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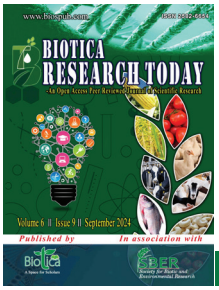

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Microbial Bio-Composting as a Sustainable Approach to Biodegradable Waste Management: A Framework for Environmental Conservation

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Abstract

There are several issues in the solid waste management sectors in India because of growing population and fast urbanization, besides poor infrastructure. Inadequate waste disposal in the Indian Himalayan Region (IHR) poses great danger to the environment and the health of the people, thus categorizing this environmental concern as a hot potato. Organic waste management can be enhanced through microbial bio-composting because a large amount of waste found in IHR is biodegradable. This literature investigates the practice of microbially assisted composting of food waste within a biocomposting facility. This review covers the benefits of this innovative waste treatment technique and particularly draws attention to existing problems with wider adoption of this technology in rural or ecologically sensitive areas. Due to its potential of improving soil health minimizing landfill requirements and curtailing GHG emissions MBCT is one of the waste management strategies that is required for the sustainable development of the Indian heterogeneous and complex environment.

Keywords: Biodegradable waste, Environmental sustainability, Microbial bio-composting, Solid waste management

Introduction

Rapidly growing urban centers and increasing population have led Indian cities to produce an estimated 62 million metric tons (MT) of municipal solid waste (MSW) annually, as plastic, e-waste and hazardous waste. Out of which only 75-80% MSW gets collected; of this only 22-28% are processed and treated; and the rest are discarded in wasteyards (Agnihotri, 2022). Although the situation is dire with properly treating only less than a quarter of the collected debris treatment works are slowly rising to this challenge. Majority of the untreated waste is thrown into the water bodies, set across open fields for combustion, or disposed of into landfills, which are destructive to the environment and a risk to the health of the people. Since 50-60% of the wastes in India are organic and biodegradable, these methods are wasteful as well as inappropriate.

Effective management of biodegradable waste presents a chance to produce useful resources such as compost or biogas (Sharholy *et al.*, 2008). But most of this organic material gets mixed up with non-biodegradable waste, because waste segregation procedures are not good enough, which means it cannot be composted or treated elsewhere. Large amounts of garbage have accumulated as a result in landfills which has contaminated soil released methane a powerful greenhouse gas and contaminated air and water.

The 13 Indian states that make up the Indian Himalayan Region (IHR) are especially susceptible to the environmental dangers associated with poor waste management. With a population of more than 50 million, this hilly area is home to fragile ecosystems that are readily disturbed by pollution. The regions rugged topography rural nature and reliance on agriculture make it difficult to apply conventional waste management techniques. For the IHR to be environmentally sustainable decentralized community-based waste management techniques like microbial bio-composting are essential.

Article History

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Through the process of microbial bio-composting organic waste is broken down by microorganisms to create nutrient-rich compost that can be applied as organic fertilizer. This technique provides an inexpensive green waste management solution especially in areas where the majority of waste is biodegradable. In this work we have elaborated how biodegradable waste can be addressed in rural and environmentally sensitive areas such as the IHR through microbial bio-composting. We also discussed the advantages difficulties and prospects of implementing microbial composting in India as a component of a larger waste management plan.

Current Status of Waste Generation and Management in India

India produces enormous volumes of solid waste daily production is estimated to be over 143,449 metric tonnes of MSW (Kumar and Agrawal, 2020). But barely two-thirds of this waste is processed and the remaining 70% is collected. Environmental degradation is exacerbated when leftover waste, the majority of which is biodegradable is burned or dumped in landfills. In cities where population density and economic activity have increased waste mismanagement is becoming an increasingly serious issue. Because there is less access to waste management infrastructure in rural and hilly areas the situation is even more dire.

With programmes like the Swachh Bharat Mission and Smart Cities Mission attempts have been made to enhance waste management systems in urban India. The objectives of these programs are to encourage recycling waste segregation and better sanitation facilities. Unfortunately urban areas have received most of the attention leaving rural areas and environmentally sensitive areas like the IHR without enough waste treatment options. These areas produce a lot of biodegradable waste, which is especially suitable for composting. Examples of this waste include kitchen scraps, garden trimmings and agricultural residues.

Due to India's inefficient waste disposal tactics, terrible consequences come to the environment. Waste materials when piled in landfills; emit gases like Methane that are harmful to the ozone layer and toxic leachate contaminates water bodies. Improper waste disposal in river basins, such as those in the IHR, where rivers sustains millions of persons with potable water, creates places that have significant health hazards due to pollution of water bodies. She also states that open burning of biomass waste also leads to the release of poisonous gas and particles into the atmosphere, which causes respiratory diseases in humans, aggravates air pollution and offers additional hazards for primary health.

Considering these complexities, the promotion of special Clean-Up techniques for waste which are acceptable within India's heterogenous social economic and geological setting in intelligence is equally important. In particular, where a predominant portion of the waste is organic, microbial bio-composting remains a viable option in less industrialized regions.

Waste Composition and Environmental Risks

Hazardous non-hazardous and biodegradable wastes make up India's municipal solid waste. Plant leftovers food scraps and other naturally occurring materials with a decomposition rate are examples of biodegradable waste. Materials that don't decompose quickly and cause long-term pollution like glass metal and plastic are classified as non-biodegradable waste. A smaller percentage of waste is hazardous, but because it is toxic it poses serious risks to the environment and public health.

Biodegradable waste makes up a significant amount of the total waste generated in rural and semi-urban areas especially in the Indian Himalayan Region. This poses a problem as well as an opportunity. On the one hand improper management of biodegradable waste can have detrimental effects on the environment including soil erosion greenhouse gas emissions and contamination of water sources (Sharholy *et al.*, 2008). Conversely composting methods can effectively handle biodegradable waste transforming a waste issue into a chance for resource recovery.

There are serious environmental risks associated with improper handling of biodegradable waste. Organic waste breaks down anaerobically, that is without oxygen, in landfills and open spaces releasing methane, which is a greenhouse gas that is 25 times more powerful than carbon dioxide (Shovon *et al.*, 2024). Decreases in the quantity of biodegradable waste dumped in landfills are crucial steps towards mitigating the methane emissions that contribute significantly to climate change.

Contamination of soil and water can also result from the incorrect disposal of biodegradable waste. Decomposing organic matter leachate contains chemicals and nutrients that can contaminate drinking water supplies by seeping into groundwater supplies. This pollution is a major health risk in areas like the IHR, where communities rely largely on natural water sources.

These hazards are mitigated by microbial bio-composting which provides an approach to convert organic waste into compost. Organic matter is stabilized by composting which lowers the possibility of leachate and other undesirable byproducts (Meena *et al.*, 2023). Additionally the final compost product can be applied to improve soil quality thereby reducing the need for chemical fertilizers, which have their own negative effects on the environment and thereby encouraging sustainable agriculture.

Microbial Bio-Composting Technology (MBCT)

Microbial Bio-Composting Technology (MBCT) uses microorganisms' innate ability to decompose organic materials to treat biodegradable waste in an environmentally friendly way. By using this process waste is turned into compost which is then added to soil to enhance its fertility and structure. Because centralized waste management facilities are not easily accessible in rural or hilly areas, MBCT is especially useful for managing biodegradable waste.

The three stages of composting are called the mesophilic phase, thermophilic phase and maturation phase. Temperature increases as easily degradable organic matter such as sugars and proteins are broken down by microorganisms during the mesophilic phase. Temperatures

above 60 °C occur during the thermophilic phase, during which more resilient materials break down including cellulose and lignin. Eventually the compost stabilizes and cools down during the maturation stage allowing it to be applied as a soil amendment.

Aeration moisture content waste composition and the kinds of microorganisms employed are some of the variables that affect the outcome of microbial composting. From basic backyard pits to intricate expansive facilities that handle tons of organic waste every day composting systems come in many different forms. Because MBCT can be applied decentralized it is perfect for areas like the IHR where the topography and population distribution render centralized waste management systems unfeasible.

The capacity of MBCT to generate superior compost that improves soil health is one of its main benefits. The compost that is created has a lot of nutrients such as potassium, phosphate and nitrogen, which are critical to plant growth. Additionally compost improves soil structure by increasing its water-holding capacity reducing erosion and promoting the activity of beneficial microorganisms. Because of this MBCT is an effective tool for supporting sustainable agriculture in rural areas as well as for waste management.

Challenges of Microbial Bio-Composting in the Indian Himalayan Region

Although microbial bio-composting has many advantages there are a number of obstacles that prevent it from being widely used especially in areas like the Indian Himalayas.

Climatic Conditions

The composting process is severely hampered by the IHRs high elevations and chilly temperatures. Low temperatures cause microbial activity to slow down which prolongs the time it takes for compost to form. In these types of climates extra precautions might be needed to ensure effective composting such as insulating compost piles or adding heat-generating methods. These adjustments may make composting systems in the area more expensive and complicated.

Infrastructure

Basic infrastructure for waste collection and management is lacking in the majority of rural areas in the IHR. Conventional waste management systems are difficult to implement in many villages due to their decentralized nature and challenging terrain. It can be expensive and logistically challenging to transport organic waste to composting sites. The initial setup costs for MBCT can be high due to the lack of established composting infrastructure necessitating a large investment from public agencies or private businesses.

Public Awareness and Participation

Although effective composting depends on waste segregation at the source many IHR communities do not understand how important proper waste segregation is. Composting systems are unlikely to be successful in the absence of sufficient community involvement and education. Promoting community involvement requires public awareness campaigns that highlight the advantages of composting as well as useful advice on waste segregation.

Government Support

Though policies encouraging composting have been implemented inconsistently especially in rural and remote areas composting is acknowledged as a sustainable waste management solution. In order to offer financial incentives technical support and regulatory frameworks that promote the adoption of MBCT in the IHR, more government backing is required.

Potential Benefits of Microbial Bio-Composting

Microbial bio-composting offers a number of advantages both socio-economic and environmental despite the challenges.

Environmental Benefits

Microbial composting lessens the amount of methane produced which is a primary cause of climate change by removing biodegradable waste from landfills. Furthermore compost enhances soil health lowering the need for chemical fertilizers, which have the potential to degrade soil and contaminate water by increasing soil health. Because it stabilizes organic matter and slows the leaching of dangerous substances into water supplies composting also lessens the chance of contaminated water.

Economic Benefits

Rural communities can benefit economically from composting because it produces a valuable product that can increase agricultural productivity. Growers have the option to either utilize the compost on their property or market it to generate revenue. For municipalities long-term financial savings are also provided by the decrease in landfill maintenance and waste disposal expenses.

Social Benefits

A sense of community responsibility for the surrounding environment can be fostered through composting which can encourage waste management. Effective composting initiatives can enhance public health by lowering illnesses linked to waste and improving the cleanliness of public areas. Additionally composting programs support rural development by generating jobs locally in the areas of waste collection processing and compost distribution.

Conclusion

In the Indian Himalayas microbial bio-composting is a viable and sustainable way to handle biodegradable waste. By turning organic waste into compost MBCT improves soil health and agricultural productivity while also lessening the environmental impact of waste disposal. Yet a number of issues such as climate limitations a lack of infrastructure the requirement for increased public awareness and government support and the need to address infrastructure deficiencies are necessary for the broad implementation of this technology in rural and environmentally sensitive areas like the IHR.

The potential of microbial bio-composting as a decentralized waste management approach that adheres to environmental sustainability principles is considerable despite these

obstacles. By converting waste into a useful resource that benefits the environment and the communities that depend on it MBCT can play a critical role in promoting sustainable living practices. Adopting sustainable practices such as composting is essential for guaranteeing long-term environmental protection and resilience in an area as ecologically delicate as the IHR.

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