ACCELERATED VERMICOMPOST PRODUCTION THROUGH MECHANIZATION—WAYS TO HANDLE CROP RESIDUES AND ENHANCE SOIL HEALTH

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Abstract. The application of mechanization in the vermicomposting process, focuses on enhancing composting efficiency, reducing production time and optimizing labor costs. Crop residues, such as rice straw, maize stalks and sugarcane trash, are abundant post-harvest by-products in India, causing environmental and social challenges due to their accumulation. Mechanical vermicomposting integrates conventional composting with machinery, including front-end loaders, shredders and irrigation systems, to streamline waste management and compost production. By maintaining optimal moisture, aeration and a targeted carbon-to-nitrogen ratio, mechanical methods significantly reduce processing time to 60-90 days compared to traditional methods. The results indicate that mechanized vermicomposting yields a high-quality product with reduced lignin content and a favorable B:C ratio, enhancing its efficacy as an organic fertilizer. The economic analysis highlights substantial labor cost savings with mechanical methods, though initial production costs are higher than that in traditional methods. Production efficiency is significantly increased, achieving 5100 kg of compost in a 30 m² vermibed unit with a benefit-cost ratio of 2.03, compared to the conventional approach which yields 1800 kg with a BCR of 1.25. The results demonstrate that mechanized vermicomposting is an effective, eco-friendly approach to sustainable waste management, supporting soil health and creating economic opportunities for farmers and stakeholders.
Keywords: *vermicomposting, mechanization, crop residues, paddy straw, maize stalks, sugarcane trash, lignin content*

Introduction

Crop residues are post-harvest agricultural remains abundantly generated during crop cultivation. In India the generation of crop residues is the highest in Uttar Pradesh (60 Mt) followed by Punjab (51 Mt) and Maharashtra (46 Mt) (Jadhav et al., 2024). Cereals create 352 Mt of residue, followed by fibers (66 Mt), oilseeds (29 Mt), pulses (13 Mt), and Sugarcane (12 Mt). Cereal crops (Rice, Wheat, Maize, Millets) accounted for 70% of agricultural residues (MNRE, 2009). The residues left on the field accumulate as waste, occupy vast areas, spread foul odors and serve as a breeding home for most pathogenic organisms, thus creating environmental and social problems. By considering the growing deficiency of plant nutrients in the field and the higher cost of using synthetic fertilizers, the organic wastes recycling is becoming more essential to

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sustain the soil health and to create employment opportunities. The composting involves the mechanical degradation of organic matter by microorganisms under controlled condition. The combination of composting and vermicomposting has been recently considered as the way of achieving stabilized quality compost (Vicentin et al., 2021). As the conventional composting procedures take as long as 6 to 8 months to produce finished compost while the mechanical composting methods offer possibilities for reducing the processing period up to 4 to 6 months (Ayilara et al., 2020). Vermicomposting is an environmentally friendly waste management technology that facilitates the decomposition of the organic portion of solid waste to a manageable state, allowing it to be easily stored, handled, and applied to agricultural fields without negative effects (Ali et al., 2015). Earthworms play a role in this process by breaking down carbon from the more biodegradable parts of organic waste, although their overall contribution to total heterotrophic respiration is minimal due to their limited assimilation capacity (Dominguez et al., 2010). Compost worms require five key conditions for optimal living: a suitable habitat known as “bedding,” a reliable food source, sufficient moisture (over 50% by weight), proper aeration, and protection from extreme temperatures (Munroe, 2007). The qualities that make vermicompost an effective fertilizer include its uniformity, high porosity, excellent water retention, stability, low carbon-to-nitrogen (C:N) ratio, and its status as a nutrient-rich, eco-friendly material (Vukovic et al., 2021). The final product of vermicomposting is a stabilized, finely textured substance similar to peat, characterized by a low C ratio, high porosity, and moisture-holding capacity, which contains nutrients in forms that plants can easily absorb (Dominguez et al., 2004). By adapting the automation techniques with mechanical vermicomposting, it will reduce the production costs, increases the market value and product quality under large scale. The established goals encompass (1) enhancing the composting process through synergizing rapid composting technologies (2), reducing the time taken in achieving a stabilized vermicompost through co-composting by involving earthworms, and (3) increasing the handling capacity of farm waste through the use of machinery.

Materials and methods

A compost complex was built at Central Farm Unit, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore and the distributor was Tamil Nadu Innovation Initiatives (TANII) scheme. It features a compost yard, vermicomposting unit, water system, sieving and packaging unit (*Fig. 1*). And also there is a established conventional vermicomposting yard for the comparison. The experimental design was laid out in Randomized Block Design (RBD) with 3 replications. The design comprised of 6 treatments include T_1- Conventional composting of paddy straw, T_2- Mechanical composting of paddy straw T_3- Conventional composting of maize stalks, T_4- Mechanical composting of maize stalks T_5- Conventional composting of sugarcane trash, T_6- Mechanical composting of sugarcane trash. The conventional compost pit measures 10’ × 4’ × 2’ and is filled with pre-digested materials. Earthworms are then added, and the compost is regularly turned and watered to maintain optimal conditions. The mechanized compost yard, measuring 30 m × 15 m, processes collected crop residues, which are dried and shredded before pre-composting. The Crop Residues was collected using a tractor-operated front-end loader, large volumes of biomass, including paddy straw, corn stalks, sugarcane trashes and cotton stalks, are collected and

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transported efficiently. This equipment can handle up to 5 tons per hour, significantly reducing labor time. The shredding process involves using a tractor-operated shredder, powered by 45 HP, shreds waste into smaller pieces, enhancing decomposition efficiency. The shredder can process up to 4 tons of crop residue per hour, supporting pre- composting. Shredded waste undergoes pre-composting to eliminate volatile substances harmful to earthworms. The used earthworms are *Eisenia foetida, Eudriluus euginae* and *Perionyx excavatus*. Windrows are maintained at 80% moisture, with periodic irrigation to optimize conditions for decomposition. To optimize the composting process, a carbon-to-nitrogen ratio of 30:1 is targeted by mixing green and dry materials. TNAU Bio-mineralizer is added to accelerate aerobic decomposition, with periodic turning of windrows to maintain temperature and aeration. A compost turner cum mixer enhances efficiency compared to conventional methods, significantly reducing cycle times by 75 days. It operates with a 70 HP tractor, ensuring thorough mixing of cow dung and shredded residues, leading to an annual income of Rs. 10-15 lakh. A 5000-L water tank and irrigation system, including micro-sprinklers, maintain moisture levels for both composting and vermicomposting, addressing labor shortages and improving efficiency. 350-360 earth worms per m^3 were released in both conventional and mechanized condition. The size of crop residues after shredding was maintained at 20 mm-25 mm. The samples were collected on 0^{th} day, 20^{th} day, 40^{th} day, 60^{th} day, 80^{th} day and 100^{th} day form each treatments. A small portion of the material from each section was taken, mixed thoroughly and then a composite sample was prepared for analysis. The samples were placed in clean, airtight containers to preserve their integrity before being transported to the lab for further examination. The concentration of parameters such as moisture content was determined by oven-dry method (Kelly, 2009), lignin content was determined by Klason lignin quantitative method (Masin et al., 2020), C:N ratio was determined by dry combustion elemental analyzing method (Malainey, 2011) in the laboratory. The data collected on multiple parameters from experiments underwent statistical analysis utilizing a randomized block design through AGRES software. The critical difference (CD) was determined at a 5% probability level.

Results and discussion

Lignin content

Lignin is a complex, hydrophobic network composed of phenylpropanoid units (Campbell, 1996). Following cellulose, lignin is the second most prevalent organic compound in plants, accounting for about 30% of the organic carbon found in the biosphere (Boerjan et al., 2003). The lignin content of all the treatments is significantly influenced by the composting duration. The significantly lower lignin content was reached on 100^{th} day was observed. (*Table 1*). The mechanical vermicomposting techniques (T_2, T_4 and T_6) resulted in lower lignin content (8.21%, 12.21% and 22.8%) when compared with conventional vermicomposting method (T_1- 14.79%, T_3- 18.91%, T_5- 26.67%) (*Fig. 2*).

Moisture content

Water makes up 75-90% of an earthworm’s body weight, making the prevention of water loss crucial for their survival. However, earthworms also possess a significant

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ability to endure challenging moisture conditions (Bhargava and Bhattacharya, 2004). The moisture content of both the conventional and mechanical vermicompost pit are gradually increased and then decreased (for drying) (Fornes et al., 2012). The moisture content in all of the treatments is significantly affected by the length of the composting period (*Table 2*). As the composting time increases, there is a significant change in moisture levels, highlighting the importance of composting duration in determining the moisture content of the treatments. At 100th day of vermicomposting the moisture content of conventional vermicomposting pit was still in increasing trend and the mechanical composting pit reach the dried moisture content of 7.77%, 9.22% and 10.94% for (T_2, T_4 and T_6) respectively (*Fig. 3*).

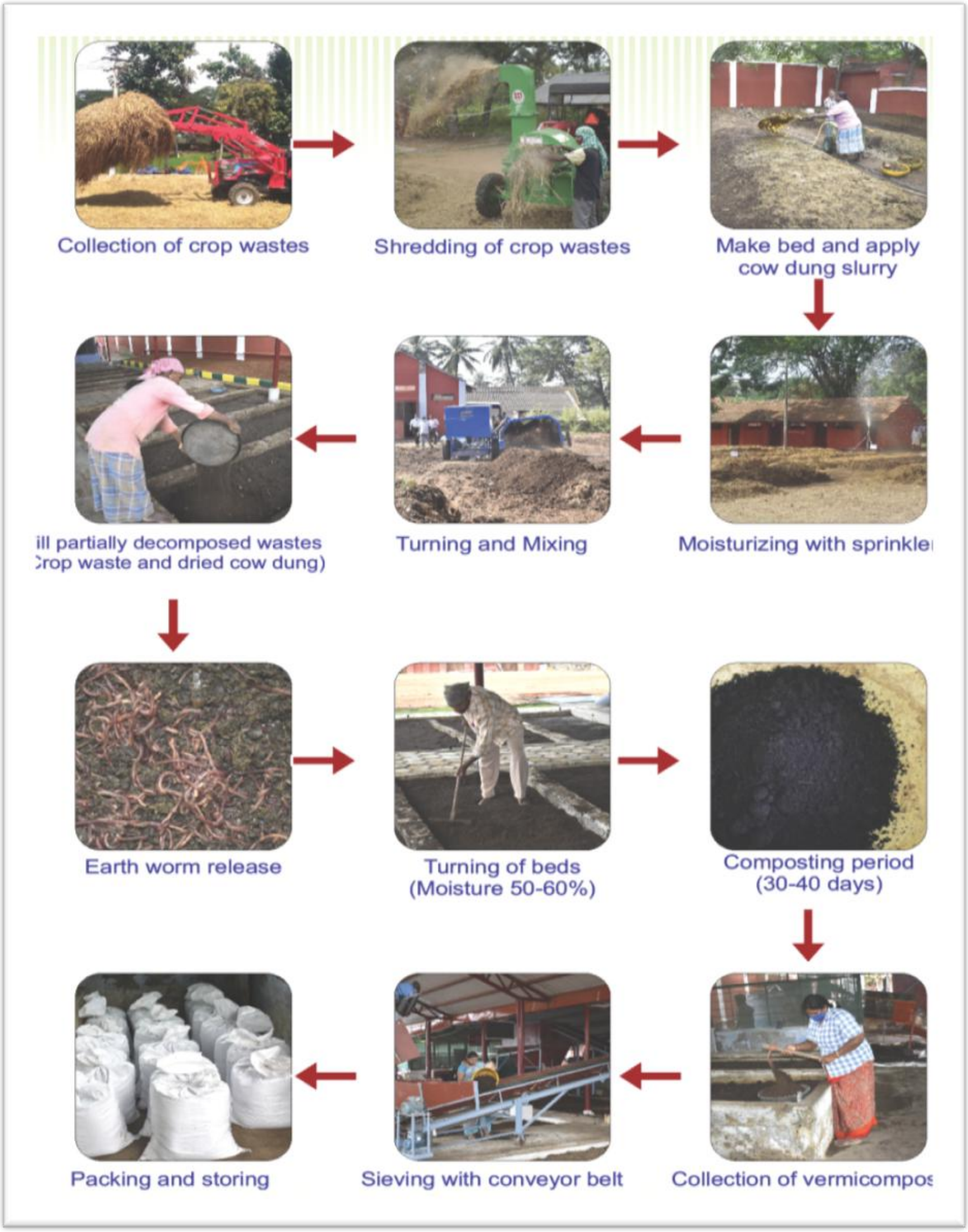

Figure 1. *Mechanical vermicompost production through mechanization*

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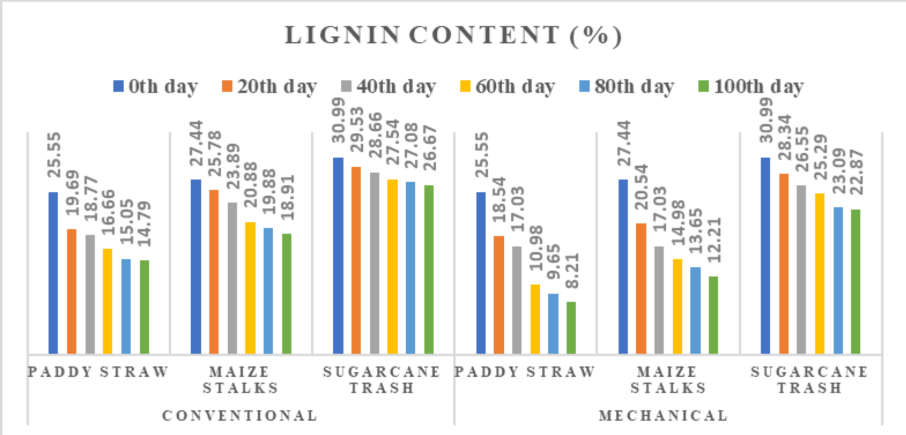

Figure 2. *Lignin content of the vermicompost using conventional method and mechanical method*

Table 1. *Effect of lignin content (per cent) on various crop residue by vermicomposting at regular interval using conventional method and mechanical method*

Treatments	0th day	20th day	40th day	60th day	80th day	100th day
T_1	25.55	19.69	18.77	16.66	15.05	14.79
T_2	25.55	18.54	17.03	10.98	9.65	8.21
T_3	27.44	25.78	23.89	20.88	19.88	18.91
T_4	27.44	20.54	17.03	14.98	13.65	12.21
T_5	30.99	29.53	28.66	27.54	27.08	26.67
T_6	30.99	28.34	26.55	25.29	23.09	22.87
Mean	27.99	23.74	21.99	19.39	18.07	17.28
SEd	0.11	0.31	0.17	0.16	0.37	0.34
CD (0.05)	0.23	0.69	0.37	0.35	0.82	0.75

Significant at $P < 0.05$

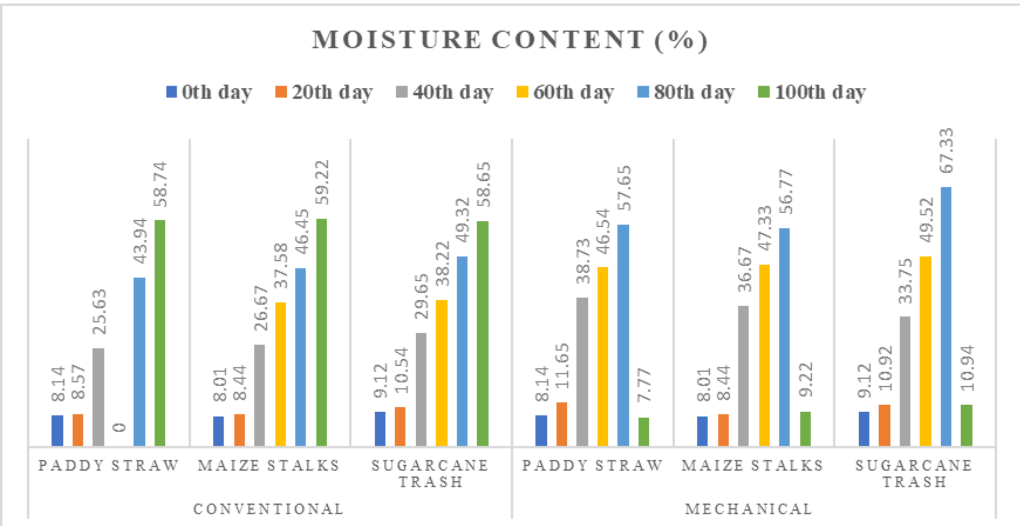

Figure 3. *Moisture content of the vermicompost using conventional method and mechanical method*

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Table 2. *Effect of moisture content (per cent) on various crop residue by vermicomposting at regular interval using conventional method and mechanical method*

Treatments	0th day	20th day	40th day	60th day	80th day	100th day
T_1	8.14	8.57	25.63	35.44	43.94	58.74
T_2	8.24	11.65	38.73	46.54	57.65	7.77
T_3	8.01	8.44	26.67	37.58	46.45	59.22
T_4	8.19	8.44	36.67	47.33	56.77	9.22
T_5	9.12	10.54	29.65	38.22	49.32	58.65
T_6	9.21	10.92	33.75	49.52	67.33	10.94
Mean	8.49	9.76	31.85	42.44	53.58	34.09
SEd	0.04	0.08	0.22	0.09	0.29	1.33
CD (0.05)	0.08	0.19	0.49	0.22	0.63	2.97

Significant at $P < 0.05$

C:N ratio

The carbon-to-nitrogen (C:N) ratio is essential for the cell synthesis, growth and metabolism of earthworms. For optimal nutrition, carbon and nitrogen must be available as substrates in the right proportions (Ndegwa et al., 2000). At 100th day the C:N ratio of the compost produced from mechanical vermicomposting pit was found to be lower (13:1, 19:1, 20:1 for the treatments T_2, T_4 and T_6 than the compost produced from conventional vermicomposting pit (32:1, 37:1, 35:1 for the treatments T_1, T_3 and T_5) (*Table 3*).

Table 3. *Effect of C:N ratio on various crop residue by vermicomposting at regular interval using conventional method and mechanical method*

Treatments	0th day	20th day	40th day	60th day	80th day	100th day
T_1	51:1	46:1	41:1	38:1	35:1	32:1
T_2	53:2	47:1	39:1	27:1	19:1	13:1
T_3	63:1	57:1	49:1	43:1	40:1	37:1
T_4	62:1	45:1	32:2	25:1	23:1	19:1
T_5	67:1	59:1	53:1	49:1	41:1	35:1
T_6	69:1	54:1	45:1	39:1	27:1	20:1

Economic analysis

Operational cost analysis

Collection of crop residue

Collection and transportation of waste from field to compost unit is one of the time-consuming and labor-intensive process as it requires huge manpower (Joseph, 2014). Large quantities of waste were collected and transported by incorporating Tractor operated front end loader for collection. A tractor-operated front-end loader can reduce costs by Rs. 5000 compared to conventional methods (*Table 4*).

Shredding of crop waste

Shredding increases the size of surface area available for action of microorganism decomposition (Sponza and Agdag, 2005). Thereby it increases the rate of

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decomposition and increases the predigested/composted material for vermicompost production. Tractor Operated Farm Waste Shredder was deployed for shredding of crop residue which was powered by a 45 HP power, this high performance and efficient machine automates the process of shredding of agro wastes of different size which was in bulk into smaller pieces. Compared to the mechanical method, conventional shredding adds an additional Rs. 2200 in costs (*Table 4*).

Turning cum mixing

The compost pile needs to be turned to prevent the pile from getting too hot (Chen et al., 2011). If it gets much above 71°C, the micro-organisms will be killed, the pile will cool, and the whole process will have to start from the beginning. By turning the pile it will not overheat, and it will be aerated also, both of which are necessary to keep the most active decomposers functioning. The conventional method for turning and mixing incurred a cost of Rs. 3100/-, while the mechanical method reduced the cost to Rs. 800/- (*Table 4*).

Irrigation

The windrows are irrigated with center post sprinkler up to twice daily to maintain optimum moisture content of 80% throughout the windrow (Montepio and Abenoja, 2019). The conventional method incurs a cost of Rs. 600/-, whereas the mechanical method, which utilizes sprinkler irrigation, significantly reduces the cost to just Rs. 200/. This shows a considerable cost-saving advantage when opting for the mechanical method (*Table 4*).

Sieving

The current vermicomposting process relies on manual worm separation, which is time-consuming and reduces efficiency due to increased worm mortality. Mechanizing this process could enhance profitability and promote a cost-effective solution for farmers (Chandra and Kumar, 2013). Manual sieving incurs a cost of Rs. 1500/-, while using a mechanical sieving system with a conveyor belt brings the cost down to Rs. 600/- (*Table 4*).

Packing

Packaging is considered an essential component of modern marketing, encompassing all stages involved in moving goods and services from the producer to the consumer (Agariya et al., 2012). Manual packing costs approximately Rs. 1900, whereas mechanical packaging reduces the cost to Rs. 1000, offering a significant cost-saving advantage (*Table 4*).

Production analysis

Producing 1 ton of vermicompost incurs a total cost of approximately Rs. 7380 per production cycle (*Table 5*). This cost includes expenses related to raw materials, labor, equipment usage, and other operational activities such as shredding, turning, mixing, sieving, and packaging. Each stage in the process contributes to the overall expenditure, reflecting the resources required to efficiently produce high-quality vermicompost at scale. The production cost of mechanical vermicomposting were found to be higher (Rs. 37638) when compared with the conventional method (Rs. 21600). But at the same

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instance the production and the B:C ratio of mechanical composting method were found to be higher (5100 kg and 2.03 respectively) than the conventional composting method (1800 kg and 1.25 respectively) (*Table 6*).

Table 4. *Comparing operation costs for conventional and mechanical method*

S. No.	**Operation**	**Cost (RS.)**	
		Conventional method	**Mechanical method**
1.	Collection of crop residue	6000/- (20 B type)	1000/-
2.	Shredding of crop waste	3000/- (10 B Type)	800/-
3.	Turning cum mixing	3100/- (4A Type; 5B Type)	800/-
4.	Irrigation	600/- (2B Type)	200/-
5.	Sieving	1500/- (5B Type)	600/-
6.	Packing	1900/- (1A Type; 5B Type)	1000/-

Quantity: 5 tons. Manual: For A type labor: Rs. 400/- day; for B type labor: Rs. 300/- day. A: Male; B: Female

Table 5. *Vermicompost production cost for one tone per cycle*

S. No.	**Inputs**	**Quantity**	**Unit value (Rs.)**	**Total cost (Rs.)**
A.	**Inputs**			
1.	Fresh cow dung required as application of slurry for pre-decomposition	400 kg	1.5/kg	600
2.	Biomineralizer for pre-decomposition	2 kg	60/kg	120
3.	Bio-fertilizer	1 kg	100/kg	200
4.	Groundnut cake	2 kg	40/kg	80
5.	Neem cake	2 kg	45/kg	90
6.	Diesel for collection of residues and shredding	4 L	85/L	340
7.	Electricity charges	--	--	200
8.	Packing charges	20 bags	25/bag	500
B	Labor wages			
1.	Labor for watering, turning, application of bio-fertilizer, groundnut cake in vermibeds, sieving and packing	3 nos.	450/no.	1350
2.	Crop residues 2000 kg – Recovery will be 60% i.e. 600 kg after pre-decomposition – labor for collection of Crop residues, shredding, Preparation of windrows for pre-decomposition, Watering, turning, application of bio-mineralizer, Shifting to vermibed etc., for 2 tons	4 nos.	450/no.	1800
3.	Capital cost per ton			3000
	Total Cost (Rs.)			7380

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Table 6. *Comparative performance of conventional and mechanical vermicompost production technology for 30 m^3 in terms of production, cost of production, gross return, net return and benefit cost ratio in a year*

Production (kg)		Production cost (rs.)		Gross return (rs.)		Net return (rs.)		BCR	
Conventional	Mechanical	Conventional	Mechanical	Conventional	Mechanical	Conventional	Mechanical	Conventional	Mechanical
1800	5100	21600	37638	27000	76500	5400	38862	1.25	2.03

Conclusion

The implementation of machinery, such as front-end loaders and tractor-operated shredders, has significantly enhanced the disposal of crop residues, allowing for large quantities to be processed in a shorter time frame. The composting period has been reduced to just 60 days through effective moisture management, utilizing irrigation systems like rain hoses and micro sprinklers, alongside regular mixing and the addition of TNAU bio-mineralizer and fresh cow dung slurry. With the capability to handle approximately 100 tons of crop waste monthly, the use of machinery has also led to notable labor savings in vermicomposting production. Awareness initiatives have engaged various stakeholders, including homemakers and farmers, through training sessions and exhibitions, promoting mechanical vermicomposting technologies. Overall, these innovations have demonstrated the potential to reduce the processing period to just 90 days, allowing for six production cycles annually. The results indicate a production efficiency increase to 85%, yielding 5100 kg in a 30 m^3 vermibed unit, and achieving a benefit-cost ratio of 2.03 compared to conventional methods.

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