient-supplying capacity (N, 0.12%; available P, 24.41 mg kg^{-1}; exchangeable K, 0.57 cmol kg^{-1}; Ca, 2.34 cmol kg^{-1}; Mg, 0.87 cmol kg^{-1}; and CEC, 12.99 cmol kg^{-1}). Soil bulk density was 1.20 g cm^{-3}. Water content at field capacity (pF 2.5) and wilting point (pF 4.2) were 0.217 cm^3 cm^{-3} and 0.043 cm^3 cm^{-3}, respectively. Soil AWC was 0.174 cm^3 cm^{-3}.

Experimental design and treatments

The field experiment, in a randomized complete block design with four replications, was conducted for three consecutive maize cropping seasons: the first in the wet season from December 2010 to March 2011, the second in the dry season from March to July 2011, and the third in late dry season from July to October 2011.The size of each subplot was 3.5 m × 4 m with 0.5-m borders between treatments constructed after the land had been cleared from existing weeds and plowed to 20-cm depth using a hand tractor. The organic amendment treatments were as follows: (1) coconut shell biochar applied once before the first maize (CSB), (2) cattle dung biochar applied once before the first maize (CDB), (3) cattle manure applied once before the first maize (CM1), (4) cattle manure applied every growing season of the three maize cropping systems (CM2),and (5) no organic amendment applied, control (C). Each organic amendment was applied at the rate of 15 Mg ha^{-1}. Biochars and cattle manure were broadcast on the surface of the soil and incorporated thoroughly into a depth of 10 cm. Subsequently, they were incubated for 7 days, by watering the soil at approximately 80% field capacity. A week after incubation, maize seed (Hybrid BC-2) was sown in each plot (one per hill) to 5 cm depth with a row spacing of 20 × 70 cm (100 plants per plot).

Phosphorus (75 kg P_2O_5 ha^{-1}) and potassium (75 kg K_2O ha^{-1}) in the form of superphosphate and KCl commercial fertilizers, respectively, were basally applied 1 d before sowing. Urea was applied at 135 kg N ha^{-1}, which was split into 54 kg N ha^{-1} (40%) and 81 kg N ha^{-1} (60%) applied at 21 and 45 d after sowing (DAS), respectively, for the first and second maize crops. In the third crop season, N was split into 54 kg N ha^{-1} (40%) at 21 DAS and each of the 30% (40.5 kg N ha^{-1}) applied at 30 and 45 DAS, respectively.

Supplemental irrigation was done twice in the first cropping season: 1 d after incorporation of biochar or manure and 1 d before sowing. Subsequently, soil moisture during the first cropping season was naturally supplied from rainfall (935.50 mm); in the second cropping season, soil moisture came from rainfall (298.75 mm) and the rest from irrigation (300 mm). During the third maize season, however, soil moisture was totally maintained from application of groundwater irrigation (total applied irrigation was 578.6 mm).

Measurements

Soil water retention and available water capacity. Undisturbed soil samples were obtained by the use of a core syringe (100 cm^3) to measure water retention. Samples were taken at harvest during the three cropping seasons and measurement was done at pF 0, 1.0, 2.0, 2.5, and 4.2. Samples for volumetric water content and bulk density were oven-dried at 110 °C for 24 h. Available water capacity (AWC) was computed from the difference between volumetric water content at water potential of -33 kPa at pF 2.5 (assumed as field capacity) and permanent wilting point at water potential of -15 MPa at pF 4.2. Determination of water potential at pF 2.5 and pF 4.2 was conducted using a pressure plate, whereas that at pF 0, 1.0, and 2.0 was conducted using sand box suction (Widianto et al 2006).

Soil moisture content, crop evapotranspiration, and water use efficiency

Variables such as soil moisture content, crop evapotranspiration (ETa), and WUE were evaluated on the third cropping season; this is the late dry crop season (July to October 2011) where irrigation was fully applied. Soil water content at 0-20 cm depth was measured every 7 d, from 5 to 110 DAS. Measurement was done at each subplot before irrigation was applied. Soil water content was determined by the gravimetric method (oven-dry basis) and converted into a percentage of volumetric bases by multiplying with bulk density. Intact soil cores (7.0 cm diameter and 5.2 cm high) (200 cm^3) were collected (three samples per treatment plot) from the soil surface for bulk density measurements. The equivalent depth of plant-available water (mm) was estimated using the following equation (Marshall et al 1996):

$$De = \frac{\theta v \times D}{100}$$

where De is equivalent water depth (mm), θv is volumetric water content (%), and D is soil depth (mm).

Crop evapotranspiration

Crop evapotranspiration was determined by an equation proposed by James (1988):

$$ETa = I + P + Cr - R - D \pm \Delta S$$

where ETa is evapotranspiration, I is total amount of applied irrigation, P is precipitation or rainfall, Cr is capillary rise, R is surface run-off, D is downward flux below the crop root zone, and ΔS is the change in soil water storage determined by substracting soil water storage before harvesting from that before planting. Precipitation and Cr were considered zero as there was no rainfall during the late dry season when the third maize crop was grown and there was no capillary rise from the groundwater as the water table in the location was very deep (>120 m). The value of R in this study was also omitted as the plot was flat and water application was under control.

Water use efficiency

Water use efficiency (WUE) was calculated using the equation WUE = (Y/ETa) where Y is economic yield (kg ha^{-1}) and ETa is actual evapotranspiration (mm).

Soil aggregate stability

Soil samples for aggregate stability analyses were taken from each plot after the harvest of the third maize crop (110 DAS) in early October 2011. Soil aggregate stability was measured by a dry and wet sieving method, which adapted a modified Yoder sieving machine (Nyangamara et al 2001) with sieves in diameters of 8.00, 4.76, 2.83, 2.0, 1.0, 0.5, and 0.30 mm. The subsample for analysis passed through a 10-mm sieve and 400 g of sieved sample was used for the measurement. The mean size aggregate retained at each sieve size was computed from the diameter of the adjacent sieve and the mean weight diameter (MWD) of soil samples was computed according to an equation proposed by Nyangamara et al (2001):

$$MWD = \Sigma^{J}_{i} X_i W_i$$

where MWD is mean weight diameter (mm), X_i is the mean diameter of the i^{th} size fraction, and $W_{i\,is}$ the proportion of the total weight of sample occurring in the i^{th} size fraction. The MWD obtained was used in the following equation to calculate aggregate stability:

$$\text{Aggregate stability\%} = \{1: (MWD_{dry} - MWD_{wet})\} \times 100$$

Particulate organic matter C

Organic matter fractionation by the wet sieving method (Hairiah 2011) using particle sizes 250, 150, and 50 μm was conducted to determine particulate organic matter C (POM-C). Five hundred grams of soil sample from each plot passed through various sieves (2 mm, 250 μm, 150 μm, and 50 μm). After sieving, the soil particles that were retained were subsequently dried at 65 °C for 24 h, then weighed. Organic C for each fraction was determined using the Walkley-Black method.

Statistical analysis

The effects of treatments on changes in water retention, WUE, and aggregate stability were analyzed using ANOVA and significance was tested by Fischer`s least significant difference (P=0.05) using MINITAB program version 13.

Results and discussion

Soil water retention

Data on water retention and AWC of soils after maize harvest in each growing season under different organic amendment treatments are shown in Figures 1 and 2, respectively. The application of biochar and cattle manure resulted in a slight increase in soil water retention as well as AWC. Overall, soil water retention (pF0, pF1.0, pF2.0, pF2.5, and pF4.2), particularly those observed during the second and third maize-growing seasons were significantly higher with organic amendment-treated soils compared with control. This result suggests that both organic amendments do have a positive impact in terms of improving the associated soil physical properties of sandy soils. At the end of the third growing season, the highest water retention (pF 2.5) was recorded with CM2 (0.313 cm^3cm^{-3}), followed by treatments CDB, CSB, CM1, and C, with 0.277, 0.276, 0.263, and 0.226 cm^3 cm^{-3}, respectively. These results indicate that application of cattle manure every growing season (CM2) and single application of biochar improved water-holding capacity by 38% and 23%, respectively. They confirm the findings of other studies (Glaser et al 2002, Karhu et al 2011). The added biochar increased soil water-holding capacity by 11% (Karhu et al, 2011). Verheijen et al (2009) pointed out that the significant role of biochar in increasing soil water-holding capacity is observed only in coarse soils and not in fine clay.

Changes in water retention, particularly at pF 2.5 and pF 4.2 (Fig. 1) in soils treated with organic amendment consequently improved soil AWC. At the end of the third maize crop (Fig. 2), the AWC of soils with biochar (CSB and CDB) and those exposed to CM1 and CM2 treatments increased by 16%, 24%, and 11%, respectively. Changes in water retention reflect the effect

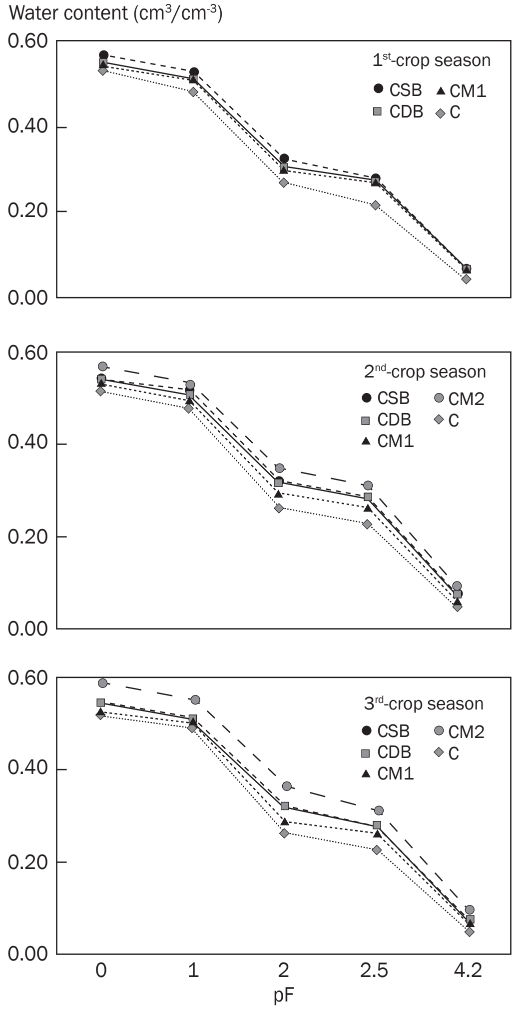
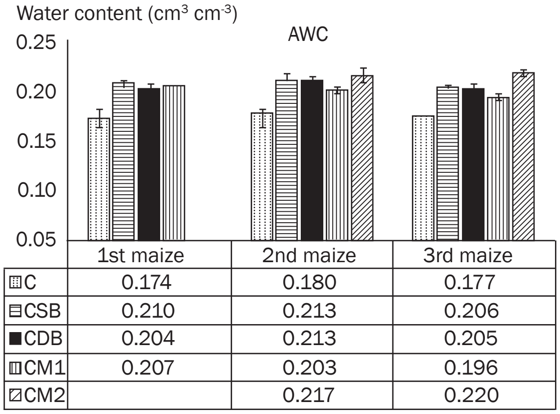


Fig. 1. Changes in water retention following organic amendment application during three maize-growing seasons on sandy loam soils of northern Lombok.



	1st maize	2nd maize	3rd maize
▥C	0.174	0.180	0.177
▤CSB	0.210	0.213	0.206
■CDB	0.204	0.213	0.205
▥CM1	0.207	0.203	0.196
▨CM2		0.217	0.220

Fig. 2. Available water capacity (AWC) (cm^3 cm^{-3}) following application of organic amendments in three maize crops on sandy loam soil, northern Lombok, eastern Indonesia.

of altered pore size distribution after organic matter application (Nyamangara et al., 2001). The significant contribution of organic amendments to pore size distribution, observed during the three consecutive crop seasons, is presented in Figure 3. The data showed that organic amendments significantly increased the percentage of micro pores (<30 μm) as well as that of meso pores (30-100 μm) but they decreased the macro pores (>100 μm). Micro pores in biochar-treated soils increased by 9%, which was lower than that found with CM2, 16%. Downie et al (2009) pointed out that biochars are typically rich in micropores (∅ <2 mm-50 mm) with high surface volume ratio (specific surface area of 750-1360 m^2 g^{-1}: volume of 0.2-0.5 cm^3 g^{-1}). When applied to sandy soil with a limited surface area (Troeh and Thompson 2005), they could significantly increase the number of micropores in the soil.

Water use efficiency of the crop

Data on ETa and WUE of the crop, evaluated for the third maize-growing season, are shown in Table 2.

During the third cropping season , soil moisture for the cropping system was supplied from irrigation every week. The total amount of applied irrigation was 578.6 mm. In the 3rd season of maize, the ΔS value was positive, meaning that soil water storage had not reached a deficit at the end of the growing season. However, the data on Table 2 clearly showed generally higher ΔS values with the added biochar and cattle manure (CM2) than with the C and CM1 treatments. This indicates that the continuous presence of organic amendments is beneficial as it improves the water-holding capacity of sandy soils. A similar trend was also found with WUE. The highest WUE (9.97 kg ha^{-1} mm^{-1}) was obtained with CM2 where cattle manure was applied every growing season. CSB, CDB, and CD1 followed subsequently and their WUE were 9.44 kg ha^{-1} mm^{-1}, 9.24 kg ha^{-1} mm^{-1}, and 8.54 kg ha^{-1} mm^{-1}, respectively. Thus, the application of cattle manure every growing season (CM2) and the single application of biochar resulted in increased WUE by 23% and 17%, respectively. The results found in

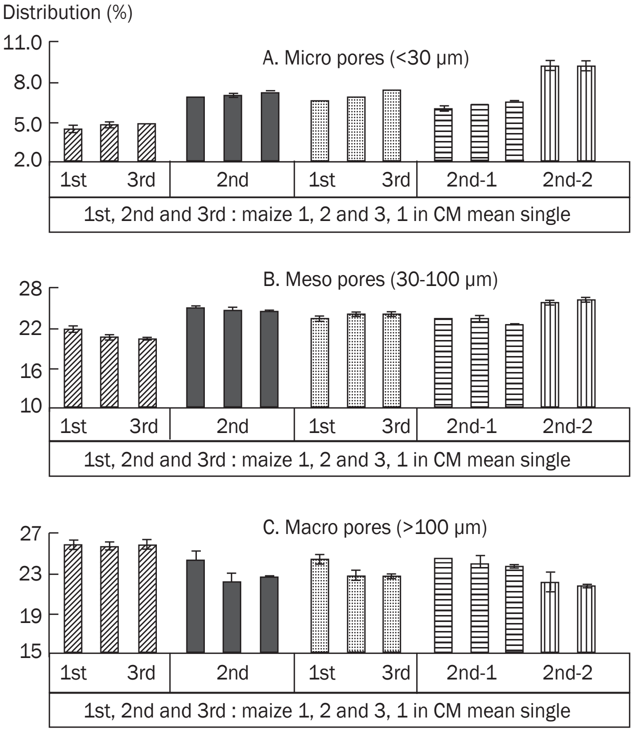


Fig. 3. Pore size distribution of soils (A = <30 μm; B = 30-100 μm; C = >100 μm) following the application of organic amendments under a maize cropping system on sandy loam of northern Lombok, eastern Indonesia.

Table 2. Evapotranspiration (ETa) and crop water use efficiency (WUE) for the 3rd maize crop (July to October 2011).[a]

Treatment	I	P	D	ΔS	ETa	Yield	WUE
			(mm)			(kg ha^{-1})	(kg mm^{-1} ha^{-1})
CSB	578.6	0	0	24.7	553.9^a	5231ab	9.44a
CDB	578.6	0	0	25.5	553.1^a	5089a	9.24a
CM1	578.6	0	0	20.0	558.6^b	4769c	8.54b
CM2	578.6	0	0	25.9	552.7^a	5508b	9.97c
C	578.6	0	0	18.1	560.5^b	4531c	8.08d

[a] I: total amount of applied irrigation, P: precipitation, D: drainage or deep percolation, ΔS: changes in soil water storage. Means with the same letter within a single column do not differ significantly (p=0.05).

this study were lower than values reported by Uzoma et al (2011), who said that application of biochar (15 t ha^{-1}) to sandy soils under a maize cropping system increased WUE by 139%. The higher WUE of crops that received organic inputs positively correlated to improved physico-chemical properties of the soil such as CEC (data not shown) and better yield (r = 0.84 and 0.90).

Soil aggregate stability

Figure 4 shows the results of soil aggregate stability analysis, which were slightly higher with organic amendments as compared with the control. The highest value of aggregate stability was seen in CM2 (66.62%), followed by single application of biochars (CSB and CDB) and cattle manure applied once (CM1) (61.37%, 61.18%, and 58.44%, respectively). After the third maize harvest, CM1 did not substantially improve soil aggregate stability. The improved stability, particularly noted in CM2 and biochar-treated soils, is associated with higher particulate organic matter C of the soil (Fig. 5) as a result of organic amendment addition. This was confirmed by the slightly high correlation between particulate organic matter C and the aggregate stability data (r=0.60). Bronick and Lal (2005) stated that particulate organic matter (POM) works as a binding agent in microaggregates and also as a core for the formation of macroaggregates. Therefore, the long-term stability of the aggregates is often related to the presence of recalcitrant C compounds (Tisdall and Oades 1982).

Particulate organic matter-C (POM-C)

Figure 5 shows that the plots receiving organic amendments (particularly those under CSB, CDB, and CM2) contained higher POM-C than the control plot. This suggests that the applied organic amendments, either in the form of biochar or cattle manure, have a positive contribution to soil C stability, which can be expected to further contribute to greater soil aggregate stability in the long run. The values of POM-C in the 50-µm fraction of CSB, CDB, and CM2 were almost twofold higher than that of C. This result indicates that a single application of biochar gives almost the same effect as cattle manure application every growing season.

The higher value of POM-C in the 50-µm fraction as recorded in plots receiving organic amendments could be used as a simple indicator of the improving trend in aggregate stability over the long term. POM-C at the micro aggregate level could actively contribute to the formation of an organo-clay-complex, which, in turn, stabilizes soil aggregates (Brodowski et al 2006). The POM-C in the micro aggregates (≤50 µm) is a relatively more stable C pool than those of other sizes and is less sensitive to soil management than macro aggregates (>250 µm) (Tisdall and Oades 1982). As biochar is part of such a micro fraction, it could also occur as an occluded POM-C and may be involved in forming the biochar-organo-clay complex, which is more resistant to degradation (Brodowski et al 2006).

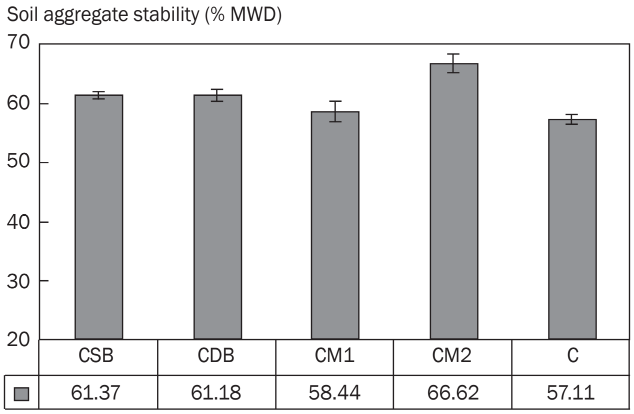


Fig. 4. Aggregate stability of soils (% MWD) after 1 year of biochar application to a maize cropping system on sandy loam soil of northern Lombok, eastern Indonesia.

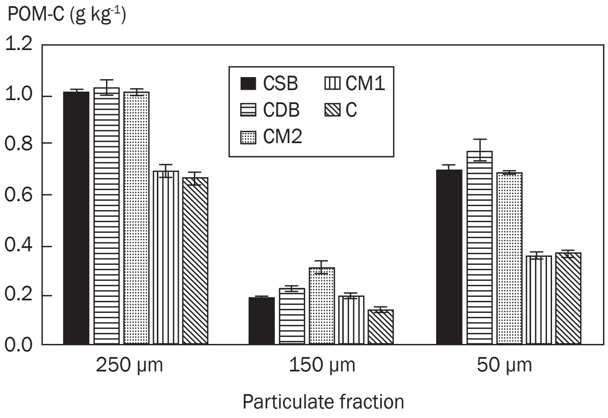


Fig. 5. Particulate organic matter-C (POM-C) of soils after harvest of the third maize crop.

Conclusion

The study compared biochar- and cattle manure-added soils to evaluate their effects on soil physical properties such as water-holding capacity, WUE, and soil aggregate stability. Results showed that biochar-added soils had improved AWC, WUE, and soil aggregate stability and this was almost the same level of improvement as that of cattle manure-added soils, especially CM2. Hence, a single application of biochar can improve the soil physical properties during at least three maize croppings with the same effect obtained through cattle manure application every cropping season. The long-term effect of biochar on soil physical properties and its role in maize production need to be evaluated for sustainable maize production on sandy loam soils of tropical semiarid areas in north Lombok, Indonesia.

References

Ahmedna M, Johns MM, Clarke SJ, Marshall WE, Rao RM. 1977. Potential of agricultural by-product-based activated carbons for use in raw sugar decolorization. J. Sci. Food Agric. 75: 117-124.

Brodowski S, John B, Flessa H, Amelung W. 2006. Aggregate-occluded black carbon in soil. Eur. J. Soil Sci. 57(4): 539-546.

Bronick CJ, Lal R. 2005. Soil structure and management: a review. Geoderma 124: 3-22.

Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S. 2008. Using poultry litter biochars as soil amendments. Austr. J. Soil Res. 46: 437–444.

Diels J, Vanlauwe B, Van der Meersh MK, Sanginga N, Merck RJ. 2004. Long-term soil organic carbon dynamics in a subhumid tropical climate: ^{13}C data and modeling with ROTHC. Soil Biol. Biochem. 36: 1739-1750.

Downie A, Crosky A, Munroe P. 2009. Physical properties of biochar. In: Biochar for environmental management: science and technology. UK: Earthscan.

Fearnside PM. 2000. Global warming and tropical land-use change: greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. Clim. Change 46: 115–158.

Glaser B, Lehmann J, Zech W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoals: a review. Biol. Fertil. Soils 35: 219-230.

Hairiah K. 2011. Soil biology analysis procedure. Soil Biology Laboratory, Department of Soil Science, Faculty of Agriculture, Brawijaya University, Malang, Indonesia.

James IG. 1988. Principles of farm irrigation system design. New York: Wiley.

Karhu K, Matilla T, Bergstrom I, Regina K. 2011.Biochar addition to agricultural soil increased CH_4 uptake and water holding capacity—results from a short-term pilot field study. Agric. Ecosyst. Environ. 140: 309-313.

Lehmann J. 2007. Bioenergy in the black. Front Ecol. Environ.5: 381-387.

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

Liang B, Lehmann J, Kinyangi D, Grossman J, O'Neill B, Skjemstad JO, Thies J, Luizao FJ, Peterson J, Neves EG. 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc.Am. J. 70: 1719-1730.

Marshall TJ, Holmes JW, Rose C.W. 1996. Soil physics. 3rd ed. Cambridge University Press.

Masulili A, Utomo WH, Syekhfani. 2010. Rice husk biochar for rice-based cropping system in acid soil. 1. The characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia. J. Agric. Sci. (Canada) 3: 25-33.

Novak JM, Busscher WJ, Laird DL, Ahmedna MA, Watts DW, Niandou MAS. 2009. Impact of biochar amendment on fertility of a southeastern coastal plain. Soil Sci.174(2): 105-112.

Nyangamara J, Gotosa J, Mpofu SE. 2001. Cattle manure effects on structure stability and water retention capacity of a granitic sandy soil in Zimbabwe. Soil Till. Res. 62: 157-162

Özçimen D, Karaosmanoglu F. 2004. Production and characterization of biochar from rapeseed cake. Renew. Energy 29: 779-787.

Steiner C, Teixeris WG, Lehmann J. 2007. Long-term effect of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant Soil 291: 257-290.

Sukartono, Utomo WH, Kusuma Z, Nugroho WH. 2011.Soil fertility status, nutrient uptake, and maize (*Zea mays* L.) yield following biochar and cattle manure application on sandy soils of Lombok, Indonesia. J. Trop. Agric. 49 (1-2): 47-52.

Tisdall JM, Oades JM. 1982.Organic matter and water-stable aggregates in soils. J. Soil Sci. 33: 141-163.

Troeh FR, Thompson LM. 2005. Soil and soil fertility. 5thed. Iowa: Blackwell. (www.interscience.wiley.com) DOI: 10.1002/ts.216

USDA (United States Department of Agriculture). 1998. Keys to soil taxonomy..Natural Resources Conservation Service. 8th ed. Washington, D.C.: USDA.

Uzoma KC, Inoue M, Andry H, Fujimaki H, Zahoor A, Nishihara E. 2011. Effect of cow manure biochar on maize productivity under sandy soil condition. Soil Use Manage. 27: 205-212.

Verheijen FGA, Jeffery S, Bastos AC, Van der Velde M,Diafas I. 2009. Biochar application to soils—a critical scientific review of effects on soil properties, processes, and functions. Luxembourg: Office for the Official Publications of the European Communities.

Notes

Authors' addresses: Sukartono and Suwardji, Research Centre and Development for Tropical Dryland Farming, University of Mataram, Jl. Majapahit 62 Mataram, Lombok; W.H. Utomo, Centre for Soil and Land Management, Brawijaya University, Malang, East Java (hadi_utomo@hotmail.com); and W.H. Nugroho, Departmentof Biometrics, Brawijaya University, Malang, Indonesia.

Evaluating the effects of biochar on N absorption and N use efficiency in maize

Widowati, W.H. Utomo, B. Guritno, and L.A. Soehono

Soil organic matter needs to be maintained and further increased to keep soil fertility. Addition of organic matter every cropping season ensures the availability of organic matter. Biochar is an alternative source that has good potential because it resists decomposition. This experiment aimed to know the influence of biochar and organic fertilizer (once provided in the first season and replicated in the second season) on the absorption and efficiency of nitrogen fertilization during the second and third cropping seasons. This study used city organic waste biochar, chicken manure biochar, chicken manure fertilizer, and compost. Biochar and organic fertilizer were applied during the first season. Organic fertilizer was again added in the second season. There were seven treatments: urea (residue of season 1 of urea), urea+PK (residue of season 1 of urea and animal manure), urea+KS (residue of season 1 of urea and compost), urea+BA (residue of season 1 of urea and animal manure biochar), urea+BS (residue of season 1 of urea and garbage biochar), urea+PK+PKb (residue of season 1 of urea and biochar animal manure with new animal manure added), and urea+KS+KSb (residue of season 1 of urea and compost with new compost added). The results of the study show that, up to the third planting season, nitrogen absorption and efficiency of nitrogen fertilization from biochar were higher than those brought about by addition of new organic fertilizer and by organic fertilizer added once. Soil organic matter, exchangeable bases, base saturation, pH, CEC, and total N soil content increased with biochar application.

Keywords: biochar, absorption, fertilization efficiency

Soil organic matter is the key to sustaining soil fertility. In wet tropical condition, organic matter is easily subjected to decomposition and mineralization. Mineralization produces CO_2 in just a few seasons (Bol et al 2000) and causes nutrient content to be low (Tiessen et al 1994). The low organic matter content in the soil contributes to low nutrient efficiency of the plant, particularly in terms of urea utilization. Organic matter should therefore be added every season to maintain soil fertility. The potential amount of organic matter is limited, and there is competition among other uses, such as for energy source and livestock feed.

To solve the problem and avoid negative consequences, experts considered using decomposition-resistant organic materials such as biochar (Lehmann et al 2003). Biochar is a carbon-based compound that is relatively stable, much more stable than noncarbonized organic compounds (Badlock and Smernik 2002). Biochar is a solid by-product derived from biomass pyrolysis.

Previous studies on the use of biochar have shown that biochar is a promising soil amendment material (Glaser et al 2002, Lehmann et al 2003, Chan et al 2007). In addition to improving soil properties, the use of biochar in tropical soil can increase soil nutrient availability in the long term (Lehmann et al 2003, Rondon et al 2007, Steiner et al 2008). The use of biochar can enhance soil productivity by improving the physical, chemical, and biological soil conditions (Glaser et al 2002, Lehmann et al 2003, Chan et al 2007). Improvement in soil structure,, increase in soil water storage capacity, and decrease in soil strength have been reported by Chan et al (2007) who conducted a study on Australian soil, which easily hardens. The use of biochar can also increase soil pH and soil CEC (Liang et al 2006, Yamato et al 2006).

In addition to the direct effects, Lehmann et al (2003) and Steiner et al (2008) reported that the use of biochar can improve the efficiency of nitrogen fertilizer, as biochar can reduce the loss of nitrogen and potasium that occurs through leaching (Widowati et al 2011, 2012a). The positive influence of biochar on soil biological fertility occurs through increasing activity of soil microorganisms (Steiner et al 2008). The increase in number of mycorrhiza colonies due to the use of biochar has been shown by Warnock et al (2007). Rondon et al (2007) showed that biochar increases nitrogen fixation in legumes. The positive influence of biochar on soil and crops has been widely studied. However, information on the stability of biochar in the next cropping season is still limited. The hypothesis is that the application of biochar improves the level of soil nitrogen content by reducing leaching and this results in better nitrogen supply for succeeding cropping seasons. The purpose of this study is to evaluate the effect of biochar on nitrogen absorption in the soil and efficiency in nitrogen use for crop growth over the years.

Materials and methods

Experimental design

The experiments were carried out in the greenhouse of Tribhuwana Tunggadewi University, Malang, Indonesia. Polyethylene bags were filled with 25 kg of air-dried soil (sand 21%, silt 55.3%, clay 23.7%, CEC 14.8 cmolc kg^{-1}, T-C 1.46 mg kg^{-1}, and T-N 0.57 mg kg^{-1}). The same bags were used in the succeeding seasons. Biochar and organic amendments such as compost and manure were applied during the first and second season at 30 and 50 t ha^{-1}, respectively. The experiments used a completely randomized block design with four replications. There were seven treatments (details in Table 1). Feedstock for biochar was dried under the sun until water content reached 17%; pyrolysis occurred at 500 °C for 2 h and 30 min. In all treatments, urea, SP_{36}, and KCl were applied each season at these doses: 135 kg N ha^{-1} (300 kg urea ha^{-1}), 36 kg P_2O_5 ha^{-1} (100 kg SP_{36} ha^{-1}), and 110 kg K_2O ha^{-1} (200 kg KCl ha^{-1}). SP_{36} and KCl fertilizers were applied 6 d after planting (DAP). Urea was applied twice, 1/3 at planting and 2/3 at 30 DAP. Seeds of corn variety Bisma were then planted; when the crop reached maximum vegetative growth at 65 DAP, it was harvested.

Table 1. Research treatment of the second season maize crop.[a]

Code	Description
Urea	Residue of season 1 of urea treatment
Urea+PK	Residue of season 1 of urea and manure treatment
Urea+KS	Residue of season 1 of urea and compost treatment
Urea+BA	Residue of season 1 of urea and manure biochar treatment
Urea+BS	Residue of season 1 of urea and waste biochar treatment
Urea+PK+PKb	Residue of season 1 of urea and manure plus new manure treatment
Urea+KS+KSb	Residue of season 1 of urea and compost plus new compost treatment

[a] PKb and KSb = new manure and compost in each season; PK = manure, KS = compost, BA = manure biochar, BS = waste biochar.

The maximum vegetative stage was identified just before panicle initiation. The first-season experiment was planned in such a way that treatments with manure and compost will be evaluated further. Therefore, two pots were prepared. The first pot was used for follow-up evaluation of the effects of organic fertilizer given in the first growing season (organic fertilizer once in a season). The second pot, coupled with new organic fertilizers (50 t ha^{-1}), was used to evaluate the performance of organic fertilizer in each planting season. All pots received the same treatment in the first growing season.

Soil physical properties, which include aggregate stability, soil bulk density, and soil porosity (Dewis and Freitas 1970) were observed at the end of vegetative growth or during harvest. Plant height was measured at 2, 3, 4, 5, 6, and 7 wk after planting (WAP) and stem diameter was measured at 3, 4, 5, 6, and 7 WAP. Plant height was measured from the soil surface to the top leaf (flag) canopy. Stem diameter was measured at the base of the plant and vertically every 20 cm up to 60 cm from the surface of soil and calipers were used for the measurement (Pesquisa Aplicada & Agrotecnologia v3 n3 Set.- Dez. 2010.print-ISSN 1983-6325(On line) e-ISSN 1984-7548). Dry biomass determination was done by cutting the aboveground plant, after which the plant was oven-dried at 80 °C until it reached constant weight. Leaf area was determined using a leaf area meter (Model 3100, LI-COR Biosciences). Root length was measured following the methods of mapping by Böhm (1976). Observations of dry weight of plant, leaf area, and total length of roots were made at the end of the maximum vegetative growth stage. These observations on the physical properties were made at the time of harvest.

The soil chemical properties were observed after harvest of the third-season crop; pH (H_2O), organic C, total N, CEC, base saturation, and cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) were obtained through soil analysis. Total nitrogen in the soil and plant was determined by Kjeldahl method. Soil organic C content was determined by Walkley and Black wet oxidation method and CEC was extracted using 1 M NH_4OAc (buffered at pH 7.0). Exchangeable bases in the solutions were measured using atomic absorption spectrophotometry (Shimatzu). The efficiency of nitrogen fertilization was then calculated by the following equation (Frank and Christian 2010):

$$\textit{Efficiency of}\ \mathrm{N}\ \textit{fertilization}\ (\%)= \frac{\mathrm{BBt\ x NBt}}{\mathrm{Na}} \quad \mathrm{x}\ 100\%$$

where BBt = dry weight of crop biomass (kg ha^{-1}), NBt = N levels in crop biomass (%), and Na = number of N given (kg ha^{-1}).

Results and discussion

Growth of maize

Plant height and stem diameter of maize for the second and third seasons are shown in Figures 1 and 2. Both indicated no significant difference among treatments. However, stem diameter for the third season showed a continuously increasing trend toward the end of the season, unlike the one for the second season which was quadratic. Root length in the third year became shorter than the one in the second year (Fig. 3) despite the bigger stems. The leaf area of the plants was similar betweeen two seasons (Fig. 4), although a significant increase among various treatments was observed upon comparison with the control in the second season. Such a difference was dispersed for the third season. Biochar application increased root length by 37%

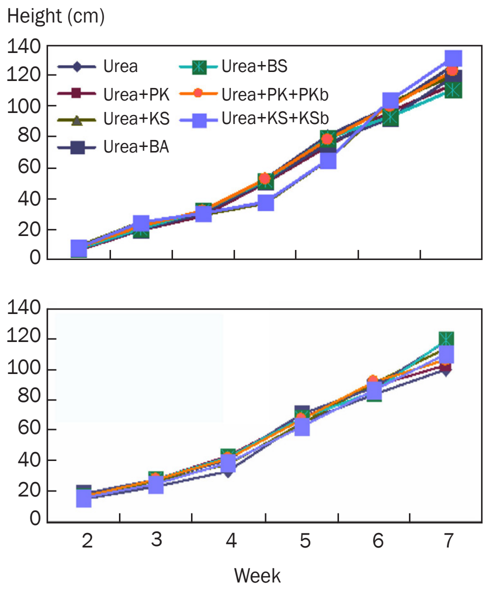


Fig. 1. Average height of the second and third cropping season maize crops (7 wk per season).

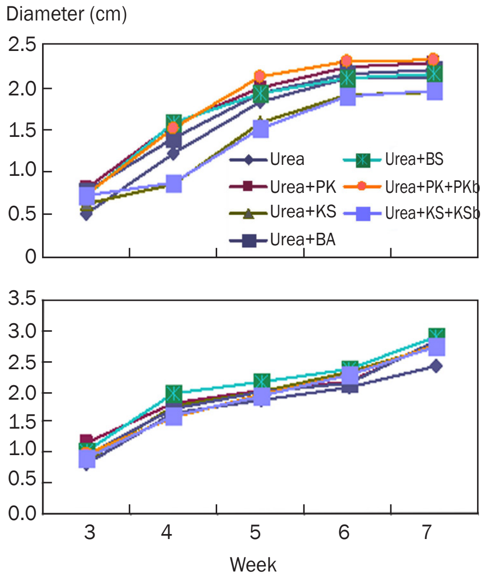


Fig. 2. Average diameter of the second and third cropping season maize crops (7 wk per season).

with manure biochar and by 56% with organic waste biochar compared with the residual effect of organic fertilizer (Fig. 4). Application of organic fertilizers every season did not change from the one-time application at the beginning of the first season. Manure biochar residues increased leaf area by 19% compared with organic fertilizer residue in the third cropping season.

Crop biomass production

During the second and third seasons, maize produced the least biomass with sole urea application, whereas urea with organic fertilizers or biochar showed significantly higher biomass production than the one with sole urea application. When organic fertilizers were applied every season, biomass production became significantly higher than one-time application in the first season, but there was no significant difference with biochar application. Although frequent application of organic fertilizers and biochar enhanced biomass production, soil N levels of these treatments were still significantly higher than one-time application of organic fertilizer or sole application of urea. The effect of biochar application was more significant for both parameters in the third season than in the second season, and this confirms findings from previous studies (Yanai et al 2007, Lehmann and Steiner 2009, Widowati et al 2011).

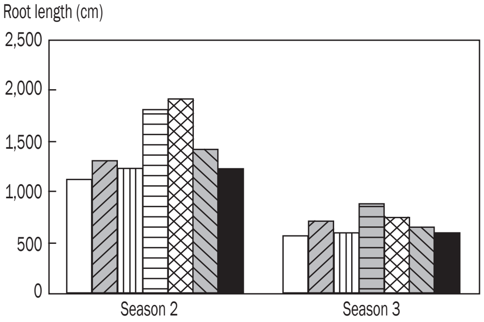


Fig. 3. Average root length of the second and third cropping season maize crops.

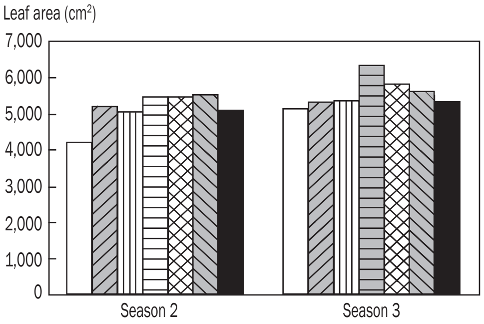


Fig. 4. Average leaf area of the second and third cropping season maize crops.

Absorption and efficiency of N

Organic fertilizer and biochar applications also improved N absorption, and thus, the efficiency of N fertilization in maize (Table 2). Application of organic fertilizers and biochar showed significantly higher N absorption than sole urea application. Frequent application of organic fertilizers and biochar resulted in significantly higher N absorption than one-time application of organic fertilizers. N absorption with biochar was the highest among all treatments in the third season. These results were almost similar to findings on N fertilization efficiency. The obtained results imply that biochar application could improve N use by crops as earlier studies had reported (Glaser et al 2002, Lehmann et al 2003). In the second season, manure biochar and organic waste biochar improved the efficiency of N fertilization by 15% and 19%, respectively, and both types of biochar by 7% (provided in each season) compared with conventional organic fertilizer. In the third season, manure biochar and waste biochar improved fertilizer N efficiency by 11% and 14%, respectively , compared with conventional organic fertilizer

Table 2. Average absorption and efficiency of N fertilization at the second and third seasons.[a]

Treatment	Absorption N (kg ha^{-1})		Efficiency of N fertilization (%)	
	Season 2	Season 3	Season 2	Season 3
Urea	56.72 a	48.43 a	42.02 a	35.87 a
Urea+PK	78.35 c	74.10 c	58.04 c	54.89 c
Urea+KS	73.01 b	71.50 c	54.08 b	52.96 c
Urea+BA	89.95 f	81.98 d	66.63 f	60.73 d
Urea+BS	86.60 ef	81.95 d	64.15 ef	60.10 d
Urea+PK+ PKb	84.46 de	71.96 c	62.56 de	53.30 c
Urea+KS+KSb	80.94 cd	67.70 b	59.96 cd	50.15 b
LSD (5%)	4.52	4.20	3.35	3.11

[a] Numbers accompanied by the same letter in the same column are not significantly different by LSD test at 5%.

(manure and compost). Novak et al. (2007) stated that biochar has a high affinity for cations so they can withstand the loss of soil nutrients due to leaching. Biochar can reduce nutrient leaching (Lehmann et al 2003); as biochar reduces N leaching from the soil and increases nutrient supply for plant growth, the need for N fertilizer is eventually reduced (Widowati et al 2012).

The increase in number of adsorbing cations is due to the increase in soil organic matter content through biochar application. In the second season, the increase in soil organic matter from manure biochar, waste biochar, manure, and compost was 50.28%, 34.16%, 20.8%, and 20.66%, respectively (Table 3). During the third season, the respective values were 68.65%, 72.61%, 12.61%, and 10.45%. As Table 4 shows, cation exchange capacity of biochar is better than that of organic fertilizers applied once. The low buffering capacity of the soil means low fertilizer use efficiency. The addition of organic fertilizer and biochar significantly affected the chemical properties of the soil. The efficiency of fertilizer N was increased by adding manure and compost, 8% and 10%, respectively, compared with a decrease by 3% (manure) in the second season and by 6% (compost) in the third season. In terms of CEC then, biochar residue in the second and third seasons was better than organic fertilizers. Soil C organic content, which increased (Table 5), could increase soil CEC (Table 4). There is a close relationship between soil carbon content and soil CEC (Saran et al 2009). Biochar is largely made up of soil carbon (Liang et al 2006).

Table 3. Average crop biomass production and n soil levels in the second and third cropping seasons.[a]

Treatment	Biomass production (kg ha^{-1})		N soil level (%)	
	Season 2	Season 3	Season 2	Season 3
Urea	2396.67 a	2201.20 a	0.17 a	0.17 a
Urea+PK	3121.80 b	3087.47 c	0.20 b	0.19 b
Urea+KS	2976.13 b	3064.13 c	0.22 c	0.21 c
Urea+BA	3407.33 c	3390.13 d	0.25 d	0.24 d
Urea+BS	3339.20 c	3331.47 d	0.25 d	0.24 d
Urea+PK+PKb	3338.40 c	3062.00 c	0.23 cd	0.21 c
Urea+KS+KSb	3354.00 c	2830.80 b	0.23 cd	0.22 c
LSD (5%)	191	100.7	0.02	0.01

[a]Numbers accompanied by the same letter in the same column are not significantly different by LSD test at 5%.

Table 4. Average soil physical properties at the second and third cropping seasons.[a]

Treatment	Porosity (%)		Aggregate (DMR, cm)		Bulk density (g cm^{-3})		Soil organic matter (%)	
	Season 2	Season 3	Season 2	Season 3	Season 2	Season 3	Season 2	Season 3
Urea	35.13	49.20 a	1.53	1.54	1.38 a	1.18 d	2.42 a	1.85 a
Urea+PK	45.57	56.10 b	2.37	1.65	1.27 a	1.03 b	2.92 b	2.08 ab
Urea+KS	44.37	56.00 b	2.31	1.62	1.32 a	1.10 c	2.92 b	2.04 ab
Urea+BA	45.70	58.00 c	2.19	1.65	1.31 a	1.01 b	3.65 d	3.12 c
Urea+BS	43.87	56.00 b	2.21	1.87	1.31 a	1.00 b	3.35 c	3.19 c
Urea+PK+ PKb	39.50	60.80 d	2.52	1.74	1.51 b	0.93 a	3.65 d	2.36 b
Urea+KS+KSb	46.97	54.60 b	2.77	1.71	1.29 a	1.12 c	3.60 d	2.39 b
LDS (5%)	tn	1.882	tn	tn	0.12	0.05	0.26	0.37

[a]Numbers accompanied by the same letter in the same column are not significantly different by LSD test at 5%

Table 5. Average soil chemical properties at the second and third cropping seasons.[a]

Treatment	CEC (meq 100 g^{-1})		Exchangeable bases ($cmol^c$ kg^{-1})		Base saturation (%)		pH (H_20)	
	Season 2	Season 3	Season 2	Season 3	Season 2	Season 3	Season 2	Season 3
Urea	32.60 a	33.25 a	16.25 a	14.66 a	50.00 a	41.50 ab	6.7 a	6.8 ab
Urea+PK	36.17 b	44.23 cd	17.19 a	18.48 bc	47.67 a	40.86 ab	6.9 b	6.8 ab
Urea+KS	36.72 bc	43.50 b	20.40 b	19.10 cd	55.33 bc	44.00 bc	7.1 c	6.7 a
Urea+BA	38.54 d	46.15 d	26.32 d	20.03 d	68.33 e	43.46 bc	7.1 c	7.1 c
Urea+BS	38.46 d	46.16 d	24.15 c	23.44 f	62.67 d	50.69 d	7.2 d	7.0 c
Urea+PK+ PKb	38.72 d	44.36 bc	23.23 c	21.35 e	60.33 cd	47.79 cd	6.7 a	6.9 bc
Urea+KS+KSb	38.01 cd	43.81 bc	19.14 b	17.21 b	50.33 ab	38.37 a	7.0 bc	6.7 a
LSD (5%)	1.70	1.43	1.83	1.27	5.30	4.05	0.10	0.15

[a] Numbers accompanied by the same letter in the same column are not significantly different by LSD test at 5%.

Soil N content

Application of organic manure and biochar significantly affected the soil's total N content after harvest. The use of organic fertilizer and biochar increased soil organic matter content and cation exchange capacity (Tables 5 and 6); this increases the negative charge that contributes to greater absorption of the released nutrients (N urea). These conditions exist as biochar is better at storing nutrient N than organic fertilizers. Chan et al (2008) reported that increased crop yield is largely attributed to the ability of the biochar to increase N availability. N levels, which were high after the first season, can increase the absorption and efficiency of fertilizer N in the second season (biochar manure and organic waste biochar). The high soil N levels in the second season can increase the absorption and efficiency of fertilizer N in the third season (organic waste biochar). Up to the third season, the soil N level of biochar is still higher than that of organic fertilizers. Soil N levels, with the addition of new organic fertilizer, do not fare better than those without additional organic fertilizer during both second and third seasons.

Soil physical and chemical properties

The soil organic matter increased by biochar improved exchangeable bases (Tables 5 and 6). The number of bases from manure biochar and organic waste biochar was higher than that from manure or compost in the second season. Such conditions can support crop growth and increase biomass production in the second and third cropping seasons.

The presence of soil organic matter is very important for various soil properties. In the second season, soil organic matter significantly affected base saturation of the soil (R^2=15.8%), total bases (R^2=30.9%), and aggregate stability (R^2=28.8%) with a significant level at 5%. The observations show that soil physical properties compared with urea fertilizer treatment only, the average biochar treatment has a porosity and aggregate stability of 30% and 54% (second season) and 17% and 19% (third season), which are higher, and soil bulk density of 5% (second season) and 15% (third season) which are lower than urea treatment. Organic fertilizers show porosity and aggregate stability of 28% and 53% (second season), and 14% and 6% (third season), which are higher, and soil bulk density of 6% (second season), and 10% (third season) which are lower than urea treatment. The provision of organic fertilizer and biochar can decrease soil content weight density in all maize cropping seasons. These results are in line with findings of Gundale and Deluca (2006): that addition of biochar has the potential to reduce soil density. At the second season, soil bulk density has a positive effect on root length (R^2=69.8%). In the second season, biochar, organic fertilizer, and the addition of new organic fertilizers affected soil organic matter. There was a significant positive effect of soil content weight density positive on biomass production (R^2=95%). The increase in soil bulk density reduced pore spaces in the soil. The increase in soil organic matter by application of organic fertilizer and biochar improved soil porosity in all maize cropping seasons. The addition of new manure during the second cropping season resulted in highest soil bulk density (1.51 g cm^{-3}) and lowest soil porosity (40%) of organic inputs.

Conclusions

1. Absorption and efficiency of nitrogen with biochar application is better than organic fertilizer given in each season and provided only once.
2. Soil organic matter, number of bases, KB, pH, CEC, and N soil content increase with biochar application.

References

Baldock JA, Smernik RJ. 2002. Chemical composition and bioavailability of thermally altered (Red pine) wood. Organic Geochem. 33: 1093-1109.

Bol R, Amelung W, Friedrich C, Ostle N. 2000. Tracing dung-derived carbon in temperate grassland using ^{13}C natural abundance measurements. Soil Biol. Biochem. 32: 1337-1343.

Böhm W. 1976. In situ estimation of root length at natural soil profiles. J. Agric. Camb. 87: 365-368.

Chan KY, van Zwieten L, Meszaros I, Downie A, Joseph S. 2007 Agronomic values of greenwaste biochar as a soil amendment. Austr. J. Soil Res. 45: 629-634.

Chan KY, van ZwietenL, Meszaros I, Downie A, Joseph S. 2008. Using poultry litter biochars as soil amendments. 46: 437- 444.

Dewis J., Freitas F. 1970. Physical and chemical methods of soil and water analysis. FAO Soils Bull. 275 p.

Frank B, Christian P. 2010. Proceedings of the OECD workshop on “Agri-environmental indicators: lessons learned and future directions”, 23-26 March 2010, Leysin, Switzerland. www.fertilizerseurope.com.

Glaser B, Lehmann J, Zech W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal: a review. Biol. Fertil. Soils 35: 219-230.

Gundale MJ, DeLuca TH. 2006. Temperature and source material influence ecological attributes of *Ponderosa* pine and Douglas-fir charcoal. For. Ecol. Manage. 231: 86-93.

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

Liang B, Lehmann J, Kinyangi D, Grossman J, O’Neill B, Skjemstad JO,Thies J, Luizao FJ, Peterson J, Neves E.G. 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J. 70: 1719-1730.

Novak JM, Busscher WJ, Laird DL, Ahmedna M, Watts DW, Niandou MAS. 2007. Impact of biochar amendment on fertility of a southeastern coastal plain soil. Soil Sci. 174: 105-112.

Rondon MA, Lehmann J, Ramírez J, Hurtado M. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. Biol. Fertil. Soils 43: 699-708.

Saran S, Elisa LC, Evelyn K, Roland B, 2009. Biochar climate change, and soil: a review to guide future research. CSIRO Land and Water Science Report 05/09.

Steiner C, Glaser B, Teixeira WG, Lehmann J, Blum WEH, Zech W. 2008. Nitrogen retention and plant absorption on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. J. Plant Nutr. Soil Sci. 171: 893-899.

Tiessen H, Cuevas E, Chacon P. 1994. The role of soil organic matter in sustaining soil fertility. Nature 371: 783-785.

Warnock DD, Lehmann J, Kuyper TW, Rillig MC. 2007. Mycorrhizal responses to biochar in soil—concepts and mechanisms. Plant Soil 300: 9-20.

Widowati, Asnah, Sutoyo. 2012. The effects of biochar and potassium fertilizer on the absorption and potassium leaching. Buana Sains 12: 83-90.

Widowati, Utomo WH, Guritno B, Soehono LA. 2012. The effect of biochar on the growth and N fertilizer requirement of maize (*Zea mays* L.) in a greenhouse experiment. J. Agric. Sci. 4: 255-262.

Widowati, Utomo WH, Soehono LA, Guritno B. 2011. Effect of biochar on the release and loss of nitrogen from urea fertilization. J. Agric. Food Technol. 1: 127–132.

Yamato M, Yasuyuki O, Irhas FW, Saifuddin A, Makoto O. 2006. Effects of the application of charred bark of *Acacia mangium* on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. Soil Sci. Plant Nutr. 52: 489-495.

Yanai Y, Toyota K, Okazaki M. 2007. Effects of charcoal addition on N_2O emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments. Soil Sci. Plant Nutr. 53: 181-188.

Notes

Authors’ addresses: Widowati, Tribhuwana Tunggadewi University, Jl. Telaga Warna, Tlogomas, Malang (widwidowati@gmail.com); W.H. Utomo, International Research Centre for Management of Degraded and Mining Land, University of Brawijaya, Malang; B. Guritno, Tuber and Root Crops Research Centre, University of Brawijaya, Malang; and L.A. Soehono, Faculty of Science, University of Brawijaya, Malang, Indonesia.

Acknowledgment: The research was partly funded by the Directorate of Higher Education, the Ministry of Indonesian National Education, through the Research Grant for PhD Studies Scheme.

Nitrogen fertilizer requirement of maize (*Zea mays* L.) on biochar-treated soil

Wani Hadi Utomo and Titiek Islami

A field experiment was conducted to study the nitrogen (N) requirement of maize (*Zea mays* L.) on biochar-treated soil. Maize was planted on soil previously planted to cassava. This 3-year study involved a control, two amendment applications (with and without biochar), and four rates of N fertilization (0, 45, 90, and 180 kg N ha^{-1}). The results show that, up to 180 kg N ha^{-1}, the relationship between N rate and grain yield was quadratic for biochar-treated soil and linear for the control soil. The efficiency of N fertilization in biochar-treated soil was higher than that in nontreated soil. This makes the N requirement of biochar-treated soil far less compared with that of non-biochar-treated soil. To produce 5 Mg ha^{-1} grain yield, 44 kg N ha^{-1} is required for soil treated with 15 Mg biochar ha^{-1}, whereas 180 kg ha^{-1} is needed for the control soil.

Keywords: soil amendment, organic farming, leaching, nitrogen efficiency

Inorganic fertilizers play a crucial role in modern agriculture. However, it is also well known that dependence on inorganic fertilizers results in soil degradation through soil nutrient imbalance, acidity, decrease in soil organic matter or increasing environmental pollution (Carpenter et al 1998, Haynes and Naidu 1998, Liu et al 2010). The decline in soil organic matter content enhances nutrient losses caused by soil erosion or nutrient leaching (Lehmann et al 2003, Logsdon et al 2002). Therefore, it is important that organic matter in the soil is improved through inorganic fertilizer application to ensure fertilizer use efficiency (Dinnes et al2002, Fageria and Baligar 2005).

In this context and with an understanding of the rapid decomposition of soil organic material, some researchers tried more recalcitrant organic matter sources for soil management (Glaser et al 2001). This material, now widely known as "biochar," has been proven to have a positive impact on both soil characteristics and crop performance (Chan et al 2008, Woolf 2008). Research has shown that biochar can enhance soil quality by improving the physical, chemical, or biological properties of the soil (Chan et al 2008, Masulili et al 2010, Rondon et al 2007, Warnock et al 2007). With its carboxyl and phenolic compounds, biochar increases the negative charge of the soil (Liang et al 2008, Masulili et al 2010) and improves soil exchangeable capacity, which reduces nutrient loss caused by leaching (Laird et al 2010).

Widowati et al (2011) observed the form of soil N released from urea application and found that, in the soil treated with biochar, $N\text{-}NH_4^+$ was the more dominant form of inorganic N rather than $N\text{-}NO_3^-$. In soils without biochar, on the other hand, $N\text{-}NO_3^-$ was more dominant. These results confirm the positive effect of biochar application on soil cation exchange capacity (Laird et al 2010), implying a possible improvement of the crop's N use efficiency (Steiner et al 2008, Widowati et al 2011). Islami et al (2011) observed that, after 3 years of applying biochar, soil N content increased. However, this increase was not directly attributed to biochar application but to the resulting reduction of nutrient loss from the applied fertilizer. This indicates possibilities regarding the use of biochar in the soil and the application dosage of inorganic fertilizers. Our study aimed to evaluate the effect of biochar on maize production and to test the hypothesis that application dosage of inorganic fertilizer can be reduced through biochar application.

Materials and methods

Experiment site

The field experiment was conducted in 2009 on a farmer's upland field in Wringinrejo, Blitar, about 60 km southwest of Malang, East Java, Indonesia (08° 05′ S, 112° 02′ E; 117 m altitude). The experimental plots had two treatments: with (15 t ha^{-1}) and without biochar. Monocropping of cassava (*Manihot esculenta*) was done in 2009 and 2010; a mixed crop of cassava and maize (*Zea mays* L.) was used in 2011.

Design of field experiment

The experiment had a split-plot design with four replications. The main plot was biochar application (with and without biochar) and the subplot is N rate (0, 45, 90, and 180 kg N ha^{-1}). The biochar used for the experiment was made from farmyard manure (FYM) using a simple method proposed by Sukartono et al (2011). The chemical properties of FYM biochar and the soil with/without biochar are shown in Table 1. Treatments involved N application with and without FYM biochar. Biochar (15 t ha^{-1}) was applied simultaneously with land preparation for the first-year crop (2009). Nitrogen fertilizer was applied (1/3 each) at basal, 30 d after transplanting, and 60 d after transplanting. Phosphorus and potassium were applied basally at 100 kg SP36 ha^{-1} and 100 kg KCl ha^{-1}, respectively. Maize was sown on 2 December 2011 and harvested on 26 April 2012.

Sampling and data analysis

The data collected were aboveground biomass at harvest, grain yield, and soil properties before and after the experiment. Two soil samples (taken from a depth of 20 cm) of about 0.5 kg each were collected from each plot and then mixed; from this, a subsample of about 0.5 kg was takend for laboratory analysis.

The soil data analyzed were as follows: pH (H_2O) measured by pH meter (Jenway 3305); organic carbon determined by the Walkley and Black method (USDA 1992); total N analyzed by Kjeldahl method (Bremner and Mulvaney 1982); available P extracted by Bray II using a UV spectrophotometer (model Vitatron); CEC extracted with 1 M NH_4Oac (buffered at pH 7.0), and exchangeable K measured using an atomic absorption spectrophotometer (Shimatzu). Aboveground biomass was measured after drying in a mechanical oven dryer at 80 ^{o}C until a constant weight was reached. Total N in the plant was measured through wet sulfuric acid digestion (Horneck and Miller 1998) and N content in the sample was determined by Kjeldahl method. Nitrogen fertilizer use efficiency was calculated using the following equation: T2,3,4

$$F_{eff}(\%) = \frac{\text{(N uptake in the treatment} - \text{N uptake in the control)}}{\text{Applied N}} \times 100$$

For statistical analysis, ANOVA was used and LSD was calculated to determine any significant difference at the 5% probability level.

Results and discussion

There was a significant effect of interaction between biochar application and N rate on crop growth, yield, N use efficiency, and soil properties (Tables 2, 3, and 4). The results given in Table 2 show that N application enhanced plant growth and crop yield—plants became taller and stover yield became higher as N dosage was increased.

When there was no N, maize grown on biochar-treated soil was taller and its stover yield higher than that of maize grown on nontreated soil. This result was also observed at the N dose of 45 kg ha^{-1}. However, at high N rates in both soils, the difference in plant height was not significant, whereas stover yield differed significantly. Between 90 and 180 kg N ha^{-1}, maize grown on biochar-treated soils did not have significant differences in plant height, stover, and grain yield, indicating that nutrient supply for plant growth was similar to each other.

Table 1. Characteristics of FYM biochar and the soil[a] used in the experiment.

Material	pH	Organic C (%)	Total N (%)	Bray II P (%)	Exchangeable K (%)	CEC (cmol kg^{-1})
FYM biochar	7.9	25.55	0.78	0.82	0.79	17.73
Soil without FYM biochar	6.9	0.91	0.08	8.04	1.73	10.76
Soil with FYM biochar	7.1	1.90	0.14	10.47	1.96	15.55

[a]P and K in the soil are expressed in ppm and cmol kg^{-1}, respectively.

Table 2. Effect of N application on plant height, dry biomass, and grain yield of maize grown under two soil amendment treatments.

Soil amendment	Nitrogen rate (kg N ha^{-1})	Plant height (cm)	Stover (Mg ha^{-1})	Grain yield (14% ww) (Mg ha^{-1})
Without biochar	0	156.27 a	2.45 a	2.53 a
	45	169.22 bc	3.27 bc	3.22 b
	90	171.46 bc	4.14 cd	4.17 bc
	180	175.38 c	5.02 ef	4.95 de
With biochar	0	168.54 b	3.14 b	3.22 a
	45	176.87 c	4.57de	4.62 cd
	90	175.65 c	5.65 fg	5.96 ef
	180	177.48 c	6.16 g	6.12 f

[a]In a column, means followed by the same letter are not significant at the 5% probability level.

Table 3. Effect of N application on N uptake and fertilization efficiency under different soil amendment treatments.[a]

Soil amendment	N rate (kg ha^{-1})	N in the stover (%)	N in the grain (%)	Total N uptake (kg ha^{-1})	F_{eff} (%)
Without biochar	0	0.65 a	0.98 ab	37.73 a	-
	45	0.72 ab	1.05 c	53.29 b	34.57 a
	90	0.74 ab	1.02 bc	75.06 c	41.47 ab
	180	0.86 c	1.10 d	91.08 d	29.63 a
With biochar	0	0.70 ab	0.96 a	56.54 b	-
	45	0.76 b	0.98 ab	74.57 c	81.86 c
	90	0.86 c	1.14 d	108.37 e	78.49 c
	180	0.95 d	1.13 d	119.37 e	45.35 b

[a]Mean values followed by the same letter in the same column imply no significant difference at the 5% level of probability.

Table 4. Soil chemical properties of biochar-treated and nontreated soils after harvest.[a]

Soil amendment	N rate (kg N ha^{-1})	Organic C (%)	Total N (%)	Available P (ppm)	CEC (cmol$_c$ kg^{-1})	Exchangeable K (cmol$_c$ kg^{-1})
Without biochar	0	0.85 a	0.08 a	9.47 a	11.45 a	1.55 a
	45	0.93 a	0.09 ab	9.89 a	10.95 a	1.70 a
	90	0.91 a	0.08 a	8.94 a	10.73 a	1.73 a
	180	0.97 a	0.08 a	9.48 a	11.47 a	1.69 a
With biochar	0	1.89 b	0.11 b	9.36 a	13.26 b	1.76 a
	45	2.09 b	0.13 bc	9.98 a	15.06 b	1.80 a
	90	1.90 b	0.12 bc	10.17 a	14.30 b	1.65 a
	180	2.04 b	0.15 c	10.05 a	13.59 b	1.73 a

[a]Mean values with the same letter in the same column imply no significant difference at the 5% probability level.

Figure 1 shows the yield response of maize with and without biochar application. The grain yield of maize without biochar increased linearly while that with biochar showed a quadratic curve, which meant almost the same amount of yield at 90 and 180 kg N ha^{-1}. This implies that higher grain yield is achievable with lower fertilizer dosage when biochar is applied and that yield is still better than that of nonbiochar-treated soils. This confirms the findings reported by Steiner et al (2007).

Fertilizer use efficiency (F_{eff}) values are shown in Table 3. Nitrogen fertilization on biochar-treated soil resulted in a significantly higher total N uptake compared with nonbiochar-treated soil and, eventually, F_{eff} was significantly higher than that of nonbiochar-treated soil. Better F_{eff} ensured higher yield in biochar-treated soils than in nonbiochar-treated soils (Fig. 1). This supports previous studies (Laird et al 2010, Widowati et al 2011) that showed reduced N losses from biochar-treated soils.

The treatments with and without biochar showed a significant difference (Table 3). F_{eff} increased at first with the increase in N up to 90 kg N ha^{-1}, but when the N dosage reached maximum, its value decreased. On the other hand, the treatment with biochar showed a constantly decreasing F_{eff} along with the increase in N. The results shown in Table 4 indicate that total N in nonbiochar-treated soil was significantly lower than that in biochar-treated soil after harvest. Total N for biochar-treated soil was not significantly different among 0, 45, and 90 kg N ha^{-1} and it was similar to the initial concentration. On the other hand, the difference between 0 and 180 kg N ha^{-1} was significant and the biochar-treated soil with 180 kg N ha^{-1} showed more N remaining in the soil after harvest. This implies that N dosage at 180 kg N ha^{-1} is more than what is required for plant growth with biochar present in the soil and that the unused N, unlike that in the control soil, was absorbed by biochar.

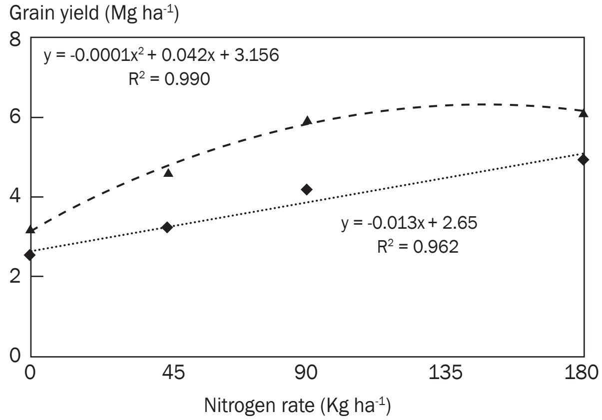


Fig. 1. Relationship between N dose and maize grain yield on biochar-treated (▲) and nonbiochar-treated (♦) soil.

Conclusions

The effect of biochar was observed and the N application dosage reviewed to evaluate the effect of biochar on fertilizer use efficiency in maize. Yield was higher when maize was grown on biochar-treated soils. With biochar application, yields obtained with fertilization rates between 90 and 180 kg N ha^{-1} were similar to each other; less N was used to obtain the same level of yield, which was achieved at maximum dosage. Unused N at maximum dosage was absorbed into the soil because of biochar. The results imply that biochar can play a role in lowering N dosage for maize production. Further studies should be done to know if the absorbed N can be saved for the next cropping.

References

Bremner JM, Mulvaney CS. 1982. Nitrogen-total. In: Page AL, Miller RH, Keeney DR (eds.). Methods of soil analyses. Part 2. Chemical and mineralogical properties. Madison: American Society of Agronomy and Soil Science Society of America, Inc.

Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol. Appl. 8: 559–568.

Chan KY, Van Zwieten BL, Meszaros I, Downie D, Joseph S. 2008. Using poultry litter biochars as soil amendments. Austr. J. Soil Res. 46: 437–444.

Dinnes DL, Karlen DL, Jaynes DB, Kaspar TC, Hatfield JL, Colvin TS, Cambardella CA. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agron. J. 94: 153–171.

Fageria NK, Baligar VC. 2005. Enhancing nitrogen use efficiency in crop plants. Adv. Agron. 88: 97–185.

Glaser B, Haumaier L, Guggenberger G, Zech W. 2001. The 'Terra Peta' phenomenon: a model for sustainable agriculture in the humid tropics. Naturwissenschaften 88: 37–41.

Haynes RJ, Naidu R. 1998. Influence of lime, fertilizer and organic manure on soil organic matter application and soil physical conditions. Nutr. Cycl. Agroecosyst. 51: 123–137.

Horneck DA, Miller RO. 1998. Determination of total nitrogen in plant tissue. In: Karla YP (ed.). Handbook of reference methods for plant analysis. p 75–83.

Islami T, Guritno B, Nurbasuki, Suryanto A. 2011. Maize yield and associated soil quality changes in cassava + maize intercropping system after 3 years of biochar application. J. Agric. Food Technol. 1: 112–115.

Laird D, Fleming P, Wang B, Horton R, Karlen D. 2010. Biochar impact on nutrient leaching from a midwestern agricultural soil. Geoderma 158: 436–442.

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

Liang B, Lehmann J, Kinyangi D, Grossman J, O'Neill B, Skjemstad JO, Thies J, Luizao FJ, Peterson J, Neves EG. 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J. 70: 1719–1730.

Liu E, Changrong Y, Xurong M, Wenqing H, So HB, Linping D, Qin L, Shuang L, Tinglu F. 2010. Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China. *Geoderma* 150: 173–180.

Logsdon SD, Kaspar TC, Meek DW, Prueger JH. 2002. Nitrate leaching as influenced by cover crops in large soil monoliths. Agron. J. 94: 807–814.

Masulili A, Utomo WH, Syekhfani Ms. 2010. Rice husk biochar for rice-based cropping system in acid soil. 1. The characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia. J. Agric. Sci. (Canada) 3: 25–33.

Rondon MA, Lehmann J, Ramirez J, Hurtado M. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with biochar additions. Biol. Fertil. Soils 43: 699–708.

Sukartono, Utomo WH, Kusuma Z, Nugroho WH. 2011. Soil fertility status, nutrient uptake, and maize (*Zea mays* L.) yield following biochar application on sandy soils of Lombok, Indonesia. J. Trop. Agric. 49: 47–52.

Steiner C, Teixeira WG, Lehmann J, Nehls T, de Macêdo JLV, Blum WEH, 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 Soil 291: 275–290.

Steiner C, Glaser B, Teixeira WG, Lehmann J, Blum WEH, Zech W. 2008. Nitrogen retention and plant uptake on a highly weathered central Amazonian Ferralsol amended with compost and charcoal. J. Plant Nutr. Soil Sci. 171: 893–899.

USDA (United States Department of Agriculture). 1992. Manual on soil survey laboratory methods. Soil Survey Investigation Report No. 42. Version 2.0. Washington, D.C.: USDA.

Warnock DD, Lehmann J, Kuyper TW, Rillig MC. 2007. Mycorrhizal responses to biochar in soil—concepts and mechanisms. Plant Soil 300: 9–20.

Widowati, Utomo WH, Soehono LA, Guritno B. 2011. Effect of biochar on the release and loss of nitrogen from urea fertilization. J. Agric. Food Technol. 1: 127–132.

Woolf D. 2008. Biochar as a soil amendment: a review of the environmental implications. http://orgprints.org/13268/1/Biochar_as_a_soil_amendment_-_a_review.pdf. Retrieved 2 October 2008.

Notes

Authors' address: Wani Hadi Utomo (wanihadi@ub.ac.id) and Titiek Islami, International Research Centre for Management of Degraded and Mining Lands, University of Brawijaya, Malang, Indonesia.

Use of biochar to improve soil characteristics and increase rice yield in swamplands

D. Nursyamsi, E. Maftuah, I. Khairullah, and Mukhlis

A swampland is a suboptimal land that has high potential in Indonesia. About 9.5 million ha has great potential for agricultural use. If a suitable management approach is applied to swampland development, it would significantly contribute to food security in Indonesia. Peat and acid sulfate soils predominate in the swampland. Some characteristics of peat soil that constrain agricultural development are its low pH, irreversible drying, low nutrient content, high organic acid content (which is toxic to plants), and easily degradable soil fertility. Meanwhile, acid sulfate soils are low in pH (3-5), release toxic elements (Fe) because of reduced condition, and low in fertility. Biochar can be used as an ameliorant to increase swampland productivity because it can increase soil pH, water retention, and soil biological activity in addition to reducing environmental problems. Results showed that biochar, combined with chicken manure, could improve some properties of peat and acid sulfate soils. In peat soil, application of biochar (6.25 t ha^{-1}) + chicken manure (1.25 t ha^{-1}) increased soil pH and available soil K, whereas in acid sulfate soil, biochar (5 t ha^{-1}) + chicken manure (0.5 t ha^{-1}) did not only increase soil pH and available soil P but also decreased soluble Fe and iron toxicity symptoms of the rice plant. The improvement in soil properties resulted in an increase in growth and yield of rice.

Keywords: biochar, soil characteristics, crop yield, swampland

Indonesia has about 33.43 million ha of swampland. About 9.5 million ha of this is suitable for agriculture and, so far, 5 million ha had been developed (Widjaja Adhi et al 1992). Judicious use of swampland amidst existing constraints may optimize the role of this ecosystem for productive and sustainable land development and management.

Swamplands are classified into three: acid sulfate soil, peat soil, and saline soil. A pyrite (FeS_2) layer in the soil surface is one of the main characteristics of these soil types. When pyrite is exposed to air (for example, upon drainage of formerly inundated lands as seen in large parts of Kalimantan), sulfides are oxidized to Fe(III) sulfates, and sulfuric acid is generated. This process results in soil acidification, rendering these soils marginally suitable for agriculture: low pH levels and presence of elements such as aluminum, iron, and manganese, which can become highly toxic to crops, result in declining crop yields. When these soils are used for rice, the most significant constraints are the (1) acidity (which includes the combined effects of pH, Al toxicity, and P deficiency) and (2) Fe stress (which is due to the combined effect of Fe toxicity and deficiencies of other divalent cations such as Ca) (Moore et al 1990). In many cases, soil pH has already declined to less than 4, and, as a result, farmers are forced to burn standing biomass to improve soil quality.

Although this practice offers some temporary improvement in crop production, it has significant environmental impacts. During dry months, farmers find it hard to control wildfire, which may turn into large-scale devastation. The current situation makes it difficult to develop alternative sources of livelihood for communities depending on acid soils. Many options prove to be not effective, even at the farm experimental level. For example, liming is too expensive in this situation. An innovative approach is needed to improve soil quality and crop production while reducing the risk of wildfire. The approach needs to be sustainable, cheap or entails no cost at all, based on traditional practices and locally available technology, and fully accepted by farmers.

One of the possibilities is the use of charcoal. Biochar is the charcoal product obtained when biomass is heated without oxygen access. In contrast to other biomass or compost, biochar is stable for hundreds and thousands of years when mixed into the soil, and thus its carbon is removed from the carbon cycle (Lehmann 2007, Renner 2007). Biochar provides a unique opportunity to improve soil fertility and nutrient-use efficiency using locally available and renewable materials in a sustainable way. Adoption of biochar management does not require new resources but makes use of existing resources in a more efficient and more environmentally conscious manner. Biochar is able to play a major role in expanding options for sustainable soil management by improving upon existing best management practices, not only to improve soil productivity but also to decrease the environmental impact on soil and water resources. Biochar should therefore not be seen as an alternative to existing soil management, but rather a valuable addition that facilitates the development of sustainable land use (Lehmann 2007).

Biochar has a number of advantages: (1) storing carbon in the soil and thus avoiding carbon dioxide (CO_2) release (Lehmann et al 2006, Laird 2008); (2) reducing nutrient leaching by increasing the soil's buffering capacity (Liang et al 2006); (3) reducing soil acidity (biochar is alkaline when synthesized under proper conditions) (Van Zwieten et al 2010), which is especially important in the current context; (4) reducing pesticide runoff and organic pollutant bioavailability since pesticides are strongly bound by biochar; (5) reducing the formation of other greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4) (Randon et al 2005, Yanai et al 2007, Spokas and Reicosky 2009, Clough et al 2010). For example, N_2O emission reductions of 50-80% in soybean plantations and grass stand and a nearly complete suppression of CH_4 upon 2% biochar addition to the soil were observed. The mechanism leading to reduced emission of N_2O and CH_4 is probably increased soil aeration, reducing the extent of anaerobic denitrification and methanogenesis, respectively (Lehmann 2007, Glaser et al 2002, Renner 2007, Rondon et al 2007, Cornelissen et al 2005).

A few scattered studies indicate that biochar amendment can result in significant soil improvement. Work in Indonesia on Sumatra (Yamato et al 2006) and Kalimantan (Masulili et al 2010) in similar ecosystems with bark biochar and rice husk biochar, respectively has shown doubling of yields for maize, cowpea, peanuts (Yamato et al 2006), and rice (Masulili et al 2010), attributable to the strong reductions in soil acidity and available toxic aluminum, accompanied by increases in available phosphate and calcium.

This paper reports some research results on biochar application in swampland and its effects on soil characteristics and plant yield.

Characteristics of swampland

Swampland island that is saturated or waterlogged for a long period or year-round and has mud in parts of the soil surface. It is distributed in lowland areas between coastal and swale or lagoon or the sea. In its natural condition, before it is opened for agriculture, a swampland is covered with mangrove, weeds, or forest vegetation. The swampland areas in Indonesia are mainly in Sumatera, Kalimantan, Papua, and Sulawesi islands, occupying 33.41 million ha consisting of tidal swamp (20.13 million ha) and back swamp (13.28 milliom ha).

Tidal swampland comprises that part of the coastal plain where inundation and drainage are determined by tidal fluctuations in the sea or in a large river. Along the sea or in the mouth of the river, frequent flooding occurs throughout the year at high tide. Water level in the tidal swampland rises as the rainy season starts, usually in October, and reaches its maximum in January or February. Subsequently, it declines in March or April and remains stagnant until June. The water table drops when the dry season arrives.

Tidal swamps have unique characteristics as they are influenced by water movement because of changing sea tides. The water depths in tidal swamps are controlled by tides as well as by rainfall. Based on the prevailing water levels in the fields, tidal swamplands can be classified into four: types A, B, C, and D (Widjaja-Adhi et al 1992).

- Type A—directly affected by sea tides; always flooded during spring and neap tides; water depth fluctuates by as much as 2.5 m within 24 h near the rivers during spring tide
- Type B—directly influenced by sea tides but flooded only during spring tide
- Type C—never flooded and thus are only influenced indirectly by sea tide; tides indirectly affect them by water infiltration through the soil; water levels affected more by rainfall than by tides; groundwater table is less than 50 cm from the land surface
- Type D—not affected by sea tides; no water infiltration occurs through the soil; groundwater table is deeper than 50 cm below the land surface

A back swamp is land that is far from the sea; its water regime is not affected by tides. Based on height and period of flooding, Widjaja-Adhi et al (1992) classified back swamps into shallow, medium, and deep. In terms of typology, swamplands are classified into peat land, acid sulfate land, and saline land. Peat and acid sulfate soils are the dominant soils in this ecosystem.

Peat soil

Peat soil is a common term that describes any wetland that accumulates soil organic material from partially decayed plant matter. Based on depth/thickness, peat soil could be split up into shallow peat (peat thickness, 50-100 cm), moderately deep peat (peat thickness 100-200 cm), deep peat (peat thickness, 200-400 cm), and very deep peat (peat thickness > 400 cm). Aside from that, based on maturity, peat soils are divided into fibrists (less decomposed), hemists (half-decomposed), saprists (highly decomposed), and mixed with any one of the three kinds of peat (Wahyunto et al 2010).

Peat soil has high water-holding capacity. This condition is related to organic material content, which is more than 70%, and porosity, which is more than 80%. Saprists have water-holding capacity less than 450%; hemists, between 450 and 850%, and fibrists, more than 850% (Notohadiprawiro 1997). Peat can retain considerable quantities of water—i.e., fibrists retain water 4.5–20 times its dry matter while saprists retain from 4.5 to 8.5 times (Hardjowigeno 1997). However, if dried to the extent that adsorptive water is lost, irreversible changes occur in the colloidal component of the peat, resulting in a marked and permanent reduction of the water retention capacity.

The porosity of peat soil is very high (80-95%), with bulk density ranging between 0.05 and 0.25 g/cm^3. This porosity is related to decomposition; highly decomposed peat has porosity lower than that of less decomposed peat. The porosity of fibrists is about 88.0%, while that of saprists is about 82.6% (Supriyo and Maas 2005).

Most peat soils are acidic (low pH) because of organic acid hydrolysis. Fulvic and humic acid are dominant in peat soil (Widjaja-Adhi 1988, Rachim 1995). Organic acid has a significant contribution to decreased soil pH (Charman 2002). Low soil pH affects the availability of nutrients, especially that of P, K, Ca, and the micronutrients (Marschner 1986).

The rate of cation exchange capacity (CEC) of peat soil is very high, between 100 and 300 cmol kg^{-1} based on soil dry weight (Hartatik and Suriadikarta 2006). This high CEC causes a response on the basis of the acid-base reaction in soil solution. To achieve balance, more reactors (ameliorants) are needed. However, as it relates to very low weight of peat soil, the rate of amelioration per area must be multiplied with a correction factor as much as 0.15-0.20 g cm^{-3} (Maas 1997).

The fertility of peat soil depends on the soil layer underneath, but generally it is unfertile. Peat soil fertility also depends on land typology. Peat soil in the back swamp is more fertile than that in the tidal swamp.

Back swamp has high soil pH, low organic C, and high base consentration (Ca, Mg, and K) (Noor et al 2005, 2007). Besides, back swamps get nutrients from sedimentation at the time of flooding. This condition causes peat soil fertility in back swamps to be better than that in tidal swamps.

Ash content can be used to determine peat fertility (Kurnain 2005). Ash content of oligotropic peat soil is generally less than 1%, except on burned peat or intensively cultivated peat, which achieves 2-4% (Adi Jaya et al 2001). The thicker the peat soil is, the lower its ash content.

Acid sulfate soil

Acid sulfate soils are divided into potential and actual (Widjaja-Adhi et al 2000). Potential acid sulfate (SMP) soils are classified as Entisol in Sulfaquents, i.e., land or soil that has (1) sulfidic materials (pyrite) at depths of 0-100 cm of the soil surface and (2) pH >3.5 (gets higher with soil depth). Actual acid sulfate (SMA) soils are classified as Inceptisol in Sulfaquepts, i.e., land or soil with (1) soil pH <3.5 and (2) a sulfuric horizon due to the oxidation of pyrite with excessive drainage (Subagyo 2006).

Acid sulfate soil is composed of marine sediments, characterized by one or more of the following 1) sulfidic material (pyrite) 2) sulfuric horizon 3) spots of jarosite, and 4) a neutralizing agent in the form of carbonate or other bases. Pyrite is formed through a series of chemical, geochemical, and biochemical processes. Sulfate ions contained in seawater are deposited on coastal plains and partly protrude into the tidal zone, which is a silicate of iron in the soil parent material bound with sulfate to form pyrite at pH around 7 and at 200 mV Eh (Van Breemen and Pons 1978, Dent 1986). Maas (2003) states that pyrite is stable at Eh ≤200 mV; its oxidation increases Eh to ≥100 mV, thus forming sulfuric acid and ferrous sulfate and causing a rise in acidity (pH <3.5).

Physicochemical properties of acid sulfate soil include soil color, maturity, permeability, acidity, salinity, toxicity, and nutrient deficiency (Van Breemen and Pons, 1978). Generally, it has dark brown color in the top layer and a gray undercoat indicating the presence of pyrite (Van Breemen, 1982). Maturity ranges from <0.7 (mature) for developed soil and >0.2 (raw) for young soil (Dent 1986). Soil permeability is slow to very slow. The more mature, the higher the permeability of the soil (Hamming et al 1990).

Acid sulfate soils with pH >4 belong to the Entisol group, while those with pH <3.5 are Inceptisols. Solubility of sulfate is followed by an increase in salinity. Toxicity of Fe, Al, H_2S, CO_2, and organic acids may occur in the soil. Iron in acid sulfate soil can be toxic to plants in the form of Fe^{2+}, especially in waterlogged conditions (Van Breemen and Pons 1978). The nutrient availability of P, Cu, Zn, and B is generally low. P availability is commonly low to very low because the P is bound to Al and Fe to form Al-P and Fe-P compounds (Moormann and van Breemen 1978). The micro elements Cu, Zn, and B in organic soil become deficient due to formation of organometal compounds. The negative charge (COO^-) of organic acids or amino acids can bind metal cations on a clay surface (Tan 1998).

The chemical processes that occur in acid sulfate soil are reduction and oxidation. The reduction process consists of pyrite formation, reduction of Fe^{3+} to Fe^{2+} and reduction of toxic compounds, whereas the oxidation process is pyrite oxidation that produces H^+ ions, jarosite, and sulfate.

Reduction process. Flooding events cause the following: (a) increase in soil pH, slowly and rarely exceeds pH 6 after 6 mo of flooding; (b) slow decrease in redox potential (Eh); (c) increase in dissolved Fe^{2+} reaching hundreds or thousands of mg kg^{-1}; (d) decrease in dissolved Al as pH increases; and (e) an increase in soil pH due to reduction of soil. SO_4^{2-} decreases in sulfate soil, nearly rare after 3-6 mo of flooding, but more quickly if soil is limed to pH >5. The increase in pH during flooding is caused by the reduction of ferric oxides to Fe^{2+} where the process consumes H^+ ions (Van Breemen and Pons 1978).

In flooded conditions, oxygen in the soil is slowly reduced. Decomposition of organic matter by anaerobic bacteria persists by exploiting the released electrons in the reduction of NO_3^- to N_2, MnO_2 to Mn^{2+}, $Fe(OH)_3$ to Fe^{2+}, and SO_4^{2-} to H_2S. Sulfide, which is formed immediately, reacts with Fe^{2+} to form ferro-sulfide compounds (Dent 1986).

Pyrite formation requires a stagnant environment, dissolved sulfate, organic matter and iron, and time (Dent 1986). The stages of pyrite formation are (a) reduction of sulfate to sulfide, (b) oxidation of sulfide to polysulfides partially, (c) reduction of Fe^{3+} to Fe^{2+}, (d) formation of iron monosulfide (FeS) from dissolved Fe^{2+}, and (e) formation of pyrite (Pons et al 1982, Dent 1986, Kyuma 2004). The whole reaction of pyrite formation is

$$2\,FeS_2\,(s) + 8\,HCO_3\,(aq) + 4\,H_2O\,(l) \rightarrow Fe_2O_3\,(s) + 4\,SO_4^{2-}\,(aq) + 8\,CH_2O + \tfrac{1}{2}\,O_2\,(g)$$

Flooding will increase soil pH to 6-7 after 2 wk and reduction of Fe^{3+} to Fe^{2+} occurs (Patrick and Reddy 1978). According to Dent (1986), young acid sulfate soil, which is rich in colloidal iron, gets high levels of dissolved Fe^{2+} after flooding. Reduction of Fe^{3+} oxide with organic material (electron donors) will consume four protons:

$$2\,Fe^{2+} + CO_2^{+\frac{1}{2}} + 5/2\,H_2O \rightarrow Fe_2O_3 + CH_2O + 4\,H^{+\frac{1}{2}}$$

The reduction of sulfate to sulfide occurs at pH >4-5, on young and old stagnant acid sulfate soil, Eh -0.12 V and -0.19 V at pH >5.0 or more acidic reaction (i.e., pH from 2.8 to 3.4) (Konsten et al 1990).

Oxidation process. Pyrite oxidation can occur with reclamation of wetlands or with a large difference between the ebb and flow of sea water during a long dry season. Pyrite initially begins in stagnant conditions, gradually turning into a toxic element and a source of natural soil acidity (Suriadikarta and Setyorini 2006). Pyrite oxidation reaction with oxygen in acid sulfate soil takes place in several stages, including chemical and biological reactions (Dent 1986, Van Breemen and Pons 1978, Kyuma 2004).

$$FeS_2 + 15/4\,O_2 + 7/2\,H_2O \rightarrow Fe(OH)_3 + 2\,SO_4^{2-} + 4\,H^+$$

If pH <3, Fe^{3+} becomes soluble and pyrite will oxidize quickly. The reaction is

$$FeS_2 + 14\,Fe^{3+} + 8\,H_2O \lozenge 15\,Fe^{2+} + 2\,SO_4^{2-} + 16\,H^+$$

The speed of pyrite oxidation tends to increase with decreasing soil pH. The decrease in soil pH rate due to oxidation of pyrite depends on the number of pyrite, oxidation rate, oxide material changes, and speed and capacity of neutrality. Calcium carbonate and exchangeable bases are materials that neutralize acidity and react with sulfuric acid (Van Breemen 1993 in Suriadikarta and Setyorini 2006).

Results of pyrite oxidation. Oxidation of pyrite by Fe^{3+} produces H^+ ions, jarosite, and sulfate. H^+ ions, then, are partly used again in the oxidation process of Fe^{2+} to Fe^{3+} by oxygen with *Thiobacillus ferrooxidans*. The end of pyrite oxidation results in Fe^{3+} hydroxide. At pH >3, Fe^{3+} hydroxide will precipitate, for example, in the form of goetit, which will eventually turn into hematite (Dent 1986). The resulting H^+ ions cause the soil to become very acidic with soil pH ranging from 3.2 to 3.8. Jarosite $[KFe_3(SO_4)_2(OH)_6]$ is a pale yellow precipitation and pyrite oxidation results in very acidic conditions with pH <3.7 and Eh >400 mV (Van Breemen 1976). Sulfate is very little absorbed by the soil colloid. Most of the sulfur is dissolved or lost with drainage water into the underlying soil and will be reduced back to sulfide (Dent 1986).

Role of biochar to increase peat land productivity

The effectiveness of biochar in peat soil can be increased through addition of other organic matter high in nutrients. It can thus be used not only as ameliorant but also as fertilizer. Analytical results show that biochar made from coconut shell has a water retention capacity of 25.30%, 1.92% total N, 0.07% total P, 0.08% total K, 25.60% organic C, 0.68% bulk density, and 63.30% porosity. Rice husk biochar has pH 6.7 and 0.68% total N (Balittra 2012). The nutrient content of biochar is affected by the kind of materials and processing method used, especially temperature and time (Lehmann and Joseph 2009).

Research conducted on peat soil of South Kalimantan showed that biochar, combined with chicken manure (F2), as many as 7.5 t ha^{-1}, could increase rice growth and yield compared with a control (without biochar) and combinations of chicken manure + *purun tikus* weed (F3) treatments (Table 1). Based on soil analysis, the F2 treatment had the most available K compared with the F3 and control treatments. F2 also had the highest pH (Table 2).

Several studies have shown that the use of biochar increased soil nutrient content and plant productivity; one was that of Glaser et al (2002). Masulili et al (2010) reported an increase in soil pH and available P, K, and Ca in the soil. However, the specific mechanism behind biochar's contribution to better plant performance in peat soil is still not widely investigated. The direct effect of biochar is nutrient release, while the indirect effect is improvement of nutrient retention capacity, soil pH, soil CEC, soil physics, and microbe populations (Steiner 2007, Duku et al 2011).

Role of biochar to increase acid sulfate soil productivity

Biochar application, combined with chicken manure (Biodetox 4), on acid sulfate soil could increase soil pH, although the highest increase was shown by Biodetox 3 treatment (combination of rice straw, *purun tikus* weed, dolomite, and chicken manure). Redox potential (Eh) increased with Biodetox 4 treatment of rice variety Impara 1, while soil Eh decreased in Impara 3 and Banyuasin (Fig. 1). However, the soil was in an oxidative condition as shown by the positive value of Eh. Impara 1 has iron toxicity tolerance, while Impara 3 has moderate tolerance for iron toxicity and submergence. Banyuasin is also moderately tolerant of iron toxicity.

Available P in the soil was affected by Biodetox treatment, except for Biodetox 1. For all rice varieties, application of Biodetox 4 increased the amount of available P in the soil, but the highest increase was shown by

Table 1. Effects of ameliorants on the growth and yield of rice in peat soil, Landasan Ulin, South Kalimantan, 2012 dry season (Balittra 2012).

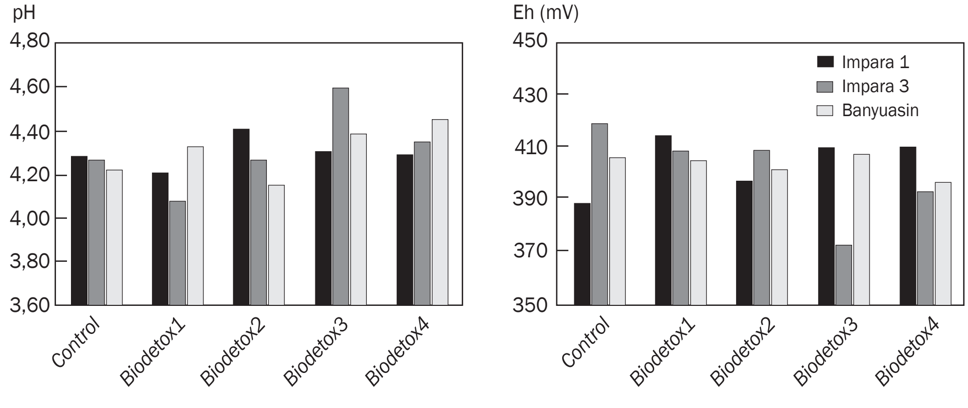
Treatment[a]	Plant height (cm)	Tillers (no.)	Dry weight (g plant^{-1})	100-grain weight (g)	Yield (t ha^{-1})
F1	87.55 a	15.43 a	28.87 a	2.55	3.58
F2	84.98 a	13.32 ab	25.02 ab	2.80	3.42
F3	84.45 a	12.22 ab	20.53 b	2.67	3.17
Control	74.23 b	8.66 b	12.23 c	2.80	3.00

[a]F1 = 2.5 t ha^{-1} chicken manure + 2.5 t ha^{-1} *purun tikus* weed + 2.5 t ha^{-1} agricultural weeds; F2 -= 1.25 t ha^{-1} chicken manure + 6.25 t ha^{-1} biochar); F3 = 0.7 t ha^{-1} chicken manure + 6.8 t ha^{-1} *purun tikus*).

Table 2. Effects of ameliorants on soil characteristics of peat soil during the plant's maximum vegetative stage, Landasan Ulin, South Kalimantan, 2012 dry season (Balittra 2012).

Treatment[a]	pH H_2O	Ntotal (%)	K-dd (cmol(+) kg^{-1})	P-Bray 1 (ppm P_2O_5)	Fe (ppm)
F1	3.55	1.82	3.84	51.69	165
F2	3.58	1.78	2.27	23.93	61
F3	3.50	1.82	1.26	101.95	67
Control	3.33	1.68	0.65	11.43	342

[a]See Table 1 for treatment descriptions.



Note: Biodetox 1 = 5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.1 t ha^{-1} dolomite + 0.1 t ha^{-1} chicken manure; Biodetox 2 = 5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure; Biodetox 3 = 5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure; Biodetox 4 = 5 t ha^{-1} biochar.

Fig. 1. Effects of ameliorants on soil pH and Eh of some rice varieties in acid sulfate soil.

Banyuasin, which is moderately iron toxicity-tolerant. This variety also showed the higher amount of available P than other varieties in the Biodetox 2 treatment. Impara 3 had lower available P compared with the control for all Biodetox treatments, except for Biodetox 4 (Fig. 2).

Application of Biodetox 4 decreased the amount of soil Fe, especially in Banyuasin. Biodetox 1 and Biodetox 2 decreased the amount of soluble Fe in Impara 1, while the decrease of soluble Fe with Biodetox 3 is shown by Impara 3. According to Masulili et al (2010), application of biochar on acid sulfate soil could decrease exchangeable Al and Fe and increase soil porosity, pH, CEC, P, exchangeable Ca, and K. Iron toxicity symptoms observed on the leaves decreased in all Biodetox treatments. However, Biodetox 4 containing biochar showed the least iron toxicity symptoms (Fig. 3).

Rice growth (plant height, number of tillers, and dry weight of plant) increased with the application of Biodetox. Biodetox 4 increased plant height, especially those of Impara 3 and Banyuasin (Table 3). Biodetox 1 and 3 increased the number of productive tillers in all varieties; Biodetox 4 increased it only in Banyuasin (Table 4). The positive response of Banyuasin may be due to its moderate tolerance for iron toxicity. Total dry weight of plants in Biodetox-treated soil was higher than that in untreated soil (control) (Table 5).

On average, Biodetox 4 application could increase rice yield, although it was lower than that obtained from Biodetox 2 and 3 treatments (Table 6). The improved soil nutrient status through the application of biochar and other ameliorants resulted in an increase of rice yield in acid sulfate soil (Masulili et al 2010).

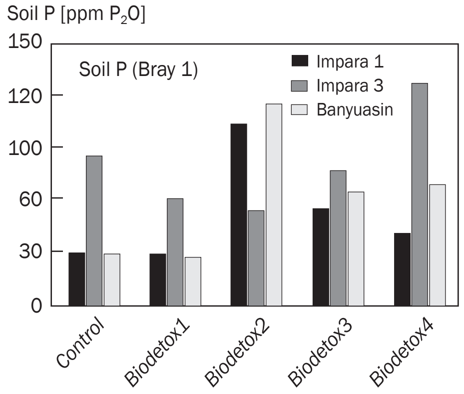


Fig. 2. Effect of ameliorants on soil P (Bray 1) content of some rice varieties in acid sulfate soil. (See Fig. 1 for biodetox treatment descriptions.)

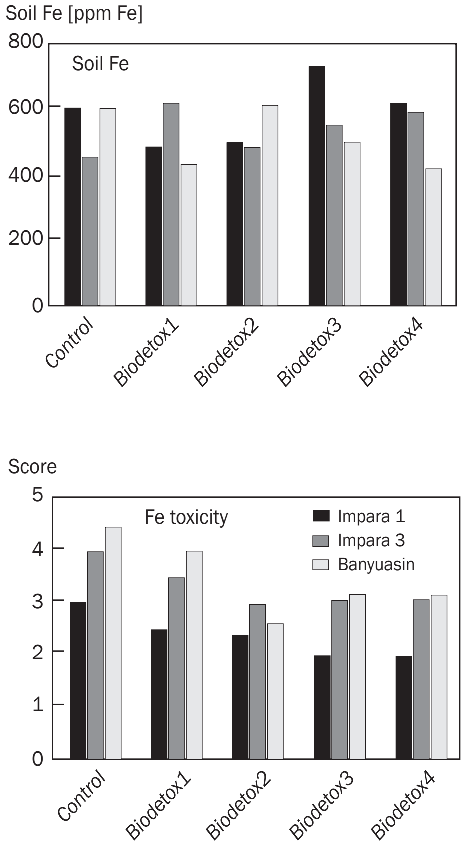


Fig. 3. Effects of ameliorants on soil Fe and iron toxicity symptoms of some rice varieties in acid sulfate soil. (See Fig. 1 for biodetox treatment descriptions.)

Conclusion

Biochar application combined with chicken manure could improve some properties of peat and acid sulfate soils. In peat soil, application of biochar (6.25 t ha^{-1}) and chicken manure (1.25 t ha^{-1}) increased soil pH and available soil K. In acid sulfate soil, biochar (5 t ha^{-1}) + chicken manure (0.5 t ha^{-1}) increased soil pH and available soil P and also decreased soluble Fe and iron toxicity symptoms of the rice plant. Improvement of soil properties resulted in an increase of rice growth and yield.

Table 3. Effect of ameliorants on plant height 90 d after planting of some rice varieties in acid sulfate soil (Balittra 2012).

Main plot	Subplot					Av
	Control	Biodetox 1	Biodetox 2	Biodetox 3	Biodetox 4	
Impara 1	74.4	68.5	76.0	81.4	72.7	74.6
Impara 3	74.0	76.8	79.5	79.3	81,.7	78.3
Banyuasin	74.3	73.5	81.0	79.1	74.8	70.5
Av	74.2	72.9	78.8	79.9	76.4	

Note: Biodetox 1 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.1 t ha^{-1} dolomite + 0.1 t ha^{-1}chicken manure); Biodetox 2 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure); Biodetox 3 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure); Biodetox 4 (5 t ha^{-1} biochar).

Table 4. Effect of ameliorants on number of productive tillers 90 d after planting of some rice varieties in acid sulfate soil (Balittra 2012).

Main plot	Subplot					Av
	Control	Biodetox 1	Biodetox 2	Biodetox 3	Biodetox 4	
Impara 1	9.53	9.27	8.27	10.87	8.53	9.29
Impara 3	8.27	8.60	7.33	9.07	7.87	8.23
Banyuasin	8.00	9.87	11.30	9.60	9.60	9.67
Av	8.60	9.24	8.97	9.84	8.67	

Note: Biodetox 1 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.1 t ha^{-1} dolomite + 0.1 t ha^{-1} chicken manure); Biodetox 2 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure), Biodetox 3 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure); Biodetox 4 (5 t ha^{-1} biochar).

Table 5. Effect of ameliorants on plant dry weight 90 d after planting of some rice varieties in acid sulfate soil (Balittra 2012).

Main plot	Subplot					Av
	Control	Biodetox 1	Biodetox 2	Biodetox 3	Biodetox 4	
Impara 1	81.7	95.0	68.3	116.7	78.3	88.0
Impara 3	78.3	80.0	66.7	76.7	73.3	75.0
Banyuasin	66.7	71.7	90.0	78.3	71.7	75.7
Av	75.6	82.2	75.0	90.6	74.4	

Note: Biodetox 1 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.1 t ha^{-1} dolomite + 0.1 t ha^{-1} chicken manure); Biodetox 2 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure); Biodetox 3 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure); Biodetox 4 (5 t ha^{-1} biochar).

Table 6. Effect of ameliorants on rice yield of some rice varieties in acid sulfate soil (Balittra 2012).

Main plot	Subplot					Av
	Control	Biodetox 1	Biodetox 2	Biodetox 3	Biodetox 4	
Impara 1	4.73	4.00	5.27	5.90	4.57	4.89
Impara 3	4.33	5.20	5.57	6.07	6.57	5.55
Banyuasin	4.77	4.80	5.63	5.70	4.73	5.13
Av	4.63	4.67	5.49	5.89	5.29	

Note:Biodetox 1 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.1 t ha^{-1} dolomite + 0.1 t ha^{-1} chicken manure); Biodetox 2 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure); Biodetox 3 (5 t ha^{-1} rice straw + 5 t ha^{-1} *purun tikus* weed + 0.2 t ha^{-1} dolomite + 0.2 t ha^{-1} chicken manure); Biodetox 4 (5 t ha^{-1} biochar).

References

Adi Jaya, Rieley JO, Artiningsih T, Sulistiyanto Y, Jagau Y. 2001, Utilization of deep tropical peatland for agriculture in Central Kalimantan. In: Rieley JO, Page SE (eds.). Proceedings of the Symposium on Peatlands for Natural Resources Function and Sustainable Management, Jakarta. Hal. 125–131.

Balithra. 2012. Laporan Hasil Penelitian. Badan Litbang Pertanian. Banjarbaru.

Charman D. 2002. Peatlands and environmental change. John Wiley & Sons., Ltd., England.

Clough TJ, Bertram JE, Ray JL, Condron LM, O' Callaghan M, Sherlock RR, Wells NS. 2010. Unweathered wood biochar impact on nitrous oxide emissions from a bovine urine-amended pasture soil. Soil Sci. Soc. Am. J. 74:852-860.

Cornelissen G, Gustafsson Ö, Bucheli TD, Jonker MTO, Koelmans AA, vanNoort PCM. 2005. Critical review: extensive sorption of HOCs to black carbon, coal and kerogen: mechanisms and consequences for sorption, bioaccumulation and biodegradation. Environ. Sci. Technol. 39: 6881-6895.

Dent DL. 1986. Acid sulphate soils: a baseline for research and development. International Livestock Research Institute,Wageningen, The Netherlands.

Duku MH, Gu S, Hagan EB. 2011. Biochar production potential in Ghana: a review. Renewable Sustainable Energy Rev. 15: 3539-3551.

Glaser B, Lehmann J, Zech W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal: a review. Biol. Fertil. Soils 35: 219-230.

Hamming SFJ, Kasi S, Vadari T, 1990. Soil permeability aspect in Pulau Petak, Kalimantan. In: Proceedings of the Workshop on Acid Sulphate Soils in the Humid Tropics, 20-22 Nov1990, AARD-LAWOO, Bogor, Indonesia. p 315-323.

Hartatik W, dan DA. Suriadikarta. 2006. Teknologi Pengelolaan Hara Lahan Gambut. *dalam* Karakteristik dan Pengelolaan Lahan Rawa. I. Las (ed). Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian. Bogor.

Hardjowigeno S.1997. Pemanfaatan gambut wawasan lingkungan. Alami 2(1):3-6.

Kurnain A. 2005. Dampak Kegiatan Pertanian dan Kebakaran atas Watak Gambut Ombrogen. *Disertasi* Program Pascasarjana UGM. Yogyakarta.

Kyuma K. 2004. Paddy soil science. Kyoto University Press (Japan) and Trans Pacific Press (Australia). 279 p.

Konsten CJM, Suping S, Aribawa IB, Widjaja-Adhi IPG. 1990. Chemical processes in acid sulphate soils in Pulau Petak, South and Central Kalimantan, Indonesia. . In: Proceedings of the Workshop on Acid Sulphate Soils in the Humid Tropics, Bogor, 20-22 November 1990. AARD and LAWOO. p 109-135.

Laird DA. 2008. The carcoal vision: a win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. Agron. J. 100: 178-181.

Lehmann J. 2007. A handful of carbon. Nature 447(7141): 143-144.

Lehmann J, Joseph S. 2009. Biochar for environmental management. Earthscan, UK.

Lehmann J, Gaunt J, Rondon M. 2006. Biochar sequestration in terrestrial ecosystem – a review. Mitigation and adaptation strategies for global change 11. p 403-427.

Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O'Neill B, Skjemstad JO, Thies J, Luizao FJ, Petersen J, Neves EG. 2006. Black carbon increases cation exchange capacity in soils. Soil Sci. Soc. Am. J. 70: 1719-1730.

Maas A. 2003. Peluang dan konsekuensi pemanfaatan lahan rawa pada masa mendatang. Makalah Pidato Pengukuhan Jabatan Guru Besar pada Fakultas Pertanian UGM. Yogyakarta.

Maas A 1997. Pengelolaan lahan gambut yang berkelanjutan dan berwawasan lingkungan. Alami 2(1): 12-16.

Masulili A, Utomo WH, dan Syechfani. 2010. Rice husk biochar for rice-based cropping system in acid soil 1. The characteristics of rice husk biochar and its influences on the properties of acid sulfate soils and rice growth in west Kalimantan, Indonesia. J. Agric. Sci. 2(1): 39-47.

Marschner H. 1986. Mineral nutrition of higher plants. Acc Press. Harcourt Jovanovich Publishers. London.

Moormann FR, Van Breemen N. 1978. Rice: soil, water, and land. International Rice Research Institute, Los Baños, Philippines.

Moore PA Jr, Attanandana A, Patrick JWH. 1990. Factors affecting rice growth on acid sulfate soils. Soil Sci. Soc. Am. J. 54: 1651-1656.

Noor M, Alwi dan Raihan M. 2005. Teknologi Peningkatan Produktivitas Lahan Gambut. *Laporan Akhir*. Balai Penelitian Pertanian Lahan Rawa. Banjarbaru.

Noor M, Supriyo dan A, Lestari Y. 2007. Teknologi Peningkatan Produktiitas dan Konservasi Lahan Gambut. *Laporan Akhir*. Balai Penelitian Pertanian Lahan Rawa (Balittra). Badan Litbang Pertanian. Banjarbaru.

Notohadiprawiro T. 1997. Etika Pengembangan Lahan Gambut untuk Pengembangan Pertanian Tanaman Pangan. Lokakarya Pengelolaan Lingkungan dalam Pengembangan Lahan Gambut. Badan Pengendalian Dampak Lingkungan (BAPEDAL). Palangkaraya.

Patrick WH Jr, Reddy CN. 1978. Chemical changes in rice soils. In: Soils and rice. International Rice Research Institute, Los Banos, Philippines. p 361-379.

Pons LJ, Breemen NV, Driessen PM. 1982. Physiography of coastal sediment and development of potential soil acidity. In: Acid sulphate weathering. SSSA Special Publication No. 10. Madison, Wisconsin, USA. p 1-18.

Rachim A. 1995. Penggunaan kation-kation polivalen dalam kaitannya dengan ketersediaan fosfat untuk meningkatkan produksi jagung pada tanah gambut. *Disertasi.* Program Pascasarjana IPB. Bogor. 268 p.

Renner R. 2007. Rethinking biochar. Environ. Sci. Technol. 41(17):5932-5933.

RondonM, Ramirez JA, Lehmann J. 2005. Greenhouse gas emissions decrease with charcoal additions to tropical soils. In: Proceedings of the 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration. Soil Carbon Center, Kansas State University, USDA, Baltimore. 208 p.

Rondon M, Lehmann J, Ramírez J, Hurtado M. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with biochar additions. Biol. Fertil. Soils 43: 699-708.

Spokas KA, Reicosky DC. 2009. Impacts of 16 different biochars on soil greenhouse gas production. Ann. Environ. Sci. 3:179-193

Steiner C. 2007. Soil charcoal amendments maintain soil fertility and establish carbon sink-research and prospects. Soil Ecol. Res. Dev. 1-6.

Subagyo H. 2006. Lahan rawa pasang surut. *Dalam:* Didi Ardi S et al. (eds.). Karakteristik dan Pengelolaan Lahan Rawa. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian. Badan Litbang Pertanian. Hal. 23-98.

Suriadikarta D A dan D Setyorini. 2006. Teknologi pengelolaan lahan sulfat masam. 117-150. *Dalam:* Didi Ardi S *et al*. (eds). Karakteristik dan Pengelolaan Lahan Rawa. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian. Badan Litbang Pertanian. Hal. 117-150.

Supriyo A, Maas. 2005. Leahing impact on chemical properties of different reclamation stages of ombrogenous peat. Paper presented at the International Symposium and Workshop on Restoration and Wise Use of Tropical Peatland: Problem of Biodiversity Fire, Poverty and Water Management, Sep 21-24, 2005, Palangkarya, Indonesia.

Tan KH. 1998. Dasar-dasar Kimia Tanah. Gadjah Mada University Press,Yogyakarta, Indonesia. 295 hal.

Van Breenen N. 1976. Genesis and solution chemistry of acid sulphate soils in Thailand. PhD dissertation, Center of Agricultural Publishing and Documentation, Wageningen.

Van Breemen N. 1982. Genesis, morphology, and classification of acid sulphate soils in coastal plains. In: Acid sulphate weathering. Soil Sci. Soc. Am. J. 10: 95-108.

Van Breemen N, Pons LJ. 1978. Acid sulfate soils and rice. In: Soils and rice. International Rice Research Institute, Manila, Philippines. p739-762.

Van Zwieten L, Kimber S, Morris S, Chan KY, Downie A, Rust J, Joseph S, Cowie A. 2010. Effect of biochar from slow pyrolysis of paper mill waste on agronomic performance and soil fertility. Plant Soil 327: 235-246.

Wahyunto, Darliah A, Agus F. 2010. Distribution, properties, and carbon stock of Indonesian peatland. In: Proceedings of the International Workshop on the Evaluation and Sustainable Management of Soil Carbon Sequestration in Asian Countries, 28-29 Sep, 2010, Bogor, Indonesia.

Widjaja-Adhi IPG. 1988. Masalah tanaman di lahan gambut Makalah disajikan dalam Pertemuan, Telenis Penelitian Usahata Menunjang Transmigrasi. Cisarua, Bogor,27-29 Feb 1988.

Widjaja-Adhi IPG, Nugroho K, Suriadikarta DA, Karama dan AS. 1992. Sumberdaya lahan rawa: Potensi, keterbatasan, dan pemanfaatan. Risalah PERNAS Pengembangn Pertanian di Lahan Rawa Pasang Surut dan Lebak. Cisarua 3-4 Maret 1992. Badan Litbang Pertanian.

Widjaja-Adhi I P G, Suriadikarta DA, Sutriadi MT, Subiksa IGM, Suastika dan IW. 2000. Pengelolaan, pemanfaatan, dan pengembangan lahan rawa. Dalam: Adimihardja A, Amien LI, Agus F, Jaenuddin dan D (eds.). Sumberdaya Lahan Indonesia dan Pengelolaannya. Pusat Penelitian Tanah dan Agroklimat, Bogor. hal. 127-164.

Yamato M, Okimori Y, Wibowo IF, Anshori S, Ogawa M. 2006. Effects of the application of charred bark of *Acacia mangium* on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. J. Soil Sci. Plant Nutr. 52: 489-495.

Yanai Y, Toyota K, Okazaki M. 2007. Effects of charcoal additionon N2O emissions resulting from rewetting air-dried soil in short-term laboratory experiments. Soil. Sci.Plant Nutr. 53: 181_188.

Notes

Authors' address: D. Nursyamsi (ddnursyamsi@yahoo.com), E. Maftuah (eni_balittra@yahoo.com), I. Khairullah (izhar_khairullah@yahoo.com), and Mukhlis (mukhlis60@yahoo.com), Indonesian Swampland Agricultural Research Institute (ISARI) Jl. Kebun Karet, Loktabat Utara, Banjarbaru 70712, South Kalimantan, Indonesia.

Gas emissions from the production and use of biochar in the peatland of Kalimantan

Abdul Hadi, Abdul Ghofur, Annisa Farida, Triharyo Subekti, and Dedi Nursyamsi

Annual production of rice husks reaches 12.5 million t in Indonesia and utilization of this byproduct has become an issue in the face of climate change. Biochar from rice husk was evaluated in this study in terms of nutrient content and gas emission during the charring process. Greenhouse gas (GHG) emission was then measured in the peat soil of an oil palm plantation to compare the GHG-suppressing effect of biochar with that of other soil ameliorants. Results showed that biochar from rice husks had higher cation exchange capacity (32 $cmol_c$ kg^{-1}) and that emission of N_2O was lower with rice husk than with other feedstock. Application of biochar to peat soils reduced GHG emission, especially that of N_2O and this is related to the reduction in number of ammonium-oxidizing bacteria. Biochar from rice husks showed 63% N_2O reduction. The results indicate that biochar from rice husk can be recommended as an ameliorant to control GHG emission from oil palm plantations.

The use of biochar for improving soil physical properties and soil fertility has been investigated in mineral soils of Indonesia (Dariah and Nurida 2012, Sutomo and Nurida 2012, Suwarji et al 2012, Widowati et al 2012). Some studies applied biochar to restore the health of contaminated soil and/or water (Hamzah et al 2012, Nurida et al 2012). Santi et al (2012) has shown that biochar is a better carrier of consortium bacteria than peat and compost. Meanwhile, Hadi et al (2012) reported that the population of cellulytic bacteria remained at about 10^7 cells g^{-1} in rice husk charcoal after 3 mo of storage; this was comparable with that of cow dung and empty fruit bunch compost.

Biochar (biological charcoal) is defined as a product of biomass combustion under conditions of limited oxygen supply. Biochar can be produced in a well-designed pyrolysis reactor such as a heaping-kiln system, which is suitable for large-scale commercial biochar and thermal energy production. In Kalimantan, biochar can also be produced from wildfire under specific conditions. Pyrolysis using a drum-type reactor is common among small companies and local farmers because of its simple structure and low cost (Pari 2013), which is favorable in the local context of judicious use of agricultural byproducts or waste such as rice husk and oil palm waste. Complete combustion produces carbon dioxide (CO_2) and H_2O. Incomplete combustion, on the other hand, produces carbon monoxide (CO) and various organic compounds, which can be determined by the course of the fire, oxygen supply, temperature, and elementary composition of the fuel (Koppmann et al 2005). High amounts of CO_2, methane (CH_4), and nitrous oxide (N_2O) are of great concern because of their significant impact on global warming. Furthermore, the loss of carbon in the form of CO_2 and CH_4 and of nitrogen (N) in the form of N_2O is also considered a nutrient loss for the plants and soil microbes (Hadi et al 2001). As N_2O has greater global warming potential than CH_4, its destructive effect on the ozone layer and subsequent contribution to ozone depletion is a cause for concern (Bouwman 1999).

There are about 33 million ha of swampland in Indonesia, 10 million of which has potential for agricultural use. Peat soil is one of the main soil types in the swampland and has high potential for GHG release due to its high organic matter content. On the other hand, rice husk production in Indonesia reaches 12.5

million t yr^{-1} and utilization of this byproduct is becoming an issue for the country's agricultural sector. In spite of extensive biochar research, information on biochar application in peat soils and its effect on GHG emission remains limited.

The purpose of this study was to assess the effect of biochar from rice husks on GHG emission in peat soils.

Materials and methods

Biochar preparation and its characterization

Peat, rice husk, cow dung, chicken manure, oil palm empty bunch, oil palm empty bunch compost, and weed compost were collected and air-dried at room temperature. After 2 wk (about 20% water content), the peat, rice husk, and other materials were burned in a pyrolysis reactor for 8 h at 250 °C. The reactor was a 200-L drum with a smokestack as gas outlet on top with four gas inlets around its body (Fig. 1). Feedstock was fully loaded into the reactor and a small amount of fuel was used to ignite the reactor. Fuel was continuously added until fire is established (about 20 min after ignition). The gas inlets were closed one by one while keeping the smoke white.

Gas samples from the smokestack were taken at 2, 4, and 8 h after closing the reactor and CO_2, CH_4, and N_2O measurements were done by gas chromatography (Shimazu, type GHG 450). The conditions for the operation of the gas chromatograph are shown in Table 1, following the specifications of Linkens and Jackson (1989). Pyrolysis was continued until the fire was extinguished. The biochar produced was made to pass through 2- and 4-mm-diameter sieves after cooling down. The weight of raw biochar as well as that of the sieved biochar were determined to calculate pyrolysis efficiency. Subsamples of 2 mm ø were taken for analysis of some parameters such as water content, cation exchange capacity (CEC), and concentrations of organic C, total N, and available P and K.

Table 1. Working conditions of the gas chromatograph for N_2O, CH_4, and CO_2 determination.

		N_2O	CH_4	CO_2
Detector		ECD	FID	TCD
Column		Porapak Q	Porapak Q	Porapak R
Temperature (°C)	Column	60	50	40
	Detector	60	50	50
	Injector	350	100	50
Carrier gas	Type	Ar + CH_4	N_2	He
	Flow rate	20 ml min^{-1}	50 ml min^{-1}	25 ml min^{-1}
Retention time		2.5 min	0.7 min	3.0 min

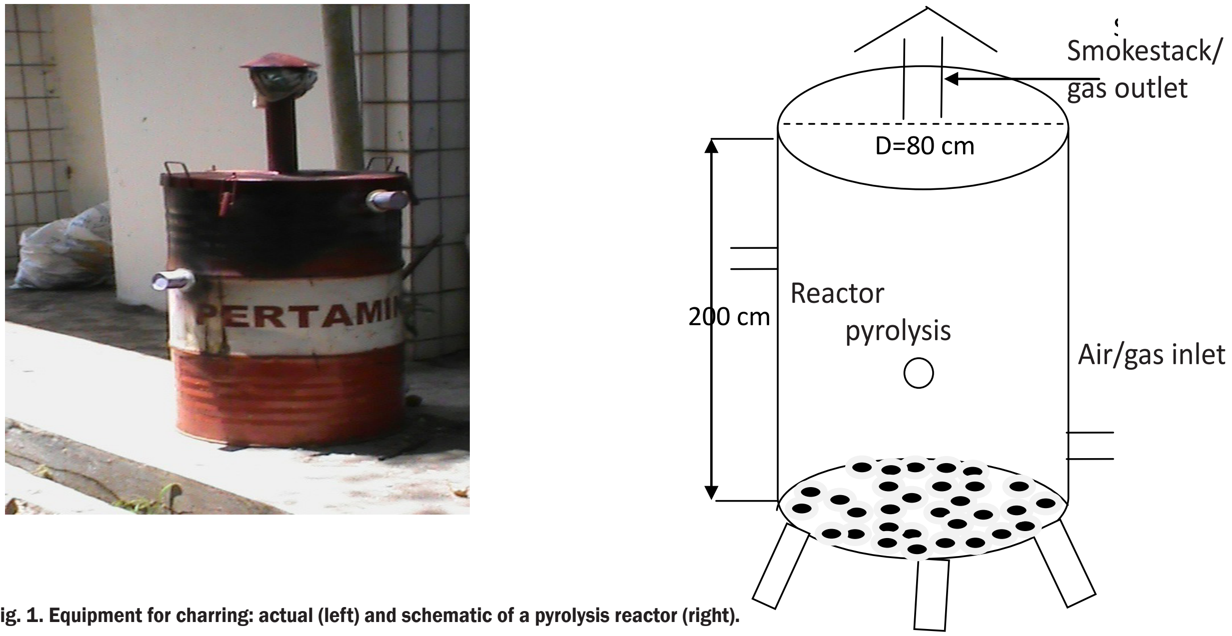


Fig. 1. Equipment for charring: actual (left) and schematic of a pyrolysis reactor (right).

Methodologies for gas and soil sampling

A palm plantation in south Kalimantan was selected for the study to evaluate the effect of biochar made from rice husk on GHG emission. Plant density was 149 trees ha^{-1} and 24 oil palm trees with similar age and growth were chosen. Rice husk charcoal, acidic mine drainage, iron slag, chicken manure, and river sediments were applied on the peat soils of four selected trees at the rate of 2 t ha^{-1}. No ameliorants including biochar were applied on four other trees. An open-top-mica chamber was constructed (50 × 50 × 50 cm dimension) and its bottom edge inserted 5 cm below the soil surface. Trees with treatments had their canopies covered by the chamber for gas sampling. Gas sampling was carried out to determine the concentrations of CH_4, N_2O, and CO_2 from the sample trees using a capillary plastic tube with a rubber septum. A small electric fan was set in a box to homogenize the air within the box prior to gas sampling. The same gas chromatography technique was used. Samples were taken at 3-wk intervals starting from 11 October until 13 December, 2011. At each sampling, samples were taken 2, 7, and 12 min after the chamber was closed (Hadi et al 2010). Soil sampling was conducted in the vicinity of the selected trees. Soil samples were taken from the surface at 0-20 cm in depth and 25 cm away from the tree after 6 and 12 wk of treatment applications. Soil samples were brought to the laboratory and analyzed for organic C content, ammonium N (NH_4), nitrate (NO_3), and population of ammonium-oxidizing bacteria (AOB). Organic C content was determined by dichromate digestion, while AOB population was determined by the MPN method as described by Page et al (1982). The concentrations of NH_4 and NO_3 were determined colorimetrically by methods described by Page et al (1982) and Hayashi et al (1997), respectively.

Statistical analysis

The frequency distributions of all gas data were first tested for normality using the Lilliefors test. If normally distributed, differences between treatments were determined by analysis of variance (ANOVA) and the least significant difference (LSD) test. All statistical analyses were performed using the SYSTAT 8.0 statistical package (SPSS 1996) and were based on $P<0.05$ significance level.

Results and discussion

Changes in nutrient content and gas emissions during charring

The changes in N, P, and K content during the charring process are shown in Table 2. In general, the P and K contents of all organic matter increased. The C and N contents of empty fruit bunch (EFB) compost increased during the process, while the C and N contents of raw EFB decreased. The yield of biochar in the pyrolysis reactor is shown as a percentage of efficiency in Table 3. The efficiency for oil palm EFB, chicken manure, rice husk, and EFB compost were 89%, 64%, 50%, and 47%, respectively. As weight of weed compost was too low to be detectible, charring efficiency determination of the weed compost failed. Nearly 93% of rice husk biochar passed a 4-mm sieve and almost 70% of the same passed a 2-mm sieve, which was only a little lower than weed compost (Table 3). Pyrolysis of all the abovementioned feedstock tested produced CO_2, CH_4, and N_2O (Table 4). Carbon dioxide ranged from 400 ppm (from peat) to 550 ppm (from chicken manure). Methane concentration ranged from 2.5 ppm (weed compost) to 3.4 ppm (rice husk), while that of N_2O ranged from 365 ppb (rice husk) to 561 ppb (chicken manure). In general, emission of CO_2 was consistent, whereas CH_4 and N_2O emissions decreased over time. Compared with the other tested feedstock, chicken manure and cow dung were higher in CO_2 and CH_4 and rice husk was higher in CH_4 but lower in N_2O. These results show that the type of fuel determines the type and concentration of gases released . They confirm the findings of a previous study (Koppmann et al 2005). Methane released from rice husk charring was almost double that of the concentration in the air.

Table 2. Changes in nutrient content of organic matter during the charring process.

Source[a]	Before charring				After charring				
	N (%)	P (ppm)	K (mg)	C (%)	N (%)	P (ppm)	K (mg)	C (%)	CEC
Peat	na	na	na	na	0.80	0.16	0.79	18.9	10.7
EFB compost	0.4	0.10	0.85	6.6	0.99	1.08	0.85	28.5	9.92
Weed compost	na	na	na	na	1.84	1.15	0.40	24.1	8.12
Cow dung	na	na	na	na	0.92	1.19	0.43	15.4	9.17
Chicken manure	na	na	na	na	0.91	1.12	0.80	15.2	6.97
Oil palm EFB	1.1	0.17	0.48	48.4	0.75	0.26	1.14	5.90	31.9
Rice husk	na	na	na	na	0.45	0.17	1.36	6.73	26.6
Weeds	na	na	na	na	1.36	2.04	1.01	7.36	31.9

[a]EFB=empty fruit bunch; CEC=cation exchange capacity.

Table 3. Charring efficiency and physical properties of biochar produced from various sources.

Source	Efficiency[a] (%)	Biochar (<4 mm ø)	Biochar (4 mm ø) (%)	Biochar (2 mm ø) (%)	Weight loss (%)	Water content (%)	WHC[b] (%)
Peat	37.0	27.0	73.0	48.6	63.0	0.9	10.6
EFB compost	47.3	38.5	61.5	53.8	52.7	4.9	177.3
Weed compost	28.1	10.6	89.4	72.3	71.9	3.4	90.4
Cow dung	32.0	34.4	65.6	43.8	68.0	0.6	35.6
Chicken manure	64.0	40.6	59.4	35.9	36.0	1.3	125.1
Oil palm EFB[c]	88.9	15.6	84.4	71.9	11.1	nd	171.3
Rice husk	50.0	7.4	92.6	69.5	50.0	nd	157.1
Weeds	nd	17.5	82.5	68.4	nd	0.8	180.8

[a]Efficiency (%) =weight after charring/weight after charring x 100; [b]WHC=water-holding capacity determined by a method described by Page at al. (1985); [c]EFB=empty fruit bunch.

Table 4. CO_2, CH_4 and N_2O emissions during the charring process.[a]

Source	CO_2 (ppm)				CH_4 (ppm)				N_2O (ppb)			
	2 h	4 h	8 h	Av	2 h	4 h	8 h	Av	2 h	4 h	8 h	Average
Peat	404.8	407.3	390.0	400.7	2.42	3.11	2.54	2.69	410.8	439.9	400.7	417.1
EFB[b] compost	538.4	477.4	444.7	486.8	2.85	2.69	2.66	2.73	480.2	494.9	473.5	482.8
Weed compost	432.3	426.4	425.9	428.2	2.47	2.58	2.45	2.50	477.0	499.0	395.7	457.2
Cow dung	520.1	512.6	509.0	513.9	2.81	2.86	2.90	2.86	551.5	453.9	559.9	521.8
Chicken manure	569.9	566.3	513.2	549.8	3.41	3.04	2.94	3.13	537.9	627.4	518.3	561.2
Rice husk	443.8	447.0	444.3	445.1	3.94	2.59	3.66	3.40	390.6	363.2	341.6	365.1

[a]Clean air CO_2=350 ppm; CH_4=1.7 ppm; N_2O=350 ppb. [b]EFB=empty fruit bunch.

Gas emission from the soil as affected by biochar application

Due to its small size (Table 3) and the low N_2O and moderate CO_2 emissions, rice husk charcoal was used in the field experiment, although its charring efficiency was lower than that of EFB. Carbon dioxide emissions can be used as an index of microbial activity in the soil (Murayama and Zahari 1996). Heterotrophic microbes prefer simple organic C as a C source rather than complex ones. All the ameliorants applied on peat soil reduced CO_2 and CH_4 effectively and this was probably due to the retention of easily decomposable C by pores of biochar (Santi and Goenadi 2012). This would further inhibit microbial activities that produce CO_2 and/or CH_4. The use of rice husk charcoal may be a promising technology to reduce CO_2 emissions from peat, a soil which is suspected to release a great amount of CO_2 (Agus et al 2008). This can also be the basis for developing an integrated oil palm-paddy system. Rice husk would be a natural choice because of its availability (in Indonesia; it reaches 12.5 million t yr^{-1} and its utilization has not been as intensive as that of other wastes (Darmadji 2012, Santi et al 2012).

Peat soil has been suspected to be a great source of N_2O emission (Hadi et al 2000, Takakai et al 2006, Hadi et al 2012) and this was confirmed by our study (Fig. 2). The use of biochar as a soil ameliorant may overcome

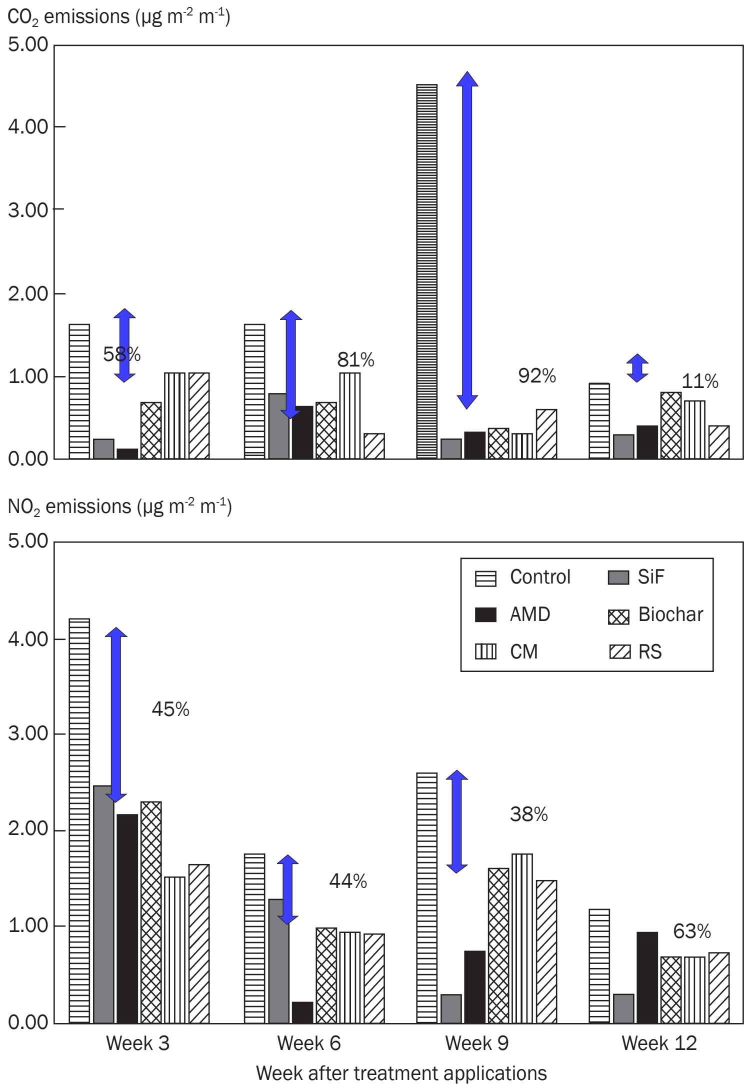


Fig. 2. Emissions of CO_2 (left) and N_2O (right) as affected by soil ameliorants. AMD=acid mine drainage; CM=chicken manure; SiF=silicate fertilizer; biochar=rice husk biochar; RS=rice straw.

this problem because rice husk charcoal reduced N_2O emissions by up to 63% (Fig. 2b). The application of biochar also affected soil characteristics such as soil pH, NH_4-N, NO_3-N, and AMO (Fig. 3). Biochar increased soil pH and the propagation of AMO bacteria and other acidophilic bacteria was suppressed, which resulted in a reduction of mineralized N in the soil (Figs. 2 and 3).

Conclusions

In Indonesia, annual rice husk production reaches 12.5 million t and utilization of this byproduct has become a pressing issue for the agricultural sector of the country. Our study showed better quality of biochar from rice husk. Biochar from rice husk showed higher efficiency in production and lower emission of CH_4 and N_2O compared with biochar from other feedstock. Furthermore, the peat soil reduced emission of CH_4 and N_2O when ameliorants were applied, including biochar from rice husks, and this was due to less propagation of AMO. This indicates that biochar from rice husk can be recommended as an ameliorant to control GHG emission from oil palm plantations.

References

Bouwman AF. 1990. Introduction. In: Bouwman AF (ed.). Soils and the greenhouse effect. John Wiley & Sons, New York. p 25-35.

Dariah A, Nurida NL. 2012. Pemanfaatan biochar untuk meningkatkan produktivitas lahan kering beriklim kering. Buana Sains 12: 33-38.

Darmadji P. 2012. Pemanfaatan cangkang sawit untuk produksi biopreservatif dan bioplavor serta applikasinya untuk peningkatan pengawetan pangan, lateks karet dan kayu. In: Suryani A, Syamsu K, Saputra D, Suparman KS, Sulaeman I, Sukmawati Y (eds.). Akselerasi inovasi industri kelapa sawit untuk meningkatkan daya saing global. Prosiding Seminar Nasional dan Kongres MAKSI, 26 Januari 2012, Bogor. p 73.

Gofur M, Subyakto, Prasetyo KW dan Ismadi. 2012. Pembuatan komposit serat mikro tandan kosong kelapa sawit-polipropilena untuk bahan komponen otomotif. In: Suryani A, Syamsu K, Saputra D, Suparman KS, Sulaeman I, Sukmawati Y (eds.). Akselerasi inovasi industri kelapa sawit untuk meningkatkan daya saing global. Prosiding Seminar Nasional dan Kongres MAKSI. 26 Januari 2012, Bogor. p 160.

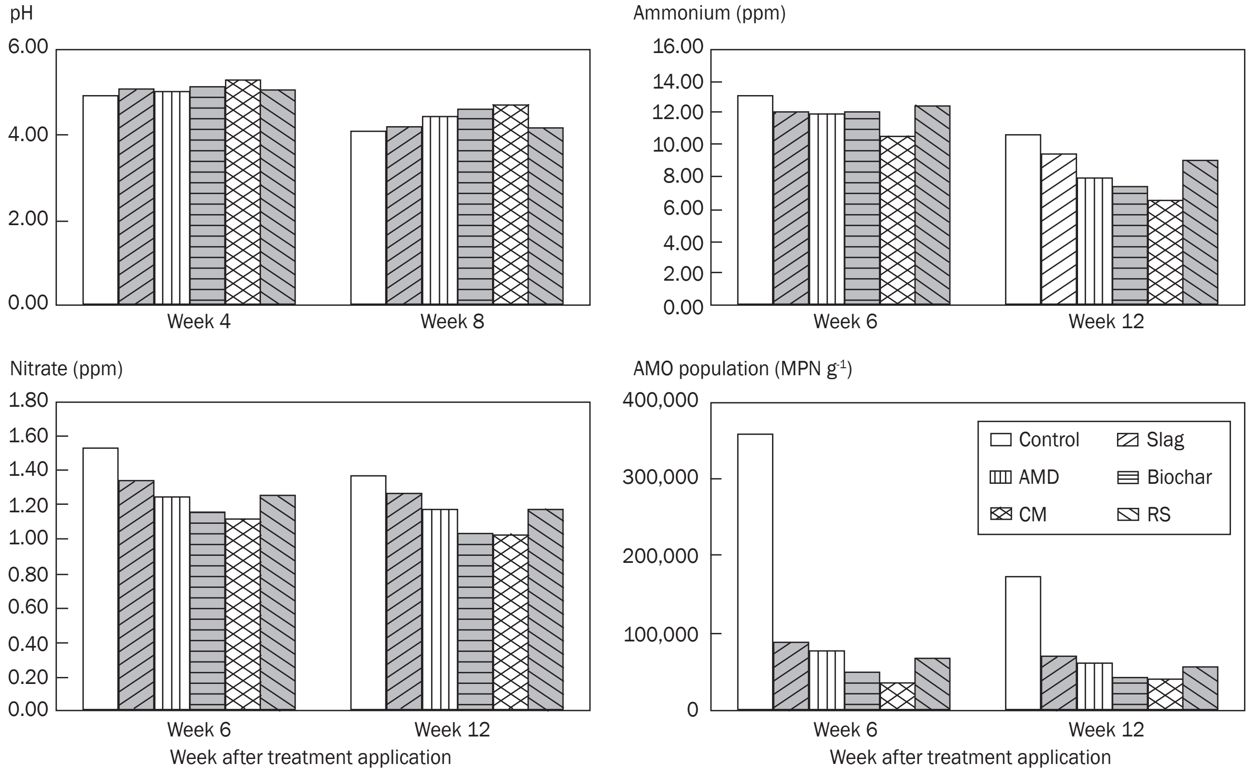


Fig. 3. Changes in soil pH (top left), concentrations of ammonium (top right), nitrate (bottom left), and population of ammonium-oxidizing bacteria (AMO) (bottom right). (See Figure 2 for abbreviations.)

Hadi A, Fatah L, Syaifuddin, Abdullah, Affandi DN, Bakar RA, Inubushi K. 2012. Greenhouse gas emissions from paddy field, oil palm and vegetable in Kalimantan, Indonesia. J. Trop. Soil 17: 105-114.

Hadi A, Inubushi K, Purnomo E, Razie F, Yamakawa K, Tsurata H. 2000. Effect of land-use changes on nitrous oxide (N_2O) emission from tropical peat lands. Chemosphere-Global Changes Sci. 2: 347-358.

Hadi A, Jumadi O, Inubushi K, Yagi K. 2007. Mitigation option for N_2O emissions from corn field in Kalimantan, Indonesia. Soil Sci. Plant Nutr. 54: 644-649.

Hamzah A, Kusuma Z, Utomo WH, Guritno B. 2012. Penggunaan tanaman *Vetiveria zezanoides* L. dan biochar untuk remediasi lahan pertanian tercemar limbah tambang emas. Buana Sains 12: 53-60.

Hayashi A, Sakamoto K, Yoshida T. 1997. A rapid method for determination of nitrate in soil by hydrazine reduction procedure. Jpn. J. Soil Sci. Plant Nutr. 68: 322-326.

Koppmann L, von-Czapiawski K, Reid JS. 2005. A review of biomass burning emissions. Part I: gases of carbon monoxide, methane, volatile organic compounds and nitrogen containing compounds. Atmos. Chem. Phys. Discuss. 5: 10455-10516.

Linkens HF, Jackson JF. 1989. Gases in plant and microbial cells. Tokyo: Springer-Verlag. p 275-307.

Page AL, Miller RH, Keeny DR.1982. Method of soil analysis. Wisconsin:American Society of Agronomy, Inc. 1027 p.

Murayama S, Zahari AB. 1996. Decomposition of tropical peat soils: 1. Decomposition kinetics of organic matter of peat soils. JARQ 30: 145-151.

Nurida NL, Rachman A, Sutono. 2012. Potensi pembenah tanah biochar dalam pemulihan sifat tanah terdegradasi dan peningkatan hasil jagung pada Typic Kanhapludults Lampung. Buana Sains 12: 33-38.

Pare G. 2013. Biochar technology as a green energy movement in Indonesia. Paper presented at the International Workshop on Wetland Environmental Management, 20 Sep 2013, Lambung Mangkurat University, Banjarmasin, Indonesia.

Santi LP, Goenadi DH. 2012. Pemanfaatan biochar asal cangkang kelapa sawit sebagai bahan pembawa mikroba pemanfaat agregat. Buana Sains 12: 33-38.

Sutono S, Nurida LN, 2012. Kemampuan biochar menegang air pada tanah bertekstur pasir. Buana Sains 12:45-52

Suwardji, Utomo, dan Sukartono WH. 2012. Kemantapan agregat setelah aplikasi biochar di tanah lempung berpasir pada pertanaman jagung di lahan kering Kabupaten Lombok Utara. Buana Sains 12: 33-38.

Takakai F, Morishima T, Hasihidoko Y, Hatano R, Limin SH, Darung U, Dohong S. 2006. Effects of agricultural land-use change and forest fire on N_2O emission from tropical peatlands, Central Kalimantan, Indonesia. Soil Sci. Plant Nutr. 52: 662-674.

Widowati, Asnah, Sutoyo, 2012. Pengaruh Pengunaan biochar dampupuk kalium terhadap pencucian dan serapan Kalium pada tanaman jagung. Buana Sains 12: 83-99.

Notes

Authors' addresses: Abdul Hadi, Division of Soil Science, Lambung Mangkurat University, Jl. A. Yani Km 3,5 Banjarbaru and Graduate School of Environment and Development Management, Brawijaya University, Jl. MT. Haryono, Malang (yatakhadi@yahoo.co.id); Abdul Ghofur and Annisa Farida, Division of Soil Science, Lambung Mangkurat University, Jl. A. Yani Km 3,5 Banjarbaru; and Triharyo Subekti and Dedi Nursyamsi, Indonesian Swamplands Research Institute, Jl. Kebun Karet, Banjarbaru, Indonesia.

Evaluation of the effects of activated carbon on POP insecticide residues in mustard in Central Java, Indonesia

Elisabeth Srihayu Harsanti, Asep Nugraha Ardiwinata, Sri Wahyuni, and Dedi Nursyamsi

Organochlorine pesticides have been widely used in Indonesia for pest control in agriculture as well as for public health purposes since 1965. Up to the present, pesticide residues remain in the plant, soil, and water systems. Persistent organic pollutant compounds (POPs) are persistent and highly toxic to humans and animals. A field experiment was conducted at the vegetable center in Magelang, Central Java, to evaluate the action of activated carbon on POP residues in a crop. The experiment used a randomized block design with three replications and seven treatments. Activated carbon-coated urea (ACU) was used in mustard cultivation and the residual POPs in soil, water, and plant samples were measured. Results showed 50% reduction in residual POPs 7 d after application of prilled urea or ACU. Inoculation of POP-degrading microbes reduced the residual POPs in the soil. Residual benzene hexachloride (BHC) and lindane in mustard biomass was lower than the maximum allowable limit, whereas other POPs in plant biomass were lower than 0.1 ppm. A greater reduction of residual POPs in plant biomass was noted in the treatment with ACU-enriched consortia microbes than with the treatment ACU + microbes. As to microbial inoculation, POP residue in plant biomass treated with ACU from coconut shell was higher than that treated with ACU from corn cobs.

Key words: activated carbon, persistent organic pollutants (POPs), urea fertilizer, mustard

Chemical products such as pesticides and herbicides have been heavily used in crop protection programs in Indonesia and the problem of persistent organic pollutants (POPs) is significant because of its effect on human health. POPs include aldrin, hexachlorobenzene, chlordane, mirex, dieldrin, toxaphene, DDT, dioxin, endrin, furans, heptachlor, and PCB. Endrin and heptachlor are considered the most dangerous POPs (UNESCO 1991). Therefore, the remediation of soil from POPs should be key to ensuring food safety and human health.

Charcoal is well-known in agriculture because of its high porosity that provides a specific surface area of around 70-100 m^2 g^{-1}. This can be 10 times higher when charcoal is turned into activated carbon (AC) by processing it under high vapor pressure at a high temperature ofaround 700-900 ^oC. The structural advantage of AC enables it to not only improve the soil biological environment but also promote safety in crop production. One benefit of using charcoal is the restoration of agricultural land through improvement of the soil microbial environment.. Activated carbon is still charcoal, but it has a higher specific surface area than the usual charcoal as it undergoes a process involving high vapor pressure.

Activated carbon application benefits the farm and the environment by improving nitrogen use efficiency through the reduction of off-farm losses of nitrogen-based fertilizer (Cox 2012) and by degrading pesticide residues that contain POPs. The Ninorganic fertilizer coated with AC releases N slowly into the soil solution, reduces NH_4^+ availability to nitrifying bacteria, and subsequently reduces NO_3 leaching or gaseous loss (N_2O has the potential as atmospheric greenhouse gas to contribute to stratospheric ozone depletion [Freney 1997]).

Activated carbon, used as coating for N fertilizer such as urea, increases urea use efficiency of agricultural plants and reduces soil N loss. The use of fertilizers with enhanced efficiency such as slow- and controlled-release fertilizers (CRF), nitrification inhibitors (NI), and urease inhibitors (UI) shows good prospects (Motavalli et al 2008). This research aimed to evaluate the effect of AC as urea coating on POP residues in a crop.

Materials and methods

The field experiment was conducted in a vegetable center at Magelang District, Central Java, Indonesia. The experiment, in complete randomized block design, had the following seven treatments:

1. Prilled urea as control (U_0)
2. Urea coated by AC (ACU) from coconut shell (U_1)
3. ACU from corn cob (U_2)
4. ACU from coconut shell-enriched consortia microbes (U_3)
5. ACU from corn cob-enriched consortia microbes (U_4)
6. ACU from coconut shell + consortia microbes (U_5)
7. ACU from corn cob + consortia microbes (U_6)

There were three replications.

ACU was prepared in the laboratory of the Indonesian Agricultural Environment Research Institute in Bogor. Microbes collected from Magelang, Central Java, were identified in the Microbiology Laboratory of LIPI-Bogor, West Java. Mustard (*Brassica rapa* L.) seeds of Prima variety were planted by direct sowing in 2 m (width) × 4 m (length) plots with a plant spacing of 40 cm × 40 cm. Sowing date was October 30, 2011 and harvesting date was December 20, 2011. Prilled urea and ACU were applied 7 d after planting (DAP) at 103 kg N ha^{-1}. Phosphorus and potassium were also applied (20 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1}) at the same time as N fertilizer application. At harvest, samples were taken to evaluate POP concentration in soil and water and in the mustard biomass.

Organochlorine POP analysis was carried out following the method of Ohsawa et al (1985) 1 and 7 d after application of prilled urea or ACU. Residual POPs in the samples were calculated using the folllowing formula:

$$[\text{POPs} \quad \text{Organoclor ine}] = \text{A x } \frac{\text{B}}{\text{C}} \text{ x } \frac{\text{D}}{\text{E}} \text{ x } \frac{\text{F}}{\text{G}} \quad .\text{in ppm}$$

Correct typo error--organochlorine

where

A is the standard concentration (μg/mL solution),

B is the sample peak area,

C is the standard peak area,

D is the volume of standard solution injected (μL),

E is the volume of sample solution injected (μL),

F is the volume of hexane-ether extract (mL),

G is the volume of supernatant (mL), and

F/G is a correction factor.

Data were analyzed statistically using analysis of variance and Duncan’s multiple range test at the 0.05 level to determine significant differences among treatments (Gomez and Gomez 1984).

Results and discussion

Seven days after application (DAA) of urea or ACU, residual POPs in the soil exposed to treatments U3, U4, U5, and U6 generally declined compared with the control U0; they increased with treatments U1 and U2 (Fig. 1). Reduction of some residual POPs was found to reach up to 80%, including lindane (54–73.5%), aldrin (27.8–83.5%), heptachlor (48–72%), endrin (54.6–72.2%), while dieldrin decreased 37.6-64.5% and endosulfan decreased 42.1–56.6%. Residues of α-BHC and DDT decreased 3.4–10.3% and 2.3–60.9%, respectively.

Residual POP concentrations in the soil were generaly lower than those seen during early plant growth; the ranges were 0–96 ppb (α-BHC), 0–21 ppb (lindane), 21–528 ppb (aldrin), 0–78 (heptachlor), 0–16 ppb (dieldrin), 0-24 ppb (DDT), 0–47 ppb (endrin), and 4–130 ppb (endosulfan). Residual POPs in the treatment with activated charcoal from corn ear were relatively lower than those from coconut shell, especially the ones involving degradation microbes. The concentrations of aldrin and DDT in U0 was higher a day after application of ACU or prilled urea compared with other POPs.

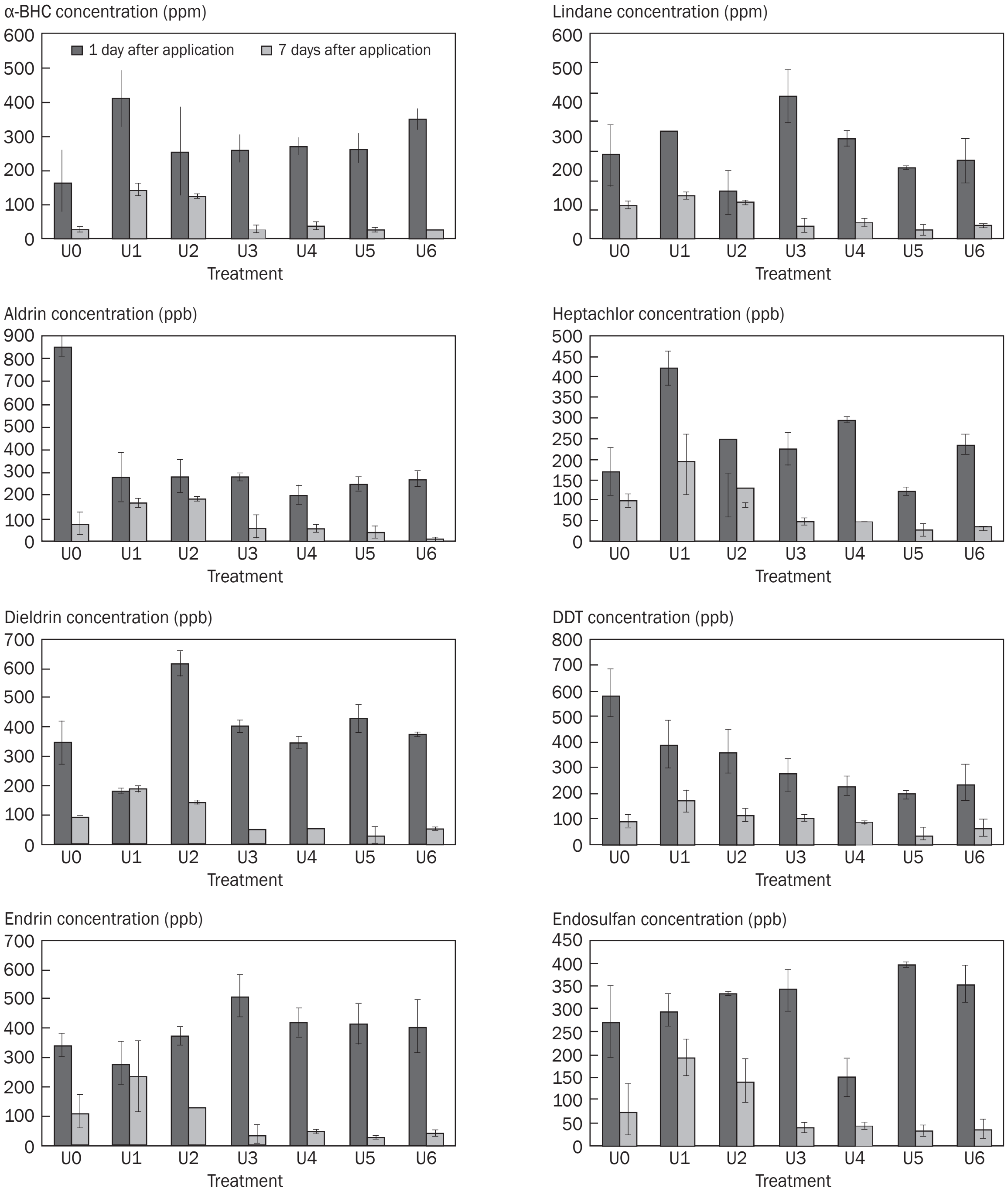


Fig. 1. Effects of ACU treatments on residual POP concentrations in the soil at different times during the growth of mustard.

With ACU treatments, residual POP concentrations in the water declined (Fig. 2). Compared with U0, POP residues in the water decreased within several ranges: 42.9–71.4% (*α*-BHC), 25–50% (lindane), 16.7–83.3%(aldrin), 33.3% (heptachlor), 14.3–85.7% (dieldrin), and 16.7–66.7% (DDT).

Residual POPs in the water were generally higher 7 DAA than in the beginning application. However, residual POPs in the soil generally declined at 7 DAA. POP residue reduction in soil at 7 DAA ranged from 50.6 to 92.6% (*α*-BHC), 25.7–90.6% (lindane), 39.6–95.2% (aldrin), 41.2–85.0% (heptachlor), 73.3–92.3% (dieldrin), 54.8–85% (DDT), 16.2–92.9% (endrin), and 33.6–91.7 % (endosulfan). The lowest residual POP concentration was found in U1. The order of the decline was as follows: U2<U0<U4<U3<U6<U5 (42.5, 59.4, 72.4, 74.3, 83.2, 85.7, 86.5%, respectively).

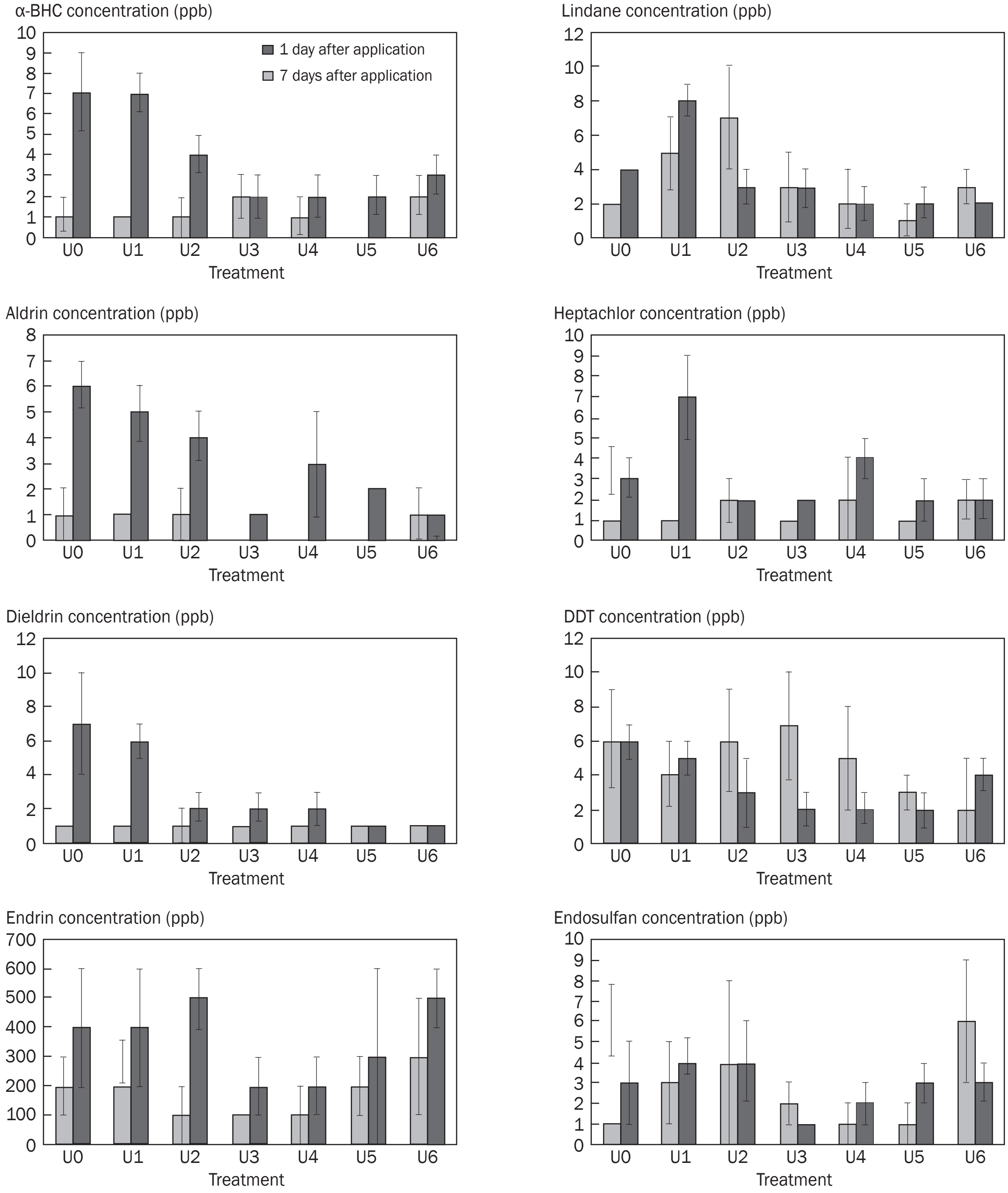


Fig. 2. Effects of ACU treatments on residual POP concentrations in the water at different times during the growth of mustard.

Figure 3 shows the level of residual POPs in mustard biomass. Residual α-BHC, aldrin, heptachlor, and lindane in mustard were more than 0.1 ppm; that of other POPs was less than 0.1 ppm. Residual POP concentrations of α BHC, lindane, aldrin, heptachlor, dieldrin, DDT, endrin, and endosulfan fell within ranges 150–1098 ppb, 21–582 ppb, 66–204 ppb, 28–200 ppb, 7–55 ppb, 0–19 ppb, 0–105 ppb, and 5–42 ppb, respectively. Residual POPs in the prilled urea treatment (U0) was relatively higher than those with ACU treatment. U5 showed a declining uptake trend; U3 and U4 showed a decline in residual POPs in the plant and this was higher than what was seen in the treatment with ACU+ microbes. The residual POPs in plant biomass with treatment of ACU from coconut shell was higher than those to which ACU from corn cobs was applied.

The dry matter yield of mustard biomass was significantly influenced by ACU treatments ($p < 0.0132$) as shown in Figure 4. Low biomass was noted in treatments U0, U4, and U6—dry matter weights were 0.86, 0.84, and 0.77 t ha^{-1}, respectively. The corresponding values for U1, U2, U3, and U5 were 1.24, 1.49, 1.38, and 1.49 t ha^{-1}.

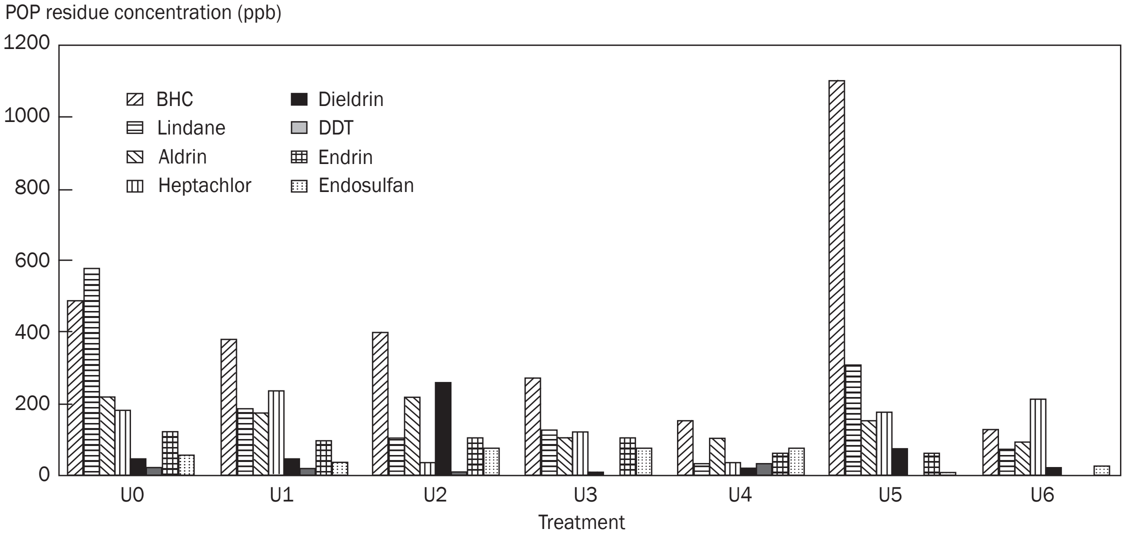


Fig. 3. POP residue concentration in mustard biomass as affected by ACU treatments, vegetable center, Magelang, Central Java.

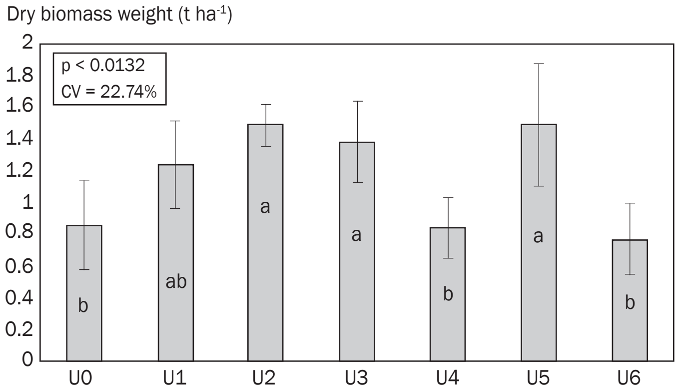


Fig. 4. Effects of ACU treatments on dry matter production of mustard. Bars followed by the same letter do not differ signifcantly, according to DMRT at the 5% level.

Conclusions

Our study showed that ACU application was able to reduce more than 50% of residual POPs in the soil at 7 DAA. Inoculation with microbes effectively reduced the residual POP concentration in the soil. Residues of α-BHC and lindane in mustard plant biomass were more than 0.1 ppm, still way below the threshold. Other residual POPs in plant biomass registered less than 0.1 ppm. Treatments of ACU with enriched consortia microbes tended to be higher in reducing residual POPs than did the treatment of ACU + microbes. In microbial inoculation, ACU from coconut shell gave higher residual POPs in plant biomass than did the one from corn cobs.

References

Cox J. 2012. Biochar in horticulture: prospects for the use of biochar in Australian Horticulture. NSW Department of Primary Industries. Australia.

DeLuca TH, Sala A. 2006. Frequent fire alters nitrogen transformations in ponderosa pine stands of the inland northwest. Ecology 87: 2511-2522.

Freney JR. 1997. Strategies to reduce gaseous emission of nitrogen from irrigated agriculture. Nut. Cycl. in Agroecosyst. 48:155-160.

Gomes KA, Gomez AA, 1984. Statistical Procedures for Agricultural Research. John Wiley & Sons, Inc.

Lee DK, Cho JS, Yoon WL. 2005. Catalytic wet oxidation of ammonia: Why is N-2 formed preferentially against NO_3^-? Chemosphere 61: 573-578.

Motavalli PP, Goyne KW, Udawatta RP. 2008. Environmental impacts of enhanced-efficiency nitrogen fertilizers. Proceedings of the Conference Use of Enhanced_ Efficiency Fertilizers for Improved Agricultural Nutrient Management. ASA-CSSA-SSSA International Annual Meeting at Indianapolis, 12-16 November 2006.

Ohsawa K, Hartati S, Nugrahati S, Sastrohamidjoyo H, Untung K, Arya N, Sumiartha K, Kuwatsuka S. 1985. Residue analysis of organochlorine and organophosphorus pesticides in soil, water and vegetables from Central Java and Bali. in Yamamoto, Sosromarsono (eds.). Ecological impact of IPM In: Indonesia. Tokyo University of Agriculture. p 59-70

Acknowledgments

This research was conducted by a grant from the Research and Technology Ministry. The authors are grateful to Mr. Slamet Riyanto, Mr. Aji M. Tohir, and Mr. Sarwoto for their assistance during the field experiment and laboratory analysis, especially in the residual POP analysis. The authors also thank Dr. Keiichi Hayashi for his constructive comments on the paper.

Notes

Authors' address: Elisabeth Srihayu Harsanti (eharsanti@yahoo.com), Asep Nugraha Ardiwinata, Sri Wahyuni, and Dedi Nursyamsi, Indonesian Agricultural Environment Research Institute and Indonesian Agency for Agricultural Research and Development, Jakarta Selatan, Indonesia.

The role and use of activated carbon in the agriculture sector to control insecticide residues

Asep Nugraha Ardiwinata and Elisabeth Srihayu Harsanti

The use (and abuse) of pesticides to control insect pests and diseases has increased. However, the major causes of concern are the undesirable side effects of these chemicals on biodiversity, environment, food quality, and human health. Activated carbon (AC) has the potential to be used for in situ remediation of agriculture land (contaminated soils and sediments). AC was also effectively used in agriculture to reduce the phytotoxicity of pesticides (organochlorine insecticide). Insecticide residues (e.g., carbofuran, chlorpyrifos, aldrin, lindane) strongly sorb to carbonaceous sorbents such as AC. The effectiveness of AC in soils and sediments can be reduced by two processes. First, sorption of AC in environmental systems can be weaker than that of pure AC. Second, AC sorption is nonlinear, which means that at high organic pollutant concentrations, sorption is reduced due to saturation of the sorbent.

Keywords: activated carbon, insecticide residue, agriculture, organochlorine

Pesticides are applied to agricultural land to protect crops and plantations from pests, diseases, and weeds that may decrease productivity. It is well known that pesticides, having become indispensable elements of modern agriculture, are considered significant sources of diffuse pollutants with great health implications on living organisms, including humans.

The U.S. Environmental Protection Agency defines a pesticide as "any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest." A pesticide may be a chemical substance or a biological agent (such as a virus or bacteria) used against pests. Farmers in hot spots are overburdened with increasing cost of cultivation, a deleterious credit system, declining productivity, increased incidence of pests and diseases, and spurious pesticides. The sole reliance on chemical pesticides for plant protection has created serious problems. In addition, problems of pest outbreaks, resistance, and resurgence demand more pesticides.

Pesticides (insecticides) have been at the center of controversy for a long time and are associated with risks to human health and/or to the environment. On the other hand, society accepts these risks within certain limits as there are also benefits linked to the use of insecticides, in particular in agricultural production. Overuse of insecticides has brought about a decline in biodiversity of nontarget organisms in hot spots.

The respondents in these hot spots noticed a significant decline in the population of birds, earthworms, and natural predators such as the green lace wing, *Chrysoperia carnea*, lady bird beetles, spiders, *Apanteles* spp., *Trichogramma* spp., *Cheloanus*, black burni, etc. in their fields. Pesticides are necessary, but they should only be part of a total pest control program; they should not comprise the entire program. Sustainable farming is a management-intensive method of growing crops at a profit while concurrently minimizing a negative impact on the environment, improving soil health, increasing biological diversity, and controlling pests. Sustainable agriculture is dependent on a whole-system approach with a focus the long-term health of the land. One should favor the philosophical definition: "A farmer should live as though he was going to die tomorrow, but he should farm as though he was going to live forever."

Activated carbon (AC) is a manufactured, clean type of black carbon (BC) and a strongly sorbing carbonaceous charcoal material. It is produced from coal, peat or coconut shells, by incomplete combustion followed by steam activation. AC is used as a strong sorbent for a wide range of organic compounds in many different applications such as gas and water purification, medicine, sewage treatment, and air filters (Norit Americas Inc. 2006). AC and BC are brought together in this paper not only because AC is a manufactured type of charcoal BC, but also since the discovery of strong sorption to BC led to the notion that deliberately introducing clean BC, in the form of AC, could reduce aqueous, available concentrations and thus be beneficial to the environment (Zimmerman et al 2004). The addition of small amounts of AC to sediments lowers the concentration of organic pollutants in pore water considerably—84–99% for polyaromatic hydrocarbon (PAH) and 92% for polychlorinated biphenyls (PCB), respectively (Zimmerman et al 2004, Cornelissen et al 2006a)—suggesting the formation of strongly bound residues in environmental systems. This is reflected by reduced bioaccumulation of PAH and PCB from AC-amended sediments compared with native systems, i.e., up to 90% (Millward et al 2005, Cornelissen et al 2006b, Sun and Ghosh 2007). AC was also effectively used in agriculture to reduce the phytotoxicity of (organochloride) pesticides to crops planted on previously treated fields (Arle et al 1948, Thurston 1953, Lichtenstein et al 1968, Mandl and Lindner 1999, Hashimoto 2007). The advantage of AC amendment is that it can be used as an in situ remediation technique, which is preferable since it involves no soil excavation, does not require an appropriate disposal site and transportation, and is therefore often more economical.

However, the effectiveness of AC in soils and sediments can be reduced by two processes. First, sorption of AC in environmental systems can be weaker than that of pure AC. This attenuation is attributed to the occupation and/or blockage of sorption sites in environmental samples possibly by oil (Kwon and Pignatello 2005), natural organic matter (Pignatello et al 2006), or other organic contaminants (Cornelissen and Gustafsson 2006). Attenuation was reported to be a factor of 2–53 for PAH and PCB in sediments (Cornelissen et al 2006a, Werner et al 2006) and is hypothesized to be considerably higher in 'oily' environments such as creosote-contaminated soils. Second, AC sorption is nonlinear (Walters and Luthy 1984, Cornelissen et al 2006a), which means that, at high organic pollutant concentrations, sorption is reduced due to saturation of the sorbent.

Problems in the agricultural environment

The use of pesticides has been increasing very rapidly because of the expansion of area cultivated under food crops and vegetables. In 1979–80, about 6500 t of pesticides were used, reaching 15,000 t in 1981–82 (Soekarna and Sundaru 1983). The first group of insecticides that was introduced by the government for agriculture was DDT and other OCs in the early 1950s, followed by organophosphates and carbamates in the late 1960s (Untung 1999). DDT has also been used for the national malaria disease eradication program; annual usage was as much as 2,600 t (1974–82), particularly applied in Java Island (UNIDO 1984).

Since the late 1990s, all OCs were reported to be banned for use in Indonesia; however, information on the stockpile of these OCs is not available at present.

In fact, until now, as the use of pesticides in the field is still uncontrolled (overuse and misuse), it will have an impact on the amount of pesticide residues in the environment. Based on research conducted by the Indonesian Agricultural and Environmental Research Institute (IAERI, Central Java of Indonesia), pesticide residues in the soil, plant, and water in rice fields of Bantul, Yogyakarta, remain, particularly organochlorine residues (Table 1). Application of pesticides in the field was such that only 40% of the pesticide is absorbed by the plants and the 60% remain in the soil. Pesticides in the soil will partly affect the soil biota and some will go into the river, and finally into the sea. Residual insecticides are not only found in plants, soil, and water but also in the blood of farmers (Table 2).

Based on these conditions, it is necessary to find a technology that can solve the organochlorine residue problems in agriculture. One way is remediation technology using AC.

Activated carbon

Activated carbon is made from agricultural waste or other materials through very high temperatures in an airless environment. Treated with oxygen, the process opens up millions of tiny pores between the carbon atoms. The use of special manufacturing techniques results in a highly porous carbon that has a surface area ranging from 300 to 2,000 $m^2\,g^{-1}$ and are widely used to adsorb contaminant substances (pesticide residues) from agricultural land. Biochar is a carbon-rich solid byproduct of low-temperature pyrolysis of biomass. Formed under complete or partial exclusion of oxygen at low temperatures between about 400 and 500 °C, carbon (biochar) generally has a low energy of adsorption, but it can be enlarged by using steam or chemicals.

Activated carbon is manufactured by the pyrolysis of carbonaceous materials of agricultural origin, such as coconut shell, rice husk, corn cobs, palm oil empty fruit bunches (POEFB), followed by activation of the chars obtained from them. The processing of AC basically involves selection of raw material, carbonization, and activation. Raw material potential for AC derived from agriculture in Indonesia are corn cobs, ± 8 million t yr^{-1}; coconut shell, ± 12 million t yr^{-1}; rice husk, ± 17.5 million t yr^{-1}; and POEFB, ± 20 million t yr^{-1}.

Activation of carbon aims to increase the specific surface area of carbon by opening the closed pores of tar, hydrocarbons, and other organic substances, thus increasing adsorption capacity. Activation is carried out in two ways: chemical and physical activation. Chemical activation is the process of breaking the carbon chains of organic compounds with the use of chemicals such as alkali metal hydroxide salts, carbonates, chlorides, sulfates, phosphates of alkaline earth metals, $ZnCl_2$ and inorganic

Table 1. Organochlorine residues (ppm) from rice, soil, and water in Bantul, Yogyakarta, 2007.

No.	Organochlorine	Rice (mg kg^{-1})	Soil (mg kg^{-1})	Water (mg L^{-1})	Maximum residue limit		
					Rice[a] (mg kg^{-1})	Soil (mg kg^{-1})	Water[b] (mg L^{-1})
1	Lindane	0.3616	0.0388	0.0012	N/A	N/A	0.08
2	Heptachlor	0.1816	0.0244	0.0008	0.02	N/A	0.0038
3	Aldrin	0.1276	0.0648	0.0010	N/A	N/A	N/A
4	Dieldrin	0.0908	0.0060	0.0012	N/A	N/A	0.0651
5	Endrin	0.0256	0.0024	0.0008	N/A	N/A	0.061
6	4,4 DDT	0.0720	0.0128	0.0037	N/A	N/A	0.001

Source:IAERI (2007). N/A = data not available. [a]Based on SNI 7313:2008 (Indonesian standard). [b]Based on Hamilton et al (2003).

Table 2. Residual insecticide (mg L^{-1}) from the blood of farmers in several locations in Central Java.

Residual insecticide	Magelang	Pati	Brebes
Lindane	0.0263–0.7732	0.0362–0.1613	0.0399–0.1336
Aldrin	0.0273–0.0922	0.0340–0.0926	0.0363–0.0989
Heptachlor	0.0087–0.0412	0.0105–0.0414	0.0105–0.0480
Endosulfan	0.0083–0.0498	0.0089–0.1493	0.0077–0.0931
Diazinon	–	0.0131–0.0168	–
Parathion	0.0216–0.0858	0.0491–0.1296	0.0688–0.2643

Source:IAERI (2007).

acids such as H_2SO_4 and H_3PO_4. Physical activation is the process of breaking the carbon chains of organic compounds with the aid of heat, steam, and CO_2. Generally, coal is heated in the furnace at a temperature of 800–900 °C. Oxidation in the air at low temperature is an exothermic reaction that is difficult to control. Heating with steam or CO_2 at higher temperature is an endothermic reaction, so it is more easily controlled. This method is most commonly used for AC production. But there are limitations.

Limitation A is the heating temperature to 200 °C. Water contained in the raw material changes into vapor, so that the biomass becomes dry with a carbon content of approximately 60%.

Limitation B is the heating temperature between 200 and 280 °C. Biomass briefly decomposes into carbon and distillates are produced. Carbon is dark brown in color and carbon content is approximately 70%.

Limitation C is the heating temperature between 280 and 500 °C. At this temperature, carbonized cellulose is produced and there is lignin decomposition resulting in a "pitch." Carbon is formed and the amount of carbon black is increased to 80%. The process practically stops at a temperature of 400 °C.

Limitation D is the heating temperature to 500 °C, a process of purifying carbon, where formation of "tar" is still ongoing. Carbon content will increase to 90%. Heating above 700 °C only produces hydrogen gas.

In general, the AC manufacturing process consists of three steps—dehydration: water removal process where raw materials are heated to a temperature of 170 °C; carbonization: breakdown of organic materials into carbon. Temperatures above 170 °C will produce CO, CO_2, and acetic acid. At 275 °C, decomposition produces "tar," methanol, and there are other adverse outcomes. Carbon formation occurs at 400-600 °C. Activation involves tar decomposition and expansion of the pores.This can be done with steam or CO_2 as activator.

Physical and chemical properties of activated carbon

Structure of porous carbons

The pores in AC are scattered over a wide range of sizes and shapes. The pores are classified by size, usually into three groups: (1) macropores have an average diameter more than 50 nm, (2) mesopores have an average diameter of 2-50 nm, and (3) micropores have an average diameter less than 2 nm (Fig. 1). These are further divided into supermicropores (0.7–20 nm) and ultramicropores (less than 0.7 nm).

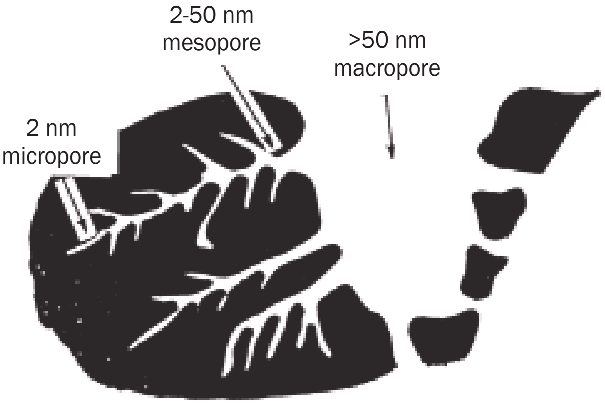


Fig. 1. Pore structure of activated carbon (Manocha 2003).

Quality standard of activated carbon

The quality of activated carbon in Indonesia is based on the parameters set under SNI 06-3730-1995 (Indonesian standard), which includes the following:

Activated carbon from coconut shell and corn cob has higher absorption (above the standard of 750 mg g^{-1}) than AC from rice husk and POEFB (Table 3).

The role of AC

AC is unique and versatile because of its extended surface area, microporous structure, high adsorption capacity, and high degree of surface reactivity. The important applications relate to its use in the removal or binding of organic pollutants from water and soil.

Application of AC in the soil apparently affects bacterial populations because AC is used as a 'good home' by microbes (Tables 5, 6, 7). AC in the soil has the role of reducing residual

Table 3. Physical and chemical properties of AC derived from agricultural waste.

Parameter	Activated carbon			
	Coconut shell	Rice husk	Corn cob	POEFB[a]
Water content (%)	5.03	6.31	10.76	6.54
Volatile matter (%)	9.42	11.92	13.28	12.60
Ash (%)	1.51	21.80	40.32	38.06
Absorption of I_2 (mg g^{-1})	901.13	330.64	887.13	315.21
Specific gravity (g mL^{-1})	0.34	0.32	0.31	0.30
Mesh	50	50	50	50

[a] POEFB: palm oil empty fruit bunch.

Table 4. Quality parameters of AC based on SNI 06-3730-1995.

Parameter	Required	
	Granular	Powder
Water content (%)	Max 4.5	Max 15
Volatile matter content (%)	Max 15	Max 25
Ash content (%)	Max 2.5	Max 10
Noncarbonaceous part (%)	0	0
Absorption of I_2 (mg g^{-1})	Min 750	Min 750
Absorption of C_6H_6 (mg g^{-1})	Min 25	-
Absorption of methylene blue (mg g^{-1})	Min 60	Min 120
Bulk specific gravity (g mL^{-1})	0.45-0.55	0.3-0.35
Escape mesh	-	Min 90
Mesh spacing (%)	90	-
Hardness (%)	80	-

Table 5. Effects of AC treatment on soil microorganism population.

Microorganism	Soil	Microorganism population (x 10^4 cfu g^{-1})	
		Without AC	With AC
Bacteria	Inceptisol	45.0	54.0
	Ultisol	12.4	14.5
Actinomycetes	Inseptisol	6.5	7.1
	Ultisol	4.4	5.1
Fungi	Inseptisol	0.55	0.50
	Ultisol	0.30	0.22

Table 6. Influence of AC on bacterial populations in rice soil.

AC treatment[a]	Bacteria (cfu g^{-1})			
	Citrobacter	*Enterobacter*	*Azotobacter*	*Azospirillum*
Control	1.0 x 10^{10}	2.0 x 10^{8}	2.2 x 10^{9}	5.0 x 10^{9}
Rice husk	7.0.x.10^{9}	1.9 x 10^{9}	1.7 x 10^{9}	3.0 x 10^{9}
Coconut shell	2.0 x 10^{9}	6.0 x 10^{9}	2.5 x 10^{9}	6.0 x 10^{9}
AC +urea	5.2 x 10^{8}	3.2 x 10^{8}	1.8 x 10^{9}	4.7 x 10^{9}
Corn cobs	2.7 x 10^{10}	1.2 x 10^{10}	1.2 x 10^{10}	1.9 x 10^{9}
POEFB	9.6 x 10^{8}	1.0 x 10^{7}	2.4 x 10^{8}	2.0 x 10^{9}
Zeolite	3.2 x 10^{8}	1.1 x 10^{8}	2.2 x 10^{8}	4.0 x 10^{9}
AC+ urea +fio	5.4 x 10^{10}	1.0 x 10^{10}	2.0 x 10^{9}	3.9 x 10^{9}

[a]POEFB: palm oil empty fruit bunch; fio: filter in inlet and outlet.

Table 7. Influence of AC on bacterial populations in soil planted with vegetables.

AC treatment	Bacteria (cfu g^{-1})						
	Citrobacter sp.	*Pseudomonas* sp.	*Serratia* sp.	*S. natans*	*Bacillus* sp.	*Azotobacter* sp.	*Azospirillum* sp.
Control	9.6 x 10^{9}	-	-	4.0 x 10^{6}	4.8 x 10^{8}	1.4 x 10^{7}	2.5 x 10^{8}
Rice husk	-	4.9 x 10^{7}	7.8 x 10^{7}	3.0 x 10^{7}	1.1 x 10^{8}	7.2 x 10^{6}	1.7 x 10^{8}
Coconut shell	-	2.1 x 10^{7}	5.7 x 10^{7}	7.0 x 10^{6}	4.7 x 10^{9}	3.5 x 10^{6}	7.2 x 10^{7}
AC+ urea	-	1.8 x 10^{8}	5.6 x 10^{7}	6.0 x 10^{6}	4.7 x 10^{9}	2.0 x 10^{7}	4.2 x 10^{8}
Corn cobs	1.2 x 10^{10}	4.0 x 10^{9}	6.0 x 10^{8}	4.0 x 10^{6}	6.5 x 10^{9}	2.2 x 10^{7}	3.0 x 10^{8}
POEFB[a]	-	7.2 x 10^{9}	-	6.8 x 10^{6}	2.5 x 10^{8}	2.2 x 10^{8}	6.8 x 10^{8}

[a]POEFB: palm oil empty fruit bunch.

insecticides in rice and water, particularly the organochlorine residues. Activated carbon can be used to coat the surfaces of urea fertilizer so that it becomes nonvolatile and is released slowly.

Coating urea with AC and application results in rice fields

Activated carbon is applied to agricultural land through AC-coated urea (ACU)—i.e., AC is applied to coat the surface of urea and this is done through the use of a rotating granulator. The adhesive used in the coating is tapioca, as much as ± 5 g. The best ratio of urea to AC is 85:15.

Ikhwani et al (2011) reported that the highest rice grain yield of 10.9 t (dried) ha^{-1} (exceeding the target of 7 t ha^{-1}) was obtained from experiments in farmers' fields in Cilandak, Anjatan District, Indramayu (West Java) using variety Inpara 4 with ACU (Tables 8 and 9).

AC treatments (particularly using coconut shell, ACU, and corn cobs) in paddy field could be done; both chlorpyrifos and lindane concentrations decreased in the outlet water by

Table 8. Effect of ACU treatment on yield of Inpara 4, Indramayu, West Java, 2011.

Treatment	Grain weight (kg plot^{-1})	Yield (dried at 14% moisture) (t ha^{-1})
Ponska[a] + urea (112.5 kg N ha^{-1}) Plant spacing (20 cm x 20 cm) Swarna Sub-1 (Inpara 4)	20.5	8.8
Ponska[a] + urea (112.5 kg N ha^{-1}) Tabela legowo[b] (6:1) (20 cm - 40 cm) x 10 cm Swarna Sub-1 (Inpara 4)	24.1	9.9
ACU equals 112.5 kg N ha^{-1} Plant spacing (20 cm x 20 cm) Swarna Sub-1 (Inpara 4)	25.1	10.9
ACU equals 112.5 kg N ha^{-1} Tabela legowo[b] (6:1) (20 cm - 40 cm) x 10 cm Swarna Sub-1 (Inpara 4)	26.0	10.8

Source: Ikhwani et al (2011). [a]Ponska fertilizer (15% N-15% P_2O_5-15% K_2O); [b]Tabela legowo = sow seed directly.

Table 9. Effect of ACU treatment on yield of IR64 and Ciherang varieties, Indramayu, West Java, 2011.

Treatment	Grain weight (kg plot^{-1})	Yield (dried at 14% moisture) (t ha^{-1})
Ponska[a] + urea (112.5 kg N ha^{-1}) Plant spacing (20 cm x 20 cm) IR64 Sub-1 (Inpara 5)	19.2	8.5
Ponska[a] + urea (112.5 kg N ha^{-1}) Tabela legowo[b] (6:1) (20 cm - 40 cm) x 10 cm IR64 Sub-1 (Inpara 5)	12.8	5.3
Ponska[a] + urea (112.5 kg N ha^{-1}) plant spacing (20 cm x 20 cm) Ciherang sub-1	18.9	8.1
Ponska[a] + urea (112.5 kg N ha^{-1}) Tabela legowo[b]** (6:1) (20 cm - 40 cm) x 10 cm Ciherang sub-1	12.8	5.2
ACU equals 112.5kg N ha^{-1} plant spacing (20 cm x 20 cm) IR64 Sub-1 (Inpara 5)	16.6	7.4
ACU equals 112.5 kg N ha^{-1} Tabela legowo[b] (6:1) (20 cm - 40 cm) x 10 cm IR64 Sub-1 (Inpara 5)	14.4	6.1
ACU equals 112.5 kg N ha^{-1} Plant spacing (20 cm x 20 cm) Ciherang Sub-1	19.5	8.4
ACU equals 112.5 kg N ha^{-1} Tabela legowo[b] (6:1) (20 cm - 40 cm) x 10 cm Ciherang Sub-1	18.4	7.7

Source: Ikhwani et al (2011). [a]Ponska fertilizer (15% N-15% P_2O_5-15% K_2O); [b]Tabela legowo = sow seed directly.

more than 50% (Fig. 2). Figure 3b shows urea fertilizer after being coated with AC.

ACU can give the highest rice yield compared with other products such as sulfur- and zeatin-coated urea (Table 10).

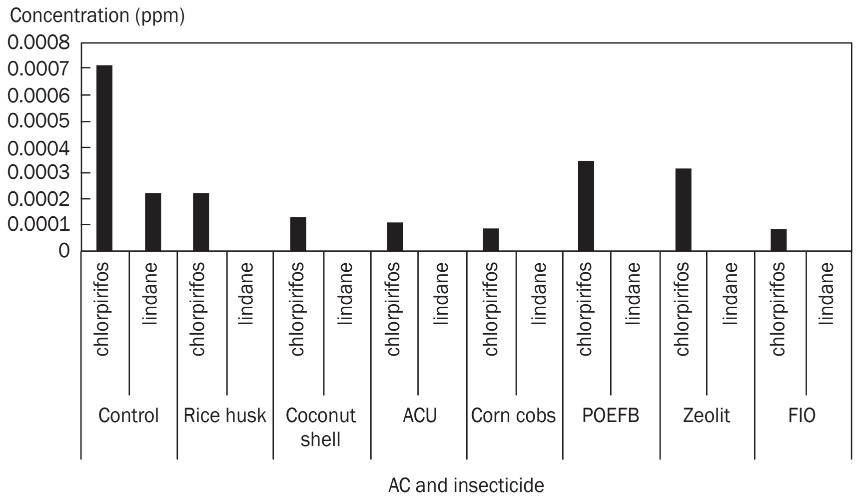


Fig. 2. Effect of AC on chlorpyrifos and lindane concentrations in outlet water from paddy fields.

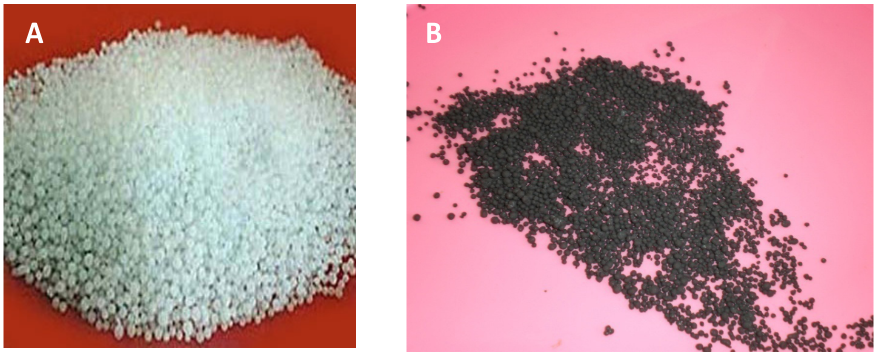


Fig. 3. (A) Urea fertilizers (B) ACU.

Table 10. Effect of urea-coated product treatments on rice yield.

Treatment[a] (200 kg ha^{-1})	Rice yield (t ha^{-1})
Regular urea	4.74
ACU	5.38
SCU	4.61
ZCU	4.00
Zeolit	5.11

Source: Sriwahyuni et al (2010). SCU=sulfur-coated urea; ZCU=zeolit-coated urea.

Economic analysis of AC use

AC production cost per kilogram of rice husk is the cheapest, while the most expensive is AC from coconut shell (Table 11). Details of the cost of production per 100 g of ACU (with composition (85 g urea + 15 g AC) from coconut shell are shown in Table 12. ACU is the cheapest of all the other urea-coated products (Table 13).

Table 11. Yield, rendement, and cost of production of AC (laboratory scale).

Raw material (RM)	Weight of RM (kg)	Yield of AC (kg)	Rendement (%)	Total cost (Rp)	Cost kg^{-1} AC (Rp)
Coconut shell	339.3	32.50	9.58	1,400,000	43,000
Rice husk	242.4	39.38	16.25	730,000	18,537
POEFB	110.0	12.38	11.25	500,000	40,400
Corn cobs	164.0	18.12	11.04	590,000	32,560

Table 12. Cost of production of ACU[a] from coconut shell (laboratory scale) and cost of applying of ACU in the field.

Description	Cost (Rp)
Cost of ACU production	
Urea (Rp 4,500 kg^{-1}, so if 85% urea = 85/100 x Rp 4,500)	3,825
AC (Rp 43.000/ kg, so if 15% AC = 15/100 x Rp 43.000)	675
Processing of ACU	750
Total cost production of ACU kg^{-1}	5,250
Cost of application	
Cost of application of urea in rice field ha^{-1} (200 kg x Rp 2000; government-subsidized)	400,000
Cost of application of urea in rice field ha^{-1} (200 kg x Rp 4500; nongovernment-subsidized)	900,000
Application of ACU in rice field ha^{-1} (200 kg x Rp 5,250)	1,050,000

[a]Composition of ACU = 85 g urea + 15 g AC.

Table 13. Price comparison of urea-coated products in the market.

Product[a]	Price (Rp)
ACU	5,250
Zeorea (ZCU)	6,000
Haracoat (SCU)	7,000

[a]SCU=sulfur-coated urea; ZCU=zeolit-coated urea.

Conclusions

Our study showed the following advantages of using AC:

1. AC from coconut shell and corn cob materials has the potential for remediation of residual insecticides because it has an I_2 absorption capacity of 901.13 and 887.13 mg g^{-1}, respectively.
2. Application of AC to the soil apparently affects bacterial populations.
3. AC can be used as a coating for urea (ACU) (composition 85 g urea and 15 g AC).
4. ACU application to the soil can increase microbial populations (degrading) of *Pseudomonas* sp., *Seratia* sp., *S. natans*, *Bacillus* sp., *Azotobacter*, and *Azospirillum*—1.8 x 10^8, 5.6 x 10^7, 6.0 x 10^6, 4.7 x 10^9, 2.0 x 10^7, and 4.2 x 10^8 cfu g^{-1}, respectively.
5. ACU treatment in rice field (Inpara 4) in Indramayu, West Java, produced the best yield of 10.9 t ha^{-1}.
6. AC treatments (particularly coconut shell, ACU, and corn cobs) in paddy field could decrease the concentrations of both chlorpyrifos and lindane.
7. Cost per kilogram of producing AC with several raw materials (coconut shell, corn cobs, rice husk, and POEFB) ranged between Rp 18,537 and 43,000.
8. Cost of production of ACU per kilogram is cheaper than that of SCU and ZCU.

The present results from case studies in Indonesia provide comprehensive information on OC contamination in rice, vegetables, soil, and water.

One of the major problems related to the agricultural environment is the accumulation of pesticide residues. One way to overcome this is through the use of AC. Activated carbon has good potential for in situ remediation of agriculture land (contaminated soils and sediments). It can also be effectively used in agriculture to reduce the phytotoxicity of pesticides (organochlorine insecticides). Continuous research on the effects of AC on environment quality is needed in Indonesia.

References

Arle HF, Leonard OA, Harris VC. 1948. Inactivation of 2,4-D on sweet-potato slips with activated carbon. Science 107: 247–248.

Cornelissen G, Gustafsson O. 2006. Effects of added PAHs and precipitated humic acid coatings on phenanthrene sorption to environmental black carbon. Environ. Pollut. 141: 526–531.

Cornelissen G, Breedveld GD, Naes K, Oen AMP, Ruus A. 2006b. Bioaccumulation of native polycyclic aromatic hydrocarbons from sediment by a polychaete and a gastropod: freely dissolved concentrations and activated carbon amendment. Environ. Toxicol. Chem. 25: 2349–2355.

Cornelissen G, Breedveld GD, Kalaitzidis S, Christanis K, Kibsgaard A, Oen AMP. 2006a. Strong sorption of native PAHs to pyrogenic and unburned carbonaceous geosorbents in sediments. Environ. Sci. Technol. 40: 1197–1203.

Hamilton D, Ambrus AA, Dieterle RM, Felsot AS, Harris CA, Holland PT, Katayama A, Kurihara N, Linders J, Unsworth J, Wong SS. 2003. Regulatory limits for pesticide residue in water. IUPAC report. Pure Appl. Chem. 75 (8): 1123–1155.

Hashimoto Y. 2007. Reduction of dieldrin concentration in cucumber fruits using *Cucurbita* rootstocks and activated carbon. J. Pestic. Sci. 32: 229–234.

Ikhwani E, Suhartatik, Makarim AK. 2011. Assembly technology of rice production on paddy field of submergence-prone to minimal productivity of 7 tons/ha. Indonesian Center Research Institute for Food Crops. (unpubl.). 12 p.

Indonesian Agricultural Environment Research Institute (IAERI). 2007. Identification and delineation of use and pollution levels of agrochemical residues in food crop and vegetables production centers in Java. IAERI.

Kwon S, Pignatello JJ. 2005. Effect of natural organic substances on the surface and adsorptive properties of environmental black carbon (char): pseudo pore blockage by model lipid components and its implications for N-2-probed surface properties of natural sorbents. Environ. Sci. Technol. 39: 7932–7939.

Lichtenstein EP, Fuhremann T, Schulz KR. 1968. Use of carbon to reduce uptake of insecticidal soil residues by crop plants–effects of carbon on insecticide adsorption and toxicity in soils. J. Agric. Food Chem. 16: 348–355.

Mandl A, Lindner W. 1999. Organochlorine pesticide residues in styrian soils and seeds of the styrian oil pumpkin: an inventory and a concept for their reduction. Int. J. Environ. Anal. Chem. 73: 1–13.

Manocha SM. 2003. Porous carbons. Sadhana. Parts 1 & 2. 28:335-348. (http://www.ias.ac.in/sadhana/Pdf2003Apr/Pe1070.pdf)

Millward RN, Bridges TS, Ghosh U, Zimmerman JR, Luthy RG. 2005. Addition of activated carbon to sediments to reduce PCB bioaccumulation by a polychaete (*Neanthes arenaceodentata*) and an amphipod (*Leptocheirus plumulosus*). Environ. Sci. Technol. 39: 2880–2887.

Norit Americas Inc. 2006. Over 150 varieties of activated carbon and here is why, <http://www.norit-americas.com/pdf/Carbon_150_Varieties_rev2.pdf>, last accessed in July 2008.

Pignatello JJ, Kwon S, Lu YF. 2006. Effect of natural organic substances on the surface and adsorptive properties of environmental black carbon (char): attenuation of surface activity by humic and fulvic acids. Environ. Sci. Technol. 40: 7757–7763.

SNI 7313:2008. Maximum residue pesticide limits for agriculture products. Indonesian Agency for Nasional Standard. 150 p. Use the name-year format here. What is SNI? There is an SNI 06-3730-1995 mentioned. Is this another reference entry?

Sun X, Ghosh U. 2007. PCB bioavailability control in *Lumbriculus variegatus* through different modes of activated carbon addition to sediments. Environ. Sci. Technol. 41: 4774–4780.

Thurston R. 1953. The effects of some soil characteristics on DDT phytotoxicity. J. Econ. Entomol. 46: 545–550.

Walters RW, Luthy RG. 1984. Equilibrium adsorption of polycyclic aromatic hydrocarbons from water onto activated carbon. Environ. Sci. Technol. 18: 395–403.

Werner D, Ghosh U, Luthy RG. 2006. Modeling polychlorinated biphenyl mass transfer after amendment of contaminated sediment with activated carbon. Environ. Sci. Technol. 40: 4211–4218.

Zimmerman JR, Ghosh U, Millward RN, Bridges TS, Luthy RG. 2004. Addition of carbon sorbents to reduce PCB and PAH bioavailability in marine sediments: physicochemical tests. Environ. Sci. Technol. 38: 5458–5464.

Notes

Authors' address: Indonesian Agricultural Environment Research Institute, Jl. Raya Jakena-Jakenn Km 05, Pati 59182, Indonesia.

Acknowledgment: The authors would like to express their gratitude to Dr. Dedi Nursyamsi and Dr. Prihasto Setyanto, former and current director of IAERI, and their staff for their assistance.

Economic analysis of biochar application in agroforestry systems

Rachman Effendi

Forest plantations in the future are expected to be the main supplier of raw materials for the national timber industry. One purpose of forest plantation development is to satisfy the energy needs of this sector as practiced by PT Sedana Arifnusa, a company that engaged in setting up forest plantations to support tobacco combustion (*omprongan*) associated with the termination of kerosene subsidy in East Lombok District. There are two alternative fuels that can be used: fuel wood and coal. Tobacco farmers in East Lombok District prefer wood but this option is not optimal as wood energy development requires high productivity of the land. This paper looks at the economic feasibility of enhancing forest plantation wood energy development with the introduction of biochar-based agroforestry systems. Moreover, this research aimed to determine alternative uses of biochar in increasing land productivity. Data were collected in October 2011 and September 2012 from forest plantation concession holders and wood energy producers in East Lombok District. The results showed that forest plantation wood energy development is feasible and a big potential for alternative fuels exists. Biochar addition can increase farmers' income by 25% (monoculture) and by 21% (mixed cropping). Addition of biochar to rice (5 t ha^{-1}) and corn (2.5 t ha^{-1}) can increase revenues by up to 69% under the partnership cropping scheme. One other important goal of biochar addition is climate change mitigation.

Keywords: agroforestry, biochar, omprongan, wood energy, economic feasibility

Forest plantations in the future are expected to become a major supplier of Indonesia's wood industry. The current national demand for timber is 57.1 million m^3 per year, while the capability of the country's natural forests and forest plantations can only supply 45.8 million m^3. The government is exerting efforts to revitalize its forestry sector through the development of forest plantations and community forests. One purpose of forest plantation development is to ensure the supply of fuelwood, which companies such as PT. Sedana Arifnusa, a consumer of tobacco leaf, consider vital.

Fuelwood is used as a substitute for kerosene used in tobacco combustion, a process called *omprongan*. TheEast Lombok District is the largest tobacco-producing area in Indonesia. In 2008,it supplied 80% of national demand for tobacco, with kerosene consumption reaching 40,000 kiloliters. Tobacco production in 2009 reached more than 50,000 t to meet 90% of that year's national demand. In the same year, 2009, the kerosene fuel (Bahan Bakar Minyak Tanah/ BBMT) subsidy for tobacco omprongan has been stopped completely. The idea is to convert into coal fuel. Other alternative sources of fuel were therefore explored to continue the farmers' business of tobacco omprongan. Two alternative fuels were found promising as they have the same price as or even cheaper than the kerosene subsidy. These are firewood (calorific value, 15 MJ kg^{-1}; price, Rp 550 kg^{-1} or Rp 37 MJ^{-1}) and coal (calorific value, 27 MJ kg^{-1}; price of Rp 1,250 kg^{-1} or Rp 46 MJ^{-1}).

The use of both alternative fuels raises some concerns about the environment. Tobacco farmers in East Lombok District prefer the use of wood as fuel for omprongan, but the local government's ban on the cutting of wood had, caused panic among them. Given this reality, an alternative solution was considered—the development of plantation energy crops for fuel and the use of biochar in the agroforestry system. But information on various aspects of development forest plantation are lacking, especially the economic side of growing energy crops.

The research was conducted to assess the economic feasibility of establishing forest plantations to boost wood energy development and of adding biochar to increase land productivity and thereby increase farmers' income. This study focused on forest plantation concession holders and farmer producers of wood energy who are involved in *Pola Mandiri* (monoculture cropping pattern) and *Pola Kemitraan* (cropping pattern [intercrop] in partnership with the community). The results of this study would help in formulating policies to improve wood energy development from forest plantations and to recommend the use of biochar to increase productivity in West Nusa Tenggara Province.

Materials and methods

Study area

The study was conducted in East Lombok District, where the number of tobacco farmers reaches 15,000. The development of wood plantations as source of firewood (fuel) for omprongan needs to be taken seriously. Geographically, East Lombok District is located between 116° and 117° east longitude and between 8° and 9° south latitude with an area of 2,679.88 km², which comprises a land area of 1,605.55 km² (59.91%) and a sea area of 1,074.33 km² (40.09 %).

The research focused on the cost structure of plantation development, describing the components of Program A (Pola Mandiri) and Program B (Pola Kemitraan), which were conducted by the tobacco company (PT Sedana Arifnusa) that operates in West Nusa Tenggara Province. The planned area for timber cultivation was 3000 ha, a big jump from the initial 250 ha. Different planting treatments were done with addition of biochar (by as much as 30 and 40% of the total amount of compost applied).

Data collection

Data were collected in October 2011 and September 2012 using field surveys and interviews with farmer respondents, forest plantation concesion holders, the wood plantation manager, and staff of various agencies and institutions involved in the marketing of wood energy or fuelwood. Primary data were obtained through direct observations in the field and interviews conducted in two subdistricts (Pringgabaya and Sambelia). The respondents included eight farmers who grow wood and intercrops and use biochar and other compost materials. Purposive sampling was done and field surveys were conducted in areas where farmers work under Program B (Pola Kemitraan) with PT Sedana Arifnusa. The interview questions elicited information on land area under *turi* cultivation and intercropping, component cost of energy wood plantation, cultivation cost of forest plantations, wood species grown, cropping patterns followed, volume/stumpage value, crop species intercropped, crop prices, volume and profit margins, and institutions involved in forest managaement.

Sample population units were farmers who planted the timber species turi (*Sesbania grandiflora*) as energy wood, primarily in partnership with forest plantation concesion holders under both agroforestry system and monoculture systems. The farmer-respondents intercropped corn and rice with timber.

Secondary data were collected from several institutions—they included the Forest Service, Industrial and Trade Services, PT Sedana Arifnusa, Forestry Research and Development Unit of Mataram, trade system agencies, and other relevant agencies. Results of various studies were likewise compiled and analyzed and so were the number of wood farmers, size of forest plantation area, and fuelwood requirement of omprongan.

The field data were tabulated. Descriptive-statistics were used to get an idea about the existing partnership between PT Sedana Arifnusa (as facilitator) and farmers with respect to wood energy demand. A quantitative analysis was conducted to assess the economic feasibility of forest plantation wood energy development underboth Pola Mandiri and Pola Kemitraan and evaluate the feasibility of adding biochar to increase land productivity. Benefit-cost ratio (BCR), net present value (NPV), and internal rate of return (IRR) were determined using the formula of Gittinger (1986).

The equations used were as follows:

a) Net present value (NPV)

NPV is the difference between the present value of profits (benefits) and the cost of the current value. The formula to calculate NPV is as follows:

$$NPV = \sum_{t=1}^{t=n} \frac{Bt - Ct}{(1+i)^t}$$

where

Bt = benefits earned each year,
Ct = cost incurred each year,
i = rate of interest,
t = time period (years), and
n = number of years.

If NPV> 0, this means that the cultivation of wood energy plantations provides a return that is equal to the rate of return that is implied and must be received (social opportunity cost of capital). NPV indicates that the larger the value, the better the business feasibility. However, if NPV <0, then it is not feasible to run the business.

b) Benefit-cost ratio (BCR)

BCR is the ratio between net benefits and NPV charged in the same year. A business will be selected if BCR >1; a business is considered failing if BCR <1. BCR is calculated using this formula:

$$BCR = \frac{\sum_{t=1}^{t=n} \frac{Bt}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{Ct}{(1+i)^t}}$$

where

Bt = benefits earned each year,
Ct = cost incurred each year,
i = rate of interest,
t = time period (years),
n = number of years,

c) Internal rate of return (IRR)

IRR indicates the ability of a project to produce a level of profit. We use this formula to calculate IRR:

$$\mathrm{IRR} = \mathrm{D_f N} + \left[\frac{\mathrm{PVP}}{\mathrm{PVP - PVN}}\ \mathrm{X}\ (\mathrm{D_f N} - \mathrm{D_f P})\right]$$

where

DfN = discount used (present value negative)
DfP = discount used (present value positive)
PVP = present value positive
PVN = present value negative

Results and discussion

Wood energy demand

East Lombok District has high potential as a producer of tobacco. There are approximately as many as 15,000 tobacco farmers residing in the area. In tobacco production, the leaves should be dried in an oven. Farmers use the oven called omprongan or the virginia tobacco oven for this drying process. The 15,000 omprongan units used in the district come in different sizes: small, medium, and large.

A small omprongan can dry 30 t of fresh leaves (from 1 ha), which would result in 30 quintals of dry leaves (yield of 10%), whereas a medium omprongan handles as much as 45 t fresh leaves (1.5 ha), which would give 45 quintals of dry leaves. The large omprongan processes 60 t of fresh leaves (2 ha) and yield 60 quintals of dry leaves.

The demand for wood fuel based on oven capacity is as follows:

a) Small oven: for a 6-day drying period, as much as 4 m^3 of fuel wood is required. As the tobacco harvest season lasts for 3 mo (from August to October), farmers can use the oven as many as 17 times. Therefore, in one season, every farmer requires as much as 68 m^3 of firewood.

b) Medium oven: this oven requires as much as 5 m^3 of wood fuel and in a season, farmers do the drying 17 times. The season-long requirement thus reaches 85 m^3 of wood fuel.

c) Large oven: Inasmuch as the weekly requirement is 7 m^3,119 m^3 of wood is needed for one season.

Thus, considering the15,000 farmers who, on average, use the small omprongan, some 1.02 million m^3 of wood fuel is required for one season. To meet this demand,extensive harvesting of wood plantations is imperative. The minimum area needed is 6,800 ha per year. This translates into 27,200 ha per year with a cutting rotation of 4 years and an annual per-hectare production of 150 m^3.

Wood energy from forest plantations

Today, the use of wood as fuel for tobacco *omprongan* in East Lombok District is quite high. There are growing concerns about increased deforestation and environmental damage. To solve the problem, the then Bupati of East Lombok District issued a policy directive prohibiting the use of wood as fuel. To help farmers who will be affected by this restriction, PT Sedana Arifnusa took the initiative to develop forest plantations as source of wood energy and introduced intercropping in the agroforestry system.

The plantation management scheme that was developed consisted of two programs:

a) Program A (Pola Mandiri)

This program is developed according to timber estate principles. The major species used is turi (*Sesbania grandiflora*) (composition of 100% turi species) and harvest rotation is 4 years. The program is managed independently/ self-managed by PT Sedana Arifnusa without partnering with farmers. Currently, trials under the program involve as much as 15 ha on land owned by the Indonesian National Army (TNI) , 4 ha in Pandak Luar area and 25 ha in Kahyangan area.

b) Program B (Pola Kemitraan)

This agroforestry-based program is developed through a partnership between PT Sedana Arifnusa and farmers. The composition of trees planted in 1 ha is as follows:

1) 100% turi species; 4,000 trees (spacing of 2.5m x 1 m)
2) a mixture of crops composed of 65% turi, 10% gmelina, 12.5% mindi, and 12.5% acacia. The 4,000 trees planted are used not only for fuel but also for timber woodwork. Intercropping plant species grown in the community are corn, padi gogo, and rice variety IR36.

Cost of forest plantation development for wood energy

The cost of developing forest plantations to supply wood energy covers the following activities: planning/preparation, land preparation, seedling provision, planting, maintenance, and harvesting. Table 1 shows the per-hectare cultivation cost of turi. Table 2 illustrates the cost of producing turi under an agroforestry system.

Table 1. Per-hectare cost of cultivating Pola Mandiri using turi species.

Activitiy	Unit	Price (Rp unit^{-1})	Requirement	
			Unit ha^{-1}	Rp ha^{-1}
1.Seed procurement (spacing 1.5 m x 2 m, number of seeds 3.666 rods)				
a. Seed requirement	Rod	510	3.666	1,869.66
b. Transportation cost	Rod	150	3.666	5,499.0
Sum (1)				2,419.56
2. Land preparation (semi-mechanical)				
a. Excavator	8 h	300.000	4	1.200.00
b. Land clearing	Workday	35.000	10	350.00
c. Tree felling	Workday	35.000	30	1.050.00
d. Weeding				-
– Round Up (Metindo)	Liter	60.000	3	180.00
– Wages	Workday	35.000	5	175.00
e. Making pathways and planting holes	Workday	35.000	20	700.00
Sum (2)				3.655.00
3. Cultivation (wages, materials, and equipment)				
a. Wages for cropping				
b. Hydrogel (growing media)				
c. Sprinkling	Workday	35.000	17	595.00
d. Water truck (lorry)	Kg	75.716	12.5	946.45
e. Watering 2nd	Workday	35.000	7	236.25
– Water truck	Truck/4 h	200.000	3	600.00
– Wages for watering	Truck/4 h	200.000	3	600.000
f. Fertilizer (NPK)	Workday	35.000	7	236.25
– Organic fertilizer	Kg	3.500	333.3	1,166.55
– Wages for fertilizing	Workday	35.000	6	210.00
Sum (3)				4,590.50
4. Maintenance				
a. Blanking	Workday	35.000	5	175.00
b. Weeding in planting areas (manual)	Workday	35.000	10	350.00
c. Weeding				
– Round Up	Liter	60.000	3	180.00
– Wages	Workday	35.000	5	175.00
d. Weeding between rows (manual)	Workday	35.000	10	350.00
c. Weeding				
> Round Up	Liter	60.000	3	180.00
> Wages	Workday	35.000	5	175.00
Sum (4)				1,585.00
5. Harvesting				
a. Chainsaw	Unit	150.000	5	750.00
b. Fuel	Liter	4.500	25	112.50
c. Tranportation	Trip	300.000	1	300.00
d. Wages of chainsaw operators	Workday	100.000	5	500.00
Sum (5)				1,662.50
Total cost				13,912.56
Revenue (75% success rate of planting)	m^3	250.000	120	30,000.00

Remarks: Average volume of 100 trees = 4 m^3; Number of trees planted = 4,000 trees ha^{-1}; Spacing = 1 m x 2.5 m; Success rate (percentage growth) = 75%.

Table 2. Per-hectare cost of cultivating Pola Mandiri species turi (Sesbania grandiflora) under an agroforestry system involving maize and rice.

Activity		Unit	Price (Rp unit^{-1})	Requirement	
				Unit ha^{-1}	Rp ha^{-1}
I. Major plant: Turi					
1	Preparation (equipment)				760.00
	a. Hoe		35,000	30	700.00
	b. Chopping knife	Piece	15,000	3	45.00
	c. Sprayer	Piece	15,000	1	15.00
2	a. Land preparation (wages and equipment)	Various	Various	Various	1,055.00
	b. Seed procurement and transportation	Various	Various	Various	2,775.00
	c. Cultivation	Various	Various	Various	630.00
	d. Chemical fertilizer	Kg	6,000	250	1,500.00
3	Maintenance (wages and materials)	Various	Various	Various	650.00
4	Harvesting				752.50
	a. Wage for cutting	Workday	20.000	3	60.00
	b. Chainsaw rent	Unit	150,000	3	450.00
	c. Fuel	Liter	4,500	15	67.50
	d. Tranportation cost	Workday	35,000	5	175.00
Total expenditure I					8,122.50
II.	Mixed cropping with rice				
1	Excavation (wages and equipment)	Ha	1,000,000	Various	1,000.00
	a. Procurement of rice seed	Kg	17,500	21.5	376.25
	b. Wage for drilling	Workday	40,000	6	240.00
	c. Cultivation and fertilization	Various	Various	Various	1,233.75
	d. Insecticides (wages and materials)	Various	Various	Various	230.00
2	Irrigation	Month	125,000	3 bln	375.00
3	Harvesting	Various	Various	Various	635.00
Total expenditure II					4,090.00
III.	Mixed cropping with maize				
	a. Procuring and tranporting seed	Kg	35,000	11	385.00
	b. Wage for drilling	Workday	40,000	6	240.00
	c. Cultivation and fertilization	Various	Various	Various	1,200.00
	d. Insecticides (wages and materials)	Various	Various	Various	210.75
Total expenditure III					2,035.75
Revenue					
a. Fuel wood (at 75% success rate of planting)		m^3	250.000	120	30,000.00
b. Output: rice (dry milled rice) (2x harvest)		Kg	3.000	2.143	12,858.00
c. Output: maize (dried grains (contract)			na	na	5,357.00
Total revenue					48,215.00

Remarks: Average volume of 100 trees = 4 m^3; number of trees planted = 4,000 trees ha^{-1}; Spacing = 1 m x 2.5m; success rate (percentage growth) = 75; maize sold in the condition of stand.

Economic analysis

The economic feasibility of cultivating sources of wood energy using turi species was determined by analyzing cost and benefits obtained from production. The details of cost and benefits in monoculture and agroforestry systems are presented in Tables 1 and 2.

Some of the assumptions used in this analysis include the following:

1. Period of analysis based on 4-year production period (harvest rotation period) of turi species.
2. Interest rate is 12%
3. Potential turi timber volume at the end of the harvesting period (with 75% success rate) is 120 m^3 ha^{-1}.
4. Price of fuel wood (turi) in wood collection points (TPn) is Rp 250,000 m^{-3}.
5. Agroforestry systems with maize and rice can only be planted in the first year; harvest frequency is twice for rice and once for maize.
6. Price of biochar of cocoa skin and charcoal compost is Rp 3,000 kg^{-1} (franco planting location).
7. Land rental is not included in the calculation and assumed to be privately owned.

The analysis was done with some planting systems that include:

a) Monoculture planting system under program A (Pola Mandiri) and program B (Pola Kemitraan) without the addition of biochar

Based on feasibility analyses using the parameters IRR, NVP, and BCR, each type of program may thus be evaluated.Both Pola Mandiri (Program A) and Pola Kemitraan (Program B) are feasible and may be recommended for West Nura Tenggara. Pola Kemitraan is more feasible to implement than Pola Mandiri. Program B must be given priority to assist tobacco farmers in that province.

b) Monoculture planting system under Program A (Pola Mandiri) and Program B (Pola Kemitraan) with addition of biochar (as much as 30%) In South Sumatra, results of trials conducted by researchers at the Forestry Research Institute of Palembang showed that addition of 30% biochar to nursery timber species bambang lanang (*Madhuca aspera* Lam.) increased the diameter and height of the 3-mo-old seedlings by 55% and 71%, respectively (see figures from Siahaan et al [2011]).

Table 3. Economic feasibility of cultivating turi as wood energy source, by program type, with (40%) and without addition of biochar.

Parameter	Pola Mandiri		Remarks	Pola Kemitraan		Remarks
	Without biochar	With 40% biochar		Without biochar	With 40% biochar	
Revenue (Rp 1000 ha^{-1})	19,067	23,832	Increased 25%	22,577	27,342	Increased 21%
Cost (Rp 1000 ha^{-1})	11,969	11,862	Decreased 1%	7,088	7,008	Decreased 2%
NPV (Rp 1000 ha^{-1})	4,236	8,395	Increased 98%	12,103	16,234	Increased 34%
BCR	1.59	2.01	Increased 26%	3.19	3.90	Increased 22%
IRR (%)	25.2	36.1	Increased 43%	58.8	70.0	Increased 19%

Table 3 shows that the value of NPV is >0, BCR is>1 and IRR is greater than the effective rate of interest. Therefore, it can be concluded that wood energy development from forest plantations is feasible and would attract investors.

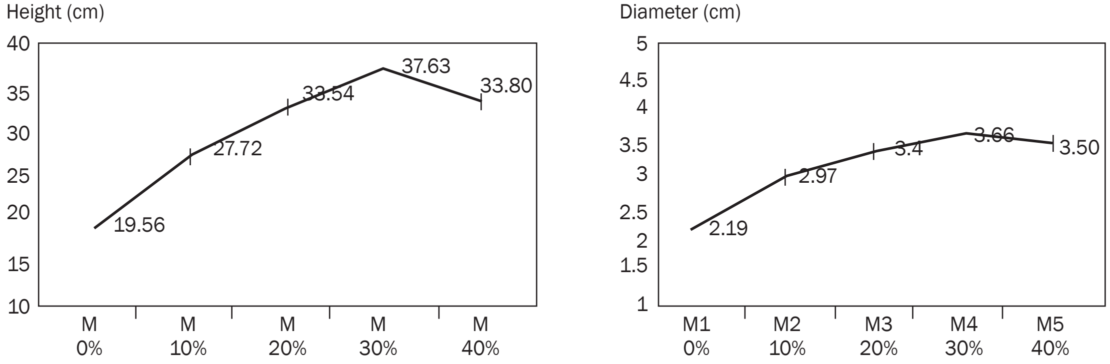


Fig. 1. Correlation of percentage of compost charcoal with height and diameter of 3-mo-old bambang lanang seedlings in the nursery (Source: Siahaan et al 2011).

Addition of 40% compost charcoal (biochar) increased the height and diameter of bawang timber by 65.5% and 46.6%, respectively (Herdiana et al 2012). Furthermore, adding as much as 30% charcoal tusam litter or litter compost mixture to mahoganyincreased the height of mahogany seedlings from 17.67 to 25.02 cm, 2.7 to 3.8 times higher than the control. The diameter reached 0.16 to 0.19 cm, about 1.8-2.1 times higher than the control (Komarayati 2004). Siahaan et al (2007) also showed similar increases in height and diameter of *Protium javanicum* seedlings, by 21.51% and 15.19%, respectively, compared with those of the control.

Research results do indicate that addition of biochar by as much as 30% of the total compost applied can be adopted for turi species in East Lombok District, West Nusa Tenggara Province. The results of the feasibility analysis for the turi monoculture cropping system with 60% organic fertilizer and 40% biochar are shown in Table 3.

c. Mixed planting under an agroforestry system (Pola Kemitraan)

Based on a Soil Research Institute study, the addition of biochar from cocoa skin to maize and padi gogo (as much as 2.5 and 5 t ha^{-1}, respectively) increased yield by 281% (from 0.37 to 1.41 t dried corn grain ha^{-1}) and 150% (from 0.4 to 1 t dry milled rice ha^{-1} (Nurida 2012). This can be done by tobacco farmers in West Nusa Tenggara.The economic feasibility of planting turi along with rice and maize is seen in Table 4.

Table 4. Feasibility of cultivating turi as source of wood energy under an agroforestry system (Pola Kemitraan).

Parameter	Without biochar	With biochar	Remarks
PT (Rp ha^{-1})	30,562.55	51,643.18	Increased 69%
BT (Rp ha^{-1})	18,030.38	27,177.03	Increased 51%
NPV (Rp ha^{-1})	12,532.16	19,699.76	Increased 57%
BCR	1.70	1.90	Increased 12%
IRR (%)	1.55	>200	Increased >29%

The addition of biochar does not result in a decrease in BCR as shown in Tables 3 and 5. Therefore, this should not discourage farmers from using biochar. The addition of biochar can increase benefit by 21% (monoculture) and by 69% (intercropping system). The decrease in BCR occurs from the shift from monoculture to a mixed cropping system. But it should likewise not discourage farmers as the increase in revenue is much greater than the increase in cost with biochar added.

It can be seen then that addition of biochar (5 t ha^{-1} for padi gogo and 2.5 t ha^{-1} for corn) in the same area is feasible as shown by the increased revenue, NPV, BCR, and IRR. Overall, the cost of forest development will increase by 50%, but farmers' income will increase by 69%. The addition of biochar will increase the profits of farmers from corn and rice with wood energy provided by turi species.

Conclusions

1. Developing forest plantations as source of alternative energy to fuel tobacco omprongan is feasible and has high potential in Nusa Tenggara Province.
2. Using biochar (30% of seed crop and 40% of cultivated crop) can increase revenue by 25% under Pola Mandiri and 21% under Pola Kemitraan.
3. The addition to rice of 5 t biochar ha^{-1} (padi gogo species) and to maize of 2.5 t biochar ha^{-1} in one stretch of forest plantation (turi species-based agroforestry) can increasedevelopment cost by 50%, but it can increase farmers' income by 69% for the Pola Kemitraan cropping system. The value of BCR does not decrease.
4. The use of biochar in crops grown under an agroforestry system is financially feasible and can be considered to enhance wood energy development.

References

Gittinger JP. 1986. Analisis ekonomi proyek-proyek. pertanian. Jakarta: Universitas Indonesia Press.

Gusmailina, Komarayati S, G. Pari dan M. Ali. 2005. Mengenal Manfaat Arang dan Arang Kompos. Makalah Diskusi Intern BP2HT IBB Palembang. Pusat Penelitian dan Pengembangan Teknologi Hasil Hutan. Bogor.

Herdiana N, Hengki S, Teten R. 2012. Effect of compost charcoal and light intensity on growth of onion seedlings. Research and Development of Forest Plantations (BP2HT), Palembang. (unpubl.)

Komarayati S. 2004. Penggunaan Arang Kompos pada Media Tumbuh Anakan Mahoni. Jurnal Penelitian Hasil Hutan No. 22 (4) 2004. Pusat Penelitian dan Pengembangan Teknologi Hasil Hutan. Bogor.

Ministry of Forestry. 2009. The nature and type 120 Uses Timber Trade Indonesia www.dephut.go.id. Accessed 18 February 2010.

Nurida NL. 2012. Aplikasi Biochar di Lahan Pertanian. Seminar Nasional Potensi Biochar dalam Mitigasi Perubahan lklim dan Perbaikan Produktivitas. Kerjasama Fakultas Kehutanan UNMUL dan GIZ Forclime. Balikpapan, 11-12 December 2012.

Peraturan Pemerintah Republik Indonesia No. 44 Tahun 1997 Tentang Kemitraan. http://www.bpkp.go.id/unit/hukum/pp/1997/044-97.pdf

Siahaan H, Nanang H, Teten R. 2011. Pengaruh Pemberian Arang Kompos dan Naungan Terhadap Pertumbuhan Bibit Bambang Lanang (The effects of compost charcoal and shading net application on growth of Bambang lanang seedlings). Laporan Hasil Penelitian Balai Penelitian dan Pengembangan Hutan Tanaman (BP2HT) Palembang. (unpubl.)

Supriyanto K. 2009. http://lomboknews.com/2009/06/02/kayu-bakar-untuk-omprongan-tembakau/. Accessed 30 October 2010.

Undang-Undang Republik Indonesia No. 9 Tahun 1995 Tentang Usaha Kecil. http://www.kadin-indonesia.or.id/enm/images/dokumen/KADIN-13-1943-31082007.pdf

Notes

Author's address: Centre for Climate Change and Policy Research and Development Forestry Research and Development, Ministry of Forestry, Indonesia.