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Bio-Enzymatic Decomposition of Crop Residue: A Scalable Solution to Stubble Burning in India

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Abstract: ***Stubble burning in Northern India remains a serious environmental and public health concern. This study investigates the potential of bio-enzyme formulations as a scalable, cost-effective alternative for crop residue decomposition. By combining expert interviews, field visits, and controlled experiments using three different bio-enzyme compositions, the study finds that higher concentrations of jaggery and yeast substantially enhance microbial activity and accelerate stubble breakdown. The findings underscore the viability of integrating bio-enzyme use with agricultural machinery and supportive policies, thereby offering a feasible path to reducing reliance on stubble burning.***

Keywords: stubble burning, bio-enzyme, crop residue management, sustainable agriculture, air pollution

1. Introduction

Stubble burning is deeply entrenched in India's agricultural practices, driven by tight cropping schedules due to mechanized harvesting and the push for double cropping. Farmers, constrained by time and lacking viable alternatives, often resort to open-field burning of crop residue—particularly in Punjab, Haryana, and Uttar Pradesh during the winter season.

This practice emits large volumes of carbon dioxide, methane, nitrous oxide, carbon monoxide, and particulate matter, resulting in severe smog conditions. The environmental fallout is compounded by public health issues such as respiratory disorders, eye irritation, and increased hospitalizations, particularly among vulnerable groups.

Despite penalties and machinery subsidies, sustainable practices remain underutilised. This research focuses on bio-enzymes as a practical alternative, capable of breaking down stubble organically and reducing the need for burning.

This study is significant because it not only validates the efficacy of bio-enzyme formulations but also proposes a realistic pathway to integrate them into current farming practices, thereby addressing both environmental and socio-economic dimensions of the stubble burning crisis.

2. Alternatives to Stubble Burning

This section outlines various alternatives that have been explored to address the stubble burning crisis by effectively disposing of crop residue in a sustainable manner. While promising, each comes with its own set of logistical, economic, or behavioural challenges that limit widespread adoption.

A. Waterlogging for decomposition

Maintaining standing water in paddy fields after harvest accelerates anaerobic decomposition of rice residue and can reduce immediate burning risk. Field evidence suggests waterlogging can temporarily reduce visible fires in areas where water conditions are favourable, but it is rarely a scalable, year-round solution across the Indo-Gangetic plains because of competing requirements for timely sowing of wheat and drainage constraints. In recent crop-season monitoring, satellite and field campaigns reported large inter-annual variability in fire counts that waterlogging alone cannot explain, indicating the measure's limited systemic impact without concurrent policy/infrastructure changes. [1]

Challenges
- Requires proper field bunding and drainage systems
- Risk of soil salinisation and nutrient leaching
- Time-consuming and not suitable for tight sowing schedules

B. Happy seeder

This machine cuts and lifts straw while simultaneously sowing seeds, allowing farmers to prepare fields without removing or burning stubble. Trials in Punjab and Haryana show the technology substantially reduces burning and conserves soil moisture. Adoption studies report variable but promising uptake in targeted areas (some sample studies showing >50% adoption in focused districts) [2]

Challenges
- High initial cost of machinery
- Requires specific soil moisture conditions
- Limited availability and adoption among smallholder farmers (patchy state-level distribution efforts.

C. Biomass Briquettes

Farmers can convert crop residues into briquettes or pellets for use in homes and industries. Studies suggest briquettes can be cost-effective when collection and distribution systems are in place. [3]

Challenges
- Requires infrastructure for collection, transport, and processing
- Limited market linkages and demand in rural areas

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D. Composting with Bio-Enzymes (e.g., PUSA Decomposer)

Bio-decomposer formulations (e.g., ICAR/PAU PUSA decomposer) deploy cellulolytic and ligninolytic microbial consortia to accelerate in-field decomposition of paddy straw, converting residue into usable organic matter in weeks to months. Indian peer-reviewed reviews and field reports find measurable improvements in decomposition rates and soil organic content when applied correctly; the PUSA approach has been widely publicised and distributed since its release in 2020. [4]

Challenges
- Requires consistent training and follow-up with farmers
- Takes time to show visible benefits

***E. Fodder** for Livestock*

Farmers can reuse crop residue as cattle feed where feasible.

Challenges
- Not all stubble types are suitable or nutritious for fodder
- Limited cattle population per household
- High volume of stubble far exceeds demand

F. Sale to Biofuel Plants:

Excess stubble can be sold to biofuel and alcohol distilleries, creating an additional income stream for farmers.

Challenges
- Requires organized supply chains and aggregation mechanisms
- Transportation costs are often prohibitive
- Biofuel units are not uniformly distributed across regions

3. Research Methodology

1) Expert insight

In an interview with environmentalist Mr. Neeraj Gulati, key insights emerged regarding the policy and economic context of stubble burning. He noted that government procurement policies, particularly the Minimum Support Price (MSP) for rice, have intensified paddy cultivation in water-deficient regions—leading to surplus stubble.

While many farmers are aware of decomposition techniques, adoption is hindered by high enzyme costs, irregular availability, and lack of infrastructure. Mr. Gulati emphasized that financial incentives alone are insufficient without systemic changes including farmer education, infrastructure development, and policy reform.

2) Field study

A field investigation in Kalyana village highlighted similar challenges. Farmers reported that mechanized harvesters leave behind stubble that is uneven and difficult to remove, especially in waterlogged fields. A noteworthy suggestion was to equip harvesters with spraying mechanisms for simultaneous enzyme application—an idea that informed our proposed engineering solution.

3) Approach followed

Our research methodology included:
- Qualitative Data: Field visits and expert interviews
- Literature Review: Scientific and technical resources
- Experimental Validation: Testing of three enzyme compositions over 30 days

Changes in mass, microbial activity (LUX meter), temperature, and pH, were tracked allowing for a holistic understanding of enzyme effectiveness.

4. Experiment design

1) Objective

To identify the most effective bio-enzyme formulation (comprising cow dung, jaggery, yeast, water, and soil) for accelerating wheat stubble decomposition.

2) Hypothesis

Higher concentrations of jaggery and yeast will stimulate microbial activity, expediting decomposition.

3) Materials
- 1 kg wheat stubble
- Three enzyme compositions
- LUX meter, pH meter, thermometer, digital scale, timer
- Containers for fermentation

4) Variables
- Independent Variable: The quantity of cow manure, jaggery, yeast, and water used.
- Dependent Variable: The time taken for stubble to decompose.
- Controlled Variables: Amount of stubble used, temperature, and type of stubble (wheat stubble in this case).

5) Bio-enzyme compositions

Table 1: Bio-enzyme compositions

Composition	Jaggery	Yeast	Cow Manure	Water	Soil
Comp1	25g	5g	500g	1 Litre	100g
Comp2	50g	10g	500g	1 Litre	100g
Comp3	75g	20g	500g	1 Litre	100g

6) Procedure

Each mixture was fermented and used to submerge 1 kg of wheat stubble. Parameters were tracked daily over 30 days, with each trial repeated thrice to ensure data reliability. This is explained in ensuing paragraphs.

a) **Preparation Phase:** Three fermentation containers were set up, each corresponding to one of the three bio-enzyme compositions. Each container was filled with the specific ratio of cow manure, jaggery, yeast, water, and soil.
b) **Stubble Immersion:** One kilogram of wheat stubble was added to each container, ensuring full submersion in the bio-enzyme solution.
c) **Monitoring Parameters:**
    - Daily recording of mass loss to track decomposition rate.
    - Measurement of temperature and pH to monitor environmental conditions inside the container.
    - Use of a LUX light meter to assess microbial activity through light absorption. The LUX meter was

calibrated under standard laboratory lighting before use to ensure accurate readings. Measurements were consistently taken at a fixed depth of 5 cm in each container to maintain uniformity across trials. A decrease in LUX values was interpreted as higher microbial activity, since increased biomass reduced light transmission through the solution.

d) **Duration:** The experiment was conducted for 30 days or until stubble mass was reduced by at least 80%, indicating substantial decomposition.

e) **Repetition and Data Logging:** Each composition was tested in triplicate to ensure data accuracy and reproducibility. Results were recorded in tabular form for comparative analysis.

5. Results

1) *Temperature trend during decomposition*

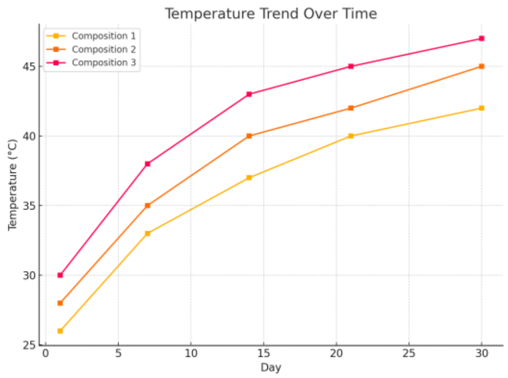

Figure 1: Temperature trend during decomposition

2) *pH trend during decomposition*

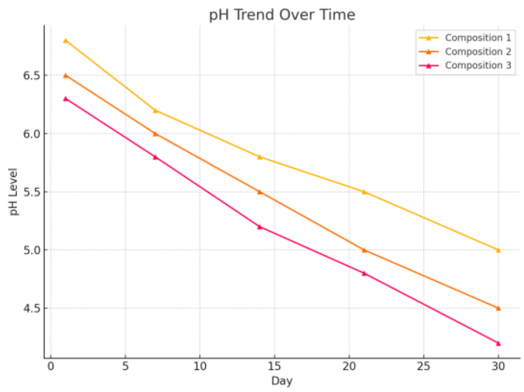

Figure 2: pH trend during decomposition

3) *Mass loss*

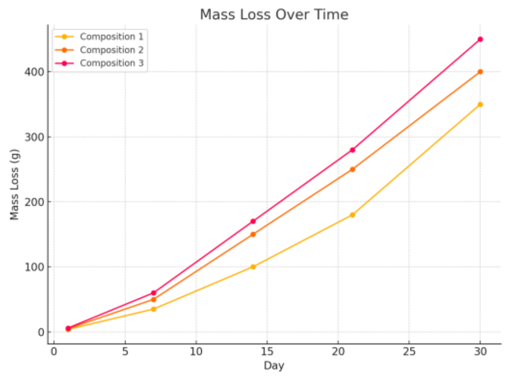

Figure 3: Mass loss trend during decomposition

4) *Key observations*

- Composition 3, which contained the highest amounts of jaggery and yeast achieved the fastest and most complete decomposition, with 45% greater mass reduction than Composition 1 by Day 30.
- The increased sugar content from jaggery and elevated yeast levels enhanced microbial activity, significantly accelerating the fermentation and breakdown process.
- Composition 1 was the least effective due to lower nutrient content.

6. Way forward

1) *Engineering integration*

To support large-scale implementation of bio-enzyme use, we propose modifying harvesters as follows:

- Storage tank, pump & nozzles to ensure even distribution during harvesting.
- Control systems to maintain consistent flow.
- GPS-based mapping can divide fields into spray zones for targeted application.
- Sensors and data logging for moisture control and performance tracking.

After being chopped into small pieces by machines like Super Straw Management Systems, the stubble is sprayed with the solution evenly through nozzles. The field is then ploughed with a rotavator to mix the solution. Later, the residues require light irrigation and 25 days to decompose. Machines like the Happy Seeder, which cut and lift rice straw, sow wheat, and deposit straw back as mulch, further support the process by ensuring uniform coverage and quicker breakdown.

Control Systems and Sensors:

- Soil moisture sensors: Ensure post-application moisture stays in the optimal range, as efficacy depends on keeping soil moist (but not waterlogged). Field trials noted that failures often occurred due to low moisture or lack of irrigation after applying the decomposer.
- Temperature sensors/loggers: Track how microbial and enzyme activity varies with temperature. Studies on residue decomposition show cooler temperatures slow down the process significantly.
- pH monitoring: Important because many fungi/bacteria in PUSA decomposer are lignocellulolytic and perform differently under varying pH levels.
- GPS-Quadrant System: A GPS-quadrant system involves dividing farmland into smaller, well-defined sections (quadrants) using satellite-based positioning. Each quadrant is digitally mapped and monitored for precise application. Data from sensors (residue thickness, soil moisture, or crop type) is linked to each quadrant. Spray systems on harvesters or tractors use this data and adjust release rates, ensuring each zone gets the right amount of solution rather than applying a uniform dose across the whole field.

2) *Improvement suggestions*

- Include more temperature controls to monitor the effect of temperature on enzyme efficiency.
- Use larger quantities of stubble to simulate real-life applications more effectively.

- Explore variations in pH to determine if acidic or alkaline conditions further enhance decomposition rates.

3) Other recommendations

- Training & Farmer Outreach, Demonstration Plots: Conduct on-farm demonstration trials in different agro-climatic zones so farmers see results in their own conditions.
- Incentives & Subsidies: Provide subsidies for buying or renting equipment (mulchers, rotavators) needed for residue chopping and incorporation.
- Policy Support & Regulation: The Gram Panchayat could focus on first spreading awareness about PUSA as an alternative to burning the stubble. Governments can set clear standards/guidelines for residue management, including minimum decomposition periods and acceptable residual levels.
- Provide regulatory support to integrate bio-decomposer use into crop residue management, air quality, and environmental laws.
- Adjustment of Agronomic Calendars & Crop Varieties
- Adjust crop calendars (e.g., use of short-duration rice varieties) to give more time between crops for residue decomposition.
- Select crop rotations or varietal patterns that reduce residue load (e.g., crops that produce less residue or residue that decomposes more easily).
- Technology Integration: Equip harvesters with enzyme sprayers to automate and standardize decomposer application during harvest.

7. Conclusion

This study validates the effectiveness of high-jaggery and yeast bio-enzyme formulations in accelerating stubble decomposition. The experimental results demonstrate a clear correlation between microbial activity and enhanced decomposition rates. Coupling these insights with farmer-friendly engineering integrations and policy support offers a feasible, sustainable alternative to stubble burning. Future efforts should prioritize field-level implementation, scalability, and farmer education to ensure widespread adoption.

Acknowledgment

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