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PERFORMANCE EVALUATION OF A SOLID MANURE INJECTOR

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ABSTRACT
A solid manure injector was developed at the Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure. The machine was able to place solid manure uniformly beneath the soil surface and cover the manure to reduce ammonia volatilization and odour emissions. The machine consists of the main frame, hopper, pulverizer, conveyor, furrow opener, furrow coverer and instrumentation system. The drive shaft directly on the wheel controls the pulverizer shaft and conveyor shaft via a chain and sprocket mechanism. The speed at which the pulverizer and conveyor operates are synchronized with the speed at the wheels. The performance of the solid manure injector was evaluated at three feed gate openings (6 cm, 12 cm and 18 cm), three forward speeds (0.66 m/s, 1.1 m/s and 1.54 m/s) and three depths (5 cm, 10 cm, and 15 cm). From the result, it was found that highest application rate with a mean of 1667.9 kg/ha was obtained at 1.54 m/s speed, 18 cm feed gate opening and 5 cm depth. Field capacity ranged between 0.28 and 0.74 ha/h while field efficiency ranged between 50% to 63% across soil depths and tractor forward speeds. Effects of speed, feed gate openings and depth and their interactions were significant ($p < 0.001$) on application rate while speed and depth and their interactions were significant on field capacity and field efficiency.

Keywords:
Solid manure, solid manure injector, application rate, field capacity, field efficiency

1. INTRODUCTION

Manure serves as a valuable asset for crop production by enhancing soil structure and improving water retention (Adugna, 2016). However, improper management can negatively impact water quality (Yu *et al*., 2019). Manure is typically classified into two types: liquid and solid. Liquid manure, which has a higher moisture content, is easier to manage but poses environmental risks such as runoff, potentially causing nutrient pollution in nearby water sources (Khoshnevisan *et al*., 2021). Solid manure, on the other hand, contains more dry matter but presents application challenges due to the labor-intensive and uneven distribution associated with traditional methods (Ayilara *et al*., 2020). Surface application of solid manure raises concerns about ammonia volatilization and odor emissions (Khoshnevisan *et al*., 2021). To mitigate these issues, the development of a solid manure injector provides a more efficient approach by injecting the manure directly into the soil, which reduces nutrient loss and enhances crop uptake. The advantages include lower ammonia volatilization, decreased odor, and reduced risk of nutrient runoff, promoting more sustainable agricultural practices. Solid manure is commonly applied using rear-discharge or side-discharge spreaders (Sathiamurthi *et al*., 2020), which spread manure across fields before it is tilled into the soil. Tractor-drawn or truck-mounted spreaders are frequently used for this purpose (Korra *et al*., 2020). Additionally, injection systems that place manure directly into the soil help to minimize nutrient loss and improve placement (Webb *et al*., 2012). These systems use tools like discs or shovels to create furrows, allowing manure to be injected below the surface, preventing runoff and volatilization, and enhancing sustainability and efficiency in agriculture. Adgidzi *et al*. (2007) developed a manure spreader equipped with a hopper, frame, power transmission unit, spreading mechanism, and wheels. Powered by a 45-kW tractor, this spreader uses a 23-spike agitator to distribute composted cow dung, achieving a discharge efficiency of 86% and a field capacity of 0.6 hectares per hour. Field tests recorded an application rate of 5.9 tonnes

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per hectare with an operating width of 1.096 meters. Ademosun *et al*. (2014) created a liquid manure injection system designed for adaptability, low draught force, and effectiveness across various soil and crop residue conditions. The system, featuring two sweeps and a 350-liter tank, was tested in sandy loam soil at different depths and speeds. Results indicated that soil disturbance and draught forces increased with injection depth, with specific draught forces ranging from 2.68 to 9.87 kN per tool.

2. MATERIALS AND METHODS

2.1 Description of the Solid Manure Injector

The solid manure injector in Figure 1 was developed at the Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria. The features of the solid manure injector include frame, hopper, pulverizer, conveyor, delivery tube, furrow opener, furrow coverer, and transport wheels.

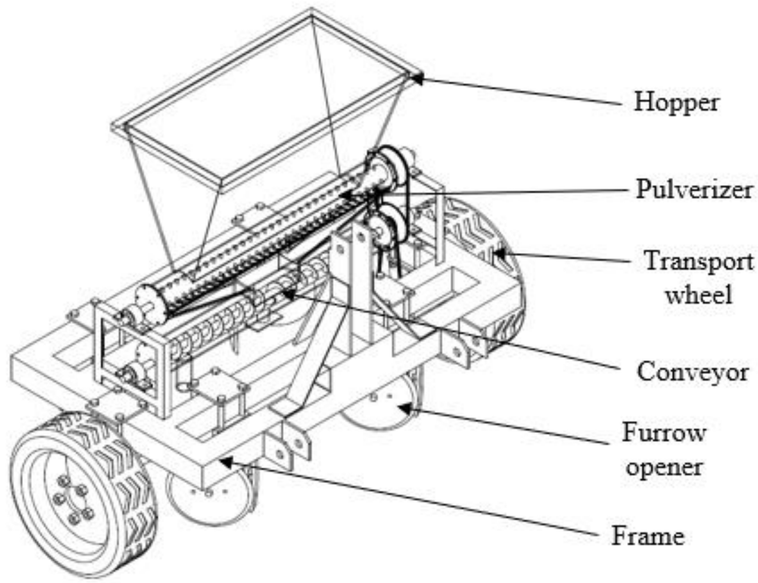

Figure 1: Annotated isometric drawing of the solid manure injector

i. **Frame:** The frame was made of 50 mm × 50 mm mild steel square pipes for rigidity, measuring 1500 mm in length and 800 mm in width.

ii. **Hopper:** The frame supports a trapezoidal hopper, which gradually feeds manure into the pulverizer through a slanted design that aligns with the manure's angle of repose. The hopper's top base measures 1200 mm × 800 mm, while the bottom base is 1200 mm × 200 mm, and it's made from 4 mm thick steel.

iii. **Pulverizer:** The pulverizer, which is 1000 mm long and 100 mm in diameter, breaks down manure into smaller particles before they are conveyed.

iv. **Conveyor:** The conveyor, a two-directional auger type with a diameter of 400 mm, transports the pulverized manure to two delivery tubes located below the conveyor. The delivery tubes are made from rectangular hollow pipe mild steel, each measuring 400 mm in length.

v. **Furrow openers and coverers:** Furrow openers of the adjustable double-disc type cut and displace soil for easy manure injection, with discs measuring 300 mm in diameter and beveled at the lower edge to facilitate cutting. A furrow coverer of the same double-disc type, also made of mild steel, follows to cover the injected manure.

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vi. **Transport wheels:** The injector is equipped with rubber transport wheels, 400 mm in diameter, which help transmit power to the pulverizer and conveyor via a chain and sprocket system.

vii. **Instrumentation System:** The injector includes an instrumentation system with a load cell containing strain gauge elements and resistors, along with data acquisition components like a load cell amplifier and hydrogen sulfide and ammonia sensors to monitor odor emissions.

2.2 Design Considerations

The design of the manure spreader is based on the following considerations:

i. The solid manure injector is simple in design with the use of locally available materials for the fabrication of the component parts.
ii. The ease of fabrication of the component parts with simple joinery methods.
iii. The hopper is designed to accommodate a large manure and reduce refill frequency
iv. Rigidity of the frame to withstand weight, stress, and potential impacts during operation.

2.3 Operation of the Solid Manure Injector

The solid manure injector is a piece of agricultural equipment designed to efficiently incorporate manure into the soil. The process begins with the loading of solid manure into a hopper. From here, the manure is gradually released into a pulverizer located beneath the hopper. This pulverization process breaks down the manure into smaller particles to facilitate subsequent handling. The pulverized manure is then sifted through a screen before entering a screw conveyor. This conveyor system transports the processed manure towards the delivery points. The manure is evenly distributed to two delivery tubes spaced one meter apart. The final stage involves the injection of the manure into the soil. The machine is equipped with a furrow opener that creates a trench into which the manure is deposited. Once the manure is in place, a furrow cover closes the trench, ensuring that the manure is effectively incorporated into the soil.

2.4 Field Test for the Evaluation of the Machine

Field performance tests were conducted at the teaching and research of the Federal University of Technology, Akure to evaluate the performance of the machine in field conditions. The machine was tested in the field of size of 120 m × 60 m. A 3 × 3 × 3 completely randomized factorial experiment with three injection depths (5 cm, 10 cm and 15 cm), three tool forward speeds (0.66, 1.1 and 1.54 m/s) and three feed gate openings (6cm, 12 cm and 18 cm) were used to evaluate the machine and replicated three times. The selected injection depths and forward speeds are commonly used in manure incorporations. Performance parameters such as application rate, field capacity, and field efficiency were determined.

2.4.1 Determination of application rate

Manure was weighed before and after application for each treatment using a weighing scale and the value was recorded. The area of the field where the manure was injected was measured (width and length). Application rate was then determined using the formula in equation 1:

$$\text{Application rate} = \frac{\text{total weight of manure (kg)}}{\text{area covered (ha)}} \quad (1)$$

2.4.2 Determination of field capacity

The capacity of a machine is the rate at which it can cover a field while performing its intended function or useful work. Field capacity was determined using the formula in equation 2:

$$\text{Field capacity (C)} = \frac{\text{Speed (S)} \times \text{Width of operation (m)}}{10} \quad (2)$$

2.4.3 Determination of field efficiency

During each treatment, the time lost during turning and adjustment of the machine was recorded while the time spent used in actual operation was also recorded. Field efficiency was then determined using the formula in equation 3:

$$\text{Field efficiency (\%)} = \frac{\text{actual time}}{\text{total time}} \times 100 \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Solid Manure Injector

The fabricated solid manure injector is presented in Figures 2 and 3

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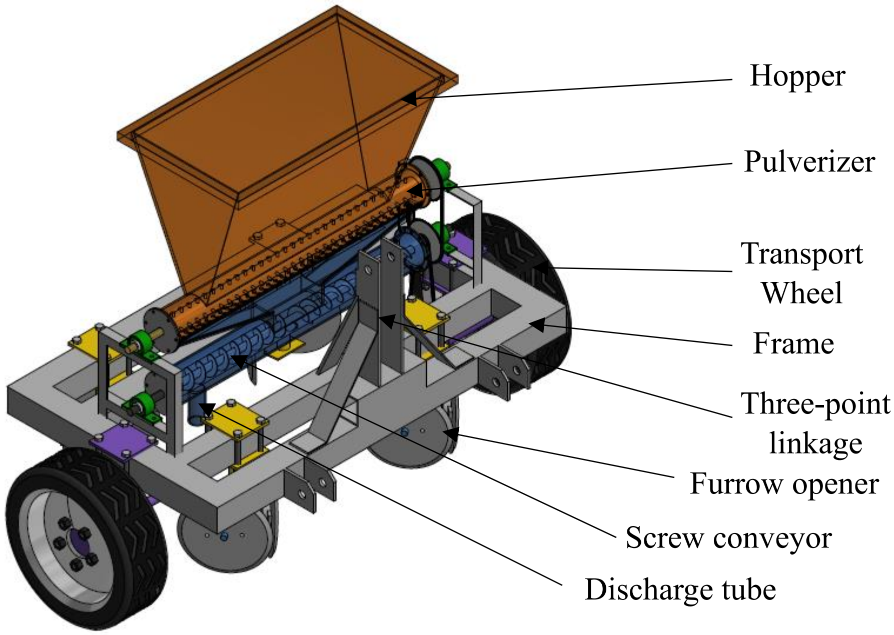

Figure 2: 3D diagram of the solid manure injector

Figure 3: Fabricated solid manure injector

3.2 Application Rate

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Table 1 presents the results of the analysis of variance (ANOVA) for the effects of speed, moisture content, and feed gate opening on the application rate of the solid manure injector.

Table 1: Variance analysis of the three main effects on application rate

Soil Depth (cm) (D)	**Forward Speed (m/s) (S)**	**Feed gate opening (cm) (FG)**		
		6 cm	**12 cm**	**18 cm**
5	0.66	236.42^{opq}	430.25^{k}	611.73^{g}
	1.1	346.30^{m}	683.95^{f}	1038.27^{c}
	1.54	549.38^{hi}	1046.30^{c}	1667.90^{a}
10	0.66	209.88^{pq}	355.56^{lm}	541.36^{i}
	1.1	325.93^{mn}	654.32^{fg}	987.65^{c}
	1.54	417.28^{kl}	846.91^{e}	1305.56^{b}
15	0.66	191.36^{q}	308.64^{mn}	468.52^{jk}
	1.1	296.91^{mno}	609.26^{gh}	915.43^{d}
	1.54	267.28^{nop}	520.99^{ij}	825.31^{e}
ANOVA		**Application rate**		
	D	< 0.001		
	S	< 0.001		
	FG	< 0.001		
	D × S	< 0.001		
	D × FG	< 0.001		
	S × FG	< 0.001		
	D × S × FG	< 0.001		

The main and interactive effects of forward speed, soil depth, and feed gate openings on application rate are shown in Table 6. Forward speed (S), soil depth (D), and feed gate openings (FG) had significant individual effects on the application rate, as well as their interactions (D × S, D × FG, S × FG, D × S × FG), all of which were highly significant ($p < 0.001$). These significant interactions indicate that the effect of each factor varies depending on the levels of the other factors.

3.1.2 Effect of feed gate openings on application rate at different speeds

Figure 4 depicts the relationship between feed gate openings (cm) and application rate (kg/h) at three different speeds: 0.66 m/s, 1.1 m/s, and 1.54 m/s**.** As the feed gate openings increase from 6 cm to 18 cm, the application rate increases for all speeds. This is shown by the upward slope of all three lines, indicating that larger feed gate openings result in a higher application rate. At 6 cm, the application rates are lowest for 0.66 m/s and highest for 1.54 m/s. This trend is consistent across all feed gate openings, showing that faster speeds result in higher application rates. Thus, application rate increases with both feed gate opening and speed. The combination of the highest speed (1.54 m/s) and the largest feed gate opening (18 cm) results in the highest application rate, while the combination of the lowest speed (0.66 m/s) and smallest feed gate opening (6 cm) produces the lowest application rate.

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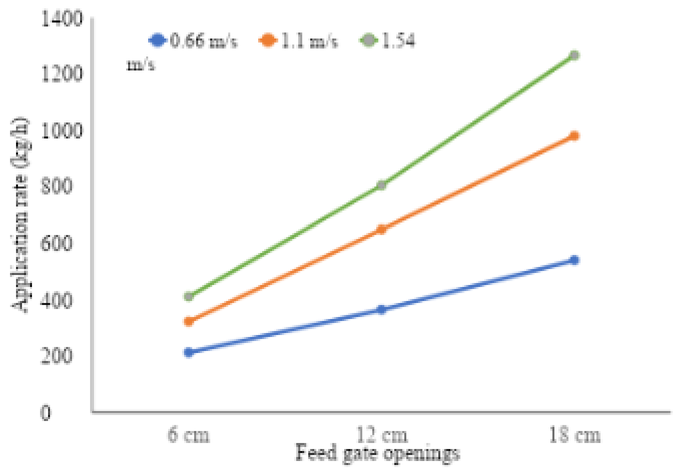

Figure 4: Effect of feed gate openings on application rate at different speeds

3.1.3 Effect of speed on application rate at different depths

Figure 5 illustrates the relationship between Speed (m/s) and Application Rate (kg/h) for three different depths: 5 cm, 10 cm, and 15 cm.

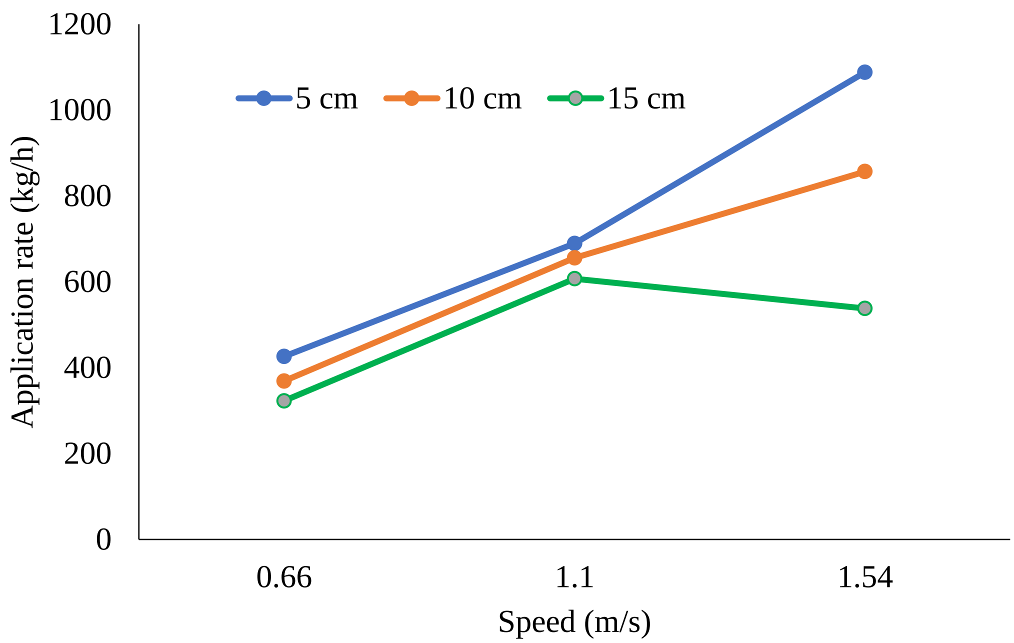

Figure 5: Effect of speed on application rate at different depths

Shallow depth (5 cm) shows the highest increase in application rate as speed increases. This suggests that lower depths are more sensitive to changes in speed, leading to a more pronounced effect on application rate. Medium depth (10 cm) shows a steady, moderate increase in application rate with increasing speed while deeper depth (15 cm) reaches

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a peak at 1.1 m/s, after which the application rate declines slightly as speed increases further to 1.54 m/s. This indicates that deeper depths may not benefit as much from increased speed in terms of application rate. Higher speeds tend to lead to higher application rates, particularly at shallow depths (5 cm), where the rate continues to increase sharply at higher speeds. At deeper depths (15 cm), higher speeds may not necessarily result in higher application rates, as seen with the slight drop in the green line at 1.54 m/s.

3.1.4 Effect of depth on application rate at different speeds

Figure 21 shows the relationship between depth (cm) on the x-axis and application rate (kg/h) on the y-axis at three different speeds: 0.66 m/s, 1.1 m/s, and 1.54 m/s.

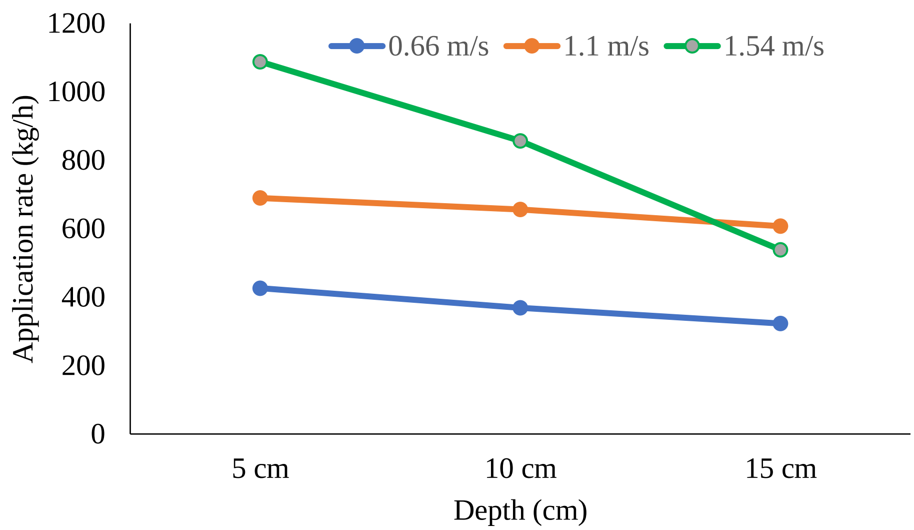

Figure 6: Effect of depth on application rate at different speeds

As depth increases from 5 cm to 15 cm, the application rate decreases at all speeds. This is evident by the downward trend of all three lines, showing that deeper depths result in lower application rates. At 5 cm depth, the application rate is highest at 1.54 m/s and lowest at 0.66 m/s. As depth increases to 10 cm and then 15 cm, the application rate decreases for all speeds, with the most significant reduction seen at 1.54 m/s. At higher speeds (1.54 m/s), the application rate decreases more sharply with increasing depth, showing that deeper depths reduce the benefits of higher speeds. Moderate speeds (1.1 m/s) show more consistency across depths, with smaller changes in application rate. Lower speeds (0.66 m/s) produce the lowest application rates overall, but the decline with depth is more gradual compared to higher speeds.

3.2 Field Capacity

The average field capacity at varying soil depths of 5, 10 and 15 cm combined with operating speeds of 0.66, 1.1 and 1.54 m/s, is illustrated in Figure 7. The highest mean field capacity of 0.74 ha/h was achieved at a forward speed of 1.54 m/s and a soil depth of 5 cm. This indicate that the greatest field capacity occurs at the highest speed and shallowest depth.

Field capacity is highest across all speeds at 5 cm depth, where it increases by 150%, from 0.3 ha/h at 0.66 m/s to 0.75 ha/h at 1.54 m/s. At a depth of 10 cm, the field capacity remains relatively stable across all speeds, showing only a slight decrease from 0.55 ha/h to 0.52 ha/h. However, at 15 cm depth, the field capacity decreases significantly dropping by 40% to approximately 0.45 ha/h compared to the field capacity at 5cm depth.

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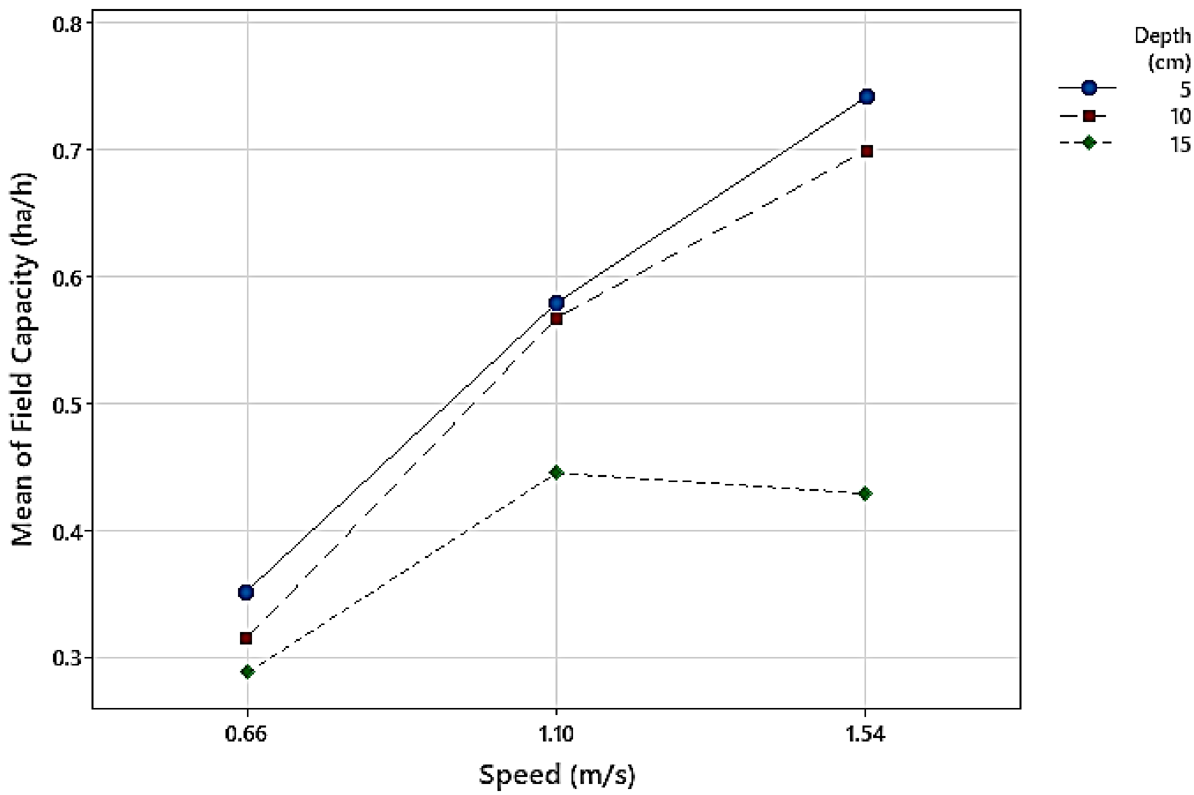

Figure 7: Effects of speed and depth on field capacity (ha/h)

3.3 Field Efficiency

The average field efficiency at different soil depths (5, 10 and 15 cm) and operating speeds (0.66, 1.1 and 1.54 m/s) is shown in Figure 8. The highest mean field efficiency, 63%, occurred at a forward speed of 0.66 m/s and a soil depth of 10 cm.

Field efficiency decreases as speed increases from 0.66 m/s to 1.1 m/s, where it reaches its lowest point at about 52% efficiency. After 1.1 m/s, efficiency rises, reaching about 54% at 1.54 m/s. At 10 cm depth, field efficiency drops to 50% at 1.1 m/s from 63% at 0.66 m/s showing the lowest efficiency among all depths. Similarly, at 15 cm depth, the pattern is similar, with efficiency declining to approximately 52% at 1.1 m/s, before rising again to 60% at 1.54 m/s.

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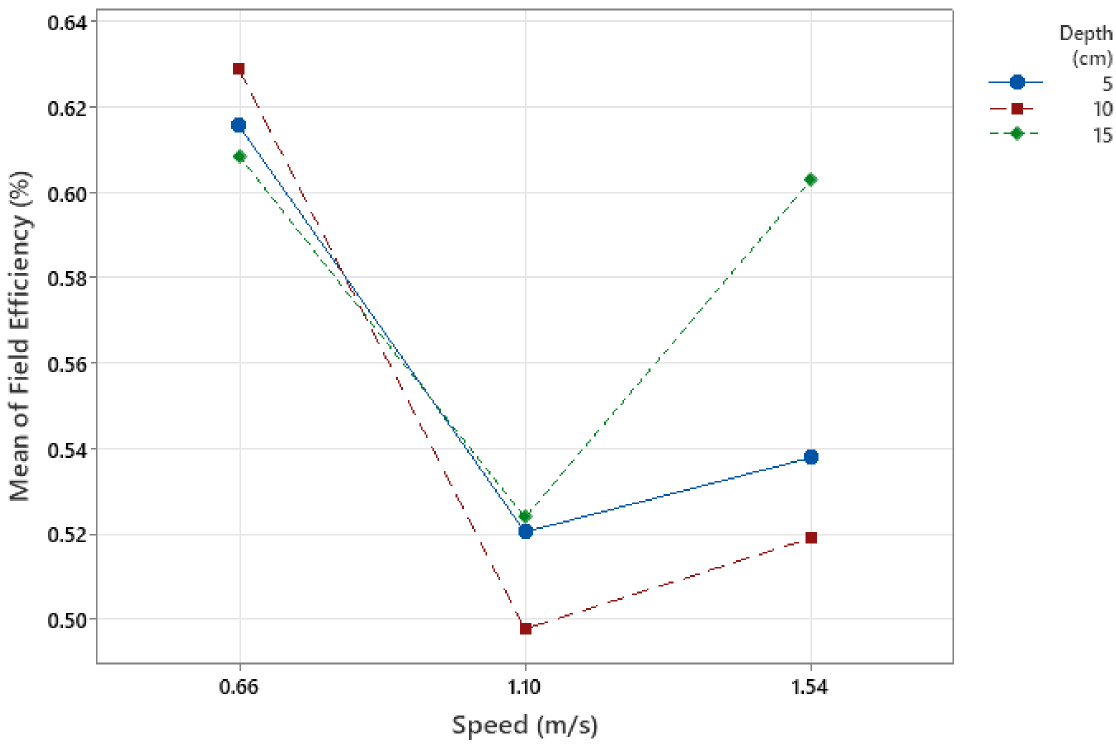

Figure 8: Effects of speed and depth on field efficiency

CONCLUSIONS

The solid manure injector was designed and fabricated by the Department of Agricultural and Environmental Engineering at the Federal University of Technology, Akure. The machine includes key components such as a hopper for manure storage, a pulverizer to break down the manure, a conveyor to transport the pulverized material to the delivery tubes, and a furrow opener and coverer to bury the manure in the soil. All main effects (speed, feed gate openings, depth), and their interactions are statistically significant ($p < 0.001$) on application rate. Highest application rate with a mean of 1667.9 kg/ha was obtained at 1.54 m/s speed, 18 cm feed gate opening and 5 cm depth. Field capacity ranged between 0.28 and 0.74 ha/h while field efficiency ranged between 50% to 63% across soil depths and tractor forward speeds. Effects of speed, feed gate openings and depth and their interactions were significant ($p < 0.001$) on application rate while speed and depth and their interactions were significant on field capacity and field efficiency.

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