

WASTE-DERIVED BIOCHAR FOR SUSTAINABLE RURAL REVITALIZATION

EDITED BY
YUQING SUN • DANIEL C.W. TSANG



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Waste-derived Biochar for Sustainable Rural Revitalization

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Edited by
Yuqing Sun
Sun Yat-Sen University
China

Daniel C.W. Tsang
Hong Kong University of Science and Technology
China

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List of Contributors

Huijun Li

State Key Lab of Biocontrol
Guangdong Provincial Key Laboratory
of Plant Stress Biology
School of Agriculture and
Biotechnology
Shenzhen Campus of Sun Yat-sen
University
Shenzhen
P. R. China

Jing Luo

School of Agriculture and
Biotechnology
Sun Yat-sen University
Guangzhou
Guangdong
China

Leichang Cao

College of Chemistry and Molecular
Sciences
Henan University
Kaifeng
China

Miami College, Henan University
Kaifeng
China

Qiang Chen

College of Environmental Science and
Engineering
Hunan University
Changsha
Hunan
China

Kui Cheng

International Cooperation Joint
Laboratory of Health in Cold Region
Black Soil Habitat of the Ministry of
Education
Harbin
China

College of Engineering, Northeast
Agricultural University
Harbin
China

Jiaqi Deng

College of Engineering, Huazhong
Agricultural University
Wuhan
P. R. China

Pavani Dulanja Dissanayake

Department of Soil Science, Faculty of
Agriculture
University of Peradeniya
Peradeniya
Sri Lanka

Le Fang

Research and Development Center
for Watershed Environmental
Eco-Engineering
Beijing Normal University
Zhuhai
P. R. China

State Key Laboratory of Wetland
Conservation and Restoration
School of Environment
Beijing Normal University
Beijing
P. R. China

Key Laboratory of Coastal Water
Environmental Management and
Water Ecological Restoration of
Guangdong Higher Education
Institutes
Beijing Normal University
Zhuhai
P. R. China

Qianzhen Fang

College of Environmental Science and
Engineering
Hunan University
Changsha
Hunan
China

Yipu Guo

Centre for Infrastructure Engineering
and Safety, School of Civil and
Environmental Engineering
The University of New South Wales
Kensington
NSW
Australia

Lanfang Han

Key Laboratory for City Cluster
Environmental Safety and Green
Development of the Ministry of
Education
School of Ecology, Environment and
Resources, Guangdong University of
Technology
Guangzhou
China

Yingying Han

Research and Development Center
for Watershed Environmental
Eco-Engineering
Beijing Normal University
Zhuhai
P. R. China

State Key Laboratory of Wetland
Conservation and Restoration
School of Environment
Beijing Normal University
Beijing
P. R. China

Key Laboratory of Coastal Water
Environmental Management and Water
Ecological Restoration of Guangdong
Higher Education Institutes
Beijing Normal University
Zhuhai
P. R. China

Shih-Hsin Ho

State Key Laboratory of Urban Water
Resource and Environment
School of Environment, Harbin
Institute of Technology
Harbin
P. R. China

Haodong Hou

College of Chemistry and Molecular
Sciences
Henan University
Kaifeng
China

Miami College, Henan University
Kaifeng
China

Fang Huang

School of Environment and Health,
Jiangnan University
Wuhan
P. R. China

Xiaochen Huang

State Key Lab of Biocontrol
Guangdong Provincial Key Laboratory
of Plant Stress Biology
School of Agriculture and
Biotechnology
Shenzhen Campus of Sun Yat-sen
University
Shenzhen
P. R. China

Xiaoqian Jiang

School of Agriculture and
Biotechnology, Sun Yat-sen
University
Guangzhou
Guangdong
China

Fanying Kong

School of Water Conservancy and Civil
Engineering, Northeast Agricultural
University
Harbin
China

Jingyi Liang

Department of Civil and
Environmental Engineering
The Hong Kong University of Science
and Technology
Clear Water Bay
Hong Kong
China

Xin Liu

College of Environment and Ecology,
Hunan Agricultural University
Changsha
China

Zhongwang Liu

School of Agriculture and
Biotechnology, Sun Yat-sen
University
Guangzhou
Guangdong
China

Zhuqing Liu

School of Water Conservancy and Civil
Engineering
Northeast Agricultural University
Harbin
China

International Cooperation Joint
Laboratory of Health in Cold Region

Black Soil Habitat of the Ministry of
Education
Harbin
China

Yong Sik Ok

Korea Biochar Research Center
Department of Environmental Science
and Ecological Engineering
Korea University
Seoul
Republic of Korea

International ESG Association
(IESGA)
Seoul
Republic of Korea

Yutao Peng

School of Agriculture and
Biotechnology, Sun Yat-sen University
Guangzhou
Guangdong
China

Fulin Qu

Centre for Infrastructure Engineering
and Safety
School of Civil and Environmental
Engineering, The University of New
South Wales
Kensington
NSW
Australia

Jianhua Qu

School of Resources and Environment,
Northeast Agricultural University
Harbin
China

Hong-Yu Ren

State Key Laboratory of Urban-Rural
Water Resource and Environment,
School of Environment
Harbin Institute of Technology
Harbin
China

Maheshika Senanayake

Korea Biochar Research Center,
Department of Environmental Science
and Ecological Engineering
Korea University
Seoul
Republic of Korea

Jiang Song

School of Water Conservancy and Civil
Engineering
Northeast Agricultural University
Harbin
China

International Cooperation Joint
Laboratory of Health in Cold Region
Black Soil Habitat of the Ministry of
Education
Harbin
China

Qingqing Song

State Key Laboratory of Urban-Rural
Water Resource and Environment
School of Environment
Harbin Institute of Technology
Harbin
China

Xueting Song

State Key Laboratory of Urban Water
Resource and Environment
School of Environment
Harbin Institute of Technology
Harbin
China

Ke Sun

State Key Laboratory of Water
Simulation
School of Environment, Beijing
Normal University
Beijing
China

Yuqing Sun

School of Agriculture and
Biotechnology, Sun Yat-sen University
Guangzhou
Guangdong
China

Jinfang Tan

School of Agriculture and
Biotechnology, Sun Yat-sen University
Guangzhou
Guangdong
China

Xiaofei Tan

College of Environmental Science and
Engineering, Hunan University
Changsha
Hunan
China

Daniel C.W. Tsang

Department of Civil and
Environmental Engineering
The Hong Kong University of Science
and Technology
Clear Water Bay
Hong Kong
China

Jieni Wang

College of Chemistry and Molecular
Sciences, Henan University
Kaifeng
China

Miami College

Henan University
Kaifeng
China

Yizhe Wang

Centre for Infrastructure Engineering
and Safety
School of Civil and Environmental
Engineering, The University of New
South Wales
Kensington
NSW
Australia

Mi Wei

School of Agriculture and
Biotechnology, Sun Yat-sen University
Guangzhou
Guangdong
China

Peng Xie

State Key Laboratory of Urban Water
Resource and Environment
School of environment, Harbin
Institute of Technology
Harbin
P. R. China

Yifan Xing

Research and Development Center
for Watershed Environmental
Eco-Engineering
Beijing Normal University
Zhuhai
P. R. China

State Key Laboratory of Wetland
Conservation and Restoration
School of Environment
Beijing Normal University
Beijing
P. R. China

Key Laboratory of Coastal Water
Environmental Management and
Water Ecological Restoration of
Guangdong Higher Education
Institutes
Beijing Normal University
Zhuhai
P. R. China

Weijian Xu

Department of Civil and
Environmental Engineering
The Hong Kong University of Science
and Technology
Clear Water Bay
Hong Kong
China

Fan Yang

School of Water Conservancy and Civil
Engineering, Northeast Agricultural
University
Harbin
China

International Cooperation Joint
Laboratory of Health in Cold Region
Black Soil Habitat of the Ministry of
Education
Harbin
China

Hailan Yang

College of Environmental Science and
Engineering, Hunan University
Changsha
Hunan
China

Baojun Yi

College of Engineering, Huazhong
Agricultural University
Wuhan
P. R. China

Su Yilin

Department of Civil and
Environmental Engineering
The Hong Kong Polytechnic
University
Kowloon
Hong Kong
China

Lingfeng Zeng

College of Environment and Ecology
Hunan Agricultural University
Changsha
China

Shuqin Zhang

College of Chemistry and Molecular
Sciences, Henan University
Kaifeng
China

Miami College
Henan University
Kaifeng
China

Ying Zhang

School of Resources and Environment
Northeast Agricultural University
Harbin
China

Northeast Institute of Geography and
Agroecology
Chinese Academy of Sciences
Changchun
China

Yuying Zhang

Department of Civil and
Environmental Engineering
The Hong Kong University of Science
and Technology
Clear Water Bay
Hong Kong
China

Ying Zhao

School of Water Conservancy & Civil
Engineering
Northeast Agricultural University
Harbin
China

International Cooperation Joint
Laboratory of Health in Cold Region

Black Soil Habitat of the Ministry of
Education
Harbin
China

Yaoyu Zhou

College of Environment and Ecology,
Hunan Agricultural University
Changsha
China

Shishu Zhu

The Key Lab of Pollution Control and
Ecosystem Restoration in Industry
Clusters, Ministry of Education
School of Environment and Energy,
South China University of Technology
Guangzhou
China

Xiefei Zhu

School of Advanced Energy,
Sun Yat-sen University
Shenzhen
Guangdong
China

Preface

With advancements in agricultural productivity and rural living standards, the daily generation of waste biomass resources—such as crop residues, fruit tree prunings, animal manure, food waste, and domestic sludge—has risen significantly. However, the indiscriminate disposal and open burning of these wastes pose severe threats to rural ecosystems. The high-value utilization of waste biomass presents a viable pathway toward establishing zero-waste communities, fostering a circular economy, and supporting global pollution mitigation efforts. Furthermore, it contributes to achieving carbon emission peaks and carbon neutrality goals. Among emerging solutions, pyrolysis (300–700 °C under oxygen-limited conditions) converts waste biomass into a carbon-rich solid known as biochar.

This book synthesizes the latest research developments, state-of-the-art knowledge, and practical case studies while providing scientific insights, identifying current challenges, and outlining future directions for biochar technologies as a novel, cost-effective, and eco-friendly approach to sustainable rural revitalization. It systematically reviews application-oriented biochar production technologies using rural waste biomass, emphasizing the tailored selection of pyrolysis conditions and pre-/post-treatment methods. Additionally, the book explores diverse applications of biochar in rural development, including:

- Renewable biofuels
- Clean compost conditioners
- Organic seedling substrates
- Slow-release fertilizers and green pesticides
- Targeted plant disease suppression
- Farmland soil conditioning and amendment
- Adsorbents/catalysts for agricultural wastewater treatment
- Carbon sequestration in soils
- Low-carbon construction materials

This book also evaluates these technologies through Technical and Economic Analysis (TEA), Environmental, Social, and Governance (ESG) frameworks, and discusses potential environmental risks.

This work will serve as a valuable reference for engineers, scientists, researchers, and graduate students in waste recycling and management, sustainable rural development, environmental engineering, civil engineering, chemical engineering, and related fields.

Tailored Biochar Production from Waste Biomass Resource in Rural Areas

Yuqing Sun¹ and Daniel C.W. Tsang²

¹ School of Agriculture and Biotechnology, Sun Yat-sen University, Guangzhou, Guangdong, China

² Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China

1.1 Introduction

The conceptual foundation for biomass conversion into biochar was first proposed by Seifritz in 1993. Over a decade later, Marris (2006) expanded upon this idea through a comprehensive theoretical investigation, which subsequently stimulated widespread academic interest following the publication of his research. With progressive advancements in scientific knowledge and technological innovation, biochar-related methodologies have undergone continuous refinement and development.

Biochar represents a carbon-dense solid substance generated via thermochemical decomposition of biomass in oxygen-restricted environments. Recent scientific investigations have expanded the range of organic feedstocks suitable for biochar fabrication, encompassing not only conventional lignocellulosic biomass but also agricultural byproducts, food waste, livestock excreta, and residual sludge from wastewater treatment. The heterogeneous nature and complex treatment requirements of municipal and rural solid waste streams demand novel processing methodologies. Current research demonstrates that such waste materials exhibit considerable potential as precursor substances for biochar generation. This transformation process offers a dual benefit: it enables effective waste valorization while simultaneously providing an environmentally sustainable strategy for solid waste treatment.

Biochar exhibits a well-developed porous architecture, considerable surface area, and numerous stable surface functional moieties, endowing it with versatile

applications across multiple environmental domains. These include but are not limited to soil enhancement and reclamation, aquatic contaminant mitigation, water resource regeneration, carbon capture and storage, as well as renewable energy applications. The material's effectiveness arises principally from its capacity to modulate carbon transformation processes, alleviate contamination by organic compounds and heavy metals, and modify microbial community dynamics and metabolic functions (Zhu et al. 2014). The remediation performance of biochar is fundamentally governed by its physicochemical characteristics, which are in turn dictated by production parameters and precursor materials. Consequently, systematic investigation of biochar fabrication methodologies and feedstock selection constitutes a critical research focus for optimizing its functional properties and environmental applications.

Contemporary advancements in biochar production technology have reached a sophisticated stage of development. Tailored synthesis approaches now enable the fabrication of high-performance biochar materials optimized for specific applications. This technological evolution is primarily motivated by the need to identify ideal preparation parameters that account for the heterogeneous nature of solid waste feedstocks, diverse application scenarios, and varying remediation objectives. With environmental pollution challenges growing increasingly intricate and multifaceted, there emerges a pressing requirement for biochar with superior functional characteristics. To meet these evolving demands, researchers are focusing on developing biochar-based composite materials through various modification strategies that augment conventional production techniques. Such engineered materials demonstrate enhanced capacity for pollutant sequestration and environmental remediation. In practical implementation, comprehensive assessment of biochar applications must consider multiple factors: the material's intrinsic properties and remediation performance, resource conversion efficiency, as well as the associated energy consumption and economic viability of production processes. This multidimensional evaluation framework ensures both optimal resource utilization and environmentally sustainable practices.

1.2 Overview of Rural Solid Wastes

In the context of accelerated economic growth in recent decades, environmental conservation has often been overlooked, resulting in numerous ecological challenges. These environmental disturbances not only compromise ecosystem equilibrium but also impose constraints on sustainable economic progress. This dual impact has consequently elevated environmental concerns to a prominent position in public discourse. Among various environmental pollutants, solid waste—classified as one of the “three major waste streams”—holds particular significance due to its direct relevance to public life. The management and treatment