THE ROLE OF BIOCHAR IN INTEGRATED FARMING SYSTEMS

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ABSTRACT

A negative consequence of the emphasis given to production of biochar as a primary product, has been the opposition from ecologists and food producers who envisage “the growing and harvesting of trees mainly to produce biochar with corresponding negative effects on the environment and on food production”. It is therefore essential that biochar is seen as a component of integrated farming systems dedicated primarily to ensuring sovereignty in both food and energy production for rural communities that will produce the biochar. The operating conditions for production of biochar -- carbonization of fibrous biomass at high temperatures (500 to 1000°C) with restricted air supply – are precisely those that apply in both down-draft and up-draft gasifiers designed for the production of a combustible gas for internal combustion engines and turbines dedicated to production of electricity, or of process heat for cooking and related purposes. In these settings the yield of biochar is from 100 to 150g per 1 kg of the original dry biomass with accompanying electricity production of the order of 0.8 KWh or the equivalent of 0.25 kg of liquid propane. The concept of integrating biochar with energy production can be extended further to an approach in which highly productive biomass crops such as sugar cane are first fractionated into food/feed, with the residual fibrous biomass being the feedstock for gasification to produce electricity (or process heat) and biochar. A similar approach can be taken with rice, which is traditionally grown for food but with the accompanying fibrous biomass largely disposed of by open-field burning with negative effects on the environment and loss of a valuable resource.

Key words: biochar, renewable energy, livestock, recycling, biodigesters

INTRODUCTION

Biochar as a component of integrated farming systems

A major challenge facing agricultural planners is in designing farming systems that combine production of food and energy with an overall negative carbon footprint. Growing of crops solely to produce biochar, as a major tool for sequestration of atmospheric carbon dioxide, is not encouraged. Such proposals are rightly criticized by environmentalists as being both undesirable and unnecessary.

The above criticisms can be largely avoided by ensuring that the farming system is geared to the needs and opportunities presented by small-scale farms and rural communities, that are best suited to utilize efficiently local resources, and to recycle wastes.

In tropical latitudes, the cropping systems best suited to integrated production of food, energy and biochar are rice, sugar cane and tree crops such as coffee, cocoa, oil palm and coconut. In all cases the primary objective is production of food or animal feed, while fibrous residues can be the feedstock for gasification. Maize is commonly grown in the tropics but should not be encouraged as the latter third of the growth cycle is concerned with transfer of nutrients from the stalk to the grain, rather than photosynthesis, as in this stage the leaves die and no longer utilize solar energy, which is thus wasted.
Sugarcane for energy, feed and biochar

A model based on sugarcane, developed and used in Colombia over the past eight years, is indicative of the potential of the small to medium scale of operation that can now be adapted to the needs of rural communities. Sugarcane stalks are crushed in a traditional 3-roll mill (as used for production of gur and panela) to yield sugarcane juice that is the basis of the feeding system for livestock (and as a sweetener for the family). The crushed stalks (bagasse) are gasified to produce a gaseous fuel (for an engine-generator producing electricity) and biochar (Fig. 1).

The model shown in Fig. 1 was designed for, and has been operating in, a small-scale farm (3ha) in the Santander province in Colombia (Rodriguez 2012). However, it can be adapted to the needs of rural communities of 50 to 100 families. At this larger scale, the sugar cane juice is concentrated to “syrup” (about 65% sugars) to ensure a stable product that can be stored and transported for use as replacement for cereal grains in the same community.

Energy, food and biochar from the rice crop

Presently, the production of biochar from the rice crop is almost exclusively from the use of rice husks as feedstock for down-draft industrial-scale gasifiers. Cambodia is at the forefront in application of this technology with an estimated 40 to 50 medium to large-scale units (250 to 500 KVA) already operating in rice mills and rural communities (Khieu Borin, personal communication). Increasingly the biochar produced in these gasifiers, considered originally as a waste product, is being used as a soil conditioner for growing vegetables and flowers. Research is underway to proceed to the next step, which is to compact the rice straw into briquettes or pellets, a form compatible with the operating conditions in a down-draft gasifier.

It can be estimated that if the 40 to 50 million tons of rice straw produced annually in Vietnam were gasified, it could produce the balance of electrical energy needed to complete that from hydro and make the country a 100% clean energy producer. The associated production of biochar would be of the order of 5 to 6 million tons. The potential is enormous. Similar calculations can be applied to Cambodia, Lao PDR and other rice-growing countries.

Biochar as a by-product from use of household cook-stoves

There has been much interest in, and development of, stoves that use the gasifier principle to produce a clean gas for cooking.

![Fig. 1. Integrated use of sugarcane for food/feed, biochar and electricity (Rodriguez 2012)](image-url)
The main aim of these initiatives was to improve the conditions under which women, in particular those in poor households, cooked the family meals, a process traditionally carried out over open fires. With the increasing awareness of the potential role of biochar in the farming system, the focus on cook stoves now includes their dual role, with production of biochar becoming as important as their use for cooking. The gasifier stove that was designed and is being constructed in Vietnam was developed originally in the Philippines (Belonia 2005) with the special purpose of using rice husks as fuel. However, it has already served a valuable purpose as the means to facilitate production of biochar for research in universities and research centers throughout Cambodia, Laos and Vietnam. Already more than 25 research papers have been produced in the region as a result of this initiative.

The role of biochar in farming systems

To data most of the emphasis given to biochar has been on its role as an amendment in soils and its potential to sequester atmospheric carbon (Lehmann and Joseph 2009). However, recent research shows that its role is much wider with potential application in all components of farming systems that involve microbial activities. This review will therefore relate primarily to research findings where biochar has been evaluated as a component of integrated farming systems.

Synergism between biochar and biodigester effluent

The first experiment in this series was carried out on a farm in the Colombian foothills where a downdraft gasifier had been installed and where effluents from tubular plastic plug-flow biodigesters were the principal sources of fertilizer (Rodriguez et al. 2009). Biochar derived from sugar cane bagasse, used as feedstock in a downdraft gasifier, was added to a fertile soil from a coffee plantation and to sub-soil taken from 1 m below the surface of an unfertilized pasture. In each case the soil was fertilized with the effluent from a biodigester charged with pig manure. Maize was used as the indicator plant over a growth period of 40 days (Fig. 2).

There was an obvious synergism between the biochar and the availability of plant nutrients. On the sub-soil, application of biochar had no effect until it was combined with biodigester effluent, when the combination of the two amendments supported the same growth of maize as that achieved on the fertile soil (Fig. 3). The impact of the combined treatment in modifying the structure and nutrient supply in the sub-soil was even more impressive (Photos 1 and 2).

Biochar versus charcoal

It is generally considered that the difference between biochar and charcoal traditionally produced from wood in simple earth-covered kilns arises from the fact that in the former the carbonization takes place at

![Fig. 2. Effect of biochar and effluent added to fertile soil and sub-soil on fresh weight of aerial part of maize (40 days of growth) (Rodriguez et al. 2009)]
much higher temperatures. It has long been known that application of charcoal to soils can be beneficial for plant growth. However, the results summarized in Figures 4 and 5 (and in Photo 3) show clearly that biochar (produced in an updraft gasifier stove from rice hulls) was a more effective soil amendment especially when the regrowth of the indicator plant (in this case water spinach) was measured over a second harvest with no further addition of the two soil amenders.

Residual effects of biochar in soils

The belief that biochar may have mean residence times in soil, ranging from 1,000 to 10,000 years (Skjemstad et al. 1998; Swift 2001), implies that there should be long term benefits in soils from application of biochar. This is in line with the observations of maintained fertility in Terra preta black soils in Amazonia (Glaser 2007). Yet, surprisingly, little attention appears to have been given to
evaluating such residual soil fertility aspects in a more modern context.

Results from an experiment in an acid soil (pH 4.7) in Pakse province, Lao PDR, planted with Taro (*Colocasia esculenta*), give some indication of positive carry-over effects of biochar applied once at the start of the trial. Increased yields relative to control plots were recorded consistently over consecutive harvests at 84 day intervals (yields for the first and third harvests are shown in Fig. 6 and Fig. 7.

Recent observations on farmer field plots in Kenya indicate that the benefits from biochar on yield of grain sorghum were greater in the second year with no further addition of biochar (http://www.re-char.com/2013/01/24/the-longterm-impact-of-biochar-in-soil-season-2/).

**Enriching biochar with biodigester effluent**

Biochar is reported to remove nutrients such as phosphorus (http://news.ifas.ufl.edu/2011/05/12/uf-researchers-develop-method-to-remove-phosphate-from-water-using-biochar/) and ammonia from wastewater. However, there appear to be no reports on the effects on plant growth of biochar after it has been used to absorb nutrients from biodigester effluent. It is possible that the combination of effluent-treated biochar with biodigester effluent would have synergistic effects on soil improvement as manifested in increased crop growth and/or reduced requirements for exogenous fertilizer.

Results of an experiment to test this hypothesis are summarized in Fig. 8 and Fig. 9. Biochar was soaked in effluent from a biodigester for periods of 24, 48, 72 or 96 hours or was not treated. The different biochars produced by this process were then added (4 kg/m²) to an acid soil (pH 4.7) with maize as the indicator plant. An additional
treatment in a factorial arrangement was the application or not of the same biodigester effluent as source of plant nutrients (at a level equivalent to 50 kg N/ha).

Soaking the biochar in the effluent for 72 hours gave a three-fold increase in above ground growth of maize and of the maize roots when effluent was also applied as fertilizer. In the absence of effluent as fertilizer there was no response to prior soaking of the biochar in effluent. These responses support the concept of the biochar acting as a habitat where microbial biofilm facilitates the action of consortia of microorganisms in releasing minerals located in close proximity to their substrates.

**Biochar and nutritive value of vegetables**

We earlier described positive effects of biochar on biomass yield of water spinach (Fig. 4 and Fig. 5). More recent experiments showed linear increases in DM yield of celery cabbage (Fig. 10) and green mustard (Fig. 11). These yield increases were accompanied by positive changes in nutritive value with increases in content of crude protein (Fig. 12) and decreases in crude fiber (Fig. 13) as biochar applications to soil were increased.

**Biochar as an additive in diets of ruminant animals**

Results of preliminary trials in Lao PDR (Leng et al. 2012a,b,c) indicate that biochar reduced methane production in an in vitro incubation with rumen fluid taken from an un-adapted buffalo (Fig. 14). When the biochar was fed at 1% of the diet to local cattle this was reflected in improved growth rates and concomitant reduction in enteric methane emissions (Fig. 15 and Fig. 16).
Fig. 8. Effect of biodigester effluent and length of time the biochar was suspended in biodigester effluent on above ground biomass yield of maize after 50 days growth 
(Southavong et al. 2012b)

Fig. 9. Effect of biodigester effluent and length of time the biochar was suspended in biodigester effluent on root weight of maize after 50 days growth 
(Southavong et al. 2012b)

Fig. 10. Relationship between level of biochar and green biomass DM yield of Celery cabbage 
(Chhay Ty et al. 2013)

Fig. 11. Relationship between level of biochar and green biomass DM yield of mustard green 
(Chhay Ty et al. 2013)
Further evidence for the effect of biochar on rumen microbial activity was that rumen fluid, taken from the cattle previously fed biochar, supported lower levels of methane production compared with rumen fluid from un-adapted cattle (Fig. 17). When the in vitro system combined rumen fluid from adapted cattle plus additional biochar, the reduction in methane production was three-fold that observed in the treatment with rumen fluid from un-adapted cattle (Leng et al. 2012c).
Fig. 15. Effect of biochar and NPN source on ratio of methane to carbon dioxide in mixed air and eructed rumen gases for “Yellow” cattle fed cassava root and cassava foliage.

Fig. 16. Reduction in methane due to biochar and nitrate in local “Yellow” cattle fed cassava root and cassava foliage supplemented or not with biochar and with urea or potassium nitrate as NPN source.

Fig. 17. Effect of adaptation to biochar in the diet, and of addition of biochar to the substrate, on percent reduction in methane production (ml methane/g DM solubilized) in an in vitro incubation of cassava root meal with cassava leaf meal and urea (Leng et al. 2012c).
Biochar as a source of biofilm in biodigesters

On the basis of the results from in vitro systems with rumen fluid taken from buffaloes and cattle, and the practice of adding activated charcoal to anaerobic biodigesters to enhance the stability and efficiency of conversion of organic wastes to methane (Aktaş and Çeçen 2007), it was hypothesized that biochar should also influence the process of fermentation in biodigesters charged with cattle excreta. After an initial lag period, incorporation of 1% biochar in the cattle manure introduced into a batch biodigester led to a consistent increase in production of biogas with an overall improvement of 31% over a 30 day period of incubation (Fig. 18). There was no further improvement with 3% of biochar in the influent. The methane content of the gas was unchanged at 43% (Fig. 19).

By contrast the effect of the biochar was
quite different when added to biodigesters managed as a continuous process with additions daily of cattle manure containing 1% (in DM) of biochar (Fig. 20 and Fig. 21). Gas production was increased but by a much smaller degree (5%) than in the batch biodigester (30% increase) and the methane content was decreased.

Research priorities

Source of the biochar

In almost all the experiments reported in this chapter, the biochar was produced from rice husks carbonized in an updraft gasifier stove (Olivier 2010). The exception was in the research of Rodriguez et al. (2010) where the biochar was from sugar cane bagasse carbonized in a downdraft gasifier. The experiments were done on-farm (Rodriguez et al. 20090) or in laboratories in newly established universities in Laos where analytical facilities were minimal, thus there are no data on the composition of the biochar.

Gasification versus pyrolysis

Competing claims are made for the virtues of biochar produced by pyrolysis compared with gasification. However, there is a lack of information on the respective merits of the biochar produced from the two processes as a component of farming systems. Comparative data from use of biochar produced by different technologies is urgently needed. From the systems standpoint, gasification appears...
to have the advantage as the products can be used efficiently on-farm at all scales of operation. By contrast, the bio-oil that is a major product from pyrolysis will require refinement at some central facility before it can be used to replace liquid fuels. Use of electricity produced as the output of gasification is facilitated by the ease of transporting it over existing transmission lines.

**Long-term effects of biochar**

The belief that biochar has mean residence times in soil, ranging from 1,000 to 10,000 years (Skjemstad et al. 1998; Swift 2001), implies that there should be long term benefits in soils from application of biochar. This is in line with the observations of maintained fertility in Terra preta black soils in Amazonia (Glaser 2007). There is also support from recent findings from Kenya [http://www.re-char.com/2013/01/24/the-longterm-impact-of-biochar-in-soil-season-2/](http://www.re-char.com/2013/01/24/the-longterm-impact-of-biochar-in-soil-season-2/) that indicated that the benefits from biochar on yield of grain sorghum were greater in the second year with no further addition of biochar. This feature of long term impact on soil fertility of the use of biochar has so far received insufficient attention from researchers.

**Biochar in the farming system**

The indications that incorporation of biochar in livestock diets has beneficial effects on productivity with reduced emissions of enteric methane need to be verified under a wide range of farming systems. Similarly, the potential role of biochar in enhancing biogas production from livestock wastes, and in purification (recuperation of plant nutrients) of waste waters, merits increasing attention.

Most reports on biochar as soil amender refer to effects on yield of biomass and its components. The finding that in green mustard vegetable the crude protein percentage was increased, and crude fiber reduced (Chhay Ty et al. 2013), implies that improvement in nutritive value of certain crops may be another virtue of soil application of biochar. Validation of these findings with other crops and vegetables is another urgent research need.

**CONCLUSION**

The potential role of biochar as a means of sequestering atmospheric carbon has so far been the main focus of attention. However, its virtues are much wider with potential impacts on soil fertility, plant yield and quality and as an additive in livestock feed, biodigesters and other liquid waste disposal systems. More important is the emphasis that biochar has given to the overall concept of the systems approach to utilization of renewable resources and recycling of wastes with maintenance or improvement in soil fertility. Biochar makes most sense when it is derived from a process that aims to optimize the varied characteristics of biomass, to satisfy the major needs of humanity which are food, energy, shelter and a healthy environment. It needs to be produced and used locally for maximum benefits.

**REFERENCES**


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