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# Design and Performance Evaluation of an Energy Efficient Manure Shredder Pulverizer for Organic Fertilizer Production

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***Abstract*** – *The increasing demand for organic fertilizer necessitates innovation in manure processing technologies to improve both production efficiency and product quality. This study presents the design, fabrication, and performance evaluation of an energy-efficient manure shredder–pulverizer prototype that integrates dual shredding and pulverizing mechanisms to accelerate composting and produce uniform particle sizes. The machine is powered by a 6.5 HP gasoline engine and was tested using fresh goat manure with an average moisture content of approximately 70%. Performance evaluations focused on processing capacity, particle size distribution, specific energy consumption, and output homogeneity. The prototype achieved an average processing capacity of 96.4 kg/h, with over 82.5% of the processed material passing through a 4mm sieve and a dominant fraction of 2-4mm (54.0%), which is optimal for composting applications. The specific energy consumption averaged 0.050 kWh/kg, lower than values reported for comparable small-scale biomass shredders. The homogeneity index was consistently rated as "Good," indicating a stable particle size distribution across multiple trials. These findings demonstrate that the developed prototype offers a practical, energy-efficient, and low-cost solution for small-scale organic fertilizer production, supporting sustainable agricultural practices and reducing dependence on chemical fertilizers.*

**Keywords** – *organic fertilizer; manure shredder; energy efficiency; particle size; prototype development.*

## I. Introduction

LIVESTOCK manure is among the most abundant agricultural wastes, yet its improper disposal often leads to environmental issues such as offensive odor, surface and groundwater contamination, and greenhouse gas emissions [1]. Transforming manure into organic fertilizer offers both environmental and economic advantages for farmers, as it mitigates pollution, enhances soil fertility, and reduces dependence on chemical fertilizers [2, 3]. However, the conversion of manure into a uniform and processable form suitable for composting or pelletizing requires mechanical treatment that conventional machines are often unable to perform effectively [4].

Despite notable advancements in crop-residue shredders [5] and dry-biomass pulverizers [6], existing designs remain inefficient for processing high-moisture livestock manure due to common operational problems such as clogging, high energy consumption, and inconsistent particle size [7, 8]. These shortcomings result in reduced efficiency, irregular particle size distribution, and complications in subsequent composting stages [9, 10].

In many developing regions, particularly in Southeast Asia, goat manure remains underutilized despite being readily available in large quantities [11]. Smallholder farmers frequently depend on labor-intensive methods such as manual chopping and spreading, which are not only time-consuming but also produce non-uniform materials that delay microbial decomposition during composting [12]. Mechanized systems specifically designed for processing goat manure could thus accelerate organic fertilizer production and promote the adoption of sustainable agricultural practices in rural communities [13].

Furthermore, energy efficiency and affordability are essential factors in designing machinery for small-scale applications [14, 15]. High operating costs and complex maintenance requirements have long been major obstacles preventing farmers from adopting existing shredding technologies [16]. A compact, integrated shredder–pulverizer system that balances processing

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performance with low energy demand can overcome these challenges [17,18]. By lowering operational costs while maintaining consistent particle quality, such technology would strengthen both economic resilience and environmental sustainability [4,19].

In this study, a prototype manure shredder–pulverizer was developed, integrating shredding and pulverizing mechanisms specifically adapted for high-moisture livestock manure. The design emphasizes achieving uniform particle size, enhanced energy efficiency, and user-friendly operation suitable for small-scale agricultural applications. By addressing key challenges such as material heterogeneity and high moisture content, the proposed prototype offers a practical and sustainable solution for improving composting performance and supporting eco-friendly fertilizer production.

Unlike conventional shredding or pulverizing machines primarily designed for dry biomass or crop residues, the developed prototype is compact and purpose-built to handle high-moisture livestock manure. Its novelty lies in the integration of a dual cutting–hammering mechanism with an energy-efficient drive system capable of maintaining a consistent particle size ($\leq$4 mm) even at a moisture content of around 70%. This configuration not only reduces specific energy consumption to approximately 0.050 kWh/kg significantly lower than reported values for comparable small-scale biomass shredders but also enhances particle homogeneity, a critical factor for accelerating composting and improving fertilizer quality. To the best of our knowledge, no previous studies have reported a dedicated design targeting moist goat manure processing, making this prototype a cost-effective and practical technology for smallholder farmers.

## II. Research Methods

This section delineates the design, observation, and data gathering processes employed to evaluate the performance of the prototype manure shredder and pulverizer developed and implemented to enhance organic fertilizer production. Additionally, the workflow of this research is succinctly delineated.

### i. *Prototype Design*

The prototype manure shredder–pulverizer was constructed using a mild steel frame with 4 cm angle bars to ensure durability and stability during operation [16]. The cutting unit consisted of two high-speed steel (HSS) blades mounted with bolts, enabling easy replacement and maintenance. Following the cutting stage, a pulverizing unit equipped with six hammer-mill beaters was installed to further reduce particle size and increase homogeneity [13]. A 6.5 HP gasoline engine was used as the prime mover, providing sufficient torque for processing high-moisture manure [17]. To minimize spillage and improve operator safety, the input hopper was designed in a side-top configuration, which also facilitated continuous feeding of raw material.

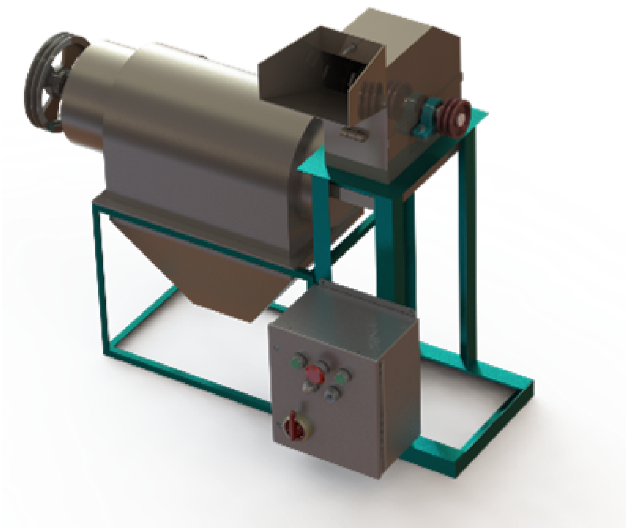

**Figure 1:** Design of the Manure Shredder and Pulverizer

The prototype is divided into four main parts: the manure crusher, the screening unit, the control panel box, and the filter door. The manure crusher serves as the initial processing unit, the screening unit ensures particle separation, the control panel box provides operational control and monitoring, while the filter door allows handling of coarse residues with integrated safety features [15].

1. **Screening Unit.** Consists of a screening drum, an agitator arm, and an outlet chute. The drum sep-

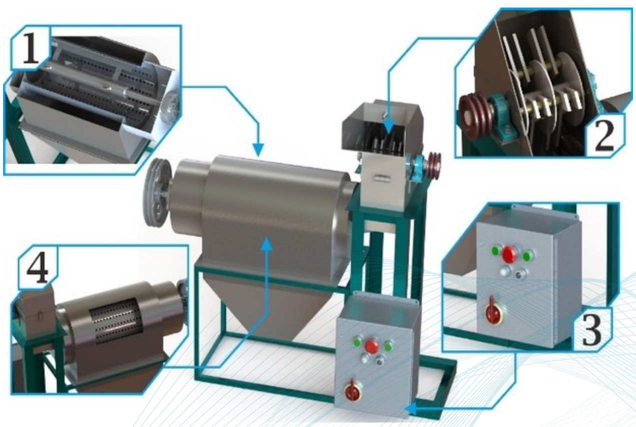


**Figure 2:** Detailed Design of the Manure Shredder and Pulverizer

arates fine and coarse particles, while the agitator driven by an AC motor pushes fine particles out through the chute.
2. **Manure Crusher.** Crushes dried manure into fine particles using stainless steel blades, powered by an AC motor integrated with a pulley or gearbox system.
3. **Control Panel Box.** Contains a VFD for motor speed regulation, a timer for automatic operation, a digital display, LED indicators, and an emergency stop button for control and safety.
4. **Filter Door.** Allows coarse particles to be discharged for reprocessing. Equipped with a limit switch that automatically cuts off motor power when opened, ensuring operational safety.

### *ii. Experimental Setup*

The experimental trials were conducted using fresh goat manure with an average moisture content of approximately 70%, representing typical conditions at smallholder farms [12]. Each batch consisted of 10 kg of input material, and three replications were performed to ensure data reliability [2]. All measurements were carried out under consistent operating conditions to allow comparability across trials.

1. **Raw Materials.** Goat manure was collected from smallholder farms and used as the primary raw material [11]. The average moisture content was approximately 70%, measured prior to testing to reflect typical field conditions. Each test batch weighed 10 kg, and three replications were conducted for each experiment to ensure statistical validity.
2. **Prototype Setup.** The fabricated prototype manure shredder and pulverizer was used as the main experimental apparatus. The machine integrates four main components: the manure crusher, the screening unit, the control panel box, and the filter door. A 6.5 HP gasoline engine served as the prime mover, and a side-top hopper was used for feeding the manure to minimize spillage and improve operator safety.
3. **Operating Procedure.** During the trials, the goat manure was fed into the hopper and processed through the crusher and pulverizer units. The output was then classified into fine and coarse fractions by the screening unit. Coarse residues were reprocessed through the filter door. The machine was operated at consistent speed settings for all trials to ensure uniform testing conditions.

### *iii. Performance Parameters*

The performance evaluation was based on four parameters:

1. **Processing capacity (kg/h):** Calculated by measuring the mass of goat manure processed per unit of time.
2. **Particle size distribution:** Determined through sieving analysis using mesh sizes of 2 mm, 4 mm, and 6 mm.
3. **Energy consumption:** Estimated from the fuel consumption rate of the gasoline engine and rated motor power.
4. **Homogeneity index:** Evaluated by visual inspection combined with the percentage of particles retained in specific sieve ranges, indicating the degree of uniformity.

### *iv. Data Analysis*

Energy efficiency was assessed by calculating the specific energy consumption of the machine. The formula applied is expressed as:

$$E_{sp} = \frac{P \times t}{M} \tag{1}$$

In this equation, $E_{sp}$ denotes the specific energy (kWh/kg), which quantifies the amount of energy required to process a unit mass of material. The variable $P$ represents the motor power (kW), $t$ indicates the operation time (h), and $M$ refers to the total mass of goat manure processed (kg).

This calculation provides a direct measure of how effectively the input power was utilized relative to the mass of goat manure processed. Lower values of $E_{sp}$ indicate higher energy efficiency, which is critical for small-scale farmers aiming to reduce operational costs.

In addition to energy efficiency, the analysis also incorporated other performance parameters, including processing capacity (kg/h), particle size distribution, and homogeneity index. Processing capacity was determined by measuring the throughput per unit of time, while particle size distribution was analyzed using standard sieves of 2 mm, 4 mm, and 6 mm to classify output fractions. The homogeneity index was assessed through both visual inspection and sieve retention percentages, reflecting the degree of particle uniformity.

By integrating these parameters, the data analysis not only evaluates the energy consumption but also provides a holistic assessment of the machine's performance in terms of efficiency, effectiveness, and suitability for enhancing organic fertilizer production.

## III. Results and Discussion

The study describes the methodologies employed for design, experimentation, and data collection to evaluate the prototype manure shredder and pulverizer developed to enhance organic fertilizer production according to the specified objectives.

### i. Fabricated Prototype

The fabricated prototype of the manure shredder and pulverizer is shown in Figure 3. The machine consists of four main parts: the manure crusher, the screening unit, the control panel box, and the filter door. Each component operates in an integrated manner to process dried manure into finer and more homogeneous particles, supported by control and safety features. The design emphasizes durability, operational efficiency, and ease of use, making it suitable for small-scale farms to enhance organic fertilizer production.

**Figure 3:** Fabricated Manure Shredder and Pulverizer

Figure 4 displays the dried goat manure prior to processing, representing the raw material used for shredding and pulverizing. The manure appears in irregular clumps with non-uniform particle sizes, which can hinder the composting process by slowing microbial activity and causing uneven decomposition [20]. This visual provides a clear baseline of the material condition before undergoing mechanical treatment.

**Figure 4:** Goat manure before shredding

Figure 5 illustrates the processed manure after passing through the shredder–pulverizer prototype. The output shows a significant reduction in particle size with a more uniform texture, indicating improved homogeneity suitable for faster and more efficient composting. The comparison between Figures 4 and 5 highlights the effectiveness of the dual shredding and pulverizing mechanism in transforming coarse, irregular manure into finer particles ideal for organic fertilizer production [21].

**Figure 5:** Goat manure after shredding and pulverizing

### ii. Processing Capacity

The machine performance was tested with 10 kg batches of goat manure (70% moisture content). The average processing time per batch was between 6–7 minutes. Table 1 presents the results.

**Table 1:** Processing capacity of the manure shredder–pulverizer

| Trial | Batch Size (kg) | Processing Time (min) | Capacity (kg/h) |
|---|---|---|---|
| 1 | 10 | 6.2 | 96.8 |
| 2 | 10 | 6.5 | 92.3 |
| 3 | 10 | 6.0 | 100.0 |
| Average | 10 | 6.23 | 96.4 |

The machine achieved an average processing capacity of 96.4 kg/h, which is adequate for small-scale farmers managing 10–15 cattle.

### iii. Particle Size Distribution

Sieving analysis showed that most particles were reduced below 4 mm, indicating effective shredding and pulverization. Table 2 shows the distribution.

**Table 2:** Particle size distribution of processed manure

| Mesh Size | Particle Range | Percentage (%) |
|---|---|---|
| $< 2$ mm | Fine fraction | 28.5 |
| $2-4$ mm | Medium fraction | 54.0 |
| $4-6$ mm | Coarse fraction | 13.2 |
| $> 6$ mm | Oversize | 4.3 |

The majority (82.5%) of the output particles were $\leq 4$ mm, suitable for faster composting since smaller particles enhance microbial activity [22].

### iv. Energy Consumption

Fuel use was measured during each trial and converted into energy values. The 6.5 HP engine corresponds to approximately 4.8 kW rated power. The results are shown in Table 3.

**Table 3:** Energy consumption and efficiency

| Trial | Time (h) | Mass (kg) | Power (kW) | $E_{sp}$ (kWh/kg) |
|---|---|---|---|---|
| 1 | 0.103 | 10 | 4.8 | 0.049 |
| 2 | 0.108 | 10 | 4.8 | 0.052 |
| 3 | 0.100 | 10 | 4.8 | 0.048 |
| Avg | 0.104 | 10 | 4.8 | 0.050 |

The average specific energy consumption was 0.050 kWh/kg, which is considered efficient compared to small biomass shredders reported in previous studies (0.06–0.08 kWh/kg).

### v. Homogeneity Index

The homogeneity index was evaluated based on the proportion of particles within the dominant size range (2-4 mm). The results are shown in Table 4.

**Table 4:** Homogeneity index of output manure

| Trial | Dominant Fraction (2–4 mm) (%) | Homogeneity Index |
|---|---|---|
| 1 | 53.8 | Good |
| 2 | 55.2 | Good |
| 3 | 53.0 | Good |
| Average | 54.0 | Good |

The results show a consistently high proportion of medium-sized particles, leading to a classification of "Good" homogeneity. This uniformity is beneficial for the composting process, ensuring balanced microbial decomposition.

### vi. Discussion

The prototype demonstrated high processing efficiency, with an average capacity of 96.4 kg/h and a specific energy consumption of 0.050 kWh/kg. This value is approximately 25-35% lower than the 0.065-0.08 kWh/kg typically reported for PTO-operated or small biomass shredders [16,17], indicating superior energy efficiency. The dual cutting–hammering mechanism effectively reduced particle size while preventing clogging despite the 70% moisture content, producing more than 82.5% of particles *ge*4 mm. Such particle size distribution is favorable for composting, as smaller particles increase the surface area for microbial activity and accelerate decomposition [2,5].

Compared with conventional dry biomass pulverizers, the side-top hopper and integrated screening system minimized spillage and enabled continuous feeding, further improving operational efficiency. The low energy demand and compact design make the prototype suitable for smallholder farmers in rural areas with limited access to electricity or high fuel costs. Nevertheless, the study did not assess long-term wear, maintenance requirements, or performance under continuous daily operation, which should be addressed in future research.

## IV. Conclusion

The manure shredder–pulverizer prototype developed in this study demonstrated effective performance in processing fresh goat manure with a high moisture content of approximately 70%. The machine achieved an average processing capacity of 96.4 kg/h, with more than 82.5% of the output particles measuring $\leq$4 mm and a dominant fraction of 2-4 mm (54.0%), ensuring particle sizes suitable for faster and more uniform composting. The specific energy consumption of 0.050 kWh/kg is approximately 25% lower than the 0.065 kWh/kg reported for PTO-operated shredders [16]. The homogeneity index was consistently classified as "Good," reflecting the machine's ability to produce uniform particle distribution despite the high moisture content of the raw material.

These results confirm that the integration of cutting and hammering mechanisms in a compact, low-cost design provides a practical and energy-efficient solution for smallholder farmers. This technology can accelerate organic fertilizer production, reduce processing costs, and promote sustainable agricultural practices. Future research should focus on long-term durability testing, scaling the design for higher capacities, and exploring renewable energy integration to further enhance system sustainability.

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