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The impact of The Physical Properties of Fertilizers and The Design of The Machine on The Performance of a Chemical Fertilizer Spreader Operating With a Variable Rate System.

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Abstract
Agricultural mechanization is crucial to accelerating farming operations and increasing the area under cultivation of various crops since technology reduces costs, shortens working hours, and provides control over numerous factors that affect production. Granular mineral fertilizers are frequently distributed using centrifugal disc spreaders because of their excellent distribution efficiency, ease of construction, and ease of usage. Having precise fertilizer placement results in lower costs and more productive output. Despite differences in soil properties and spatial diversity within the field or among plants, Variable Rate Technology (VRT) is used to guarantee that every plant receives an equal amount of nutrients.. Fertilizer application performance is considered to depend approximately one-third on the fertilizer, one-third on the spreader, and one-third on the operator's characteristics. As a research objective, the centrifugal fertilizer spreader was adapted to operate using electric power supplied by the tractor instead of the PTO, in order to reduce the load on the tractor engine. The spreader's operation is managed by an electronic circuit that allows adjustment of the application rate and the rotational speed of the spreading disc, thus controlling the spreading width behind the tractor. A factorial experiment of the RCBD type was conducted to evaluate the fertilizer granule breakage rate under the influence of two factors: disc angular speed and blade angle. In the conventional method, the average breakage rate was 9.6%, while the highest value recorded under the VRT system was 6.9%. A noticeably higher breakage rate was observed at the -25° angle with increasing speed. More stable breakage rates were recorded at 0° and 25° angles when using disc rotational speeds of 500 or 550 rpm. The effect of these factors, in addition to the tractor's forward speed, had a minimal impact on the electric power consumption per hectare.

Keywords: Centrifugal Disc Spreaders , Breakage Rate , Power Consumption , VRT

1 Introduction

Throughout history, agriculture has been one of the most significant human activities. In this context, considerable effort has been made to save time and labor by using animals and machines, integrating them with agricultural tools to carry out various farming tasks. This development has continued, particularly with the emergence and dominance of industrial agriculture in agricultural production[2]; [9]; [13]. Among the essential elements of agriculture, agricultural mechanization plays a crucial role in accelerating the completion of farming operations and increasing the cultivated area of various crops by reducing costs, shortening working hours, and enabling control over many factors affecting productivity [7] [8]; [10]. According to [11], approximately 15% of total production costs on a farm are related to energy. The energy consumption of rotary equipment is a pivotal indicator of its operation, in conjunction with qualitative characteristics of productivity and performance. However, studies addressing the amount of energy consumed by rotary machines based on their design factors and operational systems are scarce. In the majority of cases, energy consumption is analyzed using basic mathematical models without modifying machine characteristics

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[4]. At high engine speeds, certain agricultural machines waste fuel and energy since they need very little power at normal rates. Stated differently, this application is not cost-effective. Another critical factor that significantly affects crop growth and yield is the pattern of fertilizer distribution in the field. The pattern is found to be directly influenced by the physical properties of the fertilizer, with these properties exerting a direct effect on the ballistic behaviour and particle trajectories of the fertilizer. Furthermore, the study revealed that both the type of fertilizer spreader and the operator had a significant impact on the outcome [6]. Mechanical durability (strength) or granular strength index is a measure of the ability of a body to withstand mechanical influences such as granular abrasion due to friction during handling and transport, during spreading on the soil surface by a centrifugal fertilizer spreader, or incorporation into the soil upon spreading [12]. According to the American Society of Agricultural and Bioengineering Engineers (ASABE) standard (ASAE S368.4 DEC2000 (R2017) for compressing spherical materials, both the Poisson's ratio and the modulus of elasticity can be measured using a compressive testing machine. The granules are placed individually on a fixed metal base and then a flat cylindrical probe is slowly lowered to apply pressure to the urea granule particle sample. When the granules reach 20% of their collapse value, the applied pressure is stopped [14] [17]. The mechanical resistance index of the granules directly affects the rotation speed of the spreader disc and thus the spreading width. Fertilizers with high resistance are spread over a wide width due to their ability to withstand the impact force with the fins on the disc surface during high-speed rotation (<800 rpm), while less resistant fertilizers are spread over a smaller width [5].

1.1 Granule size classification

Based on the ballistic motion acquired by the fertilizer granules as they roll on the rotating disc, larger granules will be ejected farther than smaller granules. This affects the spreading width and leaching. Conversely, the larger the particle size, the longer it takes for the product to decompose and dissolve at a constant rate [16]. Fertilizer granule sizes, including urea fertilizer, are determined according to the American Society of Agricultural and Biological Engineers (ASABE) standard [1]. This standard involves measuring particle size distribution using sieves with specific mesh sizes. The standard recommends stacking the sieves in descending order of size, with the largest mesh at the top and the finest mesh at the bottom. The collection tray is placed underneath. The particle size distribution is expressed as a percentage of the total sample retained in each sieve by using an electronic scale with two decimal places. This is used to describe the particle size distribution and consistency of grain sizes, as well as the homogeneity index and size guide number (SGN). Meeting the particle size requirements in 1 ensures the fertilizer performs efficiently in agricultural environments. The SGN is typically calculated by measuring the volume of a sample of fertilizer granules and then taking the square root of the weight of the fertilizer retained in a series of sieves equation (1) [1].

1.1.1 Size Guide Number (SGN) [15]

$$\text{SGN}=(\left(\frac{\sum(\text{D}\times\text{ration})}{100}\right)\times 100 \qquad (1)$$

$$\text{SGN} = (\frac{\sum(20.65\times3.675)+(69.45\times2.675)+(0.95\times1.5)}{100})\times 100$$

1.1.2 Uniformity Index (UI)

A UI study is essential to reduce the environmental impact resulting from misallocation or overuse equation (2).

$$\text{UI}=\left(\frac{D_{60}}{D_{16}}\right)\times 100 \qquad (2)$$

- **D60**: The diameter under which 60% of the total weight (passing through the sieves) is retained.
- **D16**: The diameter under which 16% of the total weight is retained.

The D_{60} and D_{16} values are determined using linear interpolation, according to the following equations:
To calculate $\mathbf{D_{60}}$ by interpolation between the 3.35 mm sieve (70.39%) and the 2 mm sieve (0.95%), the following equation (3) is used:

$$D_{60} = D_s + \left(\frac{60-P_s}{P_b-P_s}\right) \times (D_b - D_s) \qquad (3)$$

- **Db**: Larger sieve size (mm)
- **Ds**: Smaller sieve size (mm)
- **Pb**: Higher percentage of passing material (corresponding to Db)
- **Ps** :Lower percentage of passing material (corresponding to Ds)

2 Material and Methods

2.1 Applied Machine

The Variable Rate Reduction (VRT) system is designed to be compatible with the modified Agri Saglam 400-liter single-disc fertilizer spreader, which operates via a power take-off (PTO) shaft to rotate the spreading disc, as well as the mixer located inside the fertilizer bin, as shown in Figure (1). Length (mm) 1140, width (mm) 1030, height (mm) 1108, volume (liters) 400, and weight (kg) 130. The VRT system consists of two components: the mechanical part and the electronic circuit, which operates the mechanical part based on data entered into the system by the farm manager. The mechanical part consists of a gate opening and closing lever located below the fertilizer hopper, which is a sliding hinge. The lever moves as a result of the rotation of a four-groove shaft within the hinge, driven by a stepper motor. The electronic circuit consists of an Arduino Mega 2560 R3 microcontroller, Node MCU CP2102, GPS NEO-6M Module, Stepper Motor Driver Controller 4A, High Power Motor Driver, Stepper Motor, and DC Geared Motor. The vehicle is mounted behind a 2005 Massey Ferguson 285S tractor equipped with a 4.1 L (248 cu in) Perkins A4.248 four-cylinder diesel engine. This engine has a compression ratio of 17.5:1 and operates at a rated speed of 2,000 rpm. The cylinder bore is 100 mm (3.923 in) and the stroke is 127 mm (5.00 in). It uses an oil sump air cleaner and has a 12-volt electrical system. The engine oil capacity is 9.5 L (10 qt), and the coolant capacity is 15.6 L (16.5 qt). This engine produces approximately 81 horsepower at the power take-off (PTO) shaft, with a towing capacity of up to 69.46 horsepower.

Figure–1 Agri Saglam 400-liter single-disc fertilizer spreader Connected with Massey Ferguson 285S tractor

2.2 Mechanical Impact

Laboratory testing was conducted in accordance with ASAE S368.4 DEC2000 (R2017). This standard is based on the Hertz equations for contact stresses used in solid mechanics. This standard is intended to be used to determine the mechanical properties of granular materials and their resistance to mechanical damage resulting from static loading [3]. Fully automated testing equipment was used, such as the Techlab Systems Instron Universal Testing Machine Figure (2), with a force range of 10 to 5000 N (accuracy 0.01% = 0.5 N) and selectable units in Newton-kg and pound-feet. The machine's maximum speed was 125 mm/min, and the statistics determined included maximum, minimum, average, and standard deviation. Twenty samples of fertilizer granules were tested, and the compressive strength was 5.64×106 Pa. The pressure exerted by the spreader disc on the fertilizer granules at speeds (600, 550, 500) rpm is (5.66×103, 4.75×103, 3.93×103) Pa, respectively. The test was conducted by suspending the machine behind the agricultural tractor. A chamber was made of three walls made of synthetic cork covered with a layer of air tarpaulin to reduce the effect of other factors such as the collision of fertilizer granules with other objects and to limit the effect of the machine only during the test. The ribs were 125 cm long and 125 cm high as shown in Figure (3). The mechanical impact test of the machine was conducted on the fertilizer granules before undergoing modifications to make it work with the variable rate technology. The average crushing rate was 10.04%, which is considered a high percentage compared to the results obtained during the machine's performance with the variable rate technology.

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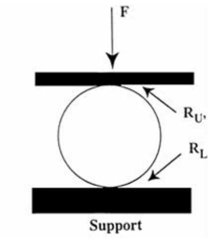

Figure-2 the Techlab Systems Instron Universal Testing Machine

Figure–3 chamber of synthetic cork covered with a layer of air tarpaulin

2.3 Machine Power Consumption Test.

A factorial test with three replicates was conducted to measure electrical power consumption at the Agricultural Extension Department farm located in the Shatra District of Dhi Qar Governorate. Three factors were used: the angular speed of the disc (600, 550, 500) rpm, the angle deviation of the blades on the disc (-25, 0, 25) degrees, and the machine's forward speed (15, 12, and 9) $km.h^{-1}$. This was to demonstrate their effect on the operation of a variable rate fertilizer spreader at a temperature of 42°C and a brick percentage of 20%. A multimeter (DC 6.5-100V 0-50A LCD Display Digital Current Voltage Power Energy Monitor) Figure (4) was installed on the low voltage electrical circuit to display the current, voltage, power, and energy consumed by the VRT system. The machine was operated for equal periods of time, both empty of fertilizer and full of fertilizer. The machine is operated by an electrical circuit that works according to the data sent to it by the system connection via an open source Node MCU CH340 unit used to build LOLIN V3 devices and connects it to the Internet via Wi-Fi through the ESP8266-12E chip that is managed by Tap Samsung with the pre-prepared program Figure (5) by controlling the amount of the feed gate opening and the angular velocity of the disc, in addition to the amount of power consumed by the mixer located inside the hopper.

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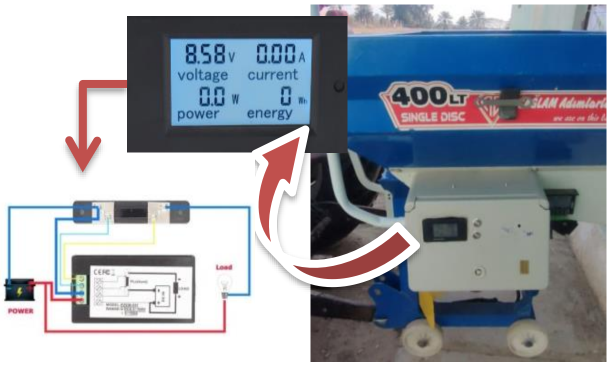

Figure–4 DC 6.5-100V 0-50A LCD Display Digital Current Voltage Power Energy Monitor

Figure–5 Tap Samsung with the pre-prepared program

3 Results and Analysis

3.1 Physical Properties of Fertilizer Granules

The results of the size analysis of the fertilizer granules for the three samples of fertilizer used, shown in the table (1), showed that the average particle size falls within the ranges of fertilizers used in crop fertilization processes in agricultural fields [3]. The difference in size between the granules is very small, which helps in spreading the fertilizers in a homogeneous manner Figure 3(6).

Table -1-the size analysis of the fertilizer granules

Category	Weight (g)	(%) Percentage	(Average Diameter mm
>4	89.5	—	—
4–3.35	206.5	20.65%	3.675
3.35–2	695	69.45%	2.675
2–<2	9.5	0.95%	1.5
<2 (Total crossing)	—	—	1.0

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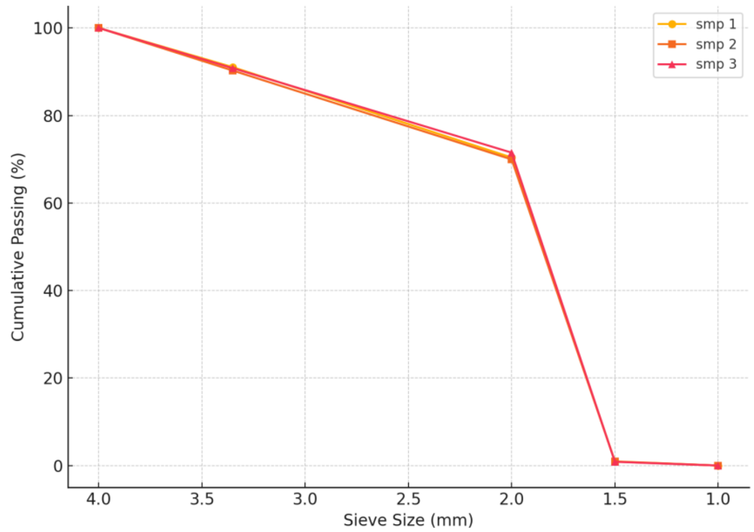
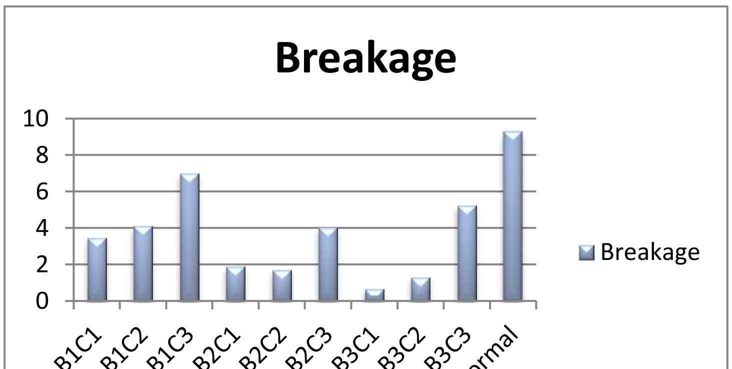


Figure–6- Cumulative Particle Size

The results were obtained after the fertilizer samples were classified using the sieves used to classify the initial fertilizer samples, according to table (2) and Figure **3**(7). The percentage of breakage was determined by the increase in the percentage of fine material (<2 mm) after the test, compared to an average percentage of fine particles of 0.90% before the experiment.

Table -2-the size analysis of the fertilizer granules

Sample	SGN (100 × mm)	UI (%)
smp 1	263.1	137.6
smp 2	262.9	137.0
smp 3	262.3	136.7



Figure–7- The percentage of breakage Distribution

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According to the analysis of variance test, the differences shown in the graph between the results obtained for the crushing ratio are not statistically significant. The values of F = 1.52 and p = 0.292, where p > 0.05, indicate that the rotation speeds tested do not have statistically significant differences in the crushing ratio at the 5% significance level. The effect of the vane angle is slightly higher, falling very close to the significance level, with a p value of ≈ 0.056. This indicates the possibility of a real effect of the angle on the crushing ratio. From the above, we can indicate that the vane attachment angle has a semi-significant effect on the mechanical impact on the fertilizer granules. An HSD analysis was conducted to accurately compare the differences between the vane attachment angles on the crushing ratio of the fertilizer granules table (3). There was no significant difference between the angles 0° and 25°, and the difference between -25° and 0°, as well as -25° and 25°, did not reach the statistical significance level figure (8).

Table -3-Multiple Comparison of Means - HSD, FWER=0.05

group1	group2	meandiff	p-adj	lower	upper	reject
-25	0	-2.38	0.0596	-4.85	0.08	False
-25	25	-2.46	0.0528	-4.94	0.01	False
0	25	-0.08	0.9	-2.55	2.39	False

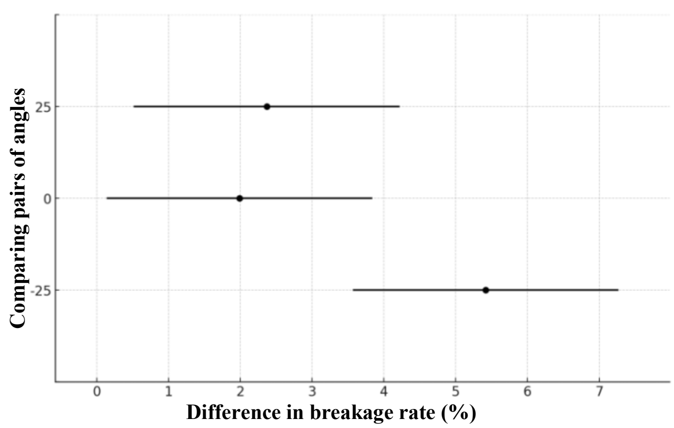

Figure-8-test results chart to illustrate the differences in breakage rate between vane mounting angles: note that the comparisons between -25° and the other two angles approach, but do not exceed, the significant limit.

The interactive diagram in Figure (9) shows the combined effect of the disc rotation speed and the vane installation angle on the fertilizer granule breakage rate.

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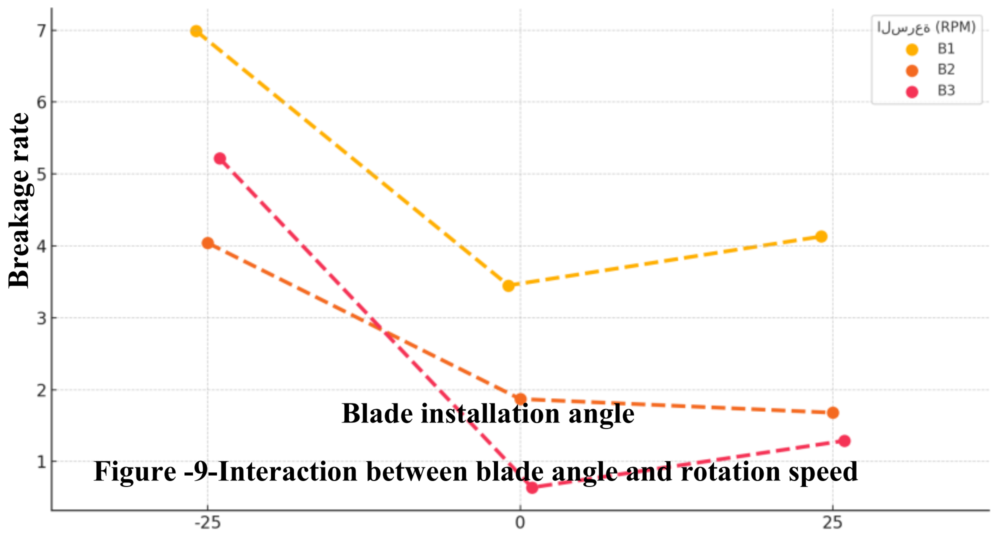

Blade installation angle

Figure -9-Interaction between blade angle and rotation speed

3.2 Electrical Power Consumption

The net energy consumption of the machine (kWh.ha^{-1}) was measured under forward speeds (9, 12, 15 km.h^{-1}), disc rotation speeds (500, 550, 600 RPM), and blade angles (0, 25, -25). The results of a three-way analysis showed no significant differences. Variance components analysis revealed that most of the variance (>91%) was not explained by the three studied factors. The reference variables (9 km.h-1, 500 RPM, -25° angle) had a slight effect on energy. The predictive equation was estimated as a linear regression model developed by studying the effect of three independent variables on the net energy consumed (Net Energy), according to Equation (4).

$$\textbf{Net Energy} = -0.00547 + 0.01349\cdot(15\ km.h^{-1}) - 0.00161\cdot(12\ km.h^{-1}) + 0.01384\cdot(550\ RPM) + 0.00041\cdot(600\ RPM) + 0.01383\cdot(\text{Blade Angle } 0°) + 0.00110\cdot(\text{Blade Angle } 25°) \quad (4)$$

Each parameter is only applied if the condition is met. If the speed is 15 km.h^{-1}, add 0.01349, but if the speed is 9 km.h^{-1}, none of the variables associated with the speed are added.

4 Conclusion

This study highlights the importance of controlling mechanical variables in variable rate fertilizer spreaders to achieve efficient spread and minimize fertilizer loss. At -25°, breakage rates significantly increased with increasing speed. More stable breakage rates were observed at 0° and 25°, where the differences were less pronounced. The differences between speeds within each angle are represented by dashed lines, reflecting the interaction between the two variables. Both the blade angle and disc speed must be carefully controlled to ensure minimal urea granule breakage, as each significantly affects granule integrity. The greatest granule breakage rates were observed at 600 rpm and -25°. The study highlights the importance of controlling mechanical variables in fertilizer spreaders to achieve efficient spread and minimize material loss, and by optimizing operational combinations, energy efficiency can be improved.

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