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SELECTION OF SUITABLE ORGANIC MANURES FOR AUGER TYPE METERING BASED ON MATERIAL PROPERTIES AND DISCHARGE PERFORMANCE

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ABSTRACT

The physical and engineering properties of organic manures play a crucial role in determining their flow behaviour and metering performance during mechanized application. This study evaluated the suitability of four organic manures-compost, vermicompost, dry spent biogas slurry, and municipal solid waste (MSW) compost for an auger type metering mechanism. The selected manures were characterized for moisture content, bulk density, tapped density, particle size, angle of repose, and coefficient of static friction. To ensure uniform testing conditions, the moisture content of all materials was maintained at 25% (w.b.) before laboratory evaluation. A laboratory prototype of an auger-type metering mechanism was tested at different auger speeds to assess discharge rate, discharge per revolution, and discharge uniformity. Compost exhibited the best metering performance, with the highest average discharge rate (4.39 kg min^{-1}), discharge per revolution (0.130 kg rev^{-1}), and the lowest coefficient of variation (2.48%), indicating excellent flowability and discharge uniformity. Dry spent biogas slurry and vermicompost showed satisfactory performance, whereas MSW compost exhibited poor flowability and inconsistent discharge. One-way ANOVA confirmed that auger speed significantly influenced manure discharge ($p < 0.05$). The findings demonstrate that the physical and engineering properties of organic manures strongly affect auger metering performance and provide a scientific basis for selecting suitable manure and designing efficient auger-based applicators for uniform manure application and improved nutrient-use efficiency in sustainable agriculture.

***Keywords*:** Organic manure, Auger-type metering mechanism, Flowability, Discharge uniformity, Physical and engineering properties

Introduction

The increasing global population and the rising demand for food have placed unprecedented pressure on agricultural production systems. According to the United Nations, the world's population is expected to reach nearly 9.7 billion by 2050, requiring a substantial increase in food production demand of 50% by 2050 to ensure global food security. At the same time, the availability of cultivable land is continuously declining due to rapid urbanization, industrialization, land degradation 33% of global land resources are degraded and climate change. Consequently, modern agriculture faces the dual challenge of increasing crop productivity while preserving soil fertility and natural resources for future generations (United Nations, 2022; FAO, 2021; FAO, 2022).

To meet the growing food demand, intensive farming practices and the extensive use of chemical fertilizers have become common worldwide; consumption exceeds 201 million tonnes of nutrients in 2024-2025, with a significant portion of consumption coming from China, India, the US, and Brazil (IFA, 2024; FAOSTAT, 2024). Although these practices have significantly increased agricultural productivity, their continuous and indiscriminate use has adversely affected soil health. Long-term dependence on chemical fertilizers has resulted in a decline in soil organic carbon, deterioration of soil structure, nutrient imbalance, reduced microbial activity, and lower water holding capacity. These changes gradually decrease soil fertility and threaten the sustainability of agricultural production. Therefore, there is an increasing need to adopt sustainable nutrient management practices that maintain crop productivity while restoring soil quality (Lehmann *et al*., 2020; FAO, 2021).

Organic manures have become more important in their role as sustainable sources of nutrients, owing to the conversion of organic waste from agriculture, animals, and municipalities to valuable soil amendments. There is the generation of over 125 billion tonnes of livestock manure and 2.24 billion tonnes of municipal solid waste annually worldwide, out of which almost 44% is biodegradable and usable in the process of making compost. In India, about 3-3.5 billion tonnes of livestock manure, 160-180 million tonnes of crop residues, and 62 million tonnes of municipal solid waste are produced per annum, thus offering sufficient raw material for the production of compost, vermicompost, dry spent biogas slurry, and MSW compost. This has the effect of improving the quality of soils, microbial action, efficiency of nutrient uptake and decreasing the use of chemical fertilizers, thus ensuring sustainable agricultural output (FAO, 2021; FAO, 2023; FAOSTAT, 2024; UNEP, 2024; CPCB, 2023).

Despite their agronomic benefits, the application of organic manures remains a major challenge. Most organic manures are bulky, heterogeneous, fibrous, and variable in moisture content, making manual application labour-intensive, time-consuming, and often non-uniform. Uneven manure distribution leads to variations in nutrient availability, crop growth, and nutrient-use efficiency. Furthermore, increasing labour shortages and rising labour costs have made manual manure application less economical and less efficient. Mechanized manure application has therefore become an essential requirement for improving field efficiency, reducing labour requirements, ensuring uniform nutrient distribution, and enhancing overall crop performance (FAO, 2022; ILO, 2023).

Among the different metering systems used in manure applicators, the auger-type metering mechanism has gained considerable attention because of its ability to deliver a continuous, controlled, and uniform flow of organic materials. The mechanism consists of a rotating helical screw that conveys manure from the hopper to the outlet at a controlled rate. The discharge rate can be regulated by changing the auger dimensions or rotational speed, allowing precise application according to field requirements. Owing to its simple construction, reliable operation, and adaptability to bulky organic materials, the auger-type metering mechanism has become one of the most promising systems for mechanized manure application (Kepner *et al*., 2005; FAO, 2022).

The performance of an auger-type metering mechanism, however, is strongly influenced by the physical and engineering properties of the manure. Properties such as moisture content, bulk density, tapped density, particle size, angle of repose, coefficient of static friction, flowability. Organic manures with excessive moisture or irregular fibrous particles are more likely to cause bridging, clogging, and inconsistent discharge, whereas materials having moderate moisture content, suitable particle size, good flowability, and lower cohesion generally provide stable discharge and improved metering accuracy. Therefore, a thorough evaluation of these properties is essential for selecting materials that are compatible with auger-type metering systems (Nalladurai *et al*., 2023; ASABE, 2023).

Although several studies have reported the design and performance of manure applicators and fertilizer metering mechanisms, limited information is available on the comparative suitability of different organic manures for auger-type metering devices. In particular, there is a lack of systematic studies integrating physical, engineering, and discharge characteristics to identify the most suitable manure for continuous and accurate metering. Addressing this gap is important for improving manure application efficiency and supporting the development of reliable mechanized nutrient management systems.

Therefore, the present study was undertaken to evaluate the suitability of selected organic manures, namely compost, vermicompost, dry spent biogas slurry, and MSW compost, for an auger-type metering mechanism under laboratory conditions. The study aimed to determine their physical and engineering properties, evaluate their discharge characteristics, and identify the most suitable organic manure based on discharge rate, discharge uniformity, flowability, and overall metering performance.

Material and Method

Experimental Site and Materials

The study was conducted in the Department of Farm Machinery and Power Engineering, College of Technology, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India, where a laboratory prototype of an auger-type metering mechanism was designed using AutoCAD and fabricated for experimental evaluation. Four organic manures compost, vermicompost, dry spent biogas slurry, and municipal solid waste (MSW) compost were selected to assess their suitability for auger metering.

Design and Development of Prototype Machine Component

A laboratory test prototype of the auger-type metering mechanism was developed to evaluate the discharge behaviour of selected organic manures. The prototype comprised a hopper, auger chamber, auger shaft with screw flight, supporting frame, manual drive system, and discharge outlet.

Auger-Type Metering Laboratory Test

A laboratory test auger-type metering test rig was developed to evaluate the discharge performance of selected organic manures. The test rig comprised a hopper, semi - circular auger trough, screw auger, auger shaft, mild steel frame, UCP pillow block bearings, chain and sprocket drive, electric motor, reduction gearbox, V-belt drive, and collection container.

Hopper

The hopper of the developed manure applicator was designed to hold and supply organic manure continuously to the auger-type metering mechanism during operation. The size and shape of the hopper were selected by considering the flow behaviour and discharge requirement of organic manure.

The size of the hopper was kept 300 mm × 300 mm. The total height of the hopper was 350 mm, which included a 100 mm vertical portion and a 250 mm slant portion. The detailed dimensions and configuration of the hopper used in the laboratory prototype machine.

Table 1: Dimensional Details of the Hopper

S. No.	Parameter	Dimension
1	Top length	300 mm
2	Top width	300 mm
3	Vertical height	100 mm
4	Slant height	250 mm
5	Total hopper height	350 mm
6	Bottom opening diameter	50 mm
7	Discharge pipe height	70 mm

Conceptual Auger Design of the Machine

The auger was designed as the main metering unit of the developed manure applicator for smooth conveying and uniform discharge of organic manure during field operation. An auger-type metering mechanism was selected because it can handle bulky and fibrous organic manure more effectively and provides continuous flow compared to other metering systems.

Design of Auger Type Metering Mechanism

Flight diameter (D) = 130 mm
Auger shaft diameter (d) = 25 mm
Pitch of auger (P) = 60 mm.
Effective auger length per row = 300 mm
Bulk density of manure (ρ) = 600 kg/m³

Discharge capacity in terms of mass flow rate is:

Formula.

$$\mathbf{A = \frac{\pi}{4}(D^2 - d^2) \times P \times \rho}$$

Q = Theoretical discharge of manure per revolution (kg rev^{-1})
D = Outside diameter of the auger flight (m)
d = Diameter of the auger shaft (m)
P = Auger pitch (m)
ρ = Bulk density of the organic manure (kg m^{-3})

$$A = \frac{3.14}{4}(0.13^2 - 0.025^2) \times 0.06 \times 600$$

Q = 0.460 kg/rev
Discharge capacity Q = 0.460 kg/rev

Power Transmission Unit

The auger metering mechanism was powered by a single-phase electric motor mounted on the base frame. Power from the electric motor was transmitted to the reduction gearbox through a V-belt and pulley arrangement.

The output shaft of the gearbox was connected to the auger shaft through a roller chain and sprocket transmission system. The chain drive ensured positive power transmission without slippage and facilitated easy modification of the speed ratio by changing sprocket sizes.

The complete transmission system was mounted on an adjustable steel base, enabling proper alignment and tensioning of both the V-belt and chain drive. This arrangement provided stable power transmission, minimized vibration and ensured uniform manure discharge throughout the laboratory tests.

Table 2: Details of Power Transmission Unit

S. No.	Item	Specification
1	Power source	Single phase electric motor
2	Primary transmission	V-belt and pulley
3	Speed reduction	Reduction gearbox
4	Secondary transmission	Roller chain and sprocket
5	Driven shaft	Auger shaft
6	Support bearings	Pillow block bearings
7	Speed control	Changing sprocket combination
8	Function	Transmit power to auger metering unit

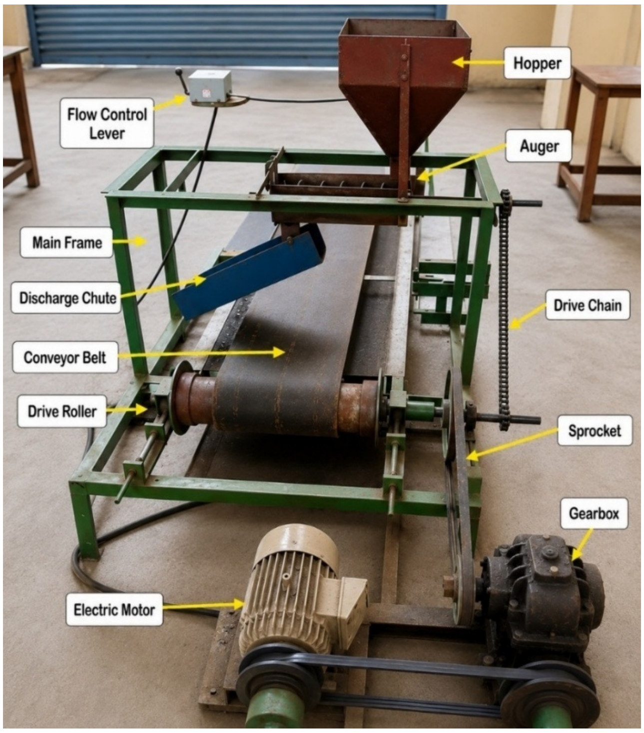

Fig. 1 : Power Transmission Unit Laboratory test setup of the manure applicator

Measurement of Physical Properties

The physical properties of organic manure were determined before the design and performance evaluation of the developed manure applicator. These properties are important because they directly influence the flow behaviour, discharge rate, metering performance, and handling characteristics of manure during machine operation.

Moisture Content

Moisture content of organic manure was determined using the oven-drying method as per IS 2720 (Part 2) 1973, Determination of Water Content. Organic manure having high moisture content was first air-dried in a shaded and well-ventilated place to reduce excess moisture naturally. The experimental procedure and equipment used for moisture content determination are shown in Fig. 2 to Fig. 5, including the prepared silica crucibles Fig. 2, electronic balance Fig. 3, hot air oven Fig. 4, and desiccator Fig. 5.

$$\text{Moisture content (MC, \%)} = \frac{W1-W2}{W1} \times 100$$

Where,
W_1 = Initial weight of sample (g)
W_2 = Final dry weight of sample (g)

Fig. 2 : Prepared silica crucibles for moisture analysis

Fig. 3 : Electronic balance for manure sample measurement

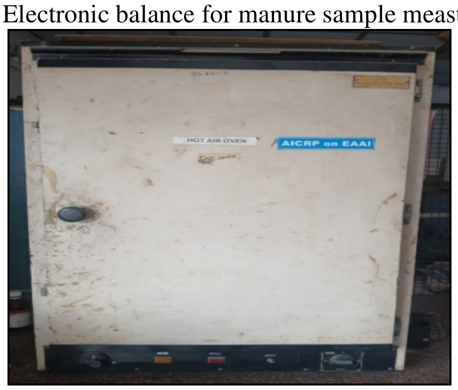

Fig. 4 : Hot air oven for oven-drying of manure samples

Fig. 5 : Desiccators for manure moisture

Bulk Density

Bulk density of organic manure was determined according to IS 2386 (Part 3): 1963 by filling a container of known volume with manure without compacting the material. The top surface of the filled container was levelled properly, and the manure-filled container was weighed. The experimental setup used for bulk density measurement is presented in Fig. 6.

$$\rho b = \frac{M}{V}$$

Where,
M = Mass of manure (kg)
V = Volume of container (m^3)

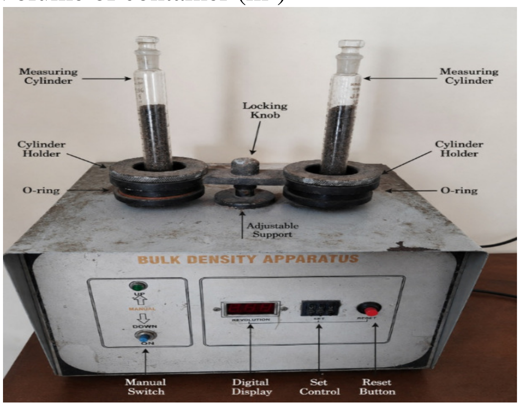

Fig. 6 : Bulk Density Measurement Apparatus

Particle Size

Particle size analysis of organic manure was carried out according to IS 460 (Part 1): 1985 using the sieve analysis method. A known quantity of manure sample was taken and placed on a set of standard sieves arranged from larger to smaller sieve openings. The experimental setup used for particle size distribution analysis with a sieve shaker is presented in Fig. 7.

$$\text{Particle size}\ (\%) = \frac{Wp}{Wt} \times 100$$

Where,
W_p = Weight of particles retained on a particular sieve (g)
W_t = Total weight of sample taken for sieve analysis (g)

Fig. 7 : Particle size distribution analysis using a sieve shaker

Engineering Properties of Organic Manure

The engineering properties of the selected organic manures were evaluated to assess their suitability for the auger-type metering device. The measured parameters included angle of repose, coefficient of static friction, and flowability.

Angle of Repose

Bulk density of organic manure was determined according to IS 2386 (Part 3): 1963 using a Bulk Density Apparatus cylinder of known volume. The manure sample was filled gently into the cylinder without pressing or compacting the material so that its natural loose condition could be maintained. The apparatus used for measuring the angle of repose and the formed manure heap are shown in Fig. 8 and Fig. 8.1, respectively.

$$\theta = \tan^{-1}\left(\frac{h}{r}\right)$$

Where,
θ = Angle of repose
h = Height of heap (mm)
r = Radius of heap (mm).

The angle of repose indicates the flow behaviour and handling characteristics of manure material.

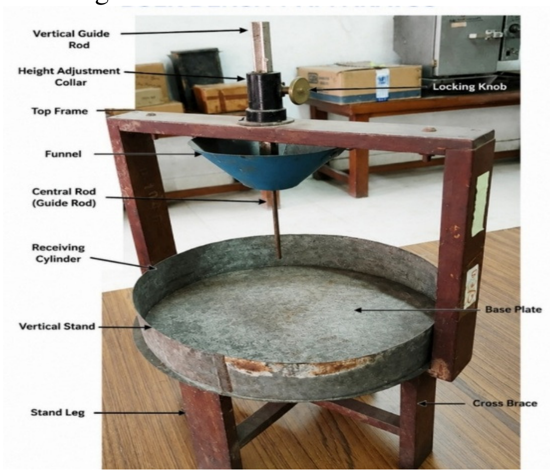

Fig. 8 : Measuring the angle of repose apparatus

Fig. 8.1 : Angle of repose measurement of organic manure

Coefficient of Friction

The coefficient of friction of organic manure was determined according to IS 1895: 1978 to study the flow behaviour of manure on different contact surfaces. The manure sample was placed on a test surface, and the inclination angle was gradually increased until the material started sliding. The experimental setup used for determining the coefficient of static friction of the manure samples is presented in Fig. 9.

$$\mu = \tan \theta.$$

Where,
μ = Coefficient of friction
θ = Angle of friction
The coefficient of friction helps in understanding the movement and flow characteristics of manure inside the hopper and metering mechanism.

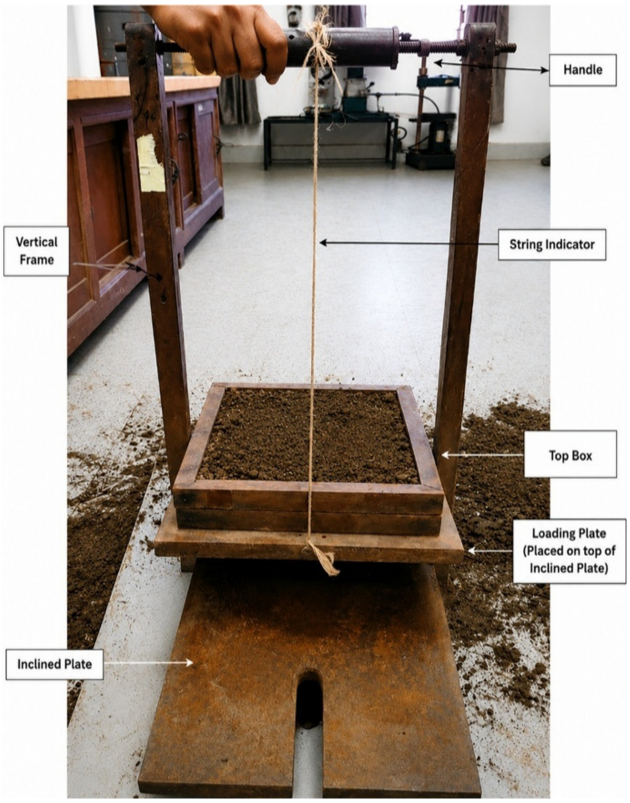

Fig. 9 : Laboratory Setup for Measuring the Coefficient of Static Friction of Manure

Flowability Characteristics

The flowability characteristics of organic manure were analysed to evaluate the smooth movement of manure through the hopper and metering mechanism during machine operation. The test was conducted by allowing manure to pass through the hopper opening under gravity flow conditions and observing the continuity of discharge.

Flowability index was calculated using the following relationship.

$$\textbf{Flowability (\%)} = \frac{Wd}{Wt} \times 100$$

Where,
W_d = Weight of manure discharged (kg)
W_t = Total weight of manure filled in hopper (kg).

Higher flowability values indicate better movement and discharge characteristics of manure through the metering system.

Laboratory Evaluation of Auger Metering Performance

The laboratory performance of the auger-type metering device was evaluated using compost, vermicompost, dry spent biogas slurry, and MSW compost under controlled conditions. Each manure was tested at different auger speeds with four replications over a 30 s test period.

Procedure for Laboratory Testing of Prototype Machine

The laboratory testing of the developed prototype manure applicator was carried out under controlled conditions to study the performance of the auger-type metering mechanism. Before starting the experiment, the organic manure materials were prepared carefully, and their moisture content was maintained at nearly 25 percent so that uniform testing conditions could be maintained throughout the study.

The experiment was conducted at different auger speeds of 10, 20, 30, 40, and 50 rpm to observe the effect of auger speed on manure discharge. During each test, the machine was operated for a fixed time period of 30 seconds.

After each test run, the collected manure was weighed using a digital weighing balance to determine the discharge quantity accurately. The same procedure was repeated for all selected auger speeds.

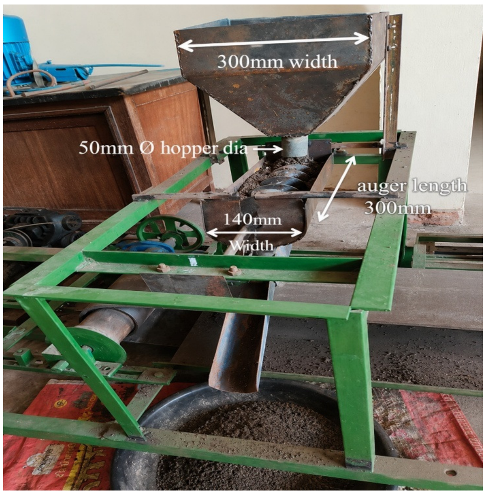

Fig. 10 : Prototype Machine for Laboratory Evaluation Manure Discharge Performance

Measured parameters

The discharge performance of the auger-type metering mechanism was evaluated using the average discharge, discharge rate, discharge per revolution, standard deviation, and coefficient of variation. Each experiment was conducted with four replications at the selected auger speeds, and the collected manure was weighed using a digital weighing balance.

Average discharge

The average discharge was determined by calculating the arithmetic mean of the manure discharged during the four replications for each auger speed.

$$\textbf{Average Discharge (g)} = \frac{\sum_{i=1}^{n} x_i}{n}$$

where:
X_i = manure discharged in each replication (g).
n = number of replications.

Discharge rate

The discharge rate represents the quantity of manure delivered by the auger per unit time and was calculated as:

$$\textbf{Discharge Rate (kg min}^{-1}\textbf{)} = \frac{\text{Average discharge (kg)}}{\text{Time (min)}}$$

where:
Discharge Rate = Rate of manure discharged by the auger (kg min^{-1})
Average discharge = Mean mass of manure collected during the test (kg)
Time = Duration of the discharge test (min)

Discharge per revolution

The discharge per revolution represents the quantity of organic manure delivered during one complete revolution of the auger shaft and was calculated using the following equation:

$$\textbf{Discharge per Revolution (kg rev}^{-1}\textbf{)} = \frac{\text{Average discharge (kg)}}{\text{Number of auger revolutions}}$$

where:
Dpr = Discharge per revolution (kg rev^{-1})
W = Average mass of organic manure discharged during the test (kg)
N = Number of auger revolutions during the test period (rev)

The discharge per revolution was used to evaluate the quantity of manure delivered by the auger in a single revolution, thereby providing a measure of the metering efficiency and consistency of the auger-type metering mechanism.

Standard deviation

The standard deviation was calculated to evaluate the variation in manure discharge among the four replications.

$$SD = \frac{\sum (Xi-X)2}{n-1}$$

where:
SD = Standard deviation
X_i = Discharge in each replication
X = Mean discharge
n = Number of replications

Coefficient of variation

The coefficient of variation (CV) was used to assess the uniformity and consistency of manure discharge. Lower CV values indicate better discharge uniformity and improved metering performance.

$$\textbf{CV (\%)} = \frac{SD}{X} \times 100$$

where:
CV = Coefficient of variation (%)
SD = Standard deviation
X = Mean discharge

Selection Criteria for Suitable Organic Manure.

The suitability of the selected organic manures for the auger-type metering mechanism was evaluated by considering both their material characteristics and discharge behaviour under laboratory conditions. The assessment focused on the ability of each manure to flow smoothly through the hopper and auger while maintaining a continuous, uniform, and stable discharge.

Statistical Analysis

The experimental data obtained from the physical, engineering, and discharge tests were analysed using descriptive statistical methods. The mean was calculated to represent the average value of each measured parameter, while the standard deviation (SD) was used to evaluate the variability among the replicated observations.

Results

Physical Properties of Organic Manures

The physical properties of the selected organic manures were determined to evaluate their suitability for the auger-type metering device. The measured parameters included moisture content, bulk density, tapped density, and particle size distribution. These properties significantly influence the handling, storage, flow behaviour, and discharge performance of manure through the metering mechanism. The experimental results provided the basic information required to compare the selected manures and to identify the most suitable material for uniform and efficient application using the auger-type metering device

Moisture Content

The moisture content of the selected organic manures is presented in Tables 3-5. Fresh moisture content varied from 51.30 to 84.40% (w.b.), with dry spent biogas slurry recording the highest moisture content (84.40%), followed by vermicompost (61.80%), compost (57.50%), and MSW compost (51.30%). After shade drying, the moisture content of all four manures was standardized to approximately 25% (w.b.) (24.86-25.14%) before laboratory testing. Maintaining a uniform moisture level improved the flowability of the materials, minimized bridging and clogging, and ensured a fair comparison of their discharge performance in the auger-type metering mechanism.

Table 3 : Oven-Drying Observations for Determination of Fresh Moisture Content

Organic manure	Weight before oven drying, W_1 (g)	Weight after oven drying, W_2 (g)	Fresh moisture content (% w.b.)
Compost	100.00	42.50	57.50
Vermicompost	100.00	38.20	61.80
Dry spent biogas slurry	100.00	15.60	84.40
MSW compost	100.00	48.70	51.30

Table 4 : Oven-Drying Observations After Shade Drying

Organic manure	Weight before oven drying, W_1 (g)	Weight after oven drying, W_2 (g)	Moisture content after oven drying (% w.b.)
Compost	100.00	75.14	24.86
Vermicompost	100.00	74.86	25.14
Dry spent biogas slurry	100.00	75.09	24.91
MSW compost	100.00	74.92	25.08
Mean	-	-	25.00

Table 5 : Moisture Content of Organic Manures Before and After Shade Drying

Organic manure	Fresh moisture content (w.b.)	Moisture content after shade drying (% w.b.)
Compost	57.50	24.86
Vermicompost	61.80	25.14
Dry spent biogas slurry	84.40	24.91
MSW compost	51.30	25.08

Maintaining a uniform moisture content of 25% (w.b.) improved manure flowability and reduced the chances of bridging and clogging during laboratory testing.

Bulk Density

The bulk density and tapped density of the selected organic manure are presented in Table 6-9. The bulk density obtained from the four trials ranged from 500 to 658 kg m^{-3}, while the tapped density varied between 568 and 694 kg m^{-3}. The average bulk density and tapped density were 595.75 kg m^{-3} and 642.75 kg m^{-3}, respectively, which were considered as 600 kg m^{-3} and 643 kg m^{-3} for engineering design and performance evaluation. The higher tapped density compared to bulk density indicates that the manure particles became more compact after tapping, which is important for predicting material flow and discharge behaviour in the auger-type metering mechanism.

Table 6 : Bulk and tapped density

Sr.No. 1	Tap Count	Volume (ml)	Calculation	Density (g/ml)	Density (kg/m³)
1	0 (Bulk)	20.0	12.50 / 20.0	0.625	625
2	60	19.0	12.50 / 19.0	0.658	658
3	50	18.5	12.50 / 18.5	0.676	676
4	50	18.0	12.50 / 18.0	0.694	694
5	50	18.0	12.50 / 18.0	0.694	694
6	50	18.0	12.50 / 18.0	0.694	694

Bulk Density: (Trial 1)
12.50 / 20.0 = 0.625 g/ml = 625 kg/m³

Tapped Density:
12.50 / 18.0 = 0.694 g/ml = 694 kg/m³

Table 7 : Bulk and tapped density

Sr.No 2	Tap Count	Volume (ml)	Calculation	Density (g/ml)	Density (kg/m³)
1	0 (Bulk)	25.0	12.50 / 25.0	0.500	500
2	60	25.0	12.50 / 25.0	0.500	500
3	50	24.0	12.50 / 24.0	0.521	521
4	50	23.0	12.50 / 23.0	0.543	543
5	50	22.0	12.50 / 22.0	0.568	568
6	50	22.0	12.50 / 22.0	0.568	568

Bulk Density: (Trial 2)
12.50 / 25.0 = 0.500 g/ml = 500 kg/m³

Tapped Density:
12.50 / 22.0 = 0.568 g/ml = 568 kg/m³

Table 8 : Bulk and tapped density

Sr.No. 3	Tap Count	Volume (ml)	Calculation	Density (g/ml)	Density (kg/m³)
1	0 (Bulk)	25.0	12.50 / 25.0	0.500	500
2	60	24.0	12.50 / 24.0	0.521	521
3	50	23.0	12.50 / 23.0	0.543	543
4	50	22.0	12.50 / 22.0	0.568	568
5	50	22.0	12.50 / 22.0	0.568	568
6	50	22.0	12.50 / 22.0	0.568	568

Bulk Density: (Trial 3)
12.50 / 25.0 = 0.500 g/ml = 500 kg/m³

Tapped Density:
12.50 / 22.0 = 0.568 g/ml = 568 kg/m³

Table 9 : Bulk and tapped density

Sr.No. 4	Tap Count	Volume (ml)	Calculation	Density (g/ml)	Density (kg/m³)
1	0 (Bulk)	20.83	12.50 / 20.8	0.600	600
2	60	20.0	12.50 / 20.0	0.625	625
3	50	19.5	12.50 / 19.5	0.641	641
4	50	19.0	12.50 / 19.0	0.658	658
5	50	18.8	12.50 / 18.8	0.665	665
6	50	18.8	12.50 / 18.8	0.665	665

Bulk Density: (Trial 4)
12.50 / 20.83 = 0.600 g/ml = 600 kg/m³

Tapped Density:
12.50 / 18.8 = 0.665 g/ml = 665 kg/m³

Table 10 : Average bulk density and tapped density of the selected organic manure

Trial	Bulk density (kg m^{-3})	Tapped density (kg m^{-3})
1	625	694
2	500	568
3	658	644
4	600	665
Average	595.75	642.75

Particle Size Distribution

The particle size distribution of compost is presented in Table 11. The results showed that the highest proportion of particles (33.19%) passed through the 1.40 mm sieve and was collected in the pan, followed by 21.55% retained on the 2.36 mm sieve and 16.82% on the 5.60 mm sieve. Smaller proportions were retained on the 4.75 mm (9.40%), 4.00 mm (8.14%), 2.00 mm (2.54%), and 1.40 mm (8.36%) sieves. The average particle size of the compost was 3.58 mm. The predominance of fine to medium-sized particles indicates good flow characteristics, allowing smooth movement through the hopper and efficient filling of the auger flights. Consequently, the observed particle size distribution was considered suitable for achieving uniform and continuous manure discharge with the auger-type metering mechanism.

Table 11: Particle Size Distribution of Compost

Sieve size (mm)	Mass retained (g)	Mass retained (%)
5.60	25.08	16.82
4.75	14.01	9.40
4.00	12.14	8.14
2.36	32.13	21.5
2.00	3.78	2.54
1.40	12.46	8.36
Pan	49.48	33.19
Total	149.08	100.00

Total mass retained (excluding the pan for this calculation):

25.08+14.01+12.14+32.13+3.78+12.46 = 99.60 g

140.45+66.55+48.56+75.83+7.56+17.44 = 356.39

Average particle size = $\frac{356.39}{99.60}$ = 3.58 mm

Average particle size = 3.58 mm.

Engineering Properties of Organic Manures

The engineering properties of the selected organic manures were assessed to evaluate their suitability for the auger-type metering mechanism. Parameters such as the angle of repose, coefficient of static friction, and flowability were measured, as they influence the movement of manure through the hopper and auger. These properties directly affect discharge uniformity, metering performance, and the likelihood of bridging or clogging. The results provided a basis for comparing the four manures and selecting the most suitable material for efficient auger metering.

Angle of Repose

The angle of repose of the selected organic manure is presented in Table 12. The measured values ranged from 44.4° to 45.8°, with an average of 45.1°, indicating good consistency among the four trials. The moderate angle of repose suggests that the manure has fair flowability, with some particle interlocking due to its irregular shape and fibrous nature. This flow behaviour indicates that the hopper wall angle should be greater than 45.1° to ensure continuous manure flow and to minimize the risk of bridging and clogging during auger operation. Therefore, the average angle of repose of 45.1° was considered an important design parameter for the hopper and auger-type metering mechanism.

Table 12 : Angle of repose of organic manure

Trial	Height (cm)	Average diameter (cm)	Average radius (cm)	h/r	Angle of repose (°)
1	16.0	32.65	16.325	0.9807	44.4
2	16.3	32.65	16.325	0.9985	44.9
3	16.5	32.65	16.325	1.0107	45.3
4	16.8	32.65	16.325	1.0291	45.8
Mean	16.40	32.65	16.325	1.0048	45.1

Coefficient of Static Friction

The coefficient of static friction of the selected organic manure is presented in Table 13. The coefficient of static friction ranged from 0.3900 to 0.4455, with a mean value of 0.4113, while the corresponding sliding angle varied from 21.31° to 24.01°, averaging 22.34°. The small variation among the five trials indicates good repeatability of the measurements. The measured coefficient of static friction suggests moderate resistance to sliding, allowing the manure to move smoothly through the hopper while maintaining controlled discharge. This value indicates a low tendency for bridging and clogging, making the manure suitable for use in the auger-type metering mechanism.

Table 13 : Coefficient of Static Friction Determined Using the Inclined Plane Method

Trial	Height (m)	Angle (°)	Coefficient of Static Friction(μ)
1	0.250	21.31	0.3900
2	0.254	21.64	0.3972
3	0.254	21.64	0.3972
4	0.280	24.01	0.4455
5	0.270	23.09	0.4267
Average	—	22.34	0.4113

Static Friction Coefficient with Angle Measuring Device

The coefficient of static friction measured using the angle measuring device is presented in Table 14. The measured angle ranged from 24° to 27°, resulting in a coefficient of static friction between 0.445 and 0.511, with an average value of 0.467. The results were consistent across all trials, indicating good repeatability. Although the measured value was slightly higher than that obtained using the inclined plane method, both methods showed similar frictional behaviour. The measured coefficient indicates adequate flow characteristics with a low tendency for bridging and clogging, confirming the suitability of the manure for use in the auger-type metering mechanism.

Table 14 : Coefficient of Static Friction Measured Using an Angle-Measuring Instrument

Trial	Measured Angle (°)	Coefficient of Static Friction (μ)
1	24	0.445
2	24	0.445
3	24	0.445
4	27	0.511
5	26	0.488
Average	25.0	0.467

Flowability

The flowability of the selected organic manures was evaluated using their bulk and tapped density values. The average bulk density and tapped density were 595.75 kg m^{-3} and 642.75 kg m^{-3}, respectively, indicating good flowability and low compressibility. Among the four manures, compost exhibited the best flow behaviour, followed by dry spent biogas slurry and vermicompost, while MSW compost showed comparatively poor flowability. Compost moved smoothly through the hopper and auger, producing a more uniform discharge with minimal bridging and clogging. In contrast, the relatively poor flow characteristics of MSW compost resulted in less consistent material movement and discharge. Overall, the results indicate that compost was the most suitable manure for the auger-type metering mechanism due to its superior flow characteristics and stable discharge performance.

Laboratory Evaluation of the Auger-Type Metering Mechanism

The laboratory evaluation was conducted to assess the discharge performance of the selected organic manures at different auger speeds. Performance was evaluated in terms of average discharge, discharge rate, discharge per revolution, and discharge uniformity. The results were used to compare the metering behaviour of the four manures and identify the most suitable material for the auger-type metering mechanism.

Table15 : Experimental - Dry spent slurry

Trial No.	Time (s)	RPM of Auger	Auger shaft rotation (rev)	Discharge (g /kg)			
1	30	20	11	770	840	812	834
2	30	30	15	1106	1214	1222	1094
3	30	40	20	1480	1452	1478	1510
4	30	50	24	1954	2016	2006	2004

Table 16 : Experimental - vermicompost

Trial No.	Time (s)	RPM of Auger	Auger shaft rotation (rev)	Discharge (g /kg)			
1	30	10	7	750	824	710	680
2	30	20	11	944	1102	1040	1014
3	30	30	13	1282	1440	1544	1550
4	30	40	19	2014	2046	2600	2024

Table 17 : Experimental - compost

Trial No.	Time (s)	RPM of Auger	Auger shaft rotation (rev)	Discharge (g /kg)			
1	30	20	10	1404	1420	1350	1442
2	30	30	15	1822	1864	1900	1926
3	30	40	20	2516	2562	2470	2460
4	30	50	23	2922	2938	3094	3040

Table 18 : Experimental- MSW compost

Trial No.	Time (s)	RPM of Auger	Auger shaft rotation (rev)	Discharge (g /kg)			
1	30	20	10	700	606	664	580
2	30	30	13	454	490	476	640
3	30	40	20	520	600	594	630
4	30	50	24	972	964	764	632

Dry Spent Biogas Slurry

The discharge performance of dry spent biogas slurry increased with increasing auger speed. The average discharge increased from 814 g/30 s at 20 rpm to 1995 g/30 s at 50 rpm, while the discharge rate increased from 1.628 to 3.990 kg min^{-1}. The discharge per revolution ranged from 0.0740 to 0.0831 kg rev^{-1}. The coefficient of variation remained low (1.40-5.90%), indicating stable and uniform discharge. The material exhibited satisfactory flow behaviour with minimal bridging, making it suitable for auger metering.

Vermicompost

The average discharge of vermicompost increased from 741 g/30 s at 10 rpm to 2171 g/30 s at 40 rpm**,** with the discharge rate increasing from 1.482 to 4.342

kg min^{-1}. The discharge per revolution varied between 0.0932 and 0.1143 kg rev^{-1}. Although vermicompost showed good discharge capacity, its discharge uniformity decreased at higher speed, with the CV increasing to 13.19%. The material flowed reasonably well through the auger but exhibited slightly higher variation than dry spent biogas slurry.

Compost

Compost showed the best discharge performance among all the tested manures. The average discharge increased from 1404 g/30 s at 20 rpm to 2998.5 g/30 s at 50 rpm**,** while the discharge rate increased from 2.808 to 5.997 kg min^{-1}. The discharge per revolution remained between 0.1251 and 0.1404 kg rev^{-1}, with consistently low CV values (2.03-2.76%). Its excellent flowability and stable discharge indicate that compost is the most suitable manure for the auger-type metering mechanism**.**

MSW Compost

MSW compost exhibited the lowest discharge performance among the four manures. The average discharge ranged from 515 to 833 g/30 s, with a discharge rate of 1.030-1.666 kg min^{-1} and discharge per revolution of 0.0293-0.0638 kg rev^{-1}. The coefficient of variation was comparatively high (8.18-20.08%), indicating poor discharge uniformity. The material showed poor flow behaviour with a greater tendency for bridging and clogging, making it the least suitable manure for the auger-type metering mechanism**.**

Comparison of Discharge Performance Statistical Analysis of Auger-Type Metering Device Performance

One-Way ANOVA Analysis

To determine whether auger speed significantly affected discharge performance, a one-way Analysis of Variance (ANOVA) was performed for each manure type. The analysis was conducted at a 95% confidence level ($\alpha = 0.05$).

Dry Spent Biogas Slurry

Table 19 : Discharge characteristics of dry spent biogas slurry

Trial	Time (s)	Auger speed (rpm)	Auger revolutions	Average discharge (g/30s)	Discharge rate (kg min^{-1})	Discharge per revolution (kg rev^{-1})	SD (g)	CV (%)
1	30	20	11	814	1.628	0.0740	31.71	3.90
2	30	30	15	1159	2.318	0.0773	68.38	5.90
3	30	40	20	1480	2.960	0.0740	23.72	1.60
4	30	50	24	1995	3.990	0.0831	27.83	1.40

The ANOVA results for dry spent biogas slurry revealed a highly significant effect of auger speed on discharge ($F = 688.72$, $p < 0.001$). The critical F value was 3.49, and the calculated F value substantially exceeded this threshold, confirming that variations in auger speed significantly influenced the discharge performance. Comparative analysis indicated that all speed levels differed significantly from each other ($p < 0.05$). The material showed stable discharge characteristics with CV values ranging from 1.40% to 5.90%, indicating good uniformity across all speeds.

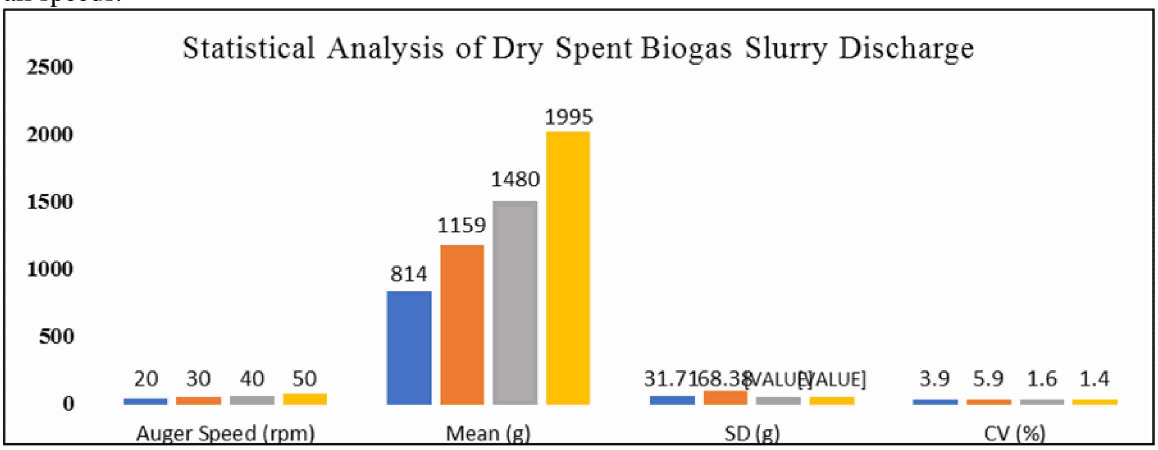

Fig. 1 : Discharge characteristics of Dry spent slurry Vermicompost

Table 20 : Discharge characteristics of vermicompost

Trial	Time (s)	Auger speed (rpm)	Auger revolutions	Average discharge (g/30s)	Discharge rate (kg min^{-1})	Discharge per revolution (kg rev^{-1})	SD (g)	CV (%)
1	30	10	7	741	1.482	0.1059	62.32	8.41
2	30	20	11	1025	2.050	0.0932	65.41	6.38
3	30	30	13	1454	2.908	0.1118	125.29	8.62
4	30	40	19	2171	4.342	0.1143	286.31	13.19

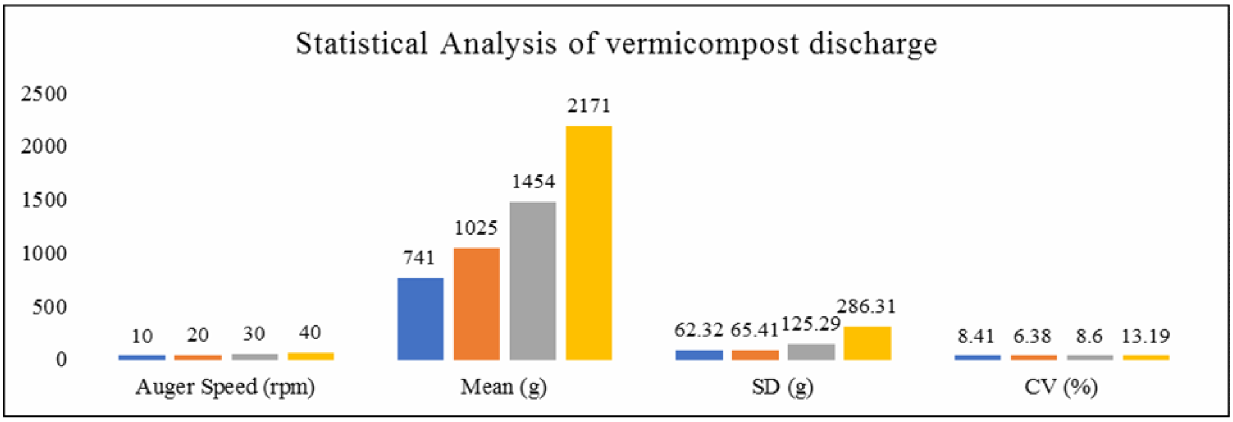

Fig. 2 : Discharge characteristics of vermicompost

The ANOVA for vermicompost showed a highly significant effect of auger speed on discharge ($F = 112.84$, $p < 0.001$). The calculated F value was substantially larger than the critical value of 3.49, confirming that auger speed significantly affected discharge performance. Pairwise comparisons revealed significant differences between all speed levels ($p < 0.05$), except between 10 rpm and 20 rpm where the difference approached significance. The CV values ranged from 6.38% to 13.19%, indicating moderate uniformity with increased variation at higher speeds.

Compost

Table 21 : Discharge characteristics of compost

Trial	Time (s)	Auger speed (rpm)	Auger revolutions	Average discharge (g/30s)	Discharge rate (kg min^{-1})	Discharge per revolution (kg rev^{-1})	SD (g)	CV (%)
1	30	20	10	1404.0	2.808	0.1404	38.79	2.76
2	30	30	15	1878.0	3.756	0.1252	45.47	2.42
3	30	40	20	2502.0	5.004	0.1251	50.76	2.03
4	30	50	23	2998.5	5.997	0.1304	80.85	2.70

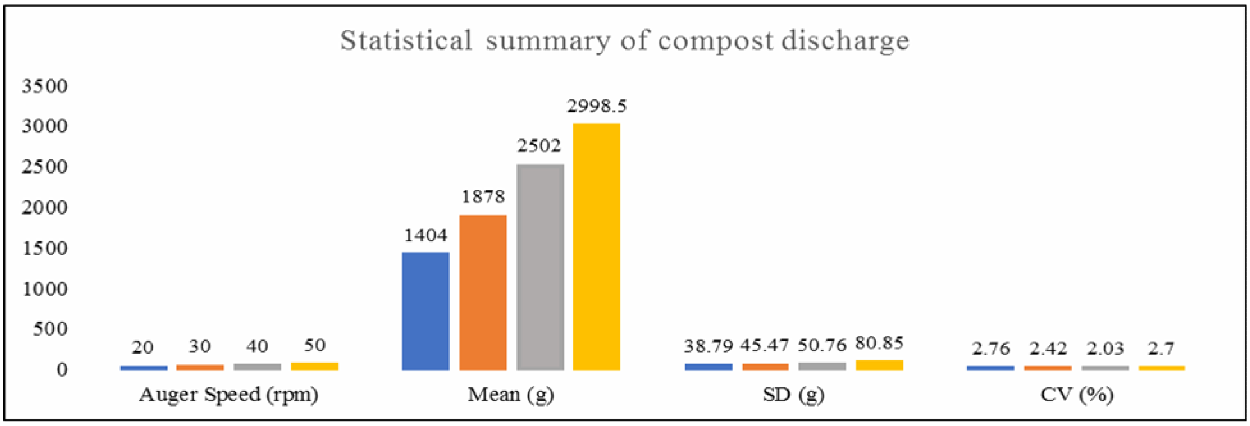

Fig. 3 : Discharge characteristics of Compost

The ANOVA for compost demonstrated the most significant effect of auger speed on discharge ($F = 604.78$, $p < 0.001$), with the highest F value among all tested manures. The calculated F value far exceeded the critical value of 3.49, confirming a strong relationship between auger speed and discharge. All speed levels were significantly different from each other ($p < 0.05$). Compost exhibited excellent uniformity with the lowest CV values (2.03% to 2.76%) among all manures tested, indicating superior and consistent metering performance.

MSW COMPOST

Table 22 : Discharge characteristics of MSW compost

Trial	Time (s)	Auger speed (rpm)	Auger revolutions	Average discharge (g/30s)	Discharge rate (kg min^{-1})	Discharge per revolution (kg rev^{-1})	SD (g)	CV (%)
1	30	20	10	637.5	1.275	0.0638	52.16	8.18
2	30	30	13	515.0	1.030	0.0396	79.72	15.48
3	30	40	20	586.0	1.172	0.0293	50.34	8.59
4	30	50	24	833.0	1.666	0.0347	167.26	20.08

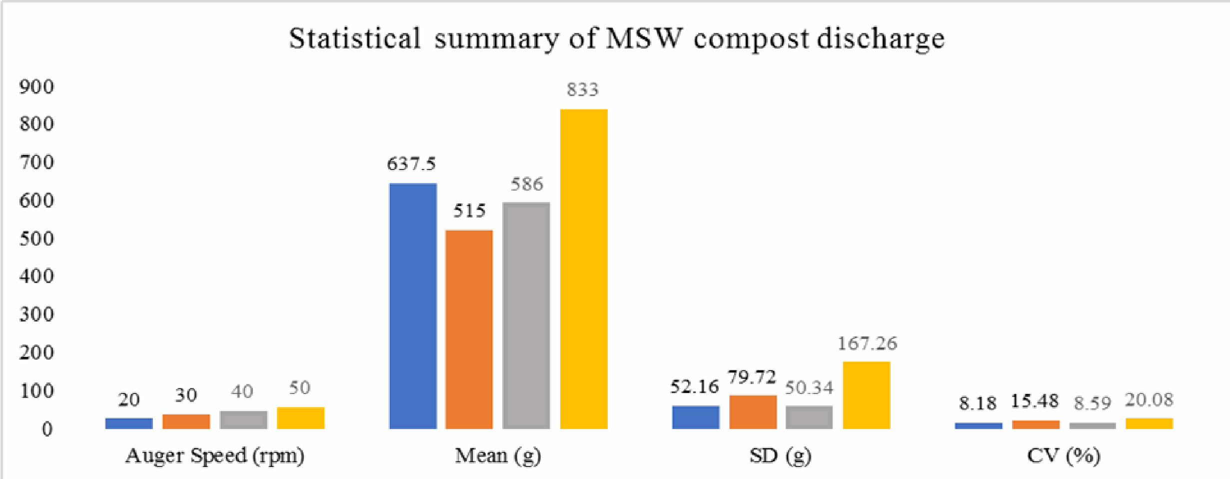

Fig. 4 : Discharge characteristics of MSW Compost

The ANOVA for MSW compost revealed a significant effect of auger speed on discharge ($F = 8.88$, $p = 0.0021$). The calculated F value exceeded the critical value of 3.49, confirming a significant relationship between auger speed and discharge. However, this was the lowest F value among all tested manures. Pairwise comparisons showed significant differences only between the 30 rpm and 50 rpm speeds ($p < 0.05$). The material exhibited the poorest performance with CV values ranging from 8.18% to 20.08%, indicating high variability and unstable flow characteristics, particularly at higher speeds.

Comparative Analysis

Table 23 : Summary of ANOVA results for all manure types

Manure Type	F value	P-value	Significance Level	R^2 Value
Compost	604.78	<0.001	Highly Significant	0.9934
Dry spent biogas slurry	688.72	<0.001	Highly Significant	0.9942
Vermicompost	112.84	<0.001	Highly Significant	0.9658
MSW compost	8.88	0.0021	Significant	0.6895

Table 24 : CV% Comparison Across Manure Types

Manure Type	CV Range (%)	Uniformity Rating
Compost	2.03 - 2.76	Excellent
Dry Spent Slurry	1.40 - 5.90	Good
Vermicompost	6.38 - 13.19	Moderate
MSW Compost	8.18 - 20.08	Poor

Table 25 : Comparative evaluation of organic manures for the auger-type metering device

Parameter	Compost	Vermicompost	Dry spent biogas slurry	MSW compost
Average discharge rate (kg min^{-1})	4.39	2.70	2.72	1.29
Average discharge per revolution (kg rev^{-1})	0.130	0.106	0.077	0.042
Average CV (%)	2.48	9.15	3.20	13.08
F value from ANOVA	604.78	112.84	688.72	8.88
P-value	<0.001	<0.001	<0.001	0.0021
Discharge performance	Excellent	Good	Moderate	Poor
Discharge uniformity	Excellent	Moderate	Good	Poor
Flowability	Excellent	Good	Moderate	Poor
Overall suitability	Highly suitable	Suitable	Moderately suitable	Least suitable
Rank	1	2	3	4

Selection of the Most Suitable Manure for Auger-Type Metering

The laboratory evaluation demonstrated clear differences in the discharge performance of the four organic manures. Compost exhibited the best metering performance, with an average discharge ranging from 1404.0 to 2998.5 g per 30 s, a discharge rate of 2.808-5.997 kg min^{-1}, discharge per revolution of 0.1251-0.1404 kg rev^{-1}, and the lowest average coefficient of variation (2.48%), indicating highly uniform and stable discharge. Dry spent biogas slurry showed satisfactory performance, with an average discharge of 814-1995 g per 30 s, a discharge rate of 1.628-3.990 kg min^{-1}, discharge per revolution of 0.0740-0.0831 kg rev^{-1}, and an average CV of 3.20%, although occasional bridging was observed because of its fibrous nature. Vermicompost produced an average discharge of 741-2171 g per 30 s, a discharge rate of 1.482-4.342 kg min^{-1}, and discharge per revolution of 0.0932-0.1143 kg rev^{-1}, with an average CV of 9.15%, indicating moderate discharge uniformity. In contrast, MSW compost recorded the lowest discharge performance, with an average discharge of 515-833 g per 30 s, a discharge rate of 1.030-1.666 kg min^{-1}, discharge per revolution of 0.0293-0.0638 kg rev^{-1}, and the highest average CV of 13.08%, reflecting poor flowability and frequent bridging and clogging. Overall, the results confirmed that compost was the most suitable organic manure for the auger-type metering mechanism because of its high discharge capacity, superior flowability, and consistent metering performance under laboratory conditions.

Conclusion

The present study evaluated the physical and engineering properties of four organic manures and assessed their discharge performance using an auger-type metering mechanism. Standardizing the moisture content to approximately 25% (w.b.) ensured consistent testing conditions and improved material flow during laboratory evaluation. The measured engineering properties, including an average bulk density of 595.75 kg m^{-3}, tapped density of 642.75 kg m^{-3}, particle size of 3.58 mm, angle of repose of 45.1°, and coefficient of static friction of 0.411, indicated that compost possessed favourable characteristics for auger metering. Auger speed significantly influenced manure discharge for all materials, with higher rotational speeds producing greater discharge rates. Among the four organic manures, compost achieved the best overall performance, recording the highest average discharge rate (4.39 kg min^{-1}), the greatest discharge per revolution (0.130 kg rev^{-1}), and the lowest coefficient of variation (2.48%), indicating excellent discharge uniformity and stable metering. Dry spent biogas slurry demonstrated good discharge consistency but lower discharge capacity, while vermicompost provided moderate performance with increased variability at higher speeds. MSW compost exhibited poor flowability, unstable discharge, and frequent bridging, making it the least suitable material for the auger-type metering mechanism. The statistical analysis further confirmed that auger speed had a significant influence on discharge characteristics, with compost showing highly consistent performance across all operating conditions. Based on the overall evaluation of flowability, discharge capacity, discharge uniformity, and statistical performance, compost was identified as the most suitable organic manure for use in the developed auger-type metering device. The findings of this study provide valuable design criteria for the development of precision organic manure applicators and demonstrate that proper selection of manure based on its physical and engineering properties can substantially improve metering accuracy, operational reliability, and uniform field application.

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