

# Saving Smallholder Farmers and Ourselves With Biochar: The Benefits of Very Small-Scale, Distributed, Artisanal Production

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Submitted: 13 March 2026 Accepted: 17 March 2026 Published: 24 March 2026

**Citation:** Shafer, D. M. (2026)., *Saving Smallholder Farmers and Ourselves With Biochar: The Benefits of Very Small-Scale, Distributed, Artisanal Production.*, *J of Agri Earth & Environmental Sciences*, 5(2), 01-03.

## Abstract

*Achieving sustainable agricultural systems is a pressing global challenge. Smallholder farmers produce a substantial portion of the world's food supply yet face increasing pressures from soil degradation, climate variability, rising agricultural input costs, and environmental degradation. Agricultural systems generate large quantities of biomass wastes that are often burned in open fields, contributing to air pollution, greenhouse gas emissions, and the loss of valuable organic matter. Biochar, carbon-rich material produced through the pyrolysis of biomass, offers a way to improve soil health while simultaneously contributing to climate change mitigation. Most biochar research and investment, however, focuses on centralized industrial production systems that are poorly suited to smallholder agricultural contexts. This paper argues that an important sustainability potential of biochar lies in very small-scale, distributed, artisanal production systems that allow farmers to convert agricultural residues into soil amendments locally. Using the framework of environmental, economic, and social sustainability, this study examines how decentralized biochar production may contribute to sustainable agriculture. Drawing on experience from community biochar initiatives in northern Thailand, the paper demonstrates that distributed biochar systems can simultaneously improve soil fertility, reduce agricultural burning, enhance climate resilience, strengthen rural livelihoods, and support sustainable land management. By placing biochar production directly in the hands of farmers, distributed systems represent a practical and scalable strategy for advancing sustainability in agricultural landscapes.*

**Keywords:** Sustainable Agriculture, Biochar, Smallholder Farmers, Distributed Production, Climate Mitigation, Soil Restoration, Agricultural Residues, Rural Sustainability.

## Introduction

Sustainability has become a central guiding principle in global discussions about agriculture, environmental management, and rural development. Sustainable agricultural systems need to balance the requirement to produce sufficient food while protecting environmental resources, supporting rural livelihoods, and mitigating climate change. Achieving this balance is particularly challenging in smallholder farming systems, where farmers often operate with limited resources and face significant environmental pressures as well as steep rocky fields and limited amounts of biomass. Smallholder farmers play a critical role in global food systems. Estimates suggest that farms smaller than two hectares account for as much as 80 percent of food in developing regions. Despite their importance, smallholder farmers frequently face

declining soil fertility, increasing climate variability, and rising input costs [1]. These challenges threaten not only rural livelihoods but also the sustainability of agricultural landscapes. Soil degradation is a critical challenge facing agriculture. The loss of soil organic matter reduces soil fertility, weakens soil structure, and decreases the ability of soils to retain water and nutrients [2]. In many smallholder farming systems, declining soil quality leads to increased reliance on chemical fertilizers, which may provide short-term productivity gains but do not restore long-term soil health and may even hurt it. At the same time, farmers produce enormous quantities of biomass residues. Crop waste such as rice straw, stubble and corn stover are often burned to clear fields or left to rot before the next planting season. While burning is convenient and inexpensive, it releases particulate

matter and rotting and burning both add greenhouse gases to the atmosphere and contribute to air pollution in many regions [3].

Biochar has emerged as a potential tool for addressing these interconnected challenges. It is produced with the pyrolysis (as opposed to consumption) of biomass wastes and consists largely of stable carbon that can persist in soils for centuries. When applied to soils, biochar can improve water retention, enhance nutrient availability, and support microbial activity [4]. Despite growing interest in biochar, most existing initiatives focus on industrial-scale production systems designed to process large quantities of biomass. Such systems require significant capital investment and complex logistics, limiting their accessibility for smallholder farmers.

This paper argues that the sustainability potential of biochar lies not in centralized industrial production but in very small-scale, distributed (artisanal) systems that allow farmers to convert agricultural residues into biochar locally. By transforming agricultural waste into a valuable soil amendment, distributed biochar systems can contribute simultaneously to environmental sustainability, economic resilience, and social sustainability.

### **Sustainability Challenges in Smallholder Agriculture**

Sustainable agriculture requires the integration of environmental stewardship, economic viability, and is improved by social equity. Smallholder farming systems often struggle to achieve this balance because of structural constraints and environmental pressures.

### **Environmental Sustainability**

Environmental sustainability in agriculture depends on maintaining soil health and biodiversity while minimizing pollution and resource depletion. Soil degradation threatens all these goals by reducing productivity and increasing the vulnerability of agricultural systems to climate change.

Globally, soil degradation has affected large areas of agricultural land due to erosion, nutrient depletion, and loss of organic matter [2]. In tropical environments, for example, high temperatures and heavy rainfall accelerate the decomposition of organic material and increase erosion risks. For smallholder farmers, restoring soil organic matter is critical to achieve sustainable agricultural productivity.

### **Economic Sustainability**

Economic sustainability refers to the ability of farming systems to remain productive and profitable over time. Many smallholder farmers operate with bad land, narrow profit margins and limited access to credit or agricultural inputs. With wars in Ukraine and the Middle East the rising cost of fertilizers, fuel and other inputs place serious financial pressure on rural households. When soil fertility declines, farmers may need to apply increasing amounts of costly fertilizers to maintain yields, creating a cycle of economic vulnerability. Low-cost soil amendments that improve soil productivity such as homemade biochar that can be produced without requiring expensive inputs can therefore play an important role in enhancing economic sustainability.

### **Social Sustainability**

Social sustainability encompasses issues of equity, resilience, and community well-being. Smallholder farmers often live in

rural areas where access to education, transportation infrastructure, and agricultural extension services can be limited. Sustainable agricultural strategies must therefore be accessible, locally manageable, and adaptable to the realities of smallholder farming systems. Technologies such as simplified biochar machines that empower farmers and communities to manage their own resources can strengthen social sustainability by promoting local resilience and self-reliance.

### **Biochar as a Tool for Sustainable Agriculture**

Biochar offers an opportunity to address all three dimensions of sustainability simultaneously. Biochar is produced when biomass is heated in a low-oxygen environment during pyrolysis. Unlike consumption in open field burning, this process converts organic material into a stable form of carbon with a highly porous structure. These characteristics allow biochar to retain water and nutrients while providing habitat for beneficial soil microorganisms.

Research has demonstrated that biochar can improve soil fertility and crop productivity, particularly in degraded tropical soils [6]. Biochar also reduces nutrient leaching and improves the efficiency of chemical fertilizer use (when artificial fertilizers are used). Most important from a sustainability perspective, biochar represents a form of long-term carbon sequestration. Because the carbon contained in biochar decomposes very slowly, it remains in soils for centuries, effectively removing carbon dioxide from the atmosphere [7]. For these reasons, biochar has been proposed as a strategy for both climate mitigation and sustainable soil management.

### **Distributed Biochar Production as a Sustainability Strategy**

While biochar has received increasing attention, most initiatives emphasize centralized industrial production systems. Such systems are often designed to generate bioenergy alongside biochar. Bioenergy producing industrial systems, however, face severe limitations in smallholder agricultural contexts. Agricultural residues are dispersed across difficult to access landscapes, making collection and transport expensive. Large facilities also require significant capital investment and technical expertise far beyond smallholder capacities. Distributed biochar production offers a more sustainable alternative.

### **Advantages of distributed systems include**

- local processing of agricultural residues
- elimination of transportation costs
- reduction of open burning
- accessibility for smallholder farmers
- adaptability to diverse agricultural systems

Small kilns and simple pyrolysis technologies allow farmers to produce biochar, often at home, using locally available materials and minimal equipment. By decentralizing production, biochar becomes a tool that farmers can manage themselves.

### **Case Study: Biochar Production in Northern Thailand**

Northern Thailand experiences severe seasonal air pollution due in part to agricultural burning. Maize cultivation in upland areas produces large quantities of crop residues that are frequently burned after harvest. The Warm Heart Foundation initiated community biochar programs to address this challenge by converting agricultural residues into biochar rather than burning them.

Farmers participating in the program learn how to produce biochar using simple kilns designed for small-scale operation. The resulting biochar is incorporated into soils, combined with compost or organic fertilizer (e.g., manures). Early observations indicate several sustainability benefits. Farmers report improved soil structure and increased water retention in biochar-amended soils. In addition, reduced agricultural burning contributes to improved air quality in surrounding communities.

### Environmental Sustainability Benefits

Distributed biochar production contributes to environmental sustainability in several ways.

#### Soil Restoration

Biochar improves soil structure, increases water retention, and enhances microbial activity.

#### Reduction of Agricultural Burning

Converting residues to biochar prevents the release of particulate matter and pollutants associated with open burning.

#### Climate Change Mitigation

Biochar stores carbon in a stable form that remains in soils for long periods.

#### Sustainable Waste Management

Agricultural residues become valuable inputs rather than environmental pollutants.

#### Economic Sustainability Benefits

Distributed biochar systems strengthen the economic sustainability of smallholder agriculture. Farmers gain access to a locally produced soil amendment that improves crop productivity without requiring costly chemical inputs. Improved soil fertility increases yields and reduces dependence on expensive purchased fertilizers and in some cases, community biochar production may create opportunities for small enterprises that produce biochar-based soil amendments for local markets.

#### Social Sustainability and Rural Resilience

Distributed biochar production can strengthen social sustainability by empowering farmers and communities to manage agricultural resources locally. Because the technology is simple and low-cost, farmers can adopt biochar production without relying heavily on external institutions or expensive infrastructure. Community-based production systems also encourage knowledge sharing and cooperation among farmers, also contributing to rural resilience and community sustainability.

### Policy Implications for Sustainable Agriculture

Policies that support distributed biochar production can contribute to multiple sustainability goals.

Potential policy strategies include:

- farmer training programs
- support for low-cost kiln technologies
- integration of biochar into soil restoration initiatives
- recognition of biochar carbon sequestration in climate mitigation programs

Such policies could simultaneously address soil degradation, rural poverty, and air pollution.

### Conclusion

Sustainability challenges in agriculture require solutions that address environmental protection, economic viability, and social resilience simultaneously. Distributed biochar production represents a promising strategy for achieving these goals. By converting agricultural residues into stable carbon that improves soil fertility, biochar systems enhance agricultural productivity while reducing environmental pollution. Empowering smallholder farmers to produce biochar locally may also offer a practical and scalable pathway toward sustainable agriculture. Supporting distributed biochar initiatives may therefore play an important role in building resilient agricultural systems and advancing global sustainability goals.

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