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(Research Article)

Performance evaluation of a rotary clod pulverizer

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Abstract

Rotary clod pulverizer is an agricultural implement, which help in reducing time used for farm operation in preparing the soil for planting. The objectives of this study were to carry out the performance evaluation of a tractor driven rotary clod pulverizer at different soil depth of 9, 18, 27, 36 and 45 cm of a sandy clay loamy textural soil. The parameters determined before, during and after experiment were; soil moisture content, bulk density, theoretical field capacity, effective field capacity, field efficiency. Thereafter, models were developed for the predictions of effective field capacity and field efficiency, as a function of the soil depth and the tractor speed. Results showed that the soil moisture content ranged between 17.07% and 19.78%, bulk density of the soil before penetration ranged between 1.25 gm/cm^3 and 1.52 g/cm^3, and ranged between 1.17 – 1.28 g/cm^3 after penetration. Across the soil depth and tractor speed, the theoretical field capacities (TFC) ranged 0.1165 ha/hr and 0.357 ha/hr, while the effective field capacity (EFC) ranged between 0.1327 and 0.2347 ha h^{-1}. The field efficiency (FE) ranged between 51.61 and 80.18% in across the soil depths and tractor speeds at 1.1, 1.6 and 2.5 km/h. The TFC values increase with tractor speed, indicating that the time required for the rotary clod pulverizer operation was lesser at higher speed than the time required for the operation at lower speed. Also, coefficient of determination (R^2) of the developed regression equation between the soil depth and tractor speed for EFC and FC prediction were 73 and 94%, respectively. This showed that the developed model is reliable and accurate for the prediction of EFC and FC.

Keywords: Rotary clod pulverizer; Tillage; Field efficiency; Theoretical field capacity

1. Introduction

Large number of traditional tillage tools are utilized in Nigeria to prepare seed beds due to the country's low degree of automation and farmers' limited access to finance and land. Other tillage tools like the rotavator, rotary plough, disc plough, etc. are less frequently used because of their higher cost. Since the majority of farmers lack literacy, they are unaware of the benefits of rotary clod pulverizer over conventional tillage systems and methods. Traditional tillage equipment uses a sliding motion, but rotary clod pulverizer employ rotating movement, which requires less power. Additionally, frictional resistance is considerable in conventional tillage while being minimal in rotary pulverizer. Rotary pulverizer can't function correctly on hard soil; thus, it also has certain drawbacks. As a result, there is a need to employ a soil hard pan breaker

The rotary clod pulverizer and soil hardpan breaker are usually coupled together in order to combinedly performs three primary function operation encompassing of ploughing, cutting, and mixing soil—replacing the harrow and the plough with the rotary clod pulverizer. It's also employed for extensive farming. The use of heavy tractors and other agricultural equipment during the causes the creation of hard pans in the soil. These tough pans are broken by hard pan breakers and mixed throughout and thoroughly with the aid of a rotary clod pulverizer. Therefore, it is the greatest main tillage

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tool for creating optimal agricultural conditions for plants and so saving a great deal of time and effort. Researchers discovered that tillage is a process used to create a seedbed or root bed with the ideal soil structure (Mahal et al., 2012). Tillage equipment, which is used for drilling, spraying, harvesting, and other tasks, needs the most power possible to prepare the seedbed (Ahmed and Haffar, 1993).

According to research studies conducted by several researchers, tillage is the most expensive activity in a farmer's budget since, among other agricultural operations like drilling, spraying, harvesting, etc., tillage machinery uses the greatest power to prepare the seedbed (Ahmed and Haffar, 1993). Soil tillage involves three key components: the physical characteristics of the soil, a power source, and a tool that is compatible with the power source. The size of the tractor that might be utilized for a certain implement depends on the draft and power requirements under various soil conditions. According to references, the geometry of the tillage implements and the soil conditions directly affect the draft needed for a specific implement (Taniguchi et al., 1999; Naderloo et al., 2009).

The performance of tools in tillage is influenced by their unique draft, energy needs, and work quality (Shrivastava et al., 1993). Better soil quality was produced by vertical rotating ploughing than by horizontal ploughing. The soil resistance of a vertical axis rotary clod pulverizer is lower than that of a horizontal one, and the amount of soil disturbed is significantly more (Azadbakht et al., 2014). In comparison to cultivator tillage, the rotary clod pulverizer reportedly saved 30–35% of time and 20–25% of operation costs. It produced work of a 25–30% greater caliber than cultivator tillage. The most effective method of transferring engine power directly to the soil with no wheel slide and far less transmission power loss is the rotary clod pulverizer (Shinde et al., 2011).

It is necessary to research the best alternative, either operationally or in terms of equipment, by which we can lower operating costs and increase system efficiency, given the current practices of seed bed preparation among farmers and the implements used to perform various operations. Therefore, the goal of this study was to assess the rotary clod pulverizer's performance as a function of soil depth and develop regression model for the prediction of the evaluation terms of the rotary clod pulverizer.

2. Material and methods

The implement fabricated in this study comprised of two units; hard pan breaking unit and clod pulverizing unit. The fabrication of the implement was carried in the workshop of the Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, while the evaluation test of the implement was carried out at the university teaching and research farm. The clod rotary pulverizer consists of the following;

- **Hitch unit:** Milled steel plate bar of 3000×100×10 mm and will be cut to size and welded to the frame.
- **Hitch pin: -** 30 × 200 mm.
- **Rotary cultivator: -** This consist of 8 (eight) circular tick plates of (200×10 mm) welded to a drive shaft (50 mm) and carried 40 cuter blades at its periphery.
- **Circular tick plate: -** 200×10 mm, this will be machined and drilled to accommodate the 16 holes for the blades at is made up of milled steel.
- **Blade: -** this will be made up of high carbon steel and forged to shape
- **Drive shaft: -** this will be made up of carbon steel 50 mm diameter which will be turned on the latte machine.
- **The drive unit: -** made of a gear box, PTO drive shaft, chain sprocket and chain curve.
- **The Rotary Cultivator:** The rotary cultivator consists of 8 (eight) circular tick plate of (200 × 10 mm) welded to a drive shaft, which could carry 40 cutter blades at the periphery.

2.1. Determination of Soil Moisture Content

Soil samples of soil were randomly collected from three different points within the location in order to determine the soil moisture content. Weight of the soil samples were measured immediately after collection, and it was recorded as the weight of the wet soil with the weight of the cylinder where the soil samples were put (W2). The soil samples were further put in the oven and dried at 105 °C for 24 hrs. After oven drying the soil samples, weight of the oven dried soil samples with the cylinder were weighted (W3). The weight of the cylinder was recorded as W1. Thereafter, the soil moisture content was determined on dry basis using the equation 1 below (Faloye and Alatise, 2017)

$$\text{Moisture content (MC)} = \frac{W2-W3}{W3-W1} \text{ ………………….. (Equation 1)}$$

2.2. Determination of Soil Bulk Density

The soil bulk density measurement was carried out with soil in a cylindrical core. Before the measurement, the diameter and height of the soil core was measured in order to determine the volume of the cylinder. The soil samples in the cores were kept in the oven at a temperature of 105°C for 24 h (Makange et al., 2015). The soil bulk density was determined using the formula below (Faloye and Alatise, 2017):

$$\text{Bulk density} = \frac{Mass\ (g)}{Volume\ (cm^3)} \text{ …………… (Equation 2)}$$

2.3. Evaluation of the Rotary Clod Pulverizer

The parameters used for the evaluation of the rotary clod pulverizer include the following; Theoretical Field Capacity (TFC), Effective Field Capacity (EFC) and Field efficiency (FE)

2.3.1. Determination Theoretical Field Capacity

The theoretical field capacity was determined using the formular given in equation 3 below according to Mehta et al. (2005).

$$\text{Theoretical Field Capacity} = \frac{W*S}{10} \text{ ……… (Equation 3)}$$

Where W is the width of the implement and S is the travel speed of the tractor (Km h^{-1})

2.3.2. Effective Field Capacity

During the experimental trial, the time lost during turning of the farm implement was recorded. Therefore, in calculating field capacity, the total time used up in performing the operation was considered in addition to the time lost for other activities like adjustment. The effective field capacity was therefore calculated from the equation given 4 below;

$$\text{Effective field capacity (S)} = \frac{A}{Tp+Ti} \text{ …………(Equation 4)}$$

Where S is the effective capacity (ha hr^{-1}), A is the area covered (ha), Tp is the productive time and Ti is the nonproductive time (h)

2.3.3. Field Efficiency

The field efficiency was calculated using the equation presented in equation 5 (Dabhi et al., 2016)

$$\text{Field efficiency} = \frac{Effective\ field\ capacity\ (\frac{ha}{h})}{Theoretical\ field\ capacity\ (\frac{ha}{h})} \text{ …………..(Equation 5)}$$

2.4. Data analysis

All the results were analysed by making plots to show their graphical illustrations using excel software. Also, the main and interaction plots between tractor speed and soil depth on the theoretical field capacity, field capacity efficiency (FC), and effective field capacity (EFC) were carried out using Minitab, version 17.0. In addition, regression equations were generated by analysing the developed response surface graph for the prediction of the field capacity efficiency and effective field capacity. The coefficient of determination (R^2) was used to judge the performance of the model in predicting the FC and EF

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3. Results and discussion

3.1. Soil Moisture Content

The moisture contents and bulk density before the operation using hardpan breaker and the clod rotary pulverizer (Table 1) at the soil depths of 9, 18, 27, 36 and 45 cm of the experimental site is illustrated in Table 1

Table 1 Soil hydrophysical properties during and after experiment

Soil depth	Bulk density before penetration	Bulk density after penetration	Moisture content (%)
9	1.32	1.21	17.07
18	1.25	1.17	18.27
27	1.33	1.25	19.78
36	1.37	1.27	18.57
45	1.52	1.28	19.27

Result from the study showed that the soil moisture contents increase down the soil depth, and similarly, the bulk density increase down the soil depth. The results from the study showed that the moisture contents were 17.07, 18.27, 19.78, 18.57, and 19.27% on average for soil depths of 9, 18, 27, 36 and 45 cm, respectively. The highest bulk density of 1.52 and 1.28 g cm^{-3} were obtained before and after penetration of the farm implement (hard pan breaker and clod pulverizer). Reduction in the bulk density was observed after the operation of the farm implement (hard pan breaker and clod pulverizer). This might be attributed to the loosening of the soil compactness.

3.2. Theoretical field capacity as a function of the soil depth and tractor speed

The result of the theoretical field capacity (TFC) is illustrated in Figure 1. The Figure showed that the average TFC were 0.165, 0.24 and 0.375 ha h^{-1} at speed of 1.1, 1.6 and 2.5 Km h^{-1}. Theoretical field capacity with the speed of 2.5 Km $h^{-1}$was more than with the speed of 1.1, 1.6 Km h^{-1}. This is because the operating the operating speed of the clod pulverizer increase with the Theoretical field capacity (Jakasania et al., 2017). The values obtained in this study is within the range of value of 0.23 and 0.28 ha h^{-1} reported by Jakasania et al. (2017).

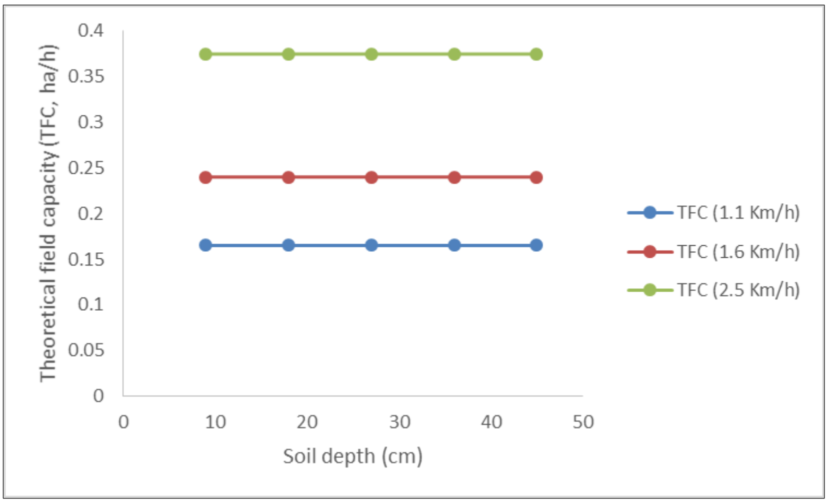

Figure 1 Theoretical field capacity and the soil depth at different speed

Figure 2. showed the relationship between the operating speed and the theoretical field capacity (Ha/h). The graphical illustration showed that the theoretical field capacity (TFC) increased with operating speed. This is evident with the positive slope with a coefficient of 0.15 (Figure 2) The coefficient of determination, r^2 of 1 was obtained in the relationship between the operating speed and the TFC, indicating that the relationship between the speed and TFC is very strong, and the generated model adequate is very good for the prediction of TFC.

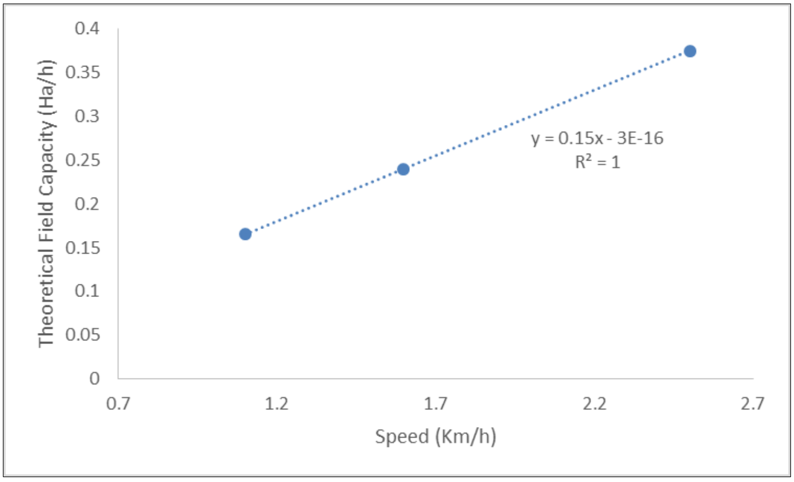

Figure 2 Relationship between the effective field capacity and the soil depth at different speed

3.3. Effective Field Capacity as a function of the soil depth and tractor speed

The average effective field capacity (EFC) at the different soil depths of 9, 18, 27, 36 and 45 cm with operating speed of 1.1, 1.6 and 2.5 Km/h is illustrated in Figure 3. The graphical illustration showed that the soil EFC change with respect to the soil depth with highest value mostly recorded at soil surface (9 cm) while the lowest value was recorded far below the soil depth. The average values across the depth for operating speed of 1.1, 1.6 and 2.5 Km/h were 0.1327, 0.1769 and 0.2347 ha/h. This result is similar and within the range of 0.17 and 0.232 ha/h reported by Jakasania et al. (2017) who used rotary plough for the breaking of soil clod.

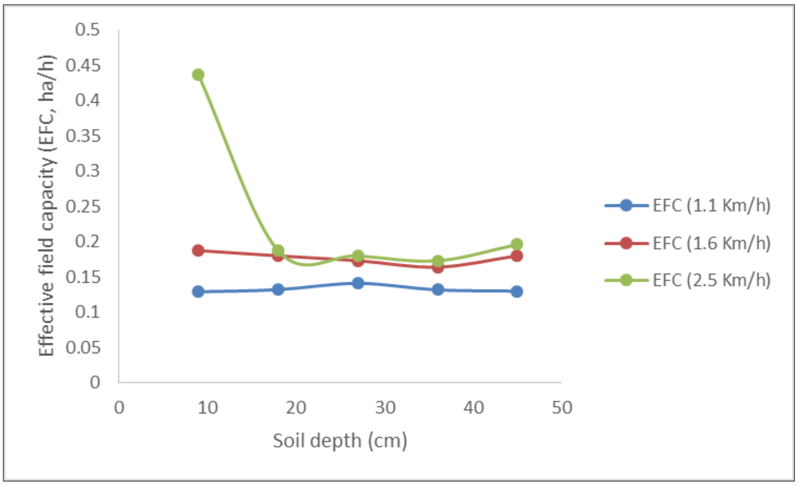

Figure 3 Effective field capacity and the soil depth at different speed

3.4. Field efficiency as a function of the soil depth and tractor speed

The average field efficiency across the soil depths of 9, 18, 27, 36 and 45 cm were 80.18, 73.71 and 51.61% for the operating speed of 1.1, 1.6 and 2.5 Km/h (Figure 4). The high value of field capacity obtained in this study, which is above 50% but less than 100% gives a clear indication that, during operation in all the soil depth the full working width of the machine could not be utilized, and that the designed and fabricated rotary clod pulverizer was efficient. The relationship between the FE and the soil depth and the FE is inconsistent, hence the need for the investigation of the main effect between the soil depth and operating speed on the FE

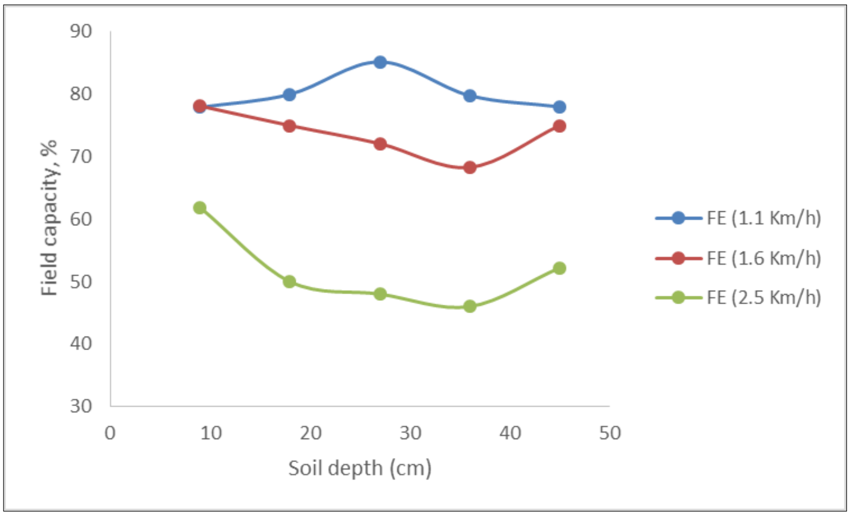

Figure 4 Field capacity and the soil depth at different speed

The main and interactive effects between the soil depth (cm) and the operating speed and FE are presented in Figures 5 and 6. The graphical illustrations showed that as the operating speed increases, the FE decreases, while the FE also decreased with increase in soil depth and experienced an upturn between 30 and 40 cm soil depth. The interaction plot between the soil depth and speed (Figure) showed that there was no interaction between the aforementioned parameters on the FE. This showed that the soil depth and operating speed does not produce a combined effect on the FE.

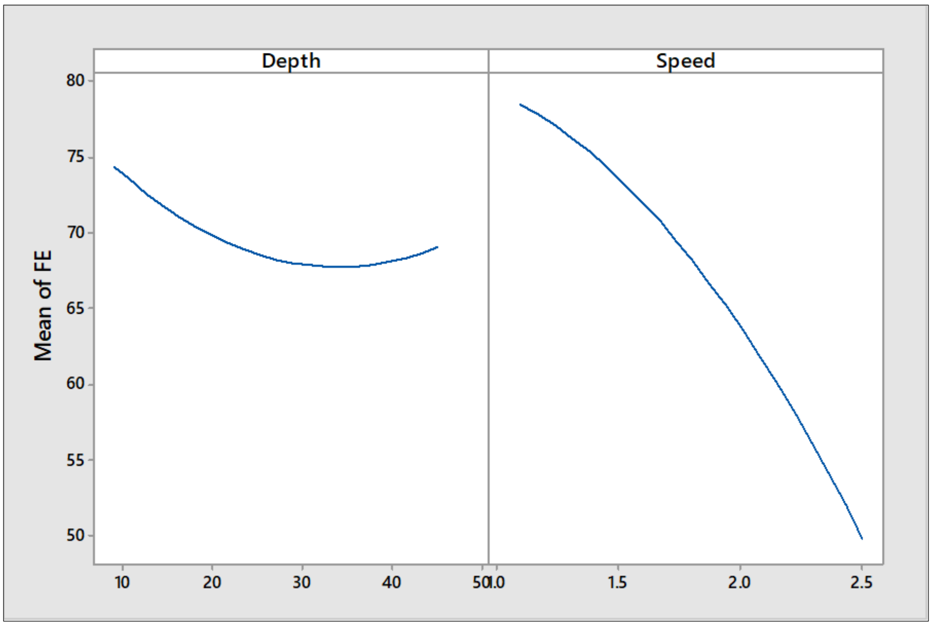

Figure 5 Graphical illustration of the main effects of soil depth, speed and direction on the field capacity efficiency

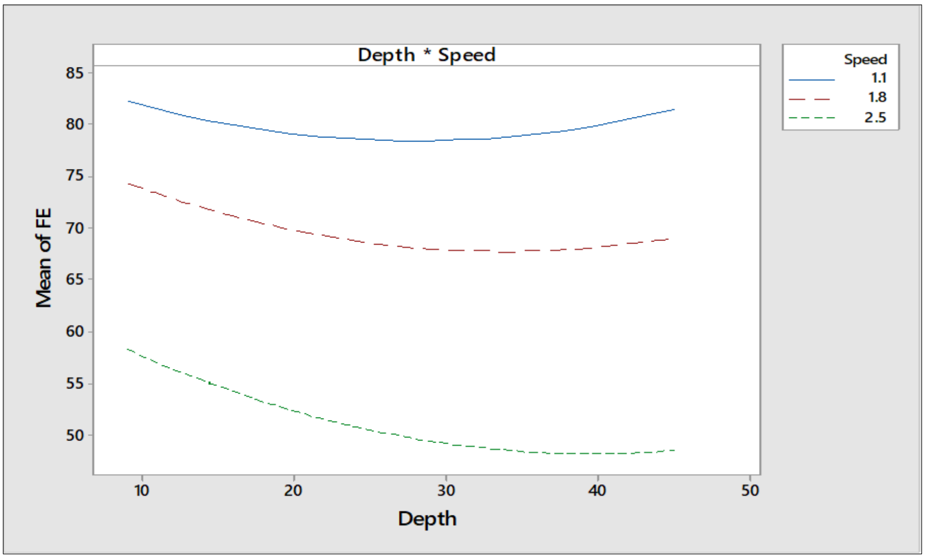

Figure 6 Graphical illustration of the interactive effects between soil depth, speed and direction on the field capacity efficiency

The relationship between the soil depth and EFC is illustrated in Figure 7. The graphical illustration showed that the effective field capacity (EFC) decrease as the soil depth increases, until it reached soil depth between 30 and 40 cm when an upturn was observed. However, the operating speed increases with increase in Effective field capacity (EFC) across the soil depths at 9, 18, 27, 36 and 45 cm.

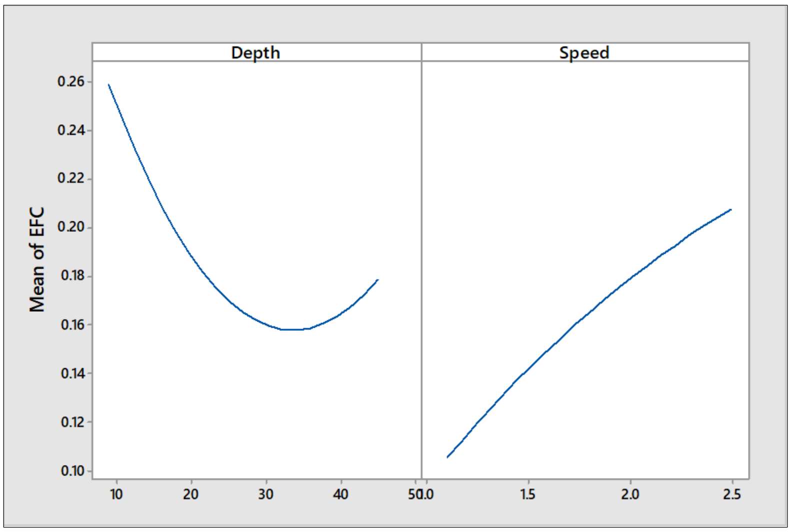

Figure 7 Graphical illustration of the main effects of soil depth, speed and direction on the effective field capacity efficiency

Graphical illustration of the interaction between soil depth and operating speed on the effective field capacity (EFC) are illustrated in Figure 8. The graph showed that there is interaction between the soil depth and operating speed. This imply that both operating speed and soil depth combined together to produce synergistic effect on the EFC.

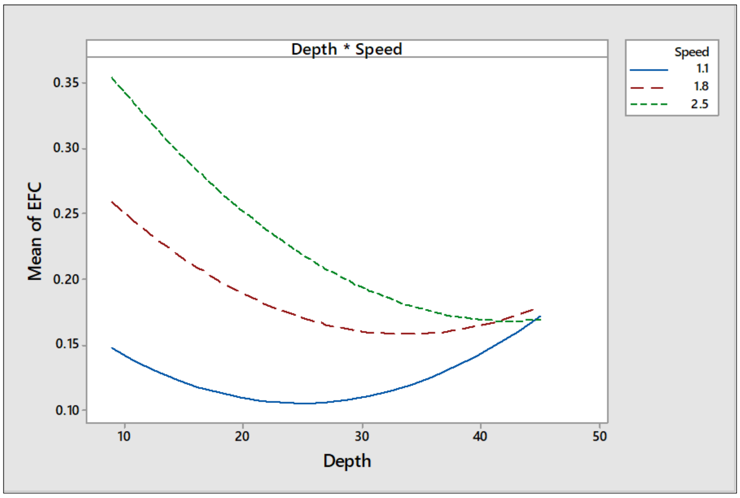

Figure 8 Graphical illustration of the interactive effects between soil depth, speed and direction on the effective field capacity efficiency

3.5. Modelling of the Rotary Evaluation Parameters

The rotary evaluation parameters have been carried out for the field efficiency and effective field capacity as a function of soil depth and tractor speed

3.5.1. Modelling of the field efficiency

The response surface plot for the relationship between the soil depth and the operating speed for the field efficiency (FE) is illustrated in Figure 9

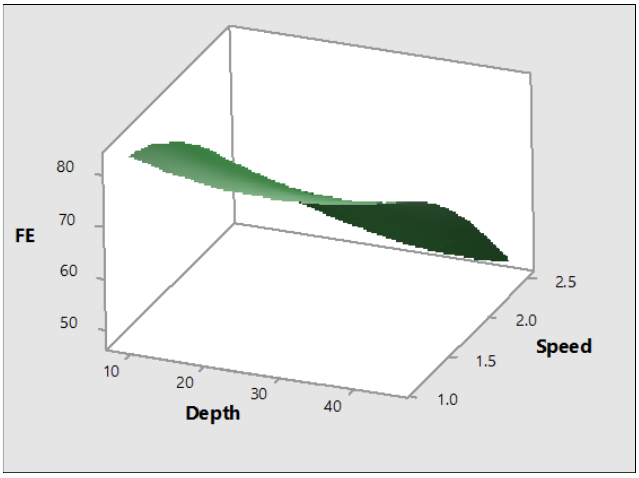

Figure 9 Response surface of the relationship between the soil depth and operational speed on the Field efficiency

The analysis of the response surface plot generates the plot presented in equation 6 below. The equation also presents the interaction between the soil depth and the operating speed for the FE prediction

$$FE = 81.3 - 0.406\,D + 14.2\,S + 0.01074\,D^2 - 8.28\,S^2 - 0.178\,D*S \quad R^2 = 0.94 \text{ ....(Equation 6)}$$

Where FE is the field efficiency (%), D is soil depth (D), S is the operating speed (S)

The equation above showed that soil depth and the operating speed explain the variation in the FE determination and prediction by 94%. Therefore, with coefficient of determination (R^2) of 0.94, the model is very strong for the prediction of the FE. The positive value obtained as coefficient of operating speed in the equation above showed that overall, the operating speed have positive effect on the FE, as such the FE increases as the FE increase. However, negative coefficient was recorded for the soil depth coefficient with respect to the FE. This might be attributed to the increase in the resistance of the soil to penetration down the soil depth. This negative coefficient implies negative value, and this might be attributed to the antagonistic effect observed on the field efficiency (FE) when soil depth and operating speed were combined together

3.5.2. Modelling of the effective field capacity (EFC)

The response surface plot for the relationship between the soil depth and the operating speed for the effective field efficiency (EFC) is illustrated in Figure 10

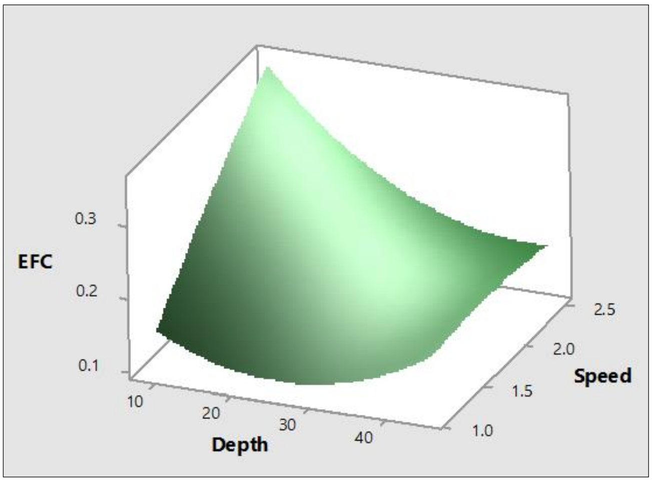

Figure 10 Response surface of the relationship between the soil depth and operational speed on the Effective Field Efficiency Capacity (EFC)

Analyzing the response surface plot generates the plot in Figure 10 produce the equation 7below. The equation presents both the individual and interaction between the soil depth and the operating speed for the EFC determination and prediction

$$\text{EFC} = -0.044 - 0.00366\,D + 0.248\,S + 0.000165\,D^2 - 0.0173\,S^2 - 0.00417\,D*S \text{ ....(Equation 7)}$$

$$R^2 = 0.73$$

Where EFC is the effective capacity (ha/h), D is soil depth (D), S is the operating speed (S)

The equation above showed that soil depth and the operating speed explain the variation in the FE determination and prediction by 73%. Therefore, with coefficient of determination (R^2) of 0.73, the model is very strong for the prediction of the EFC. Similar to the relationship between the soil depth and operating speed on the FE, the operating speed also produce a positive coefficient in the equation 7 above, thus indicating positive effect of the operating speed on the FE, as such the operating speed also increase as the EFC increased. However, negative coefficient was also recorded for the soil depth coefficient with respect to the EFC, indicating an antagonistic effect. This might also be attributed to the increase in the compactness of the soil down the soil depth. Also the negative interaction observed between soil depth and the operating speed on the EFC also imply an antagonistic effect in the combined effects of soil depth and operating speed on the effective field capacity (EFC).

4. Conclusion

In this study, hard pan breaker and a rotary clod pulverizer were developed, and the rotary clod pulverizer was thereafter evaluated. The soil bulk density obtained after the experiment was lower than before the experiment at soil depth of 9, 18, 27, 36 and 45 cm. This showed the effectiveness of the tillage implement in pulverizing the soil. The evaluation of the rotary clod pulverizer showed that the measured theoretical field capacity (TFC) was between 0.165 ha/hr and 0.357 ha/hr, and with the field efficiency (FE) of 51.61 and 80.18% across the considered soil depth and tractor speed. The highest value of TFC was observed at higher speed revealing that the time required for rotary clod pulverizer plough operation with higher speed was lower than the time required for the lower speed. The developed model gave a good coefficient of determination of 73 and 94% for EFC and FE, indicating that the EFC and FE determination are highly dependent on the soil depth and tractor speed.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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