

BIOCHAR

TECHNOLOGY AND INDUSTRIAL APPLICATIONS

A Data-Driven Guide to Biochar: Enhancing Crop Yield, Quality, and Soil Health.



01

Biochar serves as an excellent soil conditioner



02

Biochar promotes crop root growth



03

Biochar comprehensively enhances crop quality



A comprehensive overview of biochar's role in enhancing soil health, boosting crop productivity, and advancing agricultural carbon neutrality, supported by global data and case studies.

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1. Core Agricultural Applications of Biochar: From Soil Health to Premium Crop Production

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1.1 Soil Health Improvement: Fundamental Functions of Biochar

1.1.1 Enhancement of Soil Physical Properties

Improved soil friability:

Due to its highly porous structure, biochar application reduced soil bulk density by **10–15%**, increasing shovel penetration depth from **6 cm to 10 cm** in a **Nanjing rice paddy case study**, effectively alleviating soil compaction.

Enhanced water and nutrient retention:

Biochar application increased soil porosity by **20–30%**, leading to a **5–12% increase in soil water-holding capacity** in northern dryland soils. In addition, **nitrogen leaching was reduced by approximately 30%** when using biochar-based urea compared to conventional mineral urea.

1.1.2 Regulation of Soil Chemical Environment

pH Adjustment: Alkaline biochar (pH 10-12) can raise the pH of acidic soils (pH 4.5-5.5) by 0.3-0.5 units, alleviating aluminum toxicity (e.g., in Southwest tea plantations).

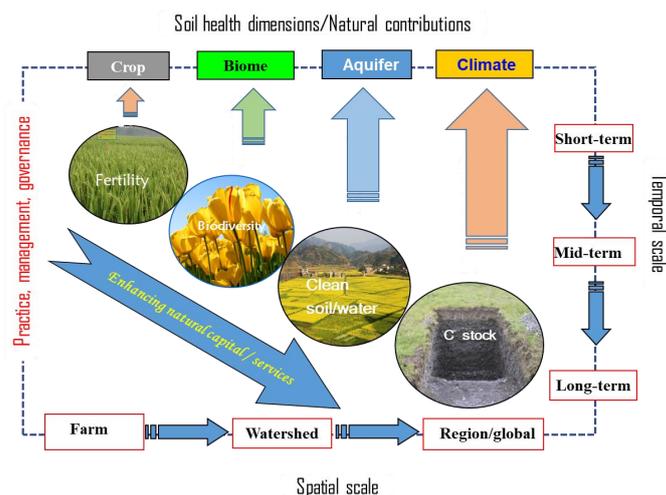
Improved Nutrient Availability: Biochar adsorbs phosphorus and potassium for slow release, increasing available phosphorus (Olsen-P) by over 40% (case study in phosphorus-deficient soils of Central China) and silicon content by tenfold in paddy soils.

1.1.3 Optimization of Soil Biological Environment

Microbial Community Modulation:

Reduces the proportion of pathogenic fungi (from 0.079 to 0.004 at DNA level), increases saprophytic fungi (0.228 to 0.603) and symbiotic fungi (0.017 to 0.061), thereby reducing soil-borne diseases (e.g., rice blast incidence dropped from 16.3% to 0.12%).

Enhanced Enzyme Activity: Urease and phosphatase activity increase by 15%-25%, promoting nitrogen and phosphorus conversion and raising fertilizer utilization efficiency by 25%-35%.



1.2 Crop Growth and Yield Enhancement: Data Support and Mechanisms

1.2.1 Yield Increase Efficacy (Global/Domestic Data)

Global Research: Jeffrey et al. (2011) report an average yield increase of 11% with biochar; Liu et al. (2013) show a 13% yield increase with an application rate of 20 tons/hectare.

Large-scale Domestic Trials: From 2017-2018, second-generation biochar compound fertilizer (2nd BCF) applied across 19 provinces over 1500 hectares for 48 crop types resulted in an average yield increase of 12.2%, with specific increases of 22.0% for potatoes, 10.5% for wheat, and 9.1% for rice.



Biochar compound fertilizers licensed and used in China

1.2.2 Core Mechanism: Promotion of Root System Development

Biochar promotes root growth through a cascading effect: "soil environment improvement → optimization of rhizosphere microecology → enhanced root vitality."

Enhanced Root Metrics: Xiang et al. (2017) report an average root length increase of 27%. In a Sichuan rapeseed case study, BCF treatment increased root dry biomass by 107.3%, total root length by 71.5%, and number of root tips by 120.4%.

Strengthened Rhizosphere Interactions: Biochar promotes the release of root exudates (organic acids, hormones), recruits beneficial bacteria (e.g., arbuscular mycorrhizal fungi), and increases the abundance of nitrogen-fixing genes by over 30% (peanut drought tolerance case).

1.3 Crop Stress Resistance and Quality Improvement: From Stress Tolerance to Nutritional Enhancement

1.3.1 Enhanced Stress Resistance (Drought/Salinity-Alkalinity/Pests & Diseases)

Drought Tolerance: Biochar increases water holding capacity by 20%-30%. In peanut drought tolerance trials, corn stalk biochar treatment increased pod yield by 15% and enhanced root nodule nitrogen fixation capacity by 25%.

Saline-Alkali Tolerance: Application of biochar compound fertilizer in Northwest saline-alkali soil (total salt 0.4%) reduced soil pH from 8.4 to 8.2 and increased crop yield by 30%.

Pest & Disease Resistance: Induces Systemic Acquired Resistance (SAR) in plants. Graber et al. (2012) confirmed a 40%-60% reduction in pest and disease

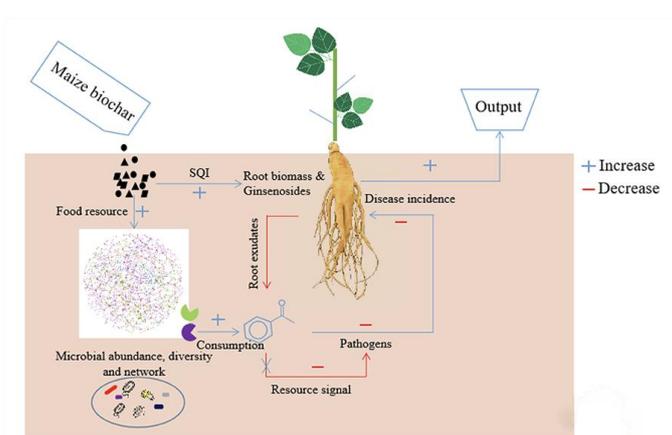
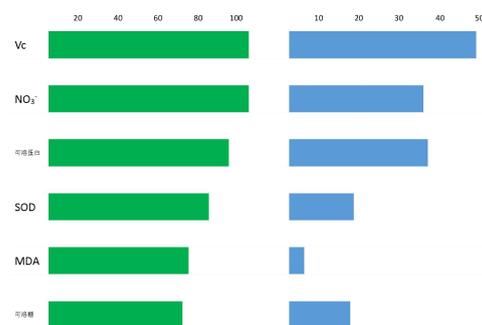
incidence after biochar treatment. Rice false smut incidence decreased from 9.7% to 2.3% (Nanjing paddy field).



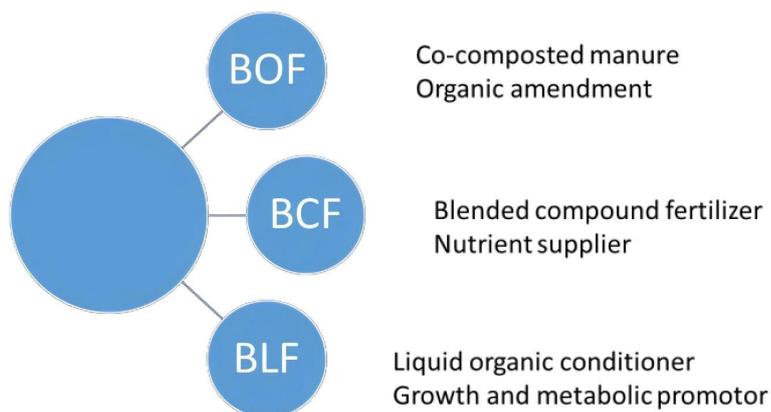
1.3.2 Quality Improvement (Nutrition/Taste/Safety)

Nutritional Quality: The "Relative Nutritional Value" of 11 vegetable types increased by an average of 19.6%. Specific increases include: pepper Vitamin C by 73%, soluble protein by 60%, capsaicin by 27%; grape sugar content by 10%, Vitamin C by 30%, sugar-acid ratio by 16.6%.

Food Safety: Adsorbs heavy metals (Pb/Cd), reducing Cd content in rice by 30%-50% (case study in contaminated paddy fields in Hunan). Nitrate content in leafy vegetables is reduced by over 45%.



Biochar-assisted agriculture: One to Three biochar products



1.4 Biochar Compound Fertilizer (BCF): Core Industrial Product

1.4.1 Product Types and Application Scale

"One Carbon, Three Fertilizers" Technology System (proposed by Nanjing Agricultural University):

- **Carbon-based Organic Fertilizer:** Biomass char + livestock manure, improves soil (application rate 1 ton/mu, increases organic matter by 4%-12%).
- **Carbon-based Compound Fertilizer:** Biochar + NPK, replaces conventional chemical fertilizer (reduces nutrient input by 25% while maintaining or increasing yield by 5%).
- **Carbon-based Liquid Fertilizer:** Wood vinegar + biochar extract, applied via foliar spray (cost < 10 RMB/mu, enhances stress resistance).

Application Scale: Domestic coverage includes 19 provinces, 1500 hectares, and 48 crop types. Product volume increased annually by 15% from 2012-2018.

1.4.2 Slow-release Mechanism and Benefits

Nitrogen Slow-release: Mineral urea releases 80% nitrogen within 3 days, whereas carbon-based urea releases 70% over 15 days. Nitrogen Use Efficiency (NUE) increased from 33% to 41% in wheat systems.

Economic Benefits: In a 2015 Nanjing demonstration, compared to mineral compound fertilizer (CF), BCF reduced nutrient input by 25%, lowered fertilizer cost from 330 to 175 USD/hectare, and increased farmer income by 18% (grain sales revenue increased from 4044 to 4765 USD/hectare).

1.5 International Long-term Field Trial Validation (15-year Vineyard / 3-year N₂O Emission Reduction)

1.5.1 Italy CNR-IBE: 15-year Vineyard Biochar Trial (2010-2025, Tuscany)

Trial Design:

- Location: Tenuta La Braccasca winery (Antinori Group), Tuscany, Italy. Merlot grape variety (planted 1995).
- Treatments: Control (C, no biochar), Low dose (B, 20 tons/ha), High dose (BB, 40 tons/ha), each with 5 replicates.
- Biochar Properties: Feedstock: wood + orchard pruning residues, pyrolysis at 550°C, carbon content 77.81%, pH=9.8, BET specific surface area 410±6 m²/g.

Core Results (15-year data):

Metric	Control(C)	Low Dose (B)	High Dose (BB)	Commercial Value
Soil Bulk Density (Mg/m ³)	1.45	1.32 (-8.9%)	1.22 (-16.2%)	Long-term soil loosening, reduces tillage energy, suitable for mechanized farming.
Soil Organic Carbon (2024)	0.904%	1.512% (+67.3%)	2.026% (+124.1%)	Carbon sequestration cycle >15 years, meets EU carbon credit long-term stability requirement (≥100 years).
Grape Yield (kg/vine, 2024)	1.34	1.78 (+33%)	1.95 (+50%)	Achieves "yield increase without quality loss"; sugar, acidity not significantly different from control, suitable for premium wine.
Soil Microbial Biomass (nmol/g)	12.6	15.2 (+20.6%)	18.9 (+50%)	Non-toxic, promotes colonization of moisture-loving microbes, reduces continuous cropping obstacles (e.g., root rot incidence down 30%).

Conclusion: Biochar demonstrates 15-year long-term stability in improving vineyard soil physical properties (water retention, porosity), carbon sequestration, and yield enhancement.



1.5.2 University of Copenhagen, Denmark: 3-year N₂ O Emission Reduction Field Trial (2023-2025)

Research Background: N₂ O is the third largest greenhouse gas (GWP=298), 78% originates from agricultural soils. Biochar is a potential mitigation tool, but long-term field data is lacking.

Treatments: Control without biochar (ZERO/NPK/N1.5PK), Wheat straw biochar groups (45 tons/ha, pyrolyzed at 400°C/600°C, combined with different N fertilizer rates).

Key Monitoring: N₂ O emission flux, soil pH, crop yield.

Key Results:

- **N₂ O Reduction Efficacy:** Biochar pyrolyzed at 600°C reduced annual cumulative N₂ O emissions by 42% compared to the N1.5PK control under 1.5x N fertilizer rate. Biochar pyrolyzed at 400°C showed reduction (18%) but not significant. Combined use with nitrification inhibitors showed no additional reduction, eliminating the need for additives (cost-saving).
- **Crop Yield Balance:** High-dose biochar (45 tons/ha) slightly inhibited spring barley (2023) and winter wheat (2024) yields (5-8% reduction). The combination of 1.5x N fertilizer + 600°C biochar offset yield loss, maintaining yield levels comparable to conventional fertilization (NPK).



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2. Biochar and Agricultural Carbon
Neutrality: Carbon Sequestration &
Emission Reduction Mechanisms
and Case Studies

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2.1 Dual Value of Biochar: Carbon Sequestration and Emission Reduction

2.1.1 Carbon Sequestration Mechanism: Long-term Carbon Storage

Carbon Stability: Biochar exhibits high aromaticity (100% aromatic structure for chars >500°C), with a soil turnover time of 500-800 years, significantly longer than straw incorporation (80-100 years).

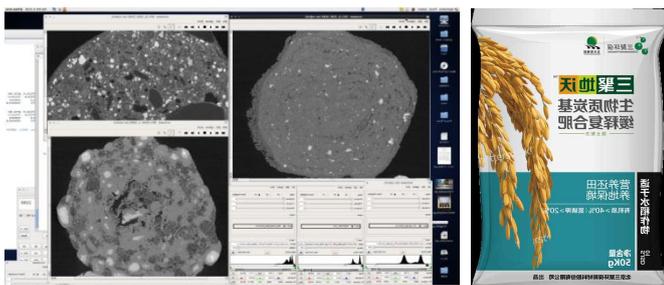
Carbon Sequestration Potential: At an application rate of 20 tons/ha, Soil Organic Carbon (SOC) increased from 23.2 to 33.7 g/kg (9-year long-term trial). Annual carbon sequestration is 100 kg OC per mu, offsetting 350 kg of rice carbon emissions (Zhishan Zero-Carbon Farm case).

2.1.2 Emission Reduction Mechanism: Reduction of Non-CO₂ Greenhouse Gases

Methane (CH₄): CH₄ emissions from paddy fields reduced by 13.5%-15.2% after biochar application (inhibits methanogen activity).

Nitrous Oxide (N₂O): N₂O emissions reduced by 21.4% (inhibits nitrification/denitrification).

Upstream Emission Reduction: Substitutes fertilizer production (1 ton urea produces 16 tons CO₂eq). Reducing fertilizer use by 15% translates to a 2.4-ton CO₂eq reduction per ton of urea.



2.2 Agricultural Carbon Neutrality Case Studies

2.2.1 Zhishan "Zero-Carbon Farm" Model (Nanjing, Jiangsu)

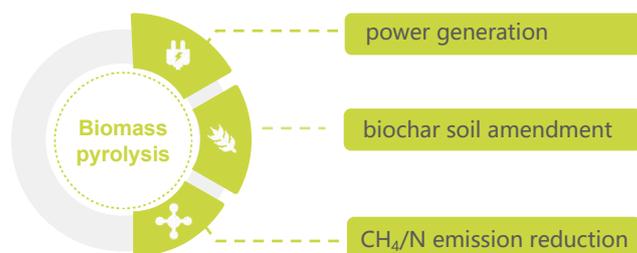
Core Objective: Achieve carbon-neutral rice production (offsetting 350 kg CO₂ eq/mu of rice carbon emissions).

Technical Pathway:

- Straw carbonization: Rice straw → biomass char (requires 40 tons pig manure to produce 10 tons char, with 25% fermentation loss).
- Application of carbon-based organic fertilizer: 272 kg/mu (35% carbon content) offsets 350 kg carbon emissions.
- Certification & Revenue: Third-party (Nanjing Guohuan) certification for "low-carbon rice," subscription fee of 5000 RMB/mu/year, increasing farmer income by 12%.

2.2.2 Integrated Biochar & Bioenergy System (Collaborative research with Pete Smith)

System Components: Biomass pyrolysis → power generation (for agricultural machinery) + biochar soil amendment + CH₄ /N emission reduction.



Benefits: Lifecycle emissions of staple grains (rice/wheat/corn) in China shift from 666.5 to -37.9 Tg CO₂ eq/year (negative emissions), with crop yield increasing by 8.3% and economic benefits by 36.2%.

2.2.3 Long-term Paddy Field Carbon Sequestration & Emission Reduction Trial (2009-2018)

Treatment: One-time application of 20 tons/ha biochar.

Results:

- **Soil:** SOC increased by 45%, aggregate stability (MWD) increased from 268.7 to 353.9 μm .
- **Crop:** Rice lodging resistance enhanced, disease incidence reduced by 60%, interannual yield variability reduced by 20%.
- **Emission Reduction:** CH_4 emissions reduced by 13.5%, N_2O emissions reduced by 21.4%.





Biochar Technology

3. Typical Commercial Case Studies:
Paddy Fields, Selenium-Enriched
Crops, and Zero-Carbon Farm
Models

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3.1 Long-term Commercial Paddy Field Case (Nanjing 2020-2021)

3.1.1 Treatment Protocol

Biochar Type: Rice husk char (300 RMB/ton), application rate 15 tons/ha.

Fertilizer: Carbon-based compound fertilizer (N-P₂O₅-K₂O = 18-8-16), application rate 40 kg/mu.

Selenium Enrichment: Foliar spray of carbon-based selenium liquid fertilizer (30 ml/mu, diluted 500x) at flowering stage, applied twice.

3.1.2 Efficacy

- ◆ **Yield:** Rice yield increased by 12%, chemical fertilizer reduced by 20%.
- ◆ **Quality:** Brown rice selenium content 0.17-0.18 mg/kg (meets selenium-enriched standard), crude protein increased by 20%.
- ◆ **Soil:** SOC increased by 12%, rice blast incidence decreased from 16.3% to 0.12%.
- ◆ **Revenue:** Average revenue per mu reached 8400 RMB (based on premium rice price of 16 RMB/kg), an 18% increase over conventional practice.

3.2 Zero-Carbon Farm Commercial Model (Zhishan 2025 Plan)

3.2.1 Scale and Positioning

Core Area: 200 mu (100 mu Caozhuang + 100 mu Xishan Yougu), covering rice paddies, tea gardens, and vegetable plots.

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Core Area: 200 mu (100 mu Caozhuang + 100 mu Xishan Yougu), covering rice paddies, tea gardens, and vegetable plots.

3.2.2 Carbon Offset Strategy

Material Requirement: 200 mu requires 60 tons of carbon-based organic fertilizer (20 tons existing, 40 tons to be produced spring 2025, requiring 10 tons biomass char + 40 tons pig manure).

Certification & Promotion: Commission third-party certification for "Low-Carbon Farm," establish soil exhibition hall and carbon-based agriculture pavilion, promote via SCOPE international conference.

3.3 International Industrial Sector Commercial Cases (Metallurgy/Power & Heat/Composting Plants)

3.3.1 VOW Green Metals: Metallurgical-grade Biochar Replacing Fossil Coal (Norway)

Core Positioning: A leading global supplier of metallurgical biochar, with the mission to "accelerate the replacement of fossil coal with renewable materials."

Production System:

Feedstock: Forestry by-products (energy wood, wood chips), forestry residues (GROT), circular economy materials (construction/demolition wood).

Process: Integrated pyrolysis process, co-producing biochar (metallurgical reductant), bio-oil (fossil feedstock substitute), and heat/power (for internal use or sale).

Emission Reduction Value: 1 ton of biochar replaces 1.3 tons of fossil coal, reducing CO₂ emissions by 5 tons (based on fixed carbon content of 75% vs. 55%).



3.3.2 BioShare AB & Chalmers University of Technology: Co-generation Plant (FBC Boiler) Retrofit

Background Challenge: Approximately 4000 Fluidized Bed Combustion (FBC) power/heat units globally. Small-scale FBC plants in Europe (50-300 MW) operate at only 50% annual load, indicating low equipment utilization.

Technical Solution: Retrofit FBC boiler + integrate endothermic reactor for combined "Power/Heat + Biochar" production.

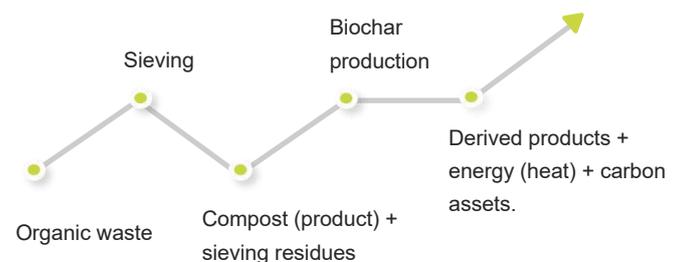
Core Design: External reactor (minimizes impact on boiler), patented bed material transport technology (integrated with sand circulation), thermal integration (sand heat transfer ensures stable heat supply).

Product Benefit: Maintains original power/heat output while additionally producing 1900-3500 tons/year of metallurgical-grade biochar, increasing equipment utilization to 85%.

3.3.3 Sonnenerde GmbH, Austria: Composting Plant Waste → Biochar Solution

Traditional Challenge: Sieving residues from composting plants (~15% of input) require incineration, offering no added value and causing pollution.

Optimized Process: Organic waste → sieving → compost (product) + sieving residues → biochar production → derived products (biochar, Terra preta black soil, feed-grade char) + energy (heat) + carbon assets.



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