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MANAGING FARM AGRO WASTE IN RURAL AREAS: EMERGING POTENTIALS AND CHALLENGES OF BIOCHAR PRODUCTION AND USE AMONG SMALLHOLDERS

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Abstract

The agricultural sector plays a crucial role in driving rural economic growth, with various government agencies at the forefront of rural agricultural development. Programs such as Young Agropreneur, Contract Farms, and Smallholder Assistance significantly aid farmers in cultivating land outside urban areas. In return, agriculture provides employment opportunities and income, ensuring that rural areas continue to function as food producers for both the local community and the growing urban population. The pressure to increase farm production to meet market demand directly raises the amount of waste produced by rural farmers. Consequently, waste management is often a significant issue for rural smallholders. In addition to the lack or absence of appropriate facilities to process agricultural waste, small rural farmers also lack exposure to methods of converting their agricultural waste and manure into biochar, an organic fertiliser. Biochar can help farmers reduce the cost of chemical fertiliser inputs and promote environmentally friendly agricultural practices. This article aims to identify the potential and challenges of biochar application among rural smallholders through a review of literature and by learning from the previous experience of smallholders under a cluster farming program in the Hulu Terengganu district, who utilised biochar for managing farming waste in a sustainable way. The article concludes that with awareness programs and constant supervision by agencies and agricultural experts, the wider usage of biochar for reducing farming input costs for small rural farmers and also encourage environmentally friendly green farming practices can be achieved.

Key words**:** *Rural farm waste, biochar, organic farming, rural smallholders, cost reduction*

INTRODUCTION

Managing plantation waste among smallholders in rural areas is often a significant challenge, especially in the context of environmental sustainability. The long-standing practices of open burning of agricultural waste or leaving it to decompose in fields are low-cost and easy for farmers to execute, but they also lead to the accumulation of agricultural waste, including crop residues, plant matter, and manure, on farms without proper disposal methods [3, 4]. This accumulation can result in environmental problems such as methane emissions, soil degradation, and water pollution due to the runoff of nutrients and organic matter [1, 16]. In worse situations, when farm areas are located near settlements, improper waste disposal and stagnant water hidden behind plant waste create ideal breeding grounds for mosquitoes and other pests that spread diseases. Also, in many rural areas, limited access to waste management infrastructure exacerbates these issues, leading to inefficient and environmentally harmful disposal practices [12, 14].

Thus, managing farm waste sustainably is crucial and must consider a "double-edged sword" strategy to safeguard environmental quality and improve the livelihoods of rural smallholders [6, 15]. To address these challenges and seize these opportunities, farmers need to adopt value-added activities

and projects, such as converting agro waste, plant residue, and manure into biochar and other organic products [8, 10, 13]. By doing so, rural farmers can improve their environmental footprint, enhance soil health, and achieve greater economic sustainability.

This article was formulated with the intention of identifying the emerging potentials and challenges of managing farming waste among smallholders in rural areas and the potential adoption of biochar production and use as a value-added project. The information shared in this article was obtained through a review of the literature on related topics and results from field observations involving a group of smallholders under a cluster farming program in the Hulu Terengganu district. The findings highlighted the potential for rural smallholders to use biochar production and usage to manage their farm agro waste sustainably, reduce farming input costs, and promote organic or semi-organic farming in rural areas.

Literature review

Farm Agro Waste and Biochar Production

Farm agro waste management is a critical component of sustainable agriculture. It directly impacts environmental sustainability by influencing greenhouse gas emissions, soil health, water quality, and biodiversity [14, 17]. By adopting sustainable waste management practices, such as converting waste into biochar, composting, integrated farming etc., farmers can reduce their environmental footprint, improve resource efficiency, and contribute to the broader goals of sustainable development and climate change mitigation [7, 16] (Figure 1). Review of literature explains that in general, farm agro waste management refers to the process of handling, treating, and disposing of waste materials generated from agricultural activities [9]. This waste includes crop residues, plant matter, manure, and other organic materials produced on farms [17]. There has been a growing debate on managing farm waste more sustainably, as agricultural expansion in rural areas has become a significant issue for environmental sustainability. Rural landscapes are dominated by agricultural lands, water bodies, and forested areas, maintaining their primary function as food production areas to feed growing markets and urban populations. The pressure to increase farm production to meet market demand directly raises the amount of waste produced by rural farmers.

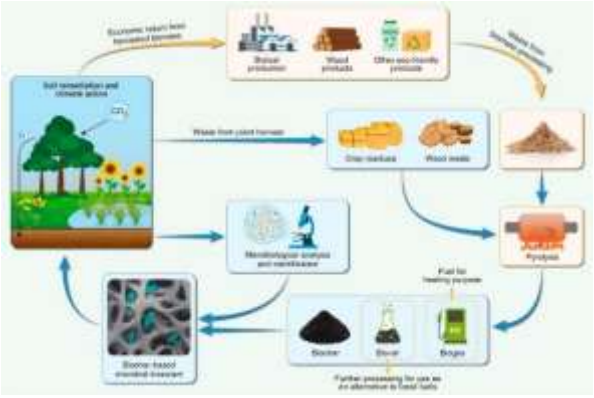

Fig. 1. Farm agro waste management for biochar production and soil remedy.
Source: [17].

Consequently, waste management is often a significant issue for rural smallholders. In addition to the lack or absence of appropriate facilities to process agricultural waste, small rural farmers also lack exposure to methods of converting their agricultural waste and manure into value-added products such as biochar, an organic fertiliser [1]. In a simple term, biochar is a stable, carbon-rich form of charcoal that is produced from biomass through a process called pyrolysis [2]. Pyrolysis involves heating organic material in the absence of oxygen, which results in the decomposition of the material and the release of volatile compounds. The remaining solid product is biochar, which can be used as a soil amendment [17].

As shown in Figure 1, farm ago waste management involves several stages, from the generation of agricultural waste to the final production of biochar which is summarised in Table 1 below.

As shown in Table 1, each stage of the process plays a crucial role in determining the characteristics and effectiveness of the final biochar product. The selection of feedstock, pyrolysis conditions, and post-processing treatments can be optimised based on the desired application of the biochar. As for this study, the researchers focus only on the

production and usage of solid biochar by a rural farming group which will be explained in the following section.

Table 1. Main process or stages involved in biochar production and use

Stage	Explanations
1. Farming and Agro Waste Generation	Agricultural and forestry activities generate organic residues like straw, stalks, husks, branches, and leaves, which are often seen as waste but can be valuable materials for producing biochar.
2. Collection and Preparation	The agro-waste is collected and prepared by drying and shredding to improve processing efficiency.
3. Pyrolysis	The prepared biomass undergoes pyrolysis, a process heating it to 350°C–700°C without oxygen, decomposing it into solid biochar, liquid bio-oil, and gaseous syngas.
4. Biochar Production	The solid component remaining after pyrolysis is biochar. Its properties, such as porosity and nutrient content, depend on the type of feedstock used and the pyrolysis conditions.
5. Cooling and Collection	After pyrolysis, the biochar is cooled and collected. It may undergo further processing, such as grinding or sieving, to achieve the desired particle size for its intended use.
6. Application	Biochar can be used in various applications, most notably as a soil amendment to improve soil fertility and water retention, reduce nutrient leaching, and sequester carbon.

Source: [2, 12, 17].

Biochar and Rural Smallholders

As explained in the previous section, the sustainable farm agro waste management for rural smallholders involves several key practices to optimise resource use, reduce waste, and improve environmental health [16]. The concept of producing solid material through decomposing under high temperature and controlled burning of farm waste without (or limited presence) of oxygen have been practiced widely by many rural small farming entities around the world [7].

Photo 1. Examples of biochar kitchens used by rural smallholders in various countries.
Source: [2, 11].

As shown in Photo 1, rural farmers developed the "biochar kitchen" to "cook" farm agro waste hence producing a solid biochar product with the three basic principles of locally-sensitive technology, low-cost and rapid execution [11].

Based on Photo 2, it is clear that rural smallholders opted for biochar with a strong connection to the three basic principles as previously mentioned which are:

(i)Locally-sensitive technology – Local farmers developed biochar kitchen to cook local farm agro waste depending on the crops the planted including maze, rice, wood/timber and other sorts of vegetables [2]. The complexity of technology ranges between very simple/basic by using mud and clay to construct biochar kitchen, to recycle drums and proper stove unit. Regardless of these scales of complexity, the technology must be acceptable by local farmers to use it on the long run basis.

(ii)Low-cost – With the increasing cost for farming over the years, rural farmers facing a tough time to sustain the farming project. Hence, a low-cost solution in managing farm agro waste and the potential for reducing farming cost input and even with some potential of earning extra income through production of biochar as organic fertiliser, will be regarded as a good new for the farmers. Most of the biochar kitchens as shown in the above figure have been constructed using low-cost materials which easily available at local level, hence reducing the initial cost for biochar production and operations [9].

(iii)Rapid execution – One of the key successes for any technologies to be introduced for rural farmers is its ability to offer rapid implementation and execution. Slow or difficult for implementation often hindered the potential users hence could end up with low support and lack of commitments for a long run. Rapid execution also will increase the interest for other farming communities to adopt to a similar project, more inclusive rather than exclusive, and also allowed for a timely assessment for any return of their initial investment in biochar kitchen project [16].

MATERIALS AND METHODS

Case Study of Vegetable Farmers in Hulu Terengganu

In early 2020, a field observation was conducted in the Kampung Sungai Ara agriculture group in Hulu Terengganu (located in the east coast of peninsular Malaysia) [11], where an informal interview session was held with several respondents about the use of biochar kitchens for processing farm leftovers into organic fertiliser (Map 1).

Map 1. Location of Hulu Terengganu in the East Coast Malaysia and the study site Kampung Sungai Ara (marked in star shape)
Source: [11, 18].

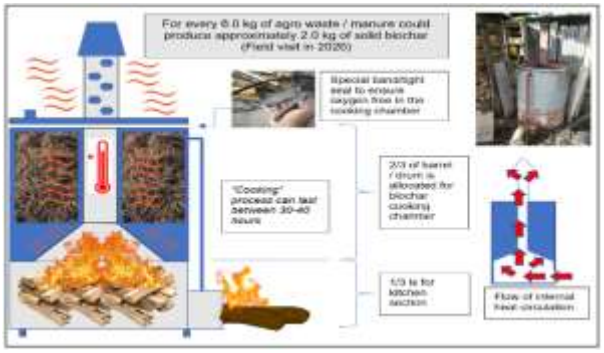

Fig. 2. Cross section of biochar kitchen that used by smallholders in Hulu Terengganu.
Source: [1]

The project was initiated by researchers from a local university in Kuala Terengganu, beginning with the distribution of two biochar kitchen units about six months prior. This number has now increased to 12 units, providing one unit for each farmer. For the farmers, the biochar kitchen is a simple yet practical tool for converting agricultural waste and livestock manure into organic fertiliser, which is then returned to their own farming projects (Figure 2). Some farmers who dedicate more time to the biochar project often produce an excess of fertilizer, which they sell to other farmers for additional income.

Key Informant Interviews

During the field visit in Kampung Sungai Ara, the researchers met *Pak Lah*, a retiree who spends his time cultivating cucumbers and red chilies in his *kebun* (farm) using the hanging fertigation method. During the visit, Pak Lah showed us his biochar station and the finished product, i.e., solid biochar, which he stores for future use (Photo 2). According to *Pak Lah*, the cooking process typically takes between 30 to 40 hours, requiring him to constantly add firewood to the main intake to maintain the burning process. It is essential to keep the barrel tightly sealed throughout the burning process.

Another respondent, *Pak Lan*, also demonstrated his biochar unit, which can produce up to 30 kg of solid biochar in a single burning cycle. Since *Pak Lan* and other farmers now use biochar, they are busy at the end of the harvest season turning agro waste and plant leftovers into biochar.

However, since the majority of farmers live nearby, biochar production offers them convenience and safety. They start the burning process, leave, and return after a few hours to add more firewood to the intake until the 30-to-40-hour of burning and cooling stages are complete. Additionally, the biochar produced is used locally, reducing the need for transportation between production and utilisation within the same farming area. According to *Pak Lah*, if they continuously burn waste, they can produce enough organic fertiliser stock for the next farming season. *Pak Lah* agrees with *Pak Lan's* statement because he manages to save up to 30% on farming inputs each season using biochar. Currently, all 12 farmers participating in the project have received 30 farm canopies from the Agricultural Department. Each canopy, measuring 8' x 60', can accommodate 40 polybags, or approximately 1,200 polybags in total.

Photo 2. From left – Pak Lah showing his biochar station; solid biochar; hanging fertigation project utilising biochar from the processing of agro-waste.
Source: Research Fieldwork [11].

Based on the field visit, the production of biochar by rural smallholders offers an alternative method for processing farm agro-waste into a value-added product, specifically solid biochar as organic fertiliser. For the farmers, producing their own biochar reduces farming costs and helps keep their farms tidy and more organised. However, the primary challenge they face is the market price for their produce, which is currently not favourable. Even if they manage to reduce farming costs by producing more biochar, the instability of vegetable prices affects their overall income. If their income remains low or stagnant, it becomes difficult for them to sustain their farming activities over the long term. The following section shall discuss the advantages and challenges of biochar.

RESULTS AND DISCUSSIONS

Advantages and Challenges of Biochar Production and Use

The literature review and field observation and interviews uncovered various benefits for smallholders in producing biochar and the extent to which biochar transforms farm waste into valuable resources, thereby improving farming practices among rural farmers. As shown in Figure 3, biochar offers a multifaceted solution to agricultural challenges by transforming waste and improving farming sustainability [16]. Through the process of pyrolysis, agricultural waste such as crop residues, manure, and other organic materials are converted into biochar, which helps mitigate waste management issues and reduces greenhouse gas emissions.

This transformation not only enhances soil fertility by retaining essential nutrients and improving soil structure and water-holding capacity but also benefits regions with arid climates or dry seasons [5]. Additionally, biochar aids in balancing soil pH, making acidic soils more productive [10]. As a stable form of carbon, biochar sequesters carbon dioxide for hundreds to thousands of years, contributing significantly to climate mitigation by reducing reliance on chemical fertilisers and enhancing soil organic matter. Economically, converting waste into biochar adds value to materials that would otherwise be discarded and boosts productivity by increasing crop yields, thus providing tangible economic benefits to farmers.

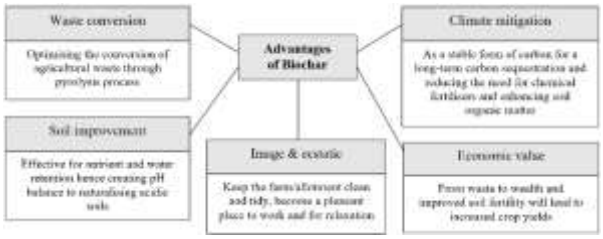

Fig. 3. Advantages of producing biochar from the agricultural farm waste
Source: [2, 11, 16, 17].

On the other hand, applying biochar in farming projects presents several challenges for rural farmers. As shown in Figure 4, rural farmers face several significant challenges in adopting biochar production, primarily due to limited access to technology and equipment like pyrolysis units. This technological gap is exacerbated by the lack of electricity in many rural areas, hindering the large-scale production of biochar. Additionally, a general lack of knowledge and training further complicates the situation, as farmers often remain unaware of the potential benefits and correct application methods for biochar.

Fig. 4. Challenges of producing biochar from the agricultural farm waste
Source: [2, 9, 11, 17].

Economic barriers also play a crucial role, as the high initial costs associated with setting up biochar production can be prohibitive for smallholders who already face financial constraints. Compounding these issues is the lack of established markets for biochar products, which diminishes economic incentives for farmers to invest in production. This problem is further aggravated by inconsistent or non-existent supportive policies, making it difficult for farmers to navigate and commit to biochar projects. Finally, poor infrastructure and logistics in rural areas add to the challenge, as inadequate transportation networks increase costs and reduce the feasibility of transporting materials needed for biochar production.

Addressing these interconnected challenges requires a comprehensive approach that includes improving access to resources, providing education and training, developing supportive policies, and establishing market structures. Addressing these challenges involves improving access to resources, providing education and training, developing supportive policies, and establishing market structures. These efforts can help unlock the potential of biochar for sustainable agricultural practices in rural areas.

CONCLUSIONS

Based on the literature review and a field visit with interviews highlighting the benefits and challenges of biochar for the on-going rural farming project [2, 9, 16, 17], this conclusion section will present preliminary recommendations for enhancing biochar production and use through a comprehensive approach involving promotion, integration into farming practices, economic support, monitoring, and collaboration for sustaining biochar application by the rural farmers:

(1)Promoting biochar production requires educating farmers on its benefits and production techniques, ensuring access to affordable pyrolysis equipment, and encouraging the use of locally available materials.

(2)Investment in research and development is crucial to optimise biochar production processes and tailor its application to different soil types. Integrating biochar into farming practices involves conducting soil tests to determine the appropriate type and amount of biochar needed, developing guidelines for effective application, and providing crop-specific recommendations to maximise benefits.

(3)Economic incentives such as subsidies and grants can motivate rural farmers to adopt biochar practices, while market development efforts can encourage the production and sale of biochar and related products.

(4)Policy support is necessary to implement sustainable agriculture practices, including the use of biochar.

(5)Monitoring and evaluation should focus on assessing the environmental and economic impacts of biochar application, establishing feedback mechanisms for continuous improvement, and developing sustainability metrics to measure productivity gains.

As a summary, a collaborative approaches as stated above should involve engaging stakeholders such as governments, NGOs, research institutions, and private sector players. Knowledge sharing through workshops, seminars, and online platforms is important, along with community involvement in biochar production projects to create local employment opportunities and enhance community resilience. Furthermore, biochar production and application, as demonstrated by rural farmers in Hulu Terengganu present a sustainable solution for transforming farm agro waste into valuable resources, promoting soil health, sequestering carbon, and enhancing economic growth in agricultural communities. By implementing the above strategies, farmers can adopt biochar as a key component of sustainable agriculture, leading to long-term environmental and economic benefits.

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