

Chapter 7

Conduct a techno-economic analysis of rice straw composting, evaluating its technical feasibility and economic viability

7.1 Background

The management of agricultural residues, such as RS, wheat straw, corn stover, and other crop byproducts, presented significant environmental and economic challenges. Traditionally, many farmers burned these residues to quickly clear fields for the next planting cycle [136]. However, this practice had severe environmental consequences, including air pollution, greenhouse gas emissions, and the depletion of valuable organic matter that could have otherwise been recycled back into the soil [136]. With the increase in global agricultural production, finding sustainable alternatives for managing these residues became more critical than ever [2]. Composting offered a viable solution by converting agricultural residues into nutrient-rich organic amendments that enhanced soil fertility, improved soil structure, and increased water retention capacity. By recycling these organic materials into compost, farmers boosted soil health and supported long-term agricultural sustainability. Despite the clear environmental benefits, large-scale adoption of composting for agricultural residues was limited by concerns about its technical feasibility and economic viability [1]. Evaluating both aspects was essential to ensure that composting could be widely implemented as an effective waste management strategy. Technically, agricultural residues, particularly those high in lignocellulosic material like RS, were resistant to microbial decomposition due to their complex structures [137]. These materials presented several challenges, such as managing the carbon-to-nitrogen (C/N) ratio, which was typically high in these residues and could slow microbial activity [137]. Inoculants, such as anaerobic digestate or manure, had the potential to enhance microbial activity and

accelerate the breakdown of these resistant materials, but their effectiveness needed further study. Additionally, proper process control, including the monitoring of temperature, aeration, and pH, was essential to ensure efficient decomposition and the production of high-quality compost [12]. Economic viability is another critical factor influencing the adoption of agricultural residue composting. Setting up a composting system required an initial capital investment in infrastructure, including composting equipment, storage facilities, and monitoring tools. Operational costs, such as labor, water, energy, and the use of additives, also needed to be considered [138]. However, the potential revenue generated from selling high-quality compost, particularly in regions with demand for organic soil amendments, could offset these costs. Additionally, composting offers environmental and regulatory benefits, such as compliance with regulations prohibiting burning and opportunities for carbon credits and other incentives for sustainable agricultural practices [139]. A techno-economic analysis of agricultural residue composting is essential to comprehensively assess both the technical challenges and the economic benefits. This analysis helps determine whether composting serves as a viable and scalable solution for farmers and agricultural businesses [2]. The evaluation covers initial infrastructure costs, ongoing operational expenses, and potential revenue from compost sales, along with environmental benefits such as reduced emissions and regulatory compliance [139]. This study aims to conduct a thorough techno-economic analysis of composting agricultural residues, focusing on the balance between costs and benefits. By examining technical requirements, economic factors, and environmental impacts, it offers insights to guide the implementation of sustainable composting practices. The findings inform policymakers, farmers, and agribusinesses about the feasibility of adopting composting over conventional methods like burning or landfilling, contributing to more sustainable agricultural systems.

7.2 Simulation of conceptual bioprocess for compost production

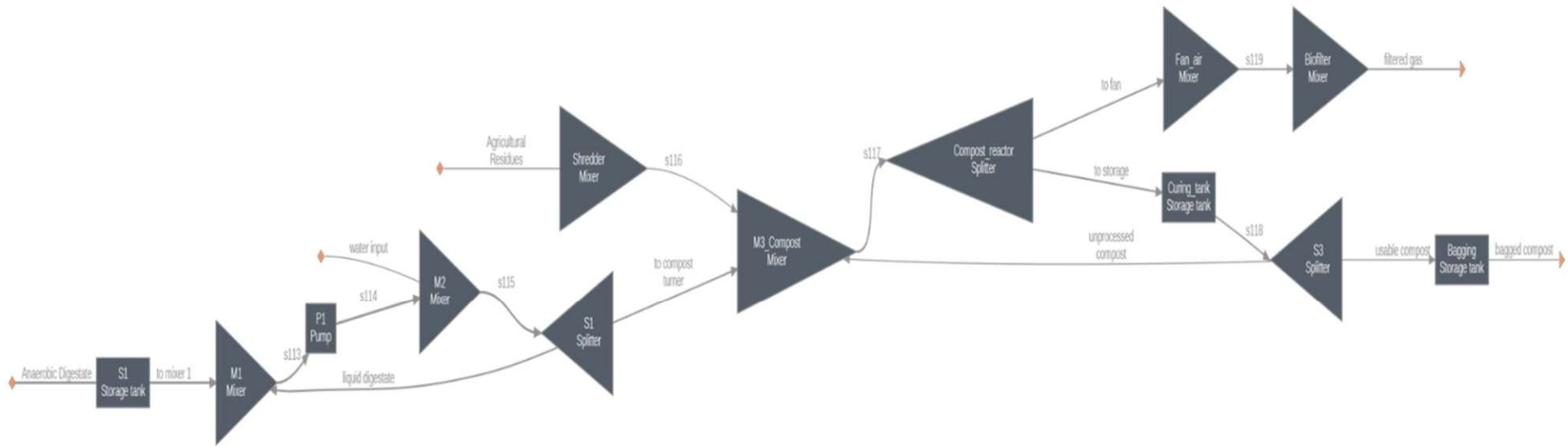


Figure 7.1. Simulation of conceptual bioprocess for compost production from agricultural residues using anaerobic digestate

The open-source code for the compost bioreactor from BioSTEAM was used with changes suitable to our process design. The composting system has been designed and cost according to Indian industry standards to ensure efficient operation and cost-effectiveness for local conditions. The system begins with a Storage Tank (S1), fabricated from stainless steel (SS304), with a capacity of 10,000 liters and a cost of ₹3,00,000 as shown in *Figure 7.1*. This tank stores ADS, which is further processed. The system includes three Mixers (M1, M2, M3_Compost), each with a capacity of 5000 liters, made from mild steel with an anti-corrosive coating. Each mixer costs ₹1,50,000, totaling ₹4,50,000. These mixers ensure proper blending of digestate, water, and compost materials before further processing. A Pump (P1), with a flow rate of 10,000 liters per hour, made from stainless steel (SS316), costs ₹1,50,000 and is used to transport the materials into the belt filter system.

The Belt Filter (S1), with a capacity of 5000 liters per hour and composed of a polypropylene filter belt supported by an SS304 frame, costs ₹4,50,000. It is used to separate liquid digestate from the solid compost materials. The system also includes a Shredder, with a capacity of 3000 kg per hour for agricultural residues, made from hardened steel, priced at ₹6,00,000. The Compost Turner, constructed from mild steel, has a capacity of 8000 kg per hour. This equipment aerates and mixes the compost, facilitating microbial activity and decomposition. The compost turner costs ₹7,00,000. The compost reactor, with a capacity of 20,000 liters, made from mild steel with an anti-corrosive lining, facilitates controlled composting with agitation. This reactor costs ₹20,00,000. After the composting process, the material is transferred to the Curing Tank (15,000 liters, SS304), costing ₹3,00,000, for final curing and maturation. The system also includes a Solid-Liquid Separator (S3), which processes 5000 liters per hour, constructed from stainless steel (SS304), costing ₹5,00,000. It separates usable compost from unprocessed material. The Packaging/Bagger system, which can process 1000 kg per hour and is made from mild steel with a polyethylene lining, costs ₹3,00,000 and is used

to package the final compost product into bags for distribution. To ensure proper air circulation during composting, Fans (Fan_air), with a capacity of 5000 cubic meters per hour, are installed, costing ₹1,00,000. Additionally, a Biofilter, capable of processing 1000 cubic meters per hour, filters and treats gases produced during composting to meet environmental standards, costing ₹3,00,000.

7.3 Minimum selling price

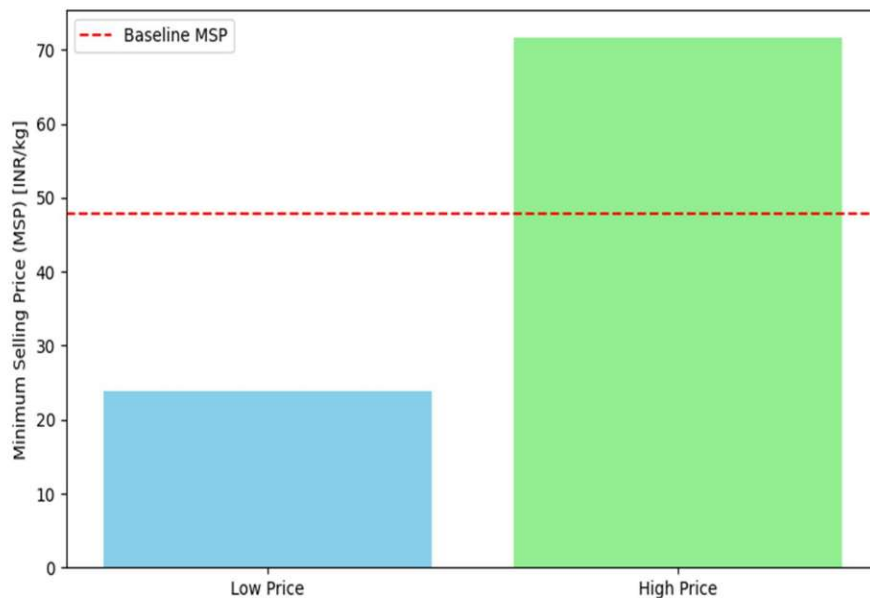


Figure 7.2. Effect of price of compost on MSP

The *Figure 7.2.* depicted a detailed analysis of the relationship between compost pricing, productivity levels, and the Minimum Selling Price (MSP) in a composting system. The chart illustrated how varying compost prices influenced the MSP. It compared two scenarios: Low Price and High Price, with the baseline MSP set at INR 47.56/kg, INR 20/kg, showing that at lower selling prices, the system was not economically viable as the selling price was well below the MSP. However, in the high-price scenario, where the compost price exceeded the baseline MSP, the system demonstrated economic feasibility, ensuring profitability. This analysis

highlighted that achieving a price above the baseline MSP was critical for sustaining the financial viability of the composting system.

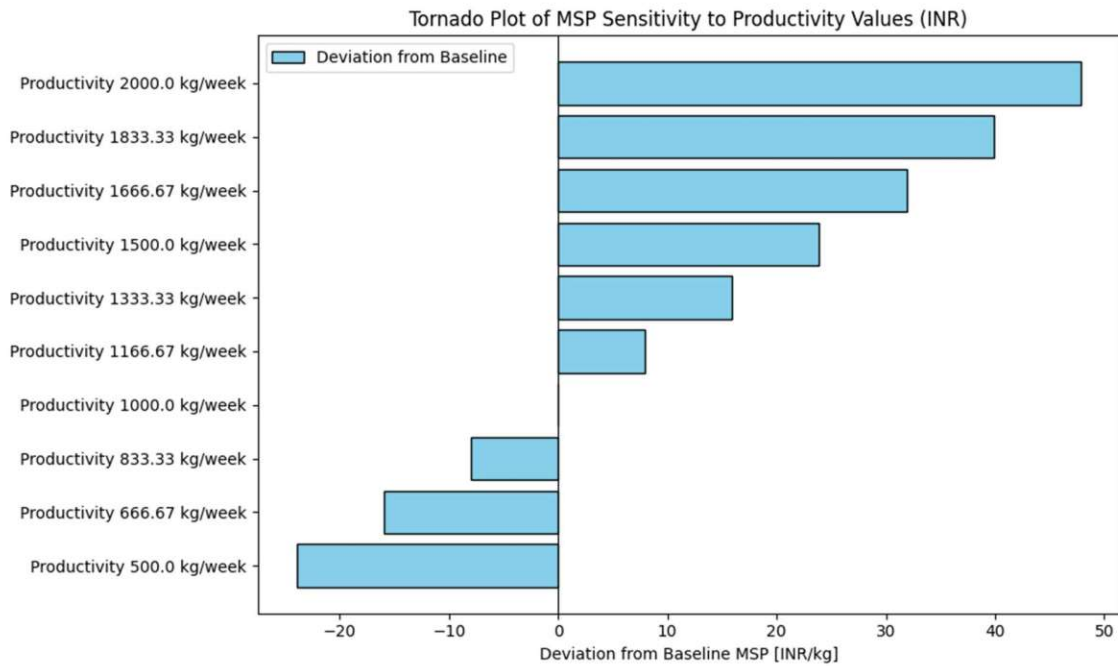


Figure 7.3. Tornado plot of MS sensitivity to productivity values (INR)

The tornado plot on the right explored the MSP's sensitivity to changes in productivity as shown in *Figure 7.3*. The blue bars represented the deviation from the baseline MSP (INR/kg), illustrating how different productivity levels, measured in kg/week, impacted the system's financial viability. Higher productivity levels, such as 2000 kg/week, resulted in lower MSPs, thereby improving the system's economic viability, as indicated by the significant positive deviation from the baseline. In contrast, lower productivity levels, such as 500 kg/week, led to higher MSPs, making the system less economically feasible. This analysis underscored the critical role of both pricing and productivity in determining the overall economic sustainability of agricultural residue composting, with higher productivity yielding more favorable financial outcomes.

7.4 System output and performance

The composting system was designed to produce 4000 kg of solid compost per day, with 50% of the liquid effluent being recycled back into the process to ensure efficient resource utilization. The system's Biofilter effectively managed 1000 cubic meters of gas per hour, controlling gases and odors emitted during the composting process. The Total Capital Investment for the system, including all necessary equipment, amounted to ₹61,50,000. The Annual Operating Costs were estimated at ₹30,55,500, which included several key components: Electricity Costs were ₹15,75,000 per year, based on a total power consumption of 75 kW, operating for 10 hours per day at ₹7 per kWh. Labor Costs amounted to ₹9,00,000 per year, employing 5 workers with a monthly salary of ₹15,000. Maintenance Costs, calculated at 7% of the total capital investment, totaled ₹4,30,500 annually, and Consumables, such as water and lubricants, were estimated to cost ₹1,50,000 annually.

In terms of revenue generation, for the system to cover its costs, the Minimum Selling Price (MSP) for compost was calculated to be ₹47.56 per kg. At this MSP, with the system producing 1,200,000 kg of compost annually (over 300 operational days), the total annual revenue would be ₹57,07,200.

After deducting the annual operating costs of ₹30,55,500, the system would generate a net income of ₹26,51,700 per year. Given the initial capital investment of ₹61,50,000, the system would break even in approximately 2 years and 4 months. After reaching the break-even point, the system would begin generating profits, ensuring a stable return on investment in the subsequent years.

7.5 Conclusion

The composting system demonstrated efficient resource optimization through the use of a splitter, which separated usable compost from unprocessed materials, improving recycling and enhancing compost quality. Environmentally, the system incorporated an integrated biofilter to

treat gaseous emissions, effectively reducing harmful pollutants and aligning with sustainable waste management practices. Financially, the system's Minimum Selling Price (MSP) of ₹47.56/kg was closely tied to productivity levels. Lower productivity (below 1000 kg/week) led to negative deviations from the MSP, reducing profitability. In contrast, higher productivity levels (around 2000 kg/week) resulted in positive deviations from the MSP, significantly improving financial performance. This analysis underscored the importance of maintaining or increasing productivity to ensure both economic viability and environmental sustainability. The results demonstrated that the system could achieve both objectives when operational efficiency was optimized.