



Microbial Bio-decomposers for Crop-Residue Management and Air-Pollution Mitigation in Northern India: A Critical Mini Review

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WebLog Open Access Publications

Article ID : wjets.2026.j1704
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OPEN ACCESS

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Received Date: 25 Sep 2026

Accepted Date: 16 Oct 2026

Published Date: 17 Oct 2026

Citation:

Prashant Ravish. Microbial Bio-decomposers for Crop-Residue Management and Air-Pollution Mitigation in Northern India: A Critical Mini Review. WebLog J Environ Sci. wjets.2026.j1704. <https://doi.org/10.5281/zenodo.23607853>

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Abstract

Open-field crop-residue burning remains an important episodic source of fine particulate matter, carbonaceous aerosol and reactive gases across northern India. Microbial bio-decomposers are increasingly promoted as a biological option for accelerating in-situ residue breakdown, but their environmental value depends on more than microbial activity alone. This critical mini review evaluates the biological basis, field efficacy, operational constraints and air-quality relevance of bio-decomposer-assisted residue management. Evidence was synthesised from peer-reviewed mechanistic studies, farmer-field and multi-location trials, semi-controlled experiments, atmospheric studies and selected institutional reports. The literature confirms that lignocellulose-degrading fungi, bacteria and actinomycetes can accelerate biochemical transformation of crop residues. However, field outcomes are strongly influenced by chopping, incorporation, moisture, starter nutrients, residue type and treatment duration. Independent multi-location evidence indicates that physical incorporation can produce larger decomposition responses than inoculation alone, while several farmer-field studies evaluate bundled management packages rather than the marginal effect of the microbial product. Consequently, pot-scale or package-level efficacy should not be interpreted as direct evidence of field-scale microbial additionality. Air-quality benefits require a further causal step: treatment must enable timely crop establishment and demonstrably displace burning. Bio-decomposers are therefore best positioned as components of integrated residue-management systems. Future studies should use operationally equivalent non-inoculated controls, standardised decomposition endpoints, multi-location validation, complete system-cost accounting and georeferenced verification of non-burning before avoided emissions are attributed to bio-decomposer programmes.

Keywords: Crop-Residue Burning; Microbial Bio-Decomposer; Paddy Straw; Sugarcane Trash; Lignocellulose; PM_{2.5}; Indo-Gangetic Plain; Residue Management

Introduction

Crop residues are simultaneously a resource and a management constraint. Retaining or incorporating residues can return carbon and nutrients to soil, protect the surface, conserve moisture and support microbial processes, whereas selective removal can supply fodder, fibre, energy and other value chains. The difficulty arises when large residue loads must be handled during a narrow interval between harvest and the next sowing. This problem is particularly acute in the rice-wheat system of north-western India, where combine harvesting leaves loose straw and anchored stubble and wheat establishment may follow within only a few weeks. Under these conditions, open burning offers rapid field clearance at low private cost, while shifting substantial costs to air quality, climate, soil fertility and public health [1-3].

Open-field combustion emits PM_{2.5} and PM₁₀, black and organic carbon, carbon monoxide, nitrogen oxides, ammonia, sulphur dioxide and volatile organic compounds. The resulting exposure is determined not only by the mass emitted but also by combustion efficiency, plume rise, boundary-layer depth, humidity, wind and the presence of other sources. National modelling for 2003-2019 attributed approximately 44,000-98,000 premature deaths annually to PM_{2.5} exposure from crop-residue burning, with Punjab, Haryana and Uttar Pradesh contributing most of the modelled burden [4]. This does not mean crop burning is the sole driver of regional pollution; transport, industry, power generation, household combustion and dust remain important. It does, however, establish residue burning as a significant and preventable seasonal source.

Table 1: Evidence hierarchy used in this critical mini review.

Evidence type	What it can establish	Main limitation	Interpretive weight
Operationally equivalent field trial	Additional effect of inoculum under the same physical management	May still be site- and season-specific	Highest for inoculum efficacy
Bundled farmer-field package	Whether an integrated package can manage residue under farm conditions	Cannot isolate inoculum from co-inputs	High for package feasibility; moderate/low for inoculum effect
Pot/glasshouse trial	Biological plausibility and treatment response under controlled conditions	Limited field heterogeneity and crop-calendar realism	Supportive, not field proof
Programme/extension report	Delivery capacity, adoption, operational scale	Selection bias, free/subsidised inputs, weak counterfactuals	Implementation evidence
Ambient monitoring/modelling	Pollution burden and exposure attributable to burning	Meteorological and source-attribution uncertainty	High for burning impacts; indirect for biodecomposer efficacy

Abbreviations: d: Days; PM: Particulate Matter

Microbial bio-decomposers have been promoted as a means of accelerating the breakdown of lignocellulosic residue so that farmers can retain or incorporate straw instead of burning it. The biological basis is credible: cellulases, xylanases and related hydrolases depolymerise structural carbohydrates, while laccases and peroxidases help modify lignin and increase access to cellulose and hemicellulose [5-8]. Yet the existence of lignocellulose-degrading microorganisms does not by itself establish that a commercial or institutional consortium provides a meaningful additional benefit in a farmer's field.

The critical question is therefore one of additionality and displacement. Does inoculation, compared with the same residue preparation, moisture, nutrient and tillage regime without inoculum, accelerate decomposition enough to protect the crop calendar? If it does, does that operational advantage change farmer behaviour and avert burning? Only after these steps can avoided emissions or exposure reasonably be attributed to a bio-decomposer programme. This mini review evaluates evidence along that chain, with paddy straw as the principal northern-Indian case and sugarcane trash included where residue-specific evidence is informative. The purpose is not to determine whether microorganisms can degrade plant residues, but to identify what is established, what remains uncertain, and what evidence is required before air-quality benefits can be claimed.

Materials and Methods

Review design and literature identification

This article was designed as a focused critical mini review rather than a systematic review or meta-analysis. For the revision, the literature search was made explicit and reproducible at the level appropriate to a mini review. Searches were conducted up to 24 September 2026 using PubMed and targeted publisher-indexed scholarly searches. Reference lists of key primary studies and recent reviews were then screened backward for additional primary or mechanistic studies. Search concepts were combined around four blocks: (i) bio-decomposer, microbial consortium, lignocellulose, cellulase, lignin and straw decomposition; (ii) paddy/rice straw, wheat residue, sugarcane trash and crop residue; (iii) India, Punjab, Haryana and Indo-Gangetic Plain; and (iv) burning, PM_{2.5}, emissions, adoption, cost, Happy Seeder, incorporation and residue management.

Priority was given to peer-reviewed primary studies that reported identifiable methods, comparators and quantitative outcomes. Controlled experiments, farmer-field trials, adoption studies, ambient monitoring and atmospheric modelling were eligible when they directly informed the causal pathway from residue management to environmental outcome. Government and programme documents were used mainly for technology protocols, implementation scale and

policy context; they were not treated as equivalent to independent efficacy trials. Recent reviews were used to establish mechanism and to identify relevant primary studies, but were not allowed to substitute for primary field evidence when the latter was available.

Evidence appraisal and synthesis

Evidence was appraised by design rather than collapsed into a single quality score. Decomposition studies were examined for operationally equivalent controls, replication, residue loading, treatment duration, moisture and nutrient management, and whether outcomes reflected visual softening, dry-mass loss, residue chemistry or crop performance. Programme reports were assessed for selection bias, treatment bundling, counterfactual validity and independence of outcome verification. Air-quality evidence was distinguished as direct measurement, emission inventory, atmospheric attribution model or scenario projection. Findings from pot or glasshouse studies are explicitly labelled as semi-controlled evidence and are not interpreted as field-scale proof.

Because treatments, residues and endpoints were highly heterogeneous, statistical pooling was not appropriate. The synthesis therefore emphasises direction and strength of evidence, consistency across designs, and limitations in causal attribution. A central rule of interpretation is used throughout: when inoculation is bundled with shredding, incorporation, irrigation, starter nitrogen or other co-inputs, the study demonstrates the performance of the package unless an operationally equivalent non-inoculated control isolates the microbial contribution (Table 1).

Results and Discussion

Biological basis and operational determinants

Crop residues are composite materials rather than uniform substrates. Cellulose microfibrils provide tensile strength; hemicellulose forms a branched matrix; lignin creates a hydrophobic aromatic network that limits enzyme access; and silica, waxes and phenolics add further resistance. Decomposition therefore proceeds through fragmentation, leaching, colonisation, enzymatic depolymerisation and microbial assimilation rather than through a single reaction [5, 6].

Fungi are particularly important because hyphae can penetrate lignified tissues and many species secrete extracellular cellulases and oxidative enzymes. Bacteria and actinomycetes contribute hydrolytic activity, accessory metabolism, nutrient transformations and functional redundancy. Mixed consortia can potentially broaden substrate use, but interactions among introduced organisms and indigenous communities may be synergistic, neutral or antagonistic. For this reason, plate-clearance zones or enzyme activity measured under laboratory conditions should be treated as screening evidence

rather than predictors of performance during cool post-harvest field conditions [7-9].

Field performance is governed at least as strongly by physical and environmental conditions as by inoculum identity. Residue chopping increases exposed surface area; incorporation increases soil contact; moisture supports microbial activity; and mineral nitrogen can alter decomposition where high-C:N residues constrain microbial growth. Chaves *et al.*, [10] showed more broadly that residue quality, placement and soil mineral N interact to control carbon and nitrogen dynamics. Consequently, any bio-decomposer trial that changes these factors simultaneously with inoculation risks attributing physical-management effects to the microbial product.

This issue is particularly important for the commonly described Pusa-type protocol. Institutional guidance couples microbial application with chopping or mulching, spraying, soil mixing or incorporation and moisture maintenance [11-13]. The technology should therefore be understood as one component of a management package rather than as a substitute for machinery. That distinction is scientifically important: if residue must still be chopped, incorporated and irrigated, then the relevant comparison is not 'decomposer versus no management' but 'the same management with versus without decomposer'.

Residue type also matters. Paddy straw combines a high C:N ratio with silica-rich surfaces and must often be managed within a short rice-to-wheat interval. Wheat straw has stronger fodder demand in many regions and may therefore present a smaller surplus-management problem. Sugarcane trash is bulky, waxy and lignocellulosic and may interact with ratoon emergence and trash-blanketing practices. The longer treatment windows used in sugarcane studies should not be transferred uncritically to paddy systems. A product effective after 45 days may still be operationally inadequate where the practical window is 15-20 days.

Field evidence and microbial additionality

Bundled farmer-field evidence: Bhattacharjya *et al.*, [14] provide one of the most informative multi-residue farmer-field datasets. Rice and wheat residues were studied in Haryana and sugarcane trash in Maharashtra. The in-situ decomposition treatment combined shredded residue with cattle dung, 0.5% nitrogen as urea, fungal, bacterial and actinomycete cultures, jaggery and curd, followed by incorporation and two irrigations. Rice and wheat were assessed after 30 days and sugarcane after 45 days.

The package produced measurable reductions in cellulose and lignin and supported crop production without a statistically significant yield penalty. Controlled microcosm comparisons in the same work suggested additional decomposition in the presence of the microbial consortium. Nevertheless, the farmer-field treatment changed several drivers of decomposition simultaneously. It therefore provides credible evidence that a biologically assisted package can manage residue, but weaker evidence for the magnitude of the inoculum-specific effect. This distinction is essential because it directly addresses whether the microbial component itself is necessary to achieve the reported field outcome.

Cost interpretation has the same problem of system boundaries. The study reported an itemised cost of about ₹11,733 ha⁻¹ for urea, cultures, jaggery, curd, shredding, rotavation and irrigation, while assuming availability of residue and cattle dung. This is very different from product-only or spray-only figures that are sometimes quoted for

bio-decomposer application. A fair comparison with Happy Seeder, Super Seeder or other pathways must use complete operational costs rather than the retail cost of the microbial formulation.

Independent multi-location evidence: incorporation versus inoculation

A particularly important counterpoint is the multi-location Punjab experiment reported by Katyal *et al.*, [15]. PAU and Pusa decomposer sprays were compared with an unsprayed control under both residue incorporation and retention. Trials were conducted at several locations in 2020-21 and repeated at two PAU sites in 2021-22. Outcomes included lignin content, C:N ratio, tensile strength and wheat yield.

The study showed a strong effect of physical placement. In the validation experiment, incorporation produced substantially larger reductions in lignin, C:N ratio and tensile strength than retention. By contrast, mean differences among the unsprayed and decomposer-sprayed treatments were non-significant for several decomposition indicators. This does not show that microbial formulations are universally ineffective. It does show that, under those field conditions, incorporation contributed more to residue degradation than the microbial spray and that decomposition cannot automatically be attributed to inoculation.

This finding materially changes the balance of the evidence. It implies that product claims should be tested against a physically equivalent control and that treatment recommendations should identify the conditions under which inoculation adds enough speed or reliability to justify its cost. Where incorporation alone achieves the operational target, the marginal value of an inoculum may be small. Where low temperature, residue chemistry or limited biological activity causes unacceptable persistence, a validated consortium could still provide value.

Other agronomic and semi-controlled evidence: Manu *et al.*, [16] evaluated microbial-consortia-mediated in-situ rice-straw management in a rice-wheat system and reported favourable yield, economics and energetics for some integrated treatments. However, the experimental combinations included residue incorporation and urea, again making it difficult to isolate the inoculum from the accompanying physical and nutrient management. Related field work on Pusa decomposer has reported changes in crop nutrient uptake under different straw-management treatments, illustrating that the technology is embedded within wider establishment systems rather than functioning as an independent input.

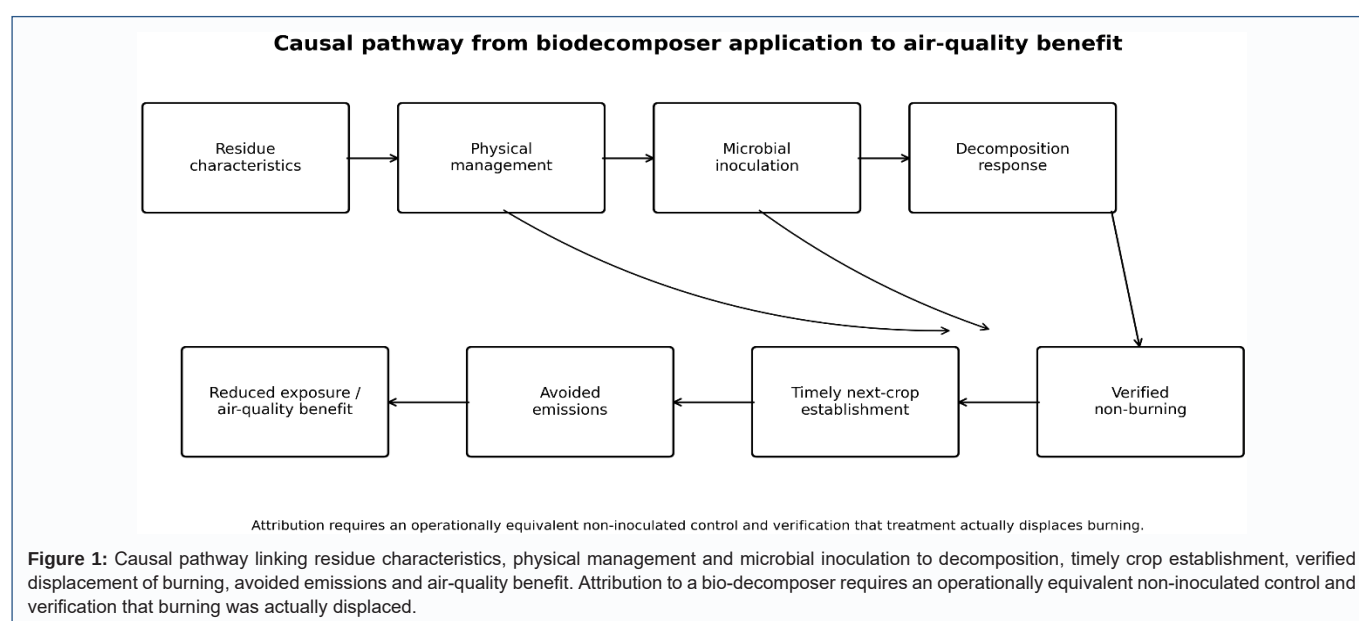
Sugarcane evidence is useful but must be kept at the correct evidentiary level. Ravish and Chaudhry [17] reported a 45-day, three-treatment, three-replicate semi-controlled experiment in which a bio-decomposer plus fermented substrate was compared with an untreated control and a substrate control. Microbial biomass carbon increased within the bio-decomposer treatment, while cellulose and lignin declined and available nutrients increased. The inclusion of a substrate control is a methodological strength because it improves separation of the microbial product from its carrier. The principal limitation is scale: pot or glasshouse conditions with favourable temperature and moisture do not reproduce commercial trash loads, spatial variability, rainfall or irrigation heterogeneity, ratoon emergence, machinery traffic or farmer timing. The study therefore supports biological efficacy but not field-scale adoption claims.

Taken together, the primary evidence supports three conclusions.

Table 2: Primary evidence most relevant to bio-decomposer additionality.

Study	Setting/design	Main treatment contrast	Key finding	Main limitation
Bhattacharjya <i>et al.</i> , [14].	Farmer fields; rice, wheat, sugarcane	Removal vs burning vs multi-input in-situ decomposition package	Residue transformed in 30 d (rice/wheat) and 45 d (sugarcane); no significant yield penalty	Inoculum bundled with shredding, dung, urea, substrates, rotavation and irrigation
Katyal <i>et al.</i> , [15].	Multi-location Punjab field trials	Unsprayed vs PAU/ Pusa decomposer under incorporation or retention	Incorporation strongly improved degradation indicators; several decomposer contrasts non-significant	Product response may be site/ season dependent
Manu <i>et al.</i> , [16].	Two-season rice-wheat field experiment	Integrated straw-management treatments with microbial consortium	Favourable yield/economic/energy outcomes in integrated treatments	Urea and physical management complicate inoculum attribution
Ravish & Chaudhry [17].	Semi-controlled sugarcane-trash experiment, n=3	Untreated vs substrate control vs biodecomposer + substrate	Higher microbial biomass and nutrient availability; cellulose/lignin decline	Pot/glasshouse scale; no commercial residue load or ratoon crop

Abbreviations: d: Days; PM: Particulate Matter



First, microorganisms can accelerate biochemical transformation of crop residues. Second, integrated residue-management packages can be agronomically workable. Third, the incremental contribution of an added inoculum is less consistently demonstrated than the performance of the complete package. This third point should be the starting point for future trials rather than treated as a minor limitation (Table 2).

From decomposition to air-quality benefit

Bio-decomposers do not remove $PM_{2.5}$ already present in ambient air. Their air-quality value is preventive and exists only when a treatment changes residue management enough to avert combustion. This makes the environmental causal chain longer than the agronomic one. A decomposition response is therefore a necessary but insufficient outcome for an air-pollution claim.

The scale of the underlying burning problem is well established. Emission inventories and source studies show that crop-residue combustion releases substantial particulate and gaseous pollutants [18-20]. Lan *et al.*, [4], using crop data, fire emissions and the GEOS-Chem adjoint model, estimated 44,000-98,000 annual premature deaths associated with $PM_{2.5}$ exposure from crop-residue burning during 2003-2019. These estimates are model-based rather than observed death counts, but they demonstrate that reducing agricultural burning can have meaningful regional health value.

Local monitoring is complementary because it captures real

seasonal exposure but is less able to isolate sources. Northern-Haryana observations reported higher particulate matter and other pollutants during crop-burning periods, including sugarcane-trash burning [21, 22]. These studies support the relevance of non-paddy residue streams, but observational contrasts remain affected by meteorology and concurrent sources. They should therefore be used as evidence of exposure during burning episodes, not as direct measurements of the air-quality benefit of bio-decomposer-treated fields.

For a bio-decomposer programme, four linked outcomes should be demonstrated. First, residue properties must change sufficiently by a predefined agronomic deadline. Second, the next crop must be established without burning. Third, investigators must estimate the counterfactual probability and mass of residue that would otherwise have been burned. Fourth, avoided emissions should be translated into ambient concentration or exposure using appropriate atmospheric analysis. Treated hectares or litres of product distributed are implementation indicators, not pollution outcomes.

Satellite monitoring also requires care. Polar-orbiting MODIS and VIIRS systems are valuable for rapid fire detection but can miss small, short-duration, cloud-obscured or late-day fires and do not directly measure burned area. High-resolution burned-area mapping and geostationary observations can therefore complement active-fire counts. The broader lesson is methodological: a programme should not claim emission reduction solely because active-fire detections

fell after deployment. Georeferenced treatment records, field audits, burned-area mapping and farmer verification are needed to establish whether the treated plots actually displaced burning.

A transparent avoided-emission framework can be expressed conceptually as: avoided emissions = treated area × crop yield × residue-to-product ratio × baseline burning fraction × pollutant-specific emission factor × verified displacement fraction. The final term is critical. If a treated field would not have been burned in the absence of the programme, its full theoretical residue mass cannot be credited as an avoided emission. This prevents overstatement when programmes are deployed in areas that already have substantial non-burning adoption (Figure 1).

Positioning bio-decomposers among residue-management alternatives

No single residue-management pathway is optimal across all farms. Happy Seeder and related direct-drilling approaches can avoid burning while retaining surface mulch and limiting soil disturbance, but performance depends on combine-residue distribution, machine availability and operator skill. Super Seeder, rotavation and ploughing can incorporate residue rapidly but may increase fuel use and soil disturbance. Surface retention can conserve moisture and moderate temperature, while baling and ex-situ utilisation can clear fields quickly where reliable biomass markets exist [3, 23, 24].

Bio-decomposers occupy a narrower functional niche. They are most plausible where residue is intended to remain in or on the field, enough moisture is available, the crop calendar permits biological transformation, and persistence of the residue would otherwise impede sowing or crop emergence. They are less compelling where direct drilling already works without accelerated decomposition or where residue has a higher-value ex-situ market. The intervention should therefore be selected according to the residue, farm size, machinery access, water availability, crop calendar and market

geography rather than through a uniform technology preference.

Economic comparisons must use common system boundaries. A low product or spray cost does not represent the cost of a complete management service if chopping, incorporation, irrigation, labour and delay risk are also necessary. Conversely, mechanical pathways should not be penalised by including full machinery operation while comparing them with only the retail cost of the microbial formulation. The correct unit of comparison is the farmer-level cost per hectare or per tonne of residue successfully managed by the required sowing date.

Adoption evidence reinforces this service-system perspective. Jambagi *et al.*, [25] found that farmers' choices between Happy Seeder and Pusa decomposer were shaped by resource access and perceived profitability, but observational adoption studies are inherently susceptible to selection effects. Government and programme reports also show that large-scale bio-decomposer use requires formulation preparation or supply, spray equipment, operators, residue preparation, water and scheduling. In practice, the 'technology' is therefore a coordinated service package, not a sachet or culture alone [26-39].

Policy should consequently judge bio-decomposers by the same outcome standard applied to alternative pathways: timely crop establishment without burning, acceptable full cost, manageable water and energy demand, no agronomic penalty, and verifiable environmental benefit. Where those criteria are met, bio-decomposers can be useful. Where a simpler pathway meets them more reliably, biological treatment should not be preferred merely because it is labelled environmentally friendly (Table 3).

Research priorities and evidence framework

The first priority is to quantify microbial additionality. Future trials should use operationally equivalent controls in which residue

Table 3: Comparative positioning of major crop-residue-management pathways.

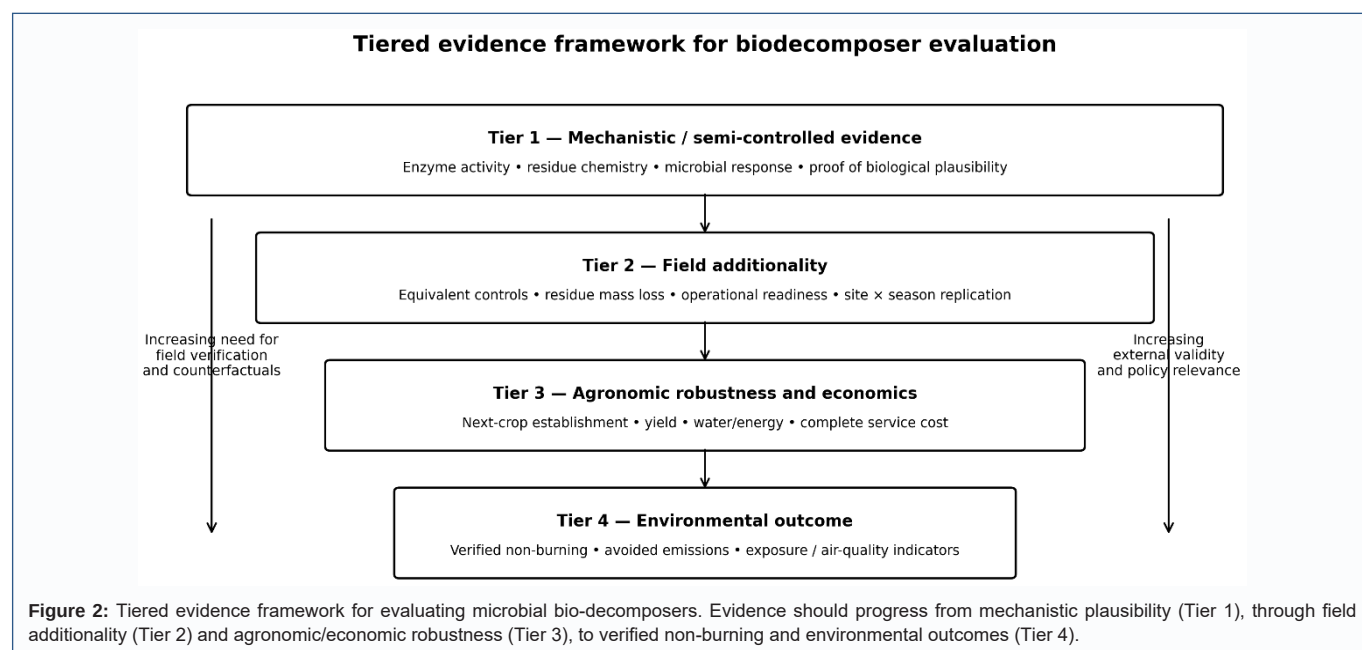
Pathway	Primary advantage	Main constraint	Best-fit situation	Key evaluation metric
Direct drilling / Happy Seeder	Rapid sowing with surface mulch and limited soil disturbance	Machine access, residue distribution, operator skill	Rice-wheat systems with compatible harvest and seeding machinery	Timely emergence and non-burning
Mechanical incorporation	Fast field clearance and residue return	Fuel, soil disturbance, temporary N immobilisation	Where rapid incorporation is feasible	Cost, fuel use, crop establishment
Biodecomposer-assisted in-situ management	Potential acceleration of retained/incorporated residue	Moisture, temperature, time; uncertain microbial additionality	Where biological acceleration solves a demonstrated persistence problem	Marginal benefit over equivalent non-inoculated control
Baling / ex-situ utilisation	Rapid removal and potential revenue	Collection, storage, transport and stable offtake	Near reliable biomass/industrial markets	Net farm value and sustainable removal rate
Composting / biochar / anaerobic conversion	Resource recovery and potential soil/energy benefits	Infrastructure, handling time, emissions and market requirements	Organised ex-situ systems	Life-cycle cost and environmental performance

Abbreviations: d: Days; PM: Particulate Matter

Table 4: Minimum design features for future bio-decomposer trials and programmes.

Domain	Minimum requirement	Why it matters	Preferred evidence
Inoculum additionality	Equivalent non-inoculated control	Separates microbial effect from physical management	Factorial multi-location field trial
Residue endpoint	Quantitative mass/chemistry plus operational readiness	Avoids subjective 'softening' claims	Predefined sampling schedule
Agronomic endpoint	Emergence, yield, N dynamics, water, pests	Tests whether decomposition solves the crop-calendar problem	At least one full succeeding crop
Scale transition	Explicit separation of pot, plot, farmer-field and programme evidence	Prevents over-generalisation	Tiered evidence framework
Air-quality outcome	Verified non-burning and counterfactual burning probability	Establishes real displacement	Georeferenced plots + field audits + burned-area mapping
Economics	Complete service cost and delay risk	Enables fair comparison with alternatives	Common system boundary

Abbreviations: d: Days; PM: Particulate Matter



size, placement, tillage, irrigation and starter nitrogen are identical and only inoculation changes. Factorial designs are preferable where resources permit because they can estimate interactions among inoculum, moisture, residue placement and nitrogen. Trials should be conducted across multiple locations and seasons and should include realistic residue loads and post-harvest temperatures.

Second, outcome definitions need standardisation. 'Decomposed' should not be based solely on visual disappearance or softening. A minimum set should include initial residue loading and particle-size distribution, dry-mass loss, moisture, cellulose, hemicellulose, lignin, total carbon and nitrogen, C:N ratio, tensile strength or penetration resistance, and relevant enzyme or viable-count measures where feasible. These biochemical indicators should be linked to practical endpoints such as seed-drill passage, crop emergence, nitrogen immobilisation, irrigation requirement, pest incidence and yield.

Third, controlled and field evidence must remain clearly separated. Pot and glasshouse studies are valuable for mechanism and treatment screening, but they cannot establish farmer-field effectiveness. A tiered evidence pathway is appropriate: Tier 1 for mechanistic and semi-controlled efficacy; Tier 2 for replicated field additionality; Tier 3 for multi-location agronomic robustness and complete cost; and Tier 4 for verified non-burning and environmental outcome assessment.

Fourth, product quality requires better reporting. Institutional and published descriptions of bio-decomposer formulations are not always consistent regarding constituent organisms or preparation. Studies should report batch identity, strain or consortium authentication where available, viable count, carrier, storage conditions, shelf life and application rate. Without such information, nominally identical 'bio-decomposer' treatments may not be reproducible across studies.

Fifth, air-quality evaluation should start with plot-level verification rather than regional correlation. Treated plots should be georeferenced before application, and burning outcomes should be verified through random audits, high-resolution burned-area products, thermal anomalies and farmer records. The counterfactual probability of

burning should be estimated explicitly. Only then should avoided residue mass and emissions be calculated. Where programme scale justifies it, meteorology-normalised ambient analyses or atmospheric modelling can assess whether the intervention produces a detectable exposure benefit.

Finally, future policy studies should compare complete systems. The relevant question is not whether bio-decomposers are 'cheap' or 'green' in isolation, but whether the full service reliably prevents burning at lower social and farmer cost than feasible alternatives in a particular context. This requires consistent accounting of machinery, labour, water, energy, crop-delay risk, nutrient effects, yield, residue value and public-health co-benefits (Table 4 and Figure 2).

Conclusions

Microbial bio-decomposers have a credible biological basis and can contribute to non-burning crop-residue management, but the current evidence does not support treating them as a stand-alone air-pollution control technology. The most important limitation is not whether microorganisms can degrade lignocellulose; that is well established. It is whether an added inoculum provides sufficient additional speed and reliability, beyond chopping, incorporation, moisture and nutrient management, to change farmer practice within the crop calendar. Farmer-field package studies show that biologically assisted in-situ management can be agronomically feasible, whereas independent multi-location evidence also shows that physical incorporation can dominate the decomposition response and that decomposer sprays may add little under some conditions. Semi-controlled sugarcane studies support biological activity but should not be presented as field-scale proof. The defensible policy position is therefore selective integration: use bio-decomposers where a validated marginal benefit exists and evaluate them alongside direct drilling, mechanical incorporation, surface retention and ex-situ recovery. Claims of air-quality benefit should progress from authenticated treatment and quantified residue change to timely crop establishment, verified non-burning, counterfactual fire displacement, avoided emissions and, where feasible, reduced population exposure.

Acknowledgements

The author acknowledges the institutional support of the Institute of Environmental Studies, Kurukshetra University, Kurukshetra, India, for facilitating the academic work underlying this review.

Funding

No specific funding was received for the preparation of this review manuscript.

Conflict of Interest

The author declares that there is no conflict of interest.

Data Availability

No new datasets were generated or analysed specifically for this critical mini review. The evidence synthesised in the manuscript is available in the cited peer-reviewed literature and publicly available institutional reports.

Author Contribution

Prashant Ravish conceptualised the review, identified and curated the literature, interpreted the evidence, and prepared and revised the manuscript.

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