Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Investigating Fertilizer Spreader Blades for Improved Flow Behaviours and Material Resilience in Palm Plantation Settings

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ARTICLE INFO

Article history:
Received 31 October 2023
Received in revised form 30 January 2024
Accepted 10 February 2024
Available online 29 February 2024

Keywords:
Fertilizer spreader machine; spreader blade design; fertilizer distribution; fertilizer projectile motion; spreader side discharge

ABSTRACT

Fertilizer spreaders play a crucial role in evenly distributing granule fertilizer across palm plantations. However, in specific areas where growth conditions are unsuitable, fertilizer application becomes unnecessary. Therefore, this study aims to improve granule fertilizer distribution efficiency through enhanced fertilizer blade design. Using Finite Element (FE) simulation, the stress deformation and deflection of the existing spreader blade were evaluated. Meanwhile, Computational Fluid Dynamics (CFD) simulation was used to investigate the influence of spreader design on fertilizer projection speed and direction in the case of open and closed side discharge. The study revealed that the applied forces increased both the critical stress deformation and deflection. To ensure the fertilizer spreads properly over the desired area, the initial velocity had to be increased proportionally with an increase in the angle of direction. These findings contributed to a deeper understanding of the relationship between fertilizer projection velocity, spreader blade strength, and flow behaviour, enabling the reduction of waste in granule fertilizer, while enhancing the operational efficiency and reliability of fertilizer spreader.

1. Introduction

Fertilizer spreaders are important tools in modern agriculture, playing a crucial role in evenly distributing granule fertilizer across vast palm plantations and other agricultural landscapes. The efficient distribution of granule fertilizer is essential for optimizing crop growth and increased yield. Additionally, their role in even nutrient distribution is crucial for healthy crop growth and yields. The success of these spreaders lies in their spreader machine design, ensuring nutrients are delivered

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https://doi.org/10.37934/arfmts.114.2.214226

precisely where needed, avoiding wastage, and promoting plant health. To achieve efficient granule fertilizer distribution, manufacturers carefully design fertilizers tailored to specific agricultural needs. Some custom formulations worked in harmony with the spreader's capabilities, enabling precise projection of nutrients across palm plantations. Ongoing research and development [1,2] strive to create more effective fertilizers to address different crops and soil requirements.

The spreader blade design is at the core of fertilizer spreaders' effectiveness. A well-designed blade ensures uniform fertilizer projection, enhancing distribution outcomes. Engineers constantly seek to improve blade designs for better efficiency and reliability, achieving accurate fertilizer projection speeds and directions while minimizing waste. The influence of spreader design becomes crucial when considering open and closed side discharge fertilizer spreaders [3]. Open side discharge spreaders cover a broad area, ideal for large palm plantations [4], but they may experience drift and uneven distribution due to wind [5]. Closed side discharge spreaders provide targeted application, reducing drift, but may require more passes to cover the whole plantation.

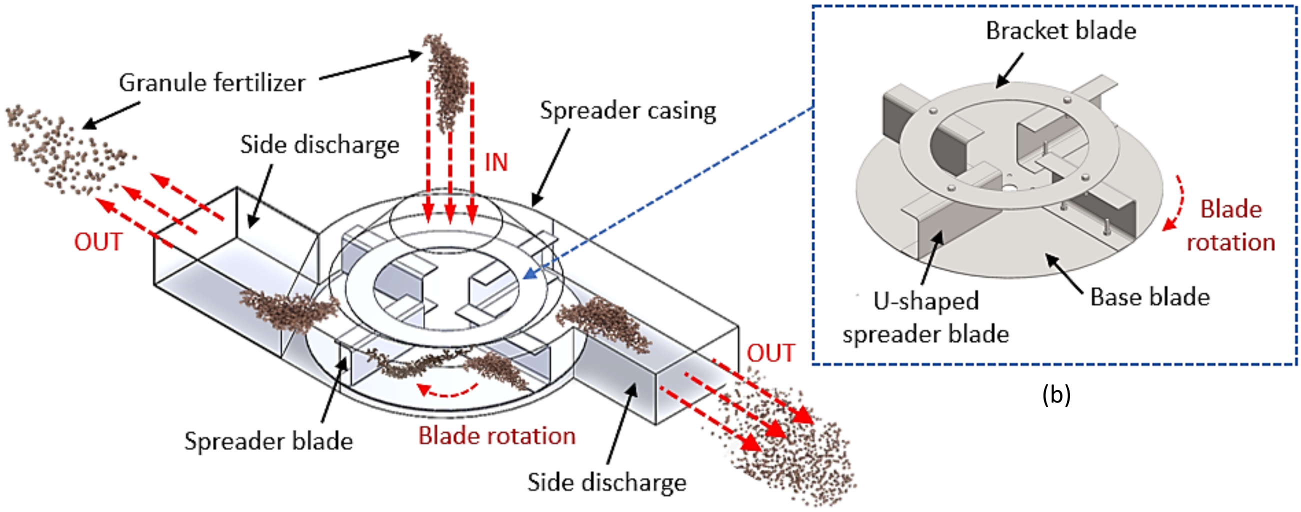
Achieving the optimum range of fertilizer distribution relies on understanding the interplay between fertilizer projection velocity, spreader blade strength, and flow behaviour. Analysing these factors helps engineers develop sophisticated fertilizer spreaders that deliver nutrients accurately and consistently [6,7]. Problems related to fertilizer spreader design and distribution methods drive agricultural research. Irregular fertilizer distribution of nutrients can affect crop growth and overall farm productivity [8]. Innovative technologies are continuously pursued to create precise and efficient fertilizer spreaders, minimizing resource wastage and environmental impact.

The importance of achieving optimal granule fertilizer distribution extends beyond palm plantations. Different crops and soil types require tailored nutrient applications. Versatile fertilizer spreaders play a crucial role in adapting to various agricultural settings and enhancing overall crop health and yield. Therefore, fertilizer spreaders are essential tools for efficient and uniform fertilizer distribution. To ensure nutrients reach crops effectively on large-scale palm plantations, the study was focused on investigating the existing fertilizer design using Finite Element (FE) and Computational Fluid Dynamics (CFD) simulations. Suggested future enhancements in the spreader blade design as well as in the fertilizer spreader machines aim to promote sustainable and productive agriculture by considering how fertilizers move through the air and how they are released from the spreader. These improvements are essential in meeting the global demand for better palm yield and reducing waste.

2. Methodology

2.1 FE Simulation of Spreader Blade

Information obtained from the field trip to the Ladang Green, Sawit Kinabalu Sdn Bhd in Gomantong, Sandakan, Sabah has been used as an important input to the granule spreader machine operation, spreader design and spreader blade material. Figure 1(a) shows the existing spreader fertilizer machine, which has a spreader blade and casing. The granule fertilizer goes into the centre part and moves towards the blade. The blade rotates at the same speed as the tractor shaft and forces the fertilizer out of the spreader system through the side discharge. This geometry shown in Figure 1(a) was used for fertilizer flow analysis using the CFD simulation. The valve of the side discharge could be open on one side or both sides for the fertilizer flow projectile motion analysis. Figure 1(b) displays a spreader blade made up of three main parts: the blade, the base blade, and the bracket blade. The base blade and bracket blade are thin plates with a hole in the middle. They support and hold the U-shaped blade. This blade geometry was used to investigate the material strength of the spreader blade using FE simulation.



(a)

(b)

Fig. 1. The spreading mechanism and components of the existing spreader fertilizer machine for palm plantation

Regarding the materials used, the spreader blade was made from mild steel AISI1018. A thin layer of paint coating was applied to the steel surfaces. This paint coating serves two purposes: to protect the steel from corrosion and to enhance the spreader's reliability in the palm plantation's climate and weather conditions. The general properties of the spreader blade material are listed in Table 1.

Table 1
The material properties of the spreader fertilizer blade

Material properties	Values
Density	7,850 kg/m3
Ultimate Tensile Strength	400-550 MPa
Yield Strength	250 MPa
Young’s Modulus of Elasticity	210 GPa
Poisson’s Ratio	0.3
Brinell Hardness	120 BHN
Melting Point	1,450 °C
Thermal Conductivity	50 W/mK
Heat Capacity	510 J/g K

Figure 2 shows mesh sensitivity analysis performed on the FE simulation of the spreader blade. The best mesh element size was found to be 5, resulting in an optimized number of mesh elements and equivalent stress deformation in the spreader blade. Therefore, there is no need to use a smaller mesh element size because it would give similar stress results. Additionally, using smaller elements would increase the number of mesh elements required in the simulation, leading to higher computation costs for the FE simulation [9]. In this study, a mesh element size of 4 mm was selected as the pre-processing parameter. This choice was made because a 4-mm mesh element size approached steadiness and had fewer elements compared to a 5-mm size, which was almost double the number when using 4 mm. Thus, using a 4-mm mesh element size led to more efficient processing time while maintaining high-quality accuracy.

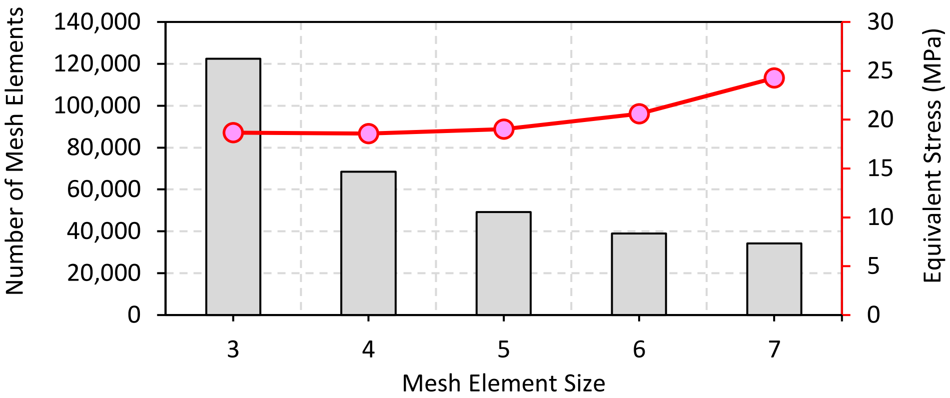
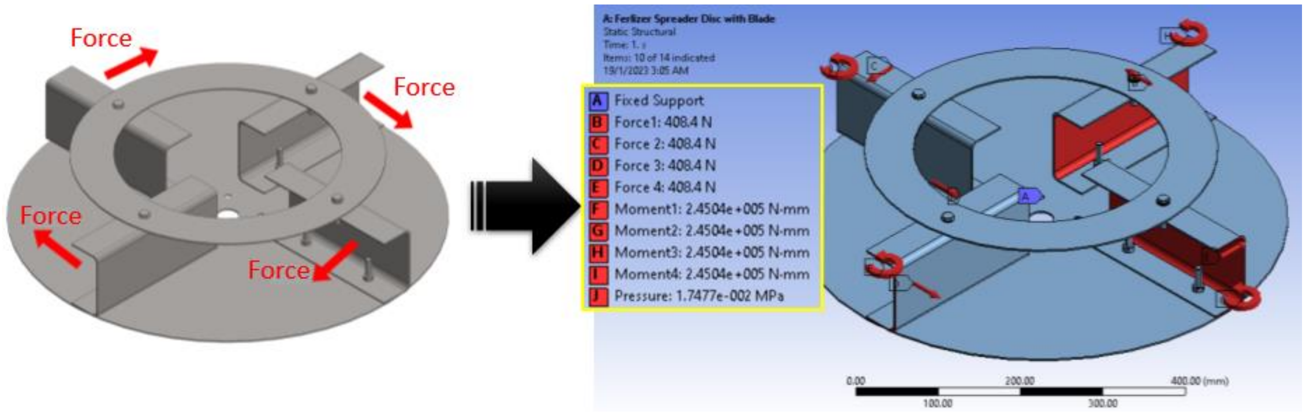


Fig. 2. Mesh sensitivity analysis for the FE simulation of the spreader blade

In the spreading process of the fertilizer, the force is exerted by the blade on the fertilizer to push it out to the farming load. Figure 3(a) shows the direction of the pushing force. However, in the FE simulation of the spreader blade using Ansys software, such ways of applying the pushing force in the simulation has caused the force to be recognized as the tensile force on the blade, and this has resulted in the exactly different outcome of deformation and stress analysed. If applying the force at the back side of the blade, the different geometry may result in inaccurate results. Hence, to obtain the real accurate result, the boundary conditions were performed on the fixed support at the base blade, where the shaft and base were connected.

Figure 3(b) shows the force was applied to the blade in the opposite direction, which meant that the force loading conditions were applied and analysed in the exactly opposite orientation. It was found out that such settings of applying the load towards the blade replicated the real situation of loading conditions accurately. Although the direction of force exerted was in the opposite direction, the result of the structural analysis on the disc with blade was aligned with the real application. Thus, the FE simulation was performed by applying the moment at the outermost surface to observe the effect of the maximum moment. Then, the pressure was applied on the curved edge in the inner surface of the blade, as there was the weakest point where the failure was more likely to occur. In this study, the mass flow rate of approximately 520 kg/min was assumed, meanwhile the blade rotation speed was set to 1,500 rev/min. The value of the blade rotation speed match the operating speed of the fertilizer spreader machine used at Ladang Green, Sawit Kinabalu Sdn Bhd, based on information gathered during the authors' communication with the company representative during the field trip in Gomantong, Sandakan, Sabah.



A: Ferlizer Spreader Disc with Blade
Static Structural
Time: 1. s
Items: 10 of 14 indicated
19/1/2023 3:05 AM

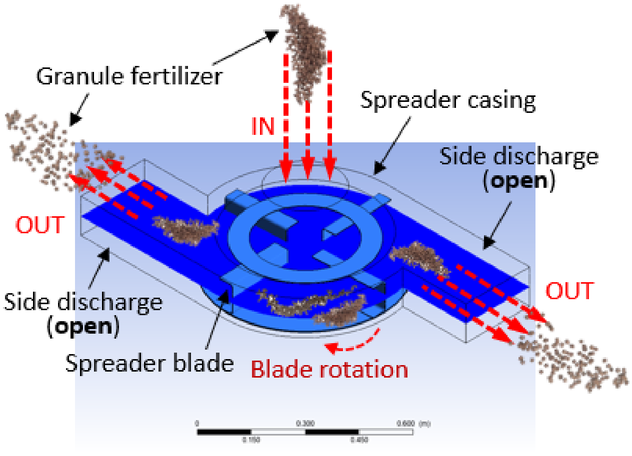
- A Fixed Support
- B Force1: 408.4 N
- C Force 2: 408.4 N
- D Force 3: 408.4 N
- E Force 4: 408.4 N
- F Moment1: 2.4504e+005 N-mm
- G Moment2: 2.4504e+005 N-mm
- H Moment3: 2.4504e+005 N-mm
- I Moment4: 2.4504e+005 N-mm
- J Pressure: 1.7477e-002 MPa

(a) (b)

Fig. 3. Boundary conditions setting in the FE simulation of the spreader blade

2.2 CFD Simulation of Fertilizer Spreader

To examine the effects of varying speeds on the movement of the fertilizer projection, Ansys-CFX immersed boundary method was used for fertilizer flow analysis simulation of a rotating blade in air. The blade was selected as the solid domain, which rotating at 20 rad/s. The spreader casing was set as the boundary of the fluid domain, and air was set as the fluid flowing within the designated boundary restricted by the fertilizer spreader housing. Using the Ansys CFX simulation, the solid domain was immersed in the fluid domain to simulate the interaction between fluid and solid objects without explicitly meshing the solid boundaries. The immersed-solid method used in the CFD simulation was a wall-boundary choice in the commercial software Ansys CFX. This has put the solid domain into the entire fluid domain. This was done by adding a momentum source to the fluid domain, which forced the fluid to move with the solid. The immersed-solid method was an effective tool for simulating the interaction between fluids and solids [10], which further simplified the simulation process and reduced computational costs. As seen in Figure 4, the CFD simulation of fertilizer spreader was performed when one valve is closed on one side (Figure 4(b)) compared to the standard condition of both valves being open (Figure 4(a)). According to the conversation between the authors and the company representative during the field trip at the Ladang Green, Sawit Kinabalu Sdn. Bhd., this setting was found to be crucial. It replicates the real operation of fertilizer being discharged through the valve during fertilizer spreading on flat and inclined fields in the palm plantation.



(a) (b)

Fig. 4. (a) The spreader fertilizer with side discharge valve open on both sides and (b) with open one side only during fertilizing operation: including the point of analysis

2.3 Fertilizer Projectile Motion

To estimate the projection of fertilizer during the fertilizer spreading operation as presented in Figure 5, the kinematic equation for projectile motion [11] shown below were used.

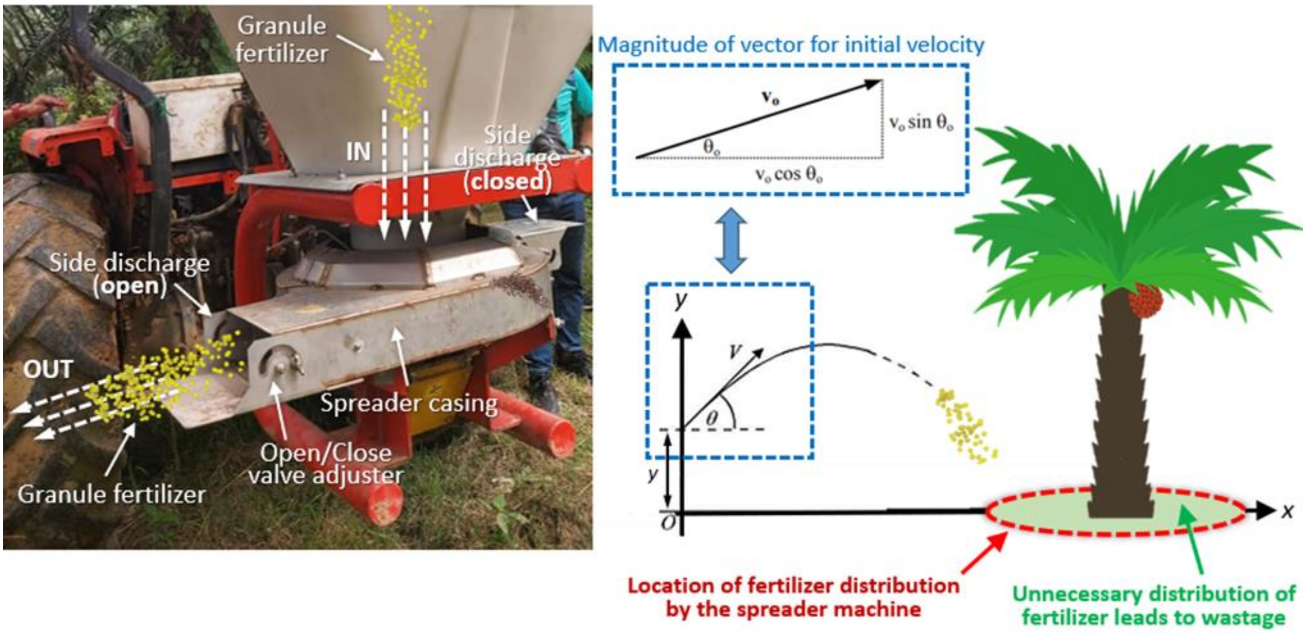
$$X = v_0 \cos\theta_0 \, t \tag{1}$$

$$v_x = v_0 \cos\theta_0 \tag{2}$$

$$y = \frac{1}{2} g t^2 + v_0 \sin\theta_0 \, t + y_o \tag{3}$$

$$v_y = v_0 \sin\theta_0 + gt \tag{4}$$

where X is range, v_0 is initial velocity vector, θ_0 is angle of direction, g is gravity, t is time of flight, y is height at point and v_y is vertical velocity.



(a) (b)

Fig. 5. (a) Fertilizer spreading mechanism showing (b) projectile motion of the fertilizer particle to reach the designated area (Green-dotted line) near the palm tree

3. Results and discussion

3.1 Strength Analysis for Fertilizer Spreader Blade

The deformation of the spreader blade shows how well it can handle applied forces. When force is applied to the spreader blade, it undergoes deformation, and the material's strength directly affects the amount of deformation it experiences. The material's strength is crucial in determining the magnitude of deformation. The FE simulation results for the existing spreader fertilizer blades are depicted in Figure 6. In the FE simulation, the applied forces were set to 300N, 400N, and 500N, resulting in maximum total deformation $d_{\max}$ values of 0.44471 mm, 0.59294 mm, and 0.74118 mm, respectively. This result showed that the blade experienced very little deformation, suggesting it can handle the forces well due to low strain on its structure. Moreover, using mild steel AISI1018 has shown that the spreader blade may not fail under these conditions. Therefore, there is no need for additional heat treatment to improve the blade's material properties. However, this analysis did not consider severe wear, which needs further evaluation to understand how the blade surface reacts under different contact loadings and speeds. For the blade's reliability and lifespan, the authors believe that erosive or abrasive wear might happen if the blade surface is exposed to severe weather conditions in the palm plantation.

The stress deformation that happens to the blade structure is essential in deciding how safe and strong the blade is during the granule fertilizer spreading. If the stress surpasses the material's strength, it will lead to failure [12]. As seen in Figure 7(a), Ansys Workbench software was employed to analyse the stress deformation occurred to the blades by looking at Von Mises stress values for varying applied forces of 300N, 400N, and 500N in the FE simulation of the spreader fertilizer blade.

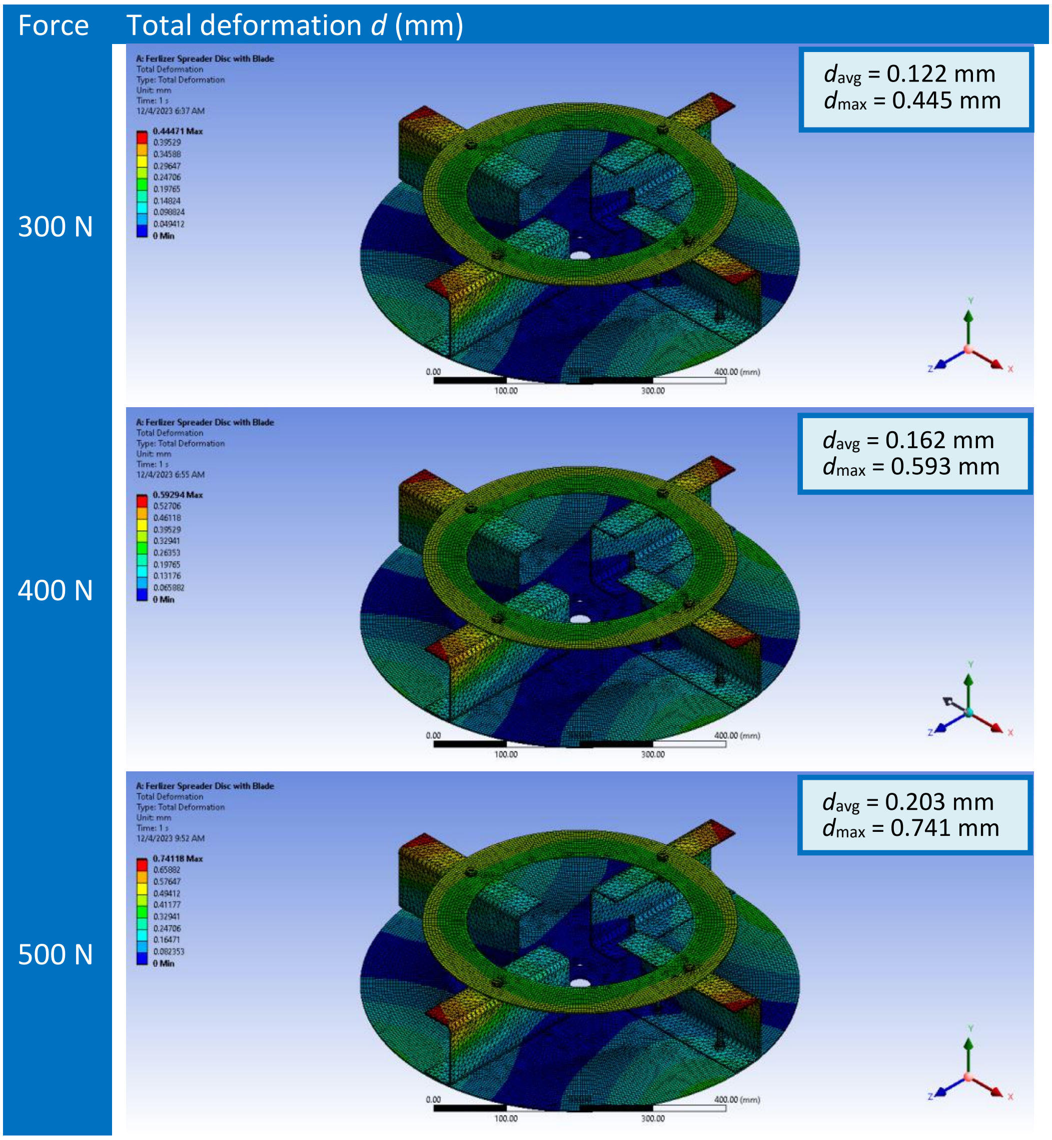
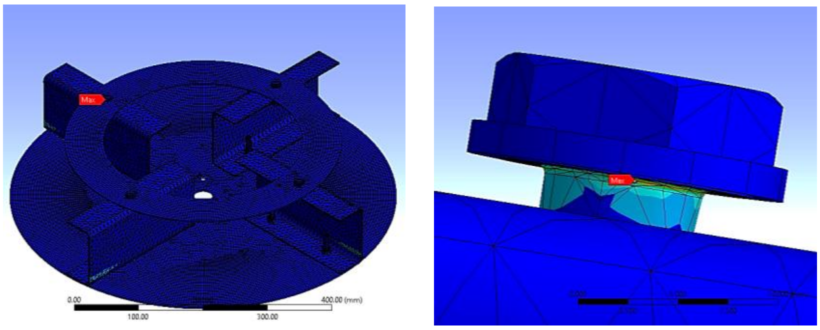


Fig. 6. Total deformation occurred to the spreader blade at different applied forces; 400 N to 500 N



(a) (b)

Fig. 7. The area of the maximum value for the Von Mises Stress; (a) Overall View; (b) Zoom in view on the neck-to-body junction of the bolt

Table 2 presents the maximum Von Mises stress values obtained were 220.78 MPa, 294.37 MPa, and 367.96 MPa for the respective applied forces. Conversely, the minimum Von Mises stress values recorded were 5.155 x 10-8 MPa, 6.873 x 10-8 MPa, and 8.592 x 10-8 MPa, respectively.

Table 2
The value of the Von Mises Stress for variable load 300N, 400N, and 500N

Force	Von Mises Stress (MPa)		
applied (N)	Minimum	Average	Maximum
300	5.155×10^{-8}	4.4854	220.78
400	6.873×10^{-8}	5.9806	294.37
500	8.592×10^{-8}	7.4757	367.96

It is important to note that the magnitude of the applied force directly influences the Von Mises stress, with increasing loads resulting in higher stress values, see Figure 8. Figure 7(b) shows the highest stress concentration was observed in the area surrounding the bolt connecting the brace blade and the spreader blade. Consequently, the choice of bolt material plays a vital role in enhancing the durability and lifespan of the spreader fertilizer blade, preventing failure. These results revealed that the spreader blade had experienced minimal stresses, as evidenced in Figure 6 with low strain levels were obtained with the similar applied forces.

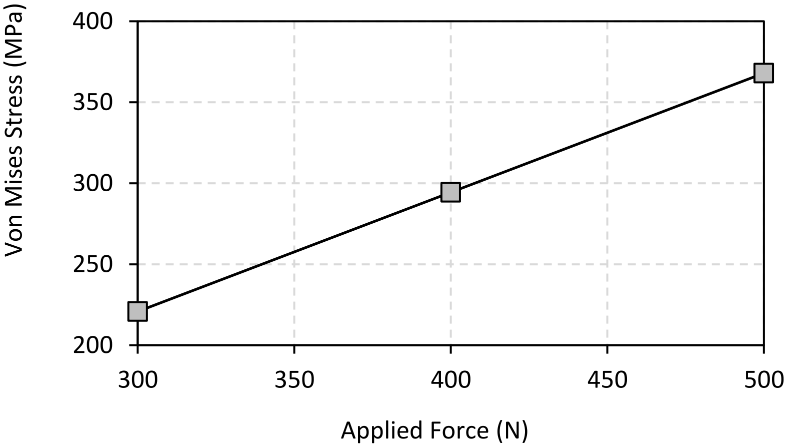


Fig. 8. The relationship between Von Mises stress and applied load forces 300N-500N

3.2 CFD Simulation of Spreader Fertilizer

Figure 9 illustrates the mechanism of the fertilizer spreader machine, depicting two different conditions

i. when the valve is open on one side
ii. when it is open on both sides.

The figure includes markers indicating the measurement points for velocity and pressure. Both conditions were subjected to the same boundary conditions, including standard environmental factors and a fixed rotation blade speed (rev/min). The velocity and pressure measurements were taken at Point 1 for the valve open on one side and at both point 1 and point 2 for the valve open on both sides. By comparing the results obtained at point 1 for both conditions (valve open on both sides and valve open on one side), the effects of the valve configuration as marked in Figure 9 on the measured variables. The velocity measured at point 1 varies between the two conditions, with the valve open on both sides representing the standard configuration for the granule fertilizer spreader. Figure 9 shows the velocity at valve one side open condition is larger than the valve open both sides. In contrast, when controlling only one side of the valve, adjustments were made to the projectile control component. These adjustments were necessary to regulate the distance at which the fertilizer is spread. The reason behind this is the importance of the relationship between fertilizer granule spreading trajectory, fertilizer spreading field, and spreading volume distribution [13,14] for achieving even and controlled spreading of granular fertilizer.

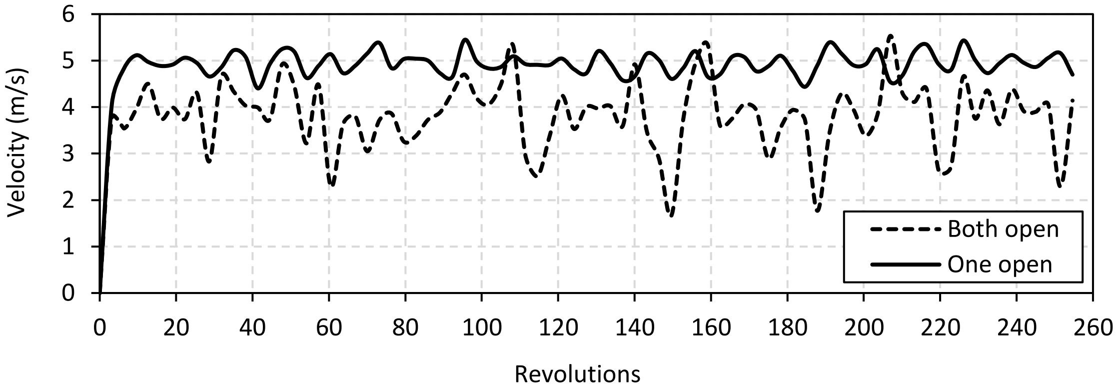


Fig. 9. The velocity on point 1 of fertilizer spreader for two valve conditions

3.3 Projection Motion

The measured average velocities at point 1, as shown in Table 3, offer essential information about the fertilizer spreading process. Lower power for translating kinetic energy leads to a more efficient distribution of fertilizer granules. It also requires less power for striking and granulating the distributed material with the blades, overcoming friction forces of the material on the blades, air friction during blade rotation, and friction in the blade support [15]. This analysis demonstrates the significance of optimizing power usage to enhance the efficiency and effectiveness of the fertilizer spreading mechanism. The inclusion of gravity (9.81 m/s) in the calculation accounts for the influence of Earth's gravitational force on the projectile motion of the granule fertilizer. Additionally, the limitation of the projectile range to X = 2 meters, as recommended by the company representative during the field trip at Ladang Green in Gomantong, Sandakan, Sabah, ensures a relevant and practical analysis.

Table 3
The angle of direction and time taken to particle reach distance X = 2 m, where g = 9.81 m/s

	Initial Velocity, v_0		Angle of Direction, $\boldsymbol{\theta_0}$ and Time, t			
	One Open	Both Open	One Open		Both Open	
			$\boldsymbol{\theta_0}$	t	$\boldsymbol{\theta_0}$	t
Average	4.947 m/s	3.826 m/s	69°	1.15 s	52° 11°	0.86 s 0.52 s
Maximum	5.446 m/s	5.530 m/s	72°	1.2 s	73°	1.24 s
Minimum	4.402 m/s	1.660 m/s	63°	1 s	-	-

Figure 10 further illustrates the average velocity at point 1, revealing that a higher velocity was achieved when one side discharge was closed. This observation implies that the spreader may be releasing an excessive amount of granule fertilizer, potentially leading to wastage and uneven distribution. As a result, a specific method must be devised to control the amount of granule fertilizer entering the spreading area. By doing so, unnecessary particles can be minimized, ensuring a more efficient and targeted application of fertilizers to the designated areas near the palm trees (Green-dotted line) as depicted in Figure 5.

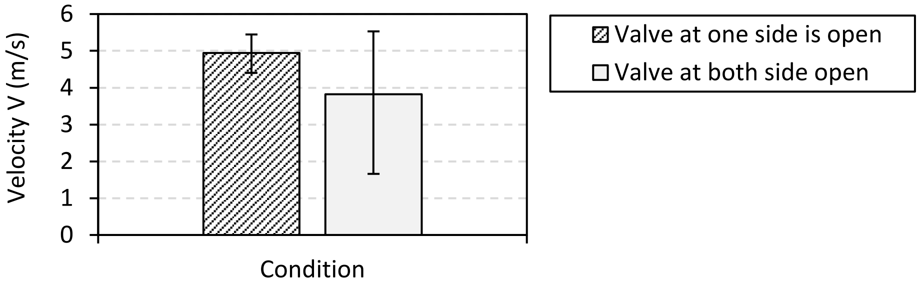
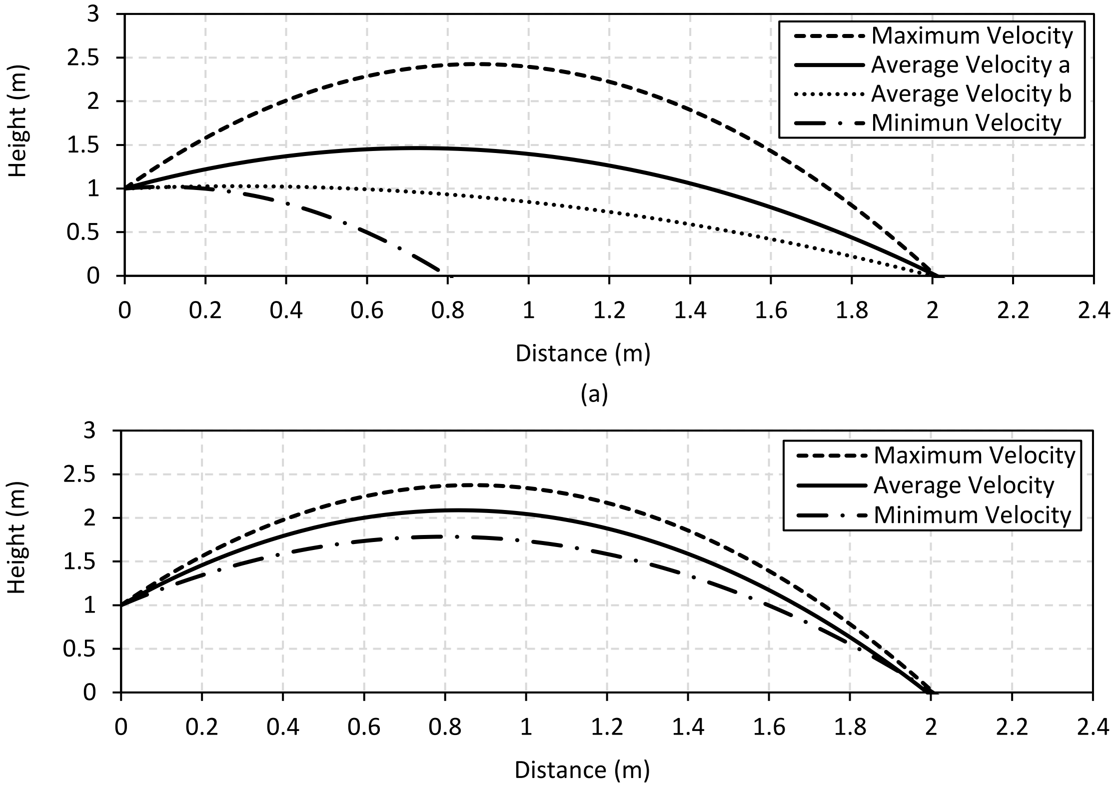


Fig. 10. The average velocity at different condition at point 1

To gain a deeper understanding of the impact of the initial velocity, the calculations were performed using equations 1 to 4 for measuring the angle of direction and time taken for particle reach to the ground at a distance of 2 m. The summarized results in Table 3 present projectile motion and its reaction time analysis of the granule fertilizer in the case of the valve open at both sides and at one side only. Figure 11(a) illustrates the projectile motion of a particle under various velocity conditions when both valves are open. At average velocity, the particle can reach a distance of 2 m and touch the ground under two different conditions: an angle of projection of 52° with a time of flight of 0.86 s and an angle of 11° with a time of flight of 0.52 s. Additionally, the particle achieves its maximum distance of 0.8 m with an angle of projection of 22° and a time of flight of 0.5 s when launched at minimum velocity. At maximum velocity, the particle reaches its farthest point with an angle of projection of 73° and a time of flight of 1.24 s.

Figure 11(b) depicts the projectile motion of the particle with one valve open. To reach 2 m on the ground, the particle requires different angle of projections for maximum, average, and minimum velocities, specifically 72°, 69°, and 63°, respectively. The corresponding times of flight for these conditions are 1.2 s, 1.15 s, and 1 s. Notably, as the launch angle increases, the time-of-flight increase, the initial velocity must be proportionately increased to maintain a constant range. This finding has significant implications for the fertilizer spreading operation. Properly adjusting the initial velocity ensures that the desired range is achieved, which is critical for effective fertilizer distribution on both flat and inclined land. By carefully considering the measured velocities and the effect of the initial velocity, this study emphasizes the importance of precision in fertilizer spreading. The results obtained indicate that controlling the initial velocity can lead to a more optimized and uniform distribution of granule fertilizer. Such precision is essential for maximizing the efficiency of the fertilizer spreading process and minimizing waste. These findings offer valuable insights for improving agricultural practices, ensuring that palm plantations and other crop fields receive the necessary nutrients in an efficient and sustainable manner.



(a)

(b)

Fig. 11. The projectile motion of the particle; (a) The valve at both sides open; (b) The valve at one side is open

4. Conclusions

In conclusion, this study achieved its objective successfully. It began by designing a spreader fertilizer system using Solidworks CAD software, and then conducted material strength analysis and flow behaviour calculations using Ansys simulation software, specifically utilizing Finite Element Method (FEM) and CFX immersed solid techniques.

The effects of applied forces on strength analysis, specifically Von Mises stress and deformation, were assessed based on the existing fertilizer spreader blade design. It was observed that as the applied forces increased, both Von Mises stress and deformation also increased. However, when using mild steel AISI1018 in this case, the spreader blade likely withstood these conditions, indicating no need for extra heat treatment to improve its material properties. The analysis carried out did not investigate the wear and tear on the blade surface, which requires additional evaluation to understand how it responds to different contact loadings and speeds. In this regard, the authors acknowledged that erosive or abrasive wear could potentially affect the blade's durability and lifespan when exposed to harsh weather conditions in the palm plantation. As a result, the possibility of implementing heat treatment or exploring different material types may be suggested as potential approaches to enhance the blade's lifespan.

On another note, the study explored into the relationship between velocity and the angle of direction during fertilizer spreading, yielding valuable insights. It was found that when the valve was open on one side, the velocity was higher compared to both sides, and the velocity had a notable impact on the angle of direction. To ensure a consistent fertilizer spreading range, it was established that the initial velocity should increase proportionally with the angle of direction.

For future improvements, a comprehensive investigation into the effects of wear on the blade surface is recommended to enhance the spreader's durability. Exploring alternative materials with better wear resistance and advanced protective coatings can potentially extend the spreader's lifespan. Additionally, optimizing the spreader's design to minimize fertilizer wastage and achieve uniform distribution offers an avenue for more efficient and environmentally friendly fertilizer spreading practices, benefiting agricultural productivity and sustainability.

Acknowledgement

This research was funded by a grant from Ministry of Higher Education of Malaysia (PRGS Grant: PRGS/1/2021/WABO4/UMS/03/1, and PRGS0014-AGR-1/2021). The authors gratefully acknowledge the support from Forest Plantation & Agroforestry, Faculty of Tropical Forestry, Universiti Malaysia Sabah and Sawit Kinabalu Sdn. Bhd. for a field trip to observe the testing of the existing fertilizer spreader machine at the Ladang Green, Sawit Kinabalu Sdn. Bhd. in Gomantong, Sandakan, Sabah. The authors appreciate the support received from Universiti Putra Malaysia (GP-IPM: UPM/GP-IPM/2022/9717500) and the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, for providing the simulation.

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