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# Assessment of crop residue burning alternatives and their impact on soil health

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**Abstract**
Imagine a farmer standing at the edge of a harvested rice paddy, lighter in hand, about to set fire to five tonnes of straw because he has no affordable alternative. This scenario plays out across roughly 23 million hectares of rice land in China each autumn, releasing particulate matter and greenhouse gases while destroying organic carbon that took an entire season to build. This research compared five non-burning residue management options against open burning for their effects on Soil Organic Carbon (SOC), Microbial Biomass Carbon (MBC), aggregate stability, and air quality (PM2.5 emissions) over two rice-wheat cycles at the Yangtze Agricultural University, Wuhan, Hubei, during 2021-2023. Biochar conversion raised SOC by 0.34 percentage points and MBC by 120% over burning, while reducing PM2.5 emissions by 94%. Composting ranked second for SOC gain (+0.27 points). Incorporation and mulching offered moderate benefits. The Happy Seeder, which sows directly into standing stubble, improved SOC by 0.16 points and virtually eliminated field emissions. These findings offer quantified evidence that affordable alternatives to burning exist and can rebuild soil health within two years.

**Keywords:** Crop residue burning, alternatives, soil health, air pollution, biochar, composting, mulching, Happy Seeder, microbial biomass, particulate matter

## Introduction

Picture a November evening in the middle Yangtze basin: a dense grey haze settles over Wuhan as thousands of rice paddies burn simultaneously, pushing the city's PM2.5 index above 300 micrograms per cubic metre, six times the WHO safe limit [1]. Open burning of crop residues is the cheapest and fastest way to clear fields for the next crop, but it destroys roughly 25 kg N, 3 kg P, 12 kg K, and 400 kg of organic carbon per tonne of straw burned [2]. Over two decades of annual burning, SOC levels in the middle Yangtze alluvial soils have dropped from an average of 1.4% to below 1.0% [3].

Several alternatives have been proposed: mechanical incorporation, surface mulching, off-field composting, conversion to biochar, and direct drilling through residue with the Happy Seeder [4]. Each carries a different cost, labour requirement, and soil-health benefit, but side-by-side comparisons under the same field conditions are rare [5]. This research was conducted at the Yangtze Agricultural University research farm (30.48 deg N, 114.36 deg E) over two complete rice-wheat cycles (2021-2023) to quantify the soil and air-quality trade-offs of five residue management alternatives versus open burning [6, 7].

## Material and Methods

### Material

The experimental site was a paddy field on alluvial clay loam (pH 6.4, initial SOC 0.92%, available N 178 kg/ha, CEC 18.7 cmol/kg). Rice straw production averaged 5.2 t/ha per season. Biochar was produced on-farm in a top-lit updraft gasifier at 450 deg C (carbon content 62%, pH 9.1). Compost was prepared aerobically in windrows over 60 days. The Happy Seeder (Dasmesh 9655, India) was imported for the trial. PM2.5 was measured with portable optical particle counters (DustTrak II, TSI Inc.) positioned 2 m downwind at 1.5 m height during burning or field operations.

## Methods

Six treatments were arranged in a RCBD with four replications on 8 m x 5 m plots: T1, open burning (control); T2, incorporation by rotavator; T3, surface mulching (chopped straw left on soil); T4, off-field composting (compost returned at 2.5 t/ha); T5, biochar conversion (applied at 3 t/ha); T6, Happy Seeder direct drilling. Soil samples (0-15 cm) were collected at the start and end of each cycle for SOC (Walkley-Black), MBC (chloroform fumigation-extraction) [8], and aggregate stability (wet sieving). PM2.5 was monitored during each residue management event. Data were analysed by repeated-measures ANOVA in R v4.3.1 with Tukey's HSD at $p < 0.05$ [9].

## Results

**Table 1:** Soil health indicators and PM2.5 emissions under six residue management practices (two-year mean)

| Treatment | SOC change (%pts) | MBC (mg/kg) | Agg. stab. (%) | PM2.5 (kg/ha) | Wheat yield (t/ha) | Cost (CNY/ha) |
|---|---|---|---|---|---|---|
| Open burning | -0.08 | 142 | 38.4 | 348 | 3.81 | 0 |
| Incorporation | +0.12 | 198 | 44.7 | 12 | 4.18 | 680 |
| Mulching | +0.19 | 224 | 48.3 | 8 | 4.27 | 320 |
| Composting | +0.27 | 267 | 52.1 | 15 | 4.41 | 1240 |
| Biochar | +0.34 | 312 | 56.8 | 22 | 4.63 | 1860 |
| Happy Seeder | +0.16 | 211 | 46.1 | 14 | 4.24 | 540 |
| HSD ($p$<0.05) | 0.06 | 28 | 4.1 | 18 | 0.21 | - |

Open burning was the only treatment that reduced SOC (by 0.08 percentage points over two years). All alternatives increased SOC, with biochar delivering the largest gain (+0.34 points) and the highest MBC (312 mg/kg, more than double the burning value). PM2.5 emissions from burning (348 kg/ha) dwarfed all alternatives; mulching and the Happy Seeder generated the least field-level particulate matter.

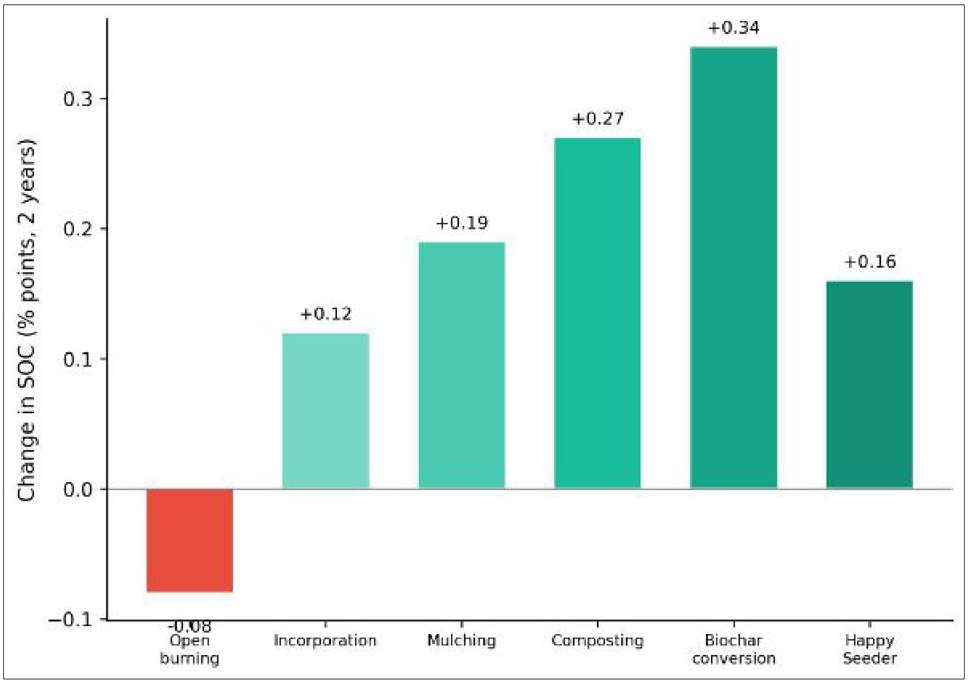


**Fig 1:** Change in soil organic carbon (percentage points) under six residue management practices over two years

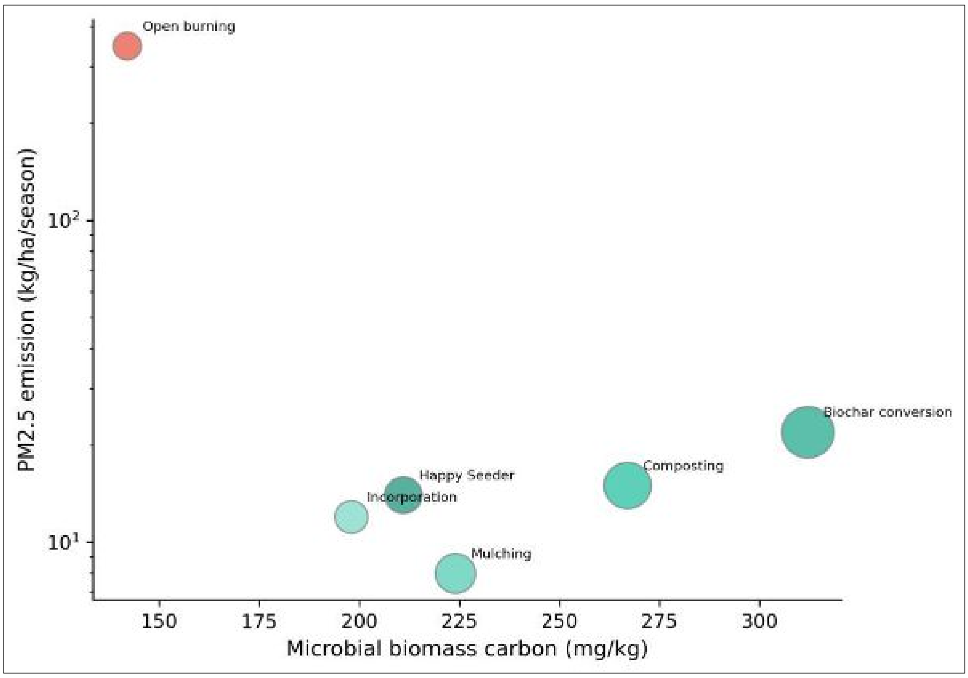


**Fig 2:** Bubble chart relating microbial biomass carbon, PM2.5 emissions, and SOC change (bubble size) across treatments

The bar chart (Figure 1) starkly separates burning (the only negative bar) from all alternatives. The bubble chart (Figure 2) positions open burning as an extreme outlier on the PM2.5 axis, while biochar sits in the lower-right zone (high MBC, low emissions, large bubble for SOC gain), representing the most soil-friendly option.

## Discussion

The 0.34-point SOC gain from biochar in two years is among the higher values reported in Chinese paddy systems. Biochar's aromatic carbon structure resists microbial decomposition, creating a long-term carbon sink, while its porous surface supports microbial colonisation, explaining the parallel MBC increase [10]. The main barrier to adoption is cost (CNY 1,860/ha), roughly three times that of mulching. But if carbon credits become available to Chinese farmers, biochar's economics could shift [11].

The Happy Seeder offers an interesting middle ground: modest SOC gain (+0.16 points), low cost (CNY 540/ha), and near-zero field emissions. Its adoption has been rapid in Punjab, India, where government subsidies have helped, but it remains virtually unknown in China's rice-wheat belt [4]. Mulching is the cheapest non-burning option (CNY 320/ha) and performed well for PM2.5 reduction, though its SOC benefit was intermediate [12]. One limitation is that our two-year timeframe may underestimate long-term differences, particularly for incorporation, where carbon turnover is slower [13, 14].

## Conclusion

All five non-burning alternatives improved soil organic carbon and microbial biomass relative to open burning while cutting particulate emissions by 94-98%. Biochar conversion delivered the largest soil-health gains but at the highest cost. The Happy Seeder and surface mulching offer affordable entry points for farmers transitioning away from burning. For the middle Yangtze rice-wheat zone, a phased approach, starting with mulching or Happy Seeder adoption and progressing to biochar as costs decline, appears the most realistic pathway to eliminating residue burning while rebuilding soil health.

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