Short Article

Effect of Tillage Depth and Forward Speed on the Performance of a Rotavator Plough Under Semi-arid Conditions

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Abstract

Mechanisation is crucial for enhancing agricultural productivity and operational efficiency, particularly in semi-arid regions. This study evaluated the performance of a CLAAS Talos 220 two-wheel-drive tractor equipped with a Shaktiman rotavator plough at tillage depths of 10 and 15 cm and forward speeds of 3, 5, and 7 km·h^{-1} in northern Iraq during the 2023–2024 cropping season. The results showed that increasing depth and speed led to higher power losses resulting from wheel slippage, increased fuel consumption, and decreased field efficiency and actual ploughing depth. The highest power loss (6.96 hp) and lowest efficiency (66.60%) were recorded at a depth of 15 cm and a speed of 7 km·h^{-1}, while the lowest power loss (0.031 hp) and the highest efficiency (80.42%) were recorded at a depth of 10 cm and a speed of 3 km·h^{-1}. It was also shown that fuel consumption increases with depth, but decreases at higher speeds, and that the actual depth of ploughing decreases due to vibrations. The results indicate that operating at an average depth of approximately 10 cm and at an average speed of about 5 km·h^{-1} is the optimal choice for energy use, improving field performance, and enhancing soil conservation.

Keywords: Field efficiency, Forward speed, Fuel consumption, Rotary tiller, Semi-arid soils, Tillage depth, Wheel slippage

Introduction

Mechanisation plays an essential role in enhancing agricultural productivity and improving operating efficiency. Modern tillage tools, especially rotavators, are essential tools for soil preparation. They improve physical properties such as aeration and water retention, while reducing the risk of wind and water erosion. Understanding the factors that influence the performance of these tools is critical for achieving sustainable agricultural practices and improving energy use. Rotavator ploughs are increasingly considered vital tools in modern mechanised agriculture due to their powerful ability to prepare the soil while improving physical properties such as aeration and water retention. It is important to clarify that the *rotary plough* and *rotavator* are distinct tools in terms of design and performance. The rotavator is primarily used for grinding soil and efficiently preparing seed troughs, with less impact on soil bulk density compared to the rotary plough. The rotary plough is used for primary tillage, where it turns the soil deeper to remove weeds and prepare the field for planting. Comparative studies between the two devices confirm these differences in functionality, fuel consumption, and operational efficiency (Singh, Goyal, Goyal, & Verma, 2016). Rotavator tillage does not excessively invert the soil, thereby lowering the risk of wind and water erosion—an aspect particularly important in fragile soils (Kim *et al.*, 2022). This advantage explains their growing popularity in regions where preserving soil structure is a fundamental concern. Nevertheless, deeper tillage operations are often accompanied by a sharp rise in draft force, leading to higher fuel consumption and greater wheel slip, as soil resistance becomes more pronounced at lower depths (Kareem & Jasim, 2023). To address this challenge, it is essential to determine an ideal tillage depth that achieves sufficient soil loosening while avoiding unnecessary energy loss. Evidence also suggests that careful tillage settings, coupled with proper engine modes, can significantly reduce fuel consumption. These improvements are particularly noticeable when the engine load corresponds to the power requirements of tillage, not just to the choice of rotavator ploughs instead of die ploughs (Siddique *et al.*, 2023).

Performance in rotavator tillage is also shaped by operational factors, including soil moisture, tyre inflation pressure, and forward speed. Poor adjustment of these parameters often results in excessive slippage and reduced productivity, highlighting the need for machine settings tailored to local soil conditions (Khalid, Dahham, & Yahya, 2022). Forward speed, in particular, demonstrates a dual effect: while higher speeds allow more land to be covered in less time, they can also compromise depth uniformity and reduce overall field efficiency. (Singh, Chatha, & Sidhu, 2018) observed that increasing speed from 3.21 to 7.04 km·h^{-1} decreased field efficiency from 67.38% to 64.81%, clearly reflecting the trade-off between operational speed and quality of soil work.

Other studies report that the combination of deeper tillage with higher travel speeds tends to magnify fuel consumption and energy losses due to elevated draft resistance and traction demands (Nkakini & Ekemube, 2020). Similarly, (Shafaei, Loghavi, & Kamgar, 2023) indicated that although faster speeds may shorten operation time, they often raise energy costs as a result of wheel slip and added mechanical stress. A moderate approach—avoiding both excessively low and excessively high speeds—appears to provide the best balance for energy efficiency and soil protection (Ayoub, Rajab, & Hilal, 2024). In the same context, (Kim, Jang, Hwang, Lee, & Nam, 2024) showed that operating at higher speeds, such as 9.64 km·h^{-1}, could lower specific fuel consumption through improved utilisation of engine power, though they cautioned that excessive speeds may compromise implement stability and reduce consistency of working depth.

In semi-arid regions such as northern Iraq, where rainfall has been declining, and temperatures continue to rise, many farmers have shifted toward rotavator ploughs as part of their soil management strategy. This transition aims to minimise the number of field passes and reduce fuel costs, reflecting broader global trends that favour rotavator tillage for its ability to prepare a seedbed in a single operation (Sarker, 2023). Accordingly, the present study aimed to evaluate the mechanical performance of rotavator ploughs under semi-arid conditions in northern Iraq, focusing specifically on variations in tillage depth and forward speed.

This study provides region-specific empirical data on the effects of tillage depth and forward speed on the performance of rotavator ploughs in semi-arid soils. Although the general effects of these factors are widely recognised, the regional context and unique soil properties have not been previously evaluated, highlighting the novelty of this work.

The objectives of this study are as follows:

1. The evaluation of the performance of a mechanisation unit consisting of a tractor paired with a rotational plough at various operating depths and speeds.
2. To examine major mechanical performance indicators, including:

- Power losses due to wheel slip
- Fuel consumption
- Field efficiency
- Actual tillage depth

The results of this research are expected to provide practical, data-driven recommendations for optimising rotavator tillage operations in semi-arid soils, thereby improving energy efficiency, field productivity, and promoting sustainable soil management.

Materials and Methods

Experimental Site

The field experiment was carried out during the 2023–2024 cropping season at Umm al-Rubaieen nursery, affiliated with the Iraqi Ministry of Agriculture. The trial commenced in mid-March (March 16, 2024). The land had remained fallow for more than a year and was characterised by irregular surface conditions, providing realistic field conditions for evaluating tillage performance.

Machinery and Equipment

Tractor:

A CLAAS Talos 220 two-wheel-drive agricultural tractor, manufactured in South Korea in 2019, was used for the field operations. It offers adequate power and traction required for rotavator tillage at various depths (Figure 1).

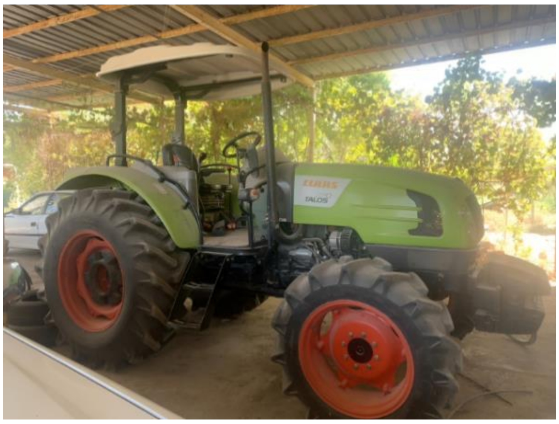

Fig. 1. The tractor used in the study (Photo taken by the author, 2024)

Rotavator Plough

The tillage implement used in the experiment was a rotavator plough, model Shaktiman SRT-8/1000, manufactured in India. This implement is particularly suitable for soil breaking and mixing operations in semi-arid regions. It has a working width of approximately 1.5 m and a total weight of about 342 kg. The plough is equipped with 54 knife-type blades mounted on the rotating shaft, which significantly enhances its efficiency in soil pulverisation and ensures a uniform seedbed preparation (Government of India, SRFMTTI, 2009) (Figure 2).

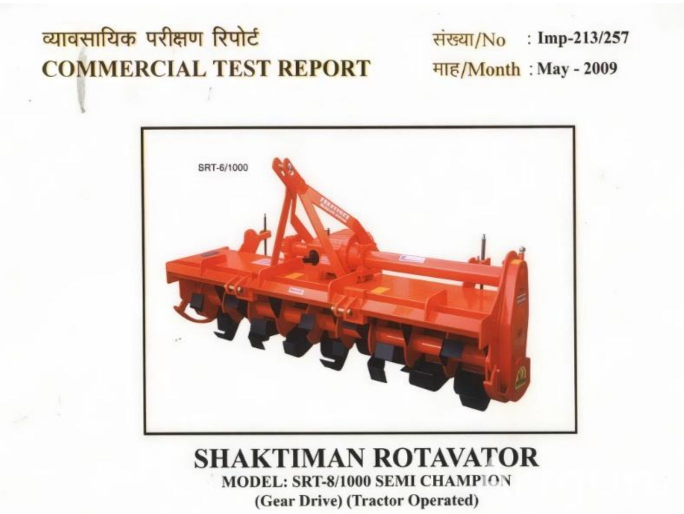

Fig. 2. The rotavator plough used in the study (Government of India, SRFMTTI, 2009)

Experimental Design

The experiment followed a factorial design (2×3) within a randomised complete block design (RCBD), to evaluate the impact of two primary factors:

Tillage depth (A): with two levels (A1= 10 cm and A2= 15 cm)

Forward speed (B): with three levels (B1= 3 $km \cdot h^{-1}$, B2= 5 $km \cdot h^{-1}$, and B3= 7 $km \cdot h^{-1}$)

This setup resulted in six treatments, each replicated three times, for a total of 18 experimental units. Each unit covered an area of 75 m^2 (50 m length × 1.5 m width).

The collected data were analysed using a two-factor analysis of variance (ANOVA) to examine the individual and combined effects of tillage depth and forward speed on the measured variables. A significance level of 0.05 was adopted to determine the statistical differences among treatments. When significant differences were observed, Duncan's multiple range test was employed to compare the treatment means and identify where the differences occurred. All analyses were carried out using SPSS statistical software (version 26).

Field Procedures

The field was levelled and prepared, with a reserve area designated for safety. Wooden markers with identification labels were installed to demarcate the start and end of each plot. Treatments were randomly assigned to experimental units using a randomisation table. Soil samples were collected from both target depths of 10 cm and 15 cm before tillage to determine soil texture and moisture content.

Measurement Methods

Theoretical Speed (Vt):

The tug was driven, tied to the plough, and the plough was raised for the specified distance, which was set at 50 metres, when the gearshift lever was placed at speed 1 heavy, and the fuel was fully opened. Then the theoretical speed for covering the specified distance was measured, and the process was repeated three times, and the rates of the obtained readings were calculated. Then the process was repeated twice, once when the speed lever was placed at 2 heavy and another time when it was placed at 3 heavy. At this stage, the theoretical speed (Vt) was measured for all the selected speeds using the following equation (Eq. 1):

$$Vt = (L/Tt) \times 3.6 \qquad (1)$$

where:

Vt: The theoretical speed of the tug ($km \cdot h^{-1}$)

L: length of the ploughing line (metres)

Tt: The theoretical time it takes to cover the distance L (seconds)

Practical Speed (Vp):

The tractor and plough were operated in ploughing mode at the specified distance and depth, referred to as the first depth (A1). This method allowed for the measurement of all studied indicators. The time taken for each repetition was also calculated to determine the practical speed of the puller for the three speeds. Then, work was carried out for the second depth (A2), and this method was repeated several times to get accurate and real numbers. Afterwards, Equation (2) was used to calculate the practical speed:

$$Vp = (L/Tp) \times 3.6 \qquad (2)$$

where:

Vp: Practical ploughing speed ($km \cdot h^{-1}$)

Tp: The time it takes to cover the distance L with the plough in operation (seconds)

Due to the unavailability of a dynamometer, the actual drawbar force could not be measured directly during the experiment. Therefore, the tractor's rated drawbar power from the catalogue was used as an approximate substitute to estimate power lost due to wheel slip, with a recommendation for future studies to include direct drawbar measurements for a more precise evaluation of plough performance.

Power (horsepower) lost by sliding

Equation 3 was used to calculate the power lost due to wheel slip, based on the tractor's rated drawbar power from the manufacturer's catalogue (Chowdhury & Kushwah, 2022):

$$Sp = \frac{Vt - Vp}{Vt} \times Ppulling \qquad (3)$$

where:

Sp: Power lost by sliding (hp)

Ppulling: Tractor's rated drawbar power from the catalogue (hp)

Vt: The theoretical speed of the tractor ($km \cdot h^{-1}$)

Vp: The Practical speed of the tractor ($km \cdot h^{-1}$)

Fuel consumption ($L \cdot ha^{-1}$):

Fuel consumption was measured by the addition method using a graduated cylinder. The tank was completely filled, then the tractor was started, and it began working directly. During the end of the work line, the tractor was turned off immediately, then the fuel was added to the tug using the graduated cylinder, and the amount of this addition is the consumed fuel according to the following equation (ASAE, 2004):

$$FC = \frac{Q \times 10}{Tl \times Wp} \quad (4)$$

where:

FC: The amount of fuel consumed per hectare ($L \cdot ha^{-1}$)

Q: The amount of fuel consumed during the treatment (ml).

Tl: Transaction length (metres)

Wp: Actual working width of tillage (metres)

Field efficiency (%):

The field capacity of a machine is its performance rate, and the machine's performance rate depends on the type of machine. The machine's productivity units are expressed in units of area per unit of time, i.e., $ha \cdot h^{-1}$ or $dunam \cdot h^{-1}$.

- Theoretical field productivity:

It is defined as the maximum productivity that can be obtained at a certain speed, assuming that the entire width of the machine is used in the work. In other words, if the machine is working 100% of the performance time and the speed specified for it in its full width, it can be calculated from the following equation:

$$FCt = S \times W \times 1000/A \quad (5)$$

where:

FCt: Theoretical field productivity ($ha \cdot h^{-1}$)

S: Theoretical speed ($km \cdot h^{-1}$)

W: Design machine width (m)

A: Area unit (m^2)

- Actual field productivity:

It is defined as the actual performance rate of the machine in the field or when handling a crop at a specific time. In other words, it is the actual area (number of hectares) that the machine covers during a specific time, and it can be calculated using Equation (6):

$$FCe = S \times W \times e/10 \quad (6)$$

where:

FCe: Actual field productivity ($ha \cdot h^{-1}$)

S: Actual speed ($km \cdot h^{-1}$)

W: Actual machine width (m)

e: Time efficiency (%) (its value for a backhoe plough is 75-90%)

The field efficiency was calculated using the ratio between theoretical field capacity (FCt) and actual field capacity (FCe), as recommended in ASAE standards. The standard field efficiency value of 80% was mentioned only for comparison purposes and was not used in any calculations.

Based on this, the field efficiency of the machine can be calculated using Equation (7):

$$FE\% = \left(\frac{FCe}{FCt}\right) \times 100 \quad (7)$$

Note that the standard field efficiency was considered 80% according to (ASAE, 2001).

Actual tillage depth:

Two metallic rulers, each measuring 30 cm in length, were employed for the measurement. The first ruler was placed vertically into the soil, while the second was positioned horizontally on the soil surface to facilitate accurate readings. The depth was measured from the soil surface to the lowest point reached by the rotavator tiller blades.

This procedure was repeated 3-5 times at different locations within the experimental plot to ensure accuracy, after which the mean depth was calculated for each experimental unit. Note that the theoretical depth at which the plough was regulated was 10 cm and the second was 15 cm, as shown in Figure 3.

Experimental Measurements and Limitations

The measured variables included tractor wheel slip (%), fuel consumption ($L \cdot ha^{-1}$), field efficiency (%), and actual tillage depth (cm). Due to equipment limitations, draft force and traction efficiency were not measured using a dynamometer. These measurements are recommended for future studies to provide a more comprehensive evaluation of plough performance. To enhance clarity, the results for each measured parameter are shown in Tables 2-5.

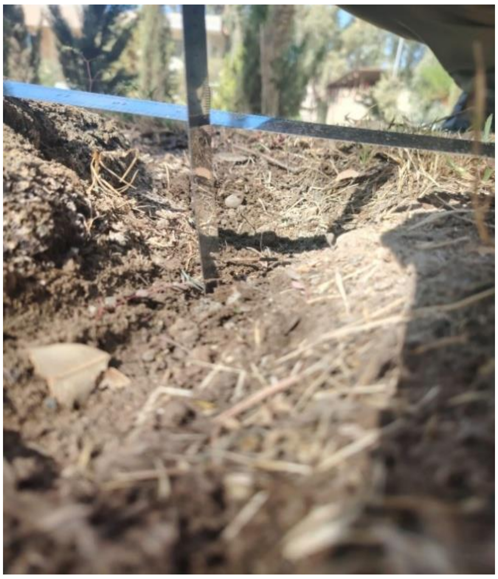

Fig. 3. The method of measuring plough depth (Photo taken by the author, 2024)

Other Measurements:

A detailed analysis of the physical and chemical soil properties was conducted to evaluate their influence on tillage performance. Soil samples were collected from depths of 10 cm and 15 cm. The soil texture at 10 cm was classified as clay-silty, with the texture at 15 cm assumed to be similar. The gravimetric moisture content was measured at 13.1% (10 cm) and 13.2% (15 cm), indicating moderate moisture levels favourable for tillage. Penetration resistance was relatively high at 672.5 kPa, suggesting compacted soil conditions that may increase tillage resistance. Bulk density was recorded as 1.48 g·cm^{-3}, reflecting significant soil compaction typical of clayey soils. Electrical conductivity ranged between 1.1 and 1.5 dS·m^{-1}, indicating low to moderate salinity levels, which might slightly affect equipment durability and soil behaviour during field operations. Soil specifications are shown in Table 1.

Table 1- Summary of key soil properties, measurement methods, and values obtained in this study

Property	*Value*	*Unit*	*Measurement method*
Sand content	11.7	%	The proportions of sand, silt, and clay were determined using the hydrometer method, which is based on Stokes' law describing the settling velocity of particles in a water suspension. This method is widely used to identify the particle size distribution in soil, helping classify soil type and understand its physical properties (Gavlak, Horneck, & Miller, 2005)
Silt content	40.63	%	
Clay content	40.51	%	
Soil texture	silty clay loam	-	Classified according to USDA particle size charts (Moorberg & Crouse, 2021)
Moisture content	13.1 (10 cm) / 13.2 (15 cm)	%	Measured using the oven-drying method at 105 °C (Gavlak *et al.*, 2005)
Penetration resistance	672.5	kPa	Assessed with a penetrometer to evaluate soil compaction (Dexter, Czyż, & Gaţe, 2007)
Bulk density	1.48	g·cm^{-3}	Measured by drying known-volume soil samples (Coughlan, & Cresswell, McKenzie, 2019)
Electrical conductivity (EC)	1.1 – 1.5	dS·m^{-1}	Determined using a soil solution and EC meter to assess salinity (USDA NRCS, 2022)

Results and Discussion

Power Loss Due to Slippage

Table 2 illustrates the effects of tillage depth (A) and forward speed (B) on power loss due to slippage. Both factors were found to have a statistically significant impact on energy loss during tillage operations. Power loss increased from 0.031 hp at a depth of 10 cm and a speed of 3 km·h^{-1} to 6.96 hp at 15 cm depth and 7 km·h^{-1}. This increase can be attributed to higher soil resistance and greater slippage at increased depths and speeds, leading to elevated energy consumption (Nkakini & Ekemube, 2020).

ANOVA Analysis:

- The main effects of tillage depth and forward speed were statistically significant ($P < 0.05$), as shown in Table 2a.
- The interaction between depth and speed (A × B) was also significant, as presented in Table 2b.

Mean Values:

Table 2c shows the mean power loss for each treatment combination. These results highlight that although some slippage (10–15%) is required to ensure adequate traction, excessive slippage significantly increases energy loss and reduces operational efficiency (Janulevičius & Damanauskas, 2022).

Table 2a- ANOVA Table for the main effects of tillage depth and forward speed on power loss due to slippage (hp)

Source	df	SS	MS	F	p-value
Depth (A)	1	3.7996	3.7996	1826.59	< 0.0001
Speed (B)	2	105.453	52.7267	25347.4	< 0.0001
A × B	2	4.3703	2.1851	1050.48	< 0.0001
Error (Residual)	12	0.0208	0.00208	—	—
Total	17	113.646	—	—	—

Table 2b- ANOVA Table for the interaction effect of tillage depth × forward speed on power loss due to slippage (hp)

Source	df	SS	MS	F	p-value
Depth (A)	1	9.975	9.975	49.39	<.0001
Speed (B)	5	165.6	33.12	163.98	<.0001
A × B	-1	0	0	0	<.0001
Error (Residual)	10	2.0197	0.002	—	—
Total	17	167.736	—	—	—

Table 2c- Mean power loss for each treatment combination (hp)

(A×B)		Velocity km.h^{-1} (B) 3	5	7	(A)
Depth cm (A)	10	0.031e	1.56d	4.67b	2.08b
	15	0.034e	2.03c	6.96a	3.00a
(B)		0.032c	1.79b	5.81a	

* Lower values indicate better performance.
* Treatments sharing the same letter are not significantly different at $P < 0.05$.

Fuel Consumption

Fuel consumption (L·ha^{-1}) was influenced by both depth and forward speed (Table 3). The highest fuel consumption (15.40 L·ha^{-1}) occurred at 15 cm depth and 3 km·h^{-1}, whereas the lowest (7.46 L·ha^{-1}) was observed at 10 cm depth and 7 km·h^{-1}. This pattern is explained by the longer operation time at low speeds and higher traction resistance at deeper tillage (Siddique *et al.*, 2023) & (Kim *et al.*, 2024).

ANOVA Analysis:

Main effects of depth and speed were significant (Table 3a).

The interaction (A × B) was also statistically significant (Table 3b).

Mean Values:

Table 3c displays the mean fuel consumption for each treatment combination. These data clearly show that higher speeds and shallower depths generally reduce fuel consumption, while deeper tillage at low speed increases it.

Table 3a- ANOVA Table for the main effects of tillage depth and forward speed on fuel consumption ($L \cdot ha^{-1}$)

Source	df	SS	MS	F	p-value
Depth (A)	1	9.9755	9.9755	49.39	< 0.0001
Speed (B)	2	151.8	75.9009	375.79	< 0.0001
A × B	2	3.8228	1.9114	0.46	0.0049
Error (Residual)	12	2.0197	0.20197	—	—
Total	17	167.74	—	—	—

Table 3b- ANOVA Table for the interaction effect of tillage depth × forward speed on fuel consumption ($L \cdot ha^{-1}$)

Source	df	SS	MS	F	p-value
Depth (A)	1	9.975	9.975	49.39	<.0001
Speed (B)	5	165.6	33.12	163.98	<.0001
A × B	-1	0	0	0	<.0001
Error (Residual)	10	2.0197	—	—	—
Total	17	167.736	—	—	—

Table 3c- Mean fuel consumption for each treatment combination ($L \cdot ha^{-1}$)

(A×B)		Velocity $km \cdot h^{-1}$ (B) 3	5	7	(A)
Depth cm (A)	10	14.87a	9.52c	7.46e	10.62b
	15	15.40a	12.25b	8.68d	12.11a
(B)		15.13a	10.88b	8.07c	

* Lower values indicate better performance.

* Treatments sharing the same letter are not significantly different at P < 0.05.

Field Efficiency

Field efficiency (%) is a critical indicator of tillage performance (Table 4). The highest efficiency (80.21%) was recorded at 10 cm depth and 3 $km \cdot h^{-1}$, while the lowest efficiency (66.53%) occurred at 15 cm depth and 7 $km \cdot h^{-1}$. Reduced efficiency at higher depths and speeds is attributed to increased slippage and time lost during manoeuvring and resetting traction paths (Singh *et al.*, 2018).

ANOVA Analysis:

- Both main factors (A and B) significantly affected field efficiency (Table 4a).
- Interaction between depth and speed (A × B) was also significant (Table 4b).

Mean Values

Table 4c shows the mean field efficiency for each treatment combination. These values illustrate that shallower depths and moderate speeds optimise field efficiency.

Table 4a- ANOVA Table for the main effects of tillage depth and forward speed on field efficiency (%)

Source	Df	SS	MS	F	p-value
Depth (A)	1	27.011	27.0113	56.05	< 0.0001
Speed (B)	2	344.71	172.356	357.66	< 0.0001
A × B	2	5.2	2.60001	5.4	0.0257
Error (Residual)	12	4.819	0.48189	—	—
Total	17	381.9	—	—	—

Table 4b- ANOVA Table for the interaction effect of tillage depth × forward speed on field efficiency (%)

Source	Df	SS	MS	F	p-value
Depth (A)	1	27.011	27.01	56.05	<.0001
Speed (B)	5	376.92	75.38	156.43	<.0001
A × B	-1	0	0	2	<.0001
Error (Residual)	10	4.818	—	—	—
Total	17	381.9	—	—	—

Table 4c- Mean field efficiency for each treatment combination (%)

(A×B)		Velocity km·h^{-1} (B) 3	5	7	(A)
Depth cm (A)	10	80.21a	74.30c	70.46e	74.99a
	15	78.21b	72.88d	66053f	72.54b
(B)		79.21a	73.59b	68.50c	

* High values indicate better performance.
* Similar letters indicate no significant difference at P < 0.05.

Actual Achieved Depth

Table 5 illustrates the actual achieved depth under different operational conditions. The highest depth (13.70 cm) was recorded at a nominal depth of 15 cm and a forward speed of 3 km·h^{-1}, while the lowest depth (9.10 cm) occurred at 10 cm depth and 7 km·h^{-1}. The reduction in achieved depth at higher speeds is attributed to increased vibration and decreased implement stability. These findings are consistent with previous studies indicating that higher speeds can reduce actual depth while increasing energy consumption (Tayel, Shaaban, & Mansour, 2015) & (Choudhary, Upadhyay, Patel, Naresh, & Jain, 2021).

ANOVA Analysis:

- Main effects of depth and speed were significant (Table 5a).
- The interaction effect (A × B) was also significant (Table 5b).

Mean Values:

Table 5c shows the mean achieved depth for each treatment combination. These results highlight that lower speeds and moderate depths allow the implement to closely reach the desired penetration.

Table 5a- ANOVA Table for the main effects of tillage depth and forward speed on actual achieved depth (cm)

Source	df	SS	MS	F	p-value
Depth (A)	1	59.623	59.6232	534.93	< 0.0001
Speed (B)	2	2.5999	1.29994	11.66	0.0024
A × B	2	0.1682	0.08412	0.75	0.4952

Error (Residual)	12	1.1146	0.11146	—	—
Total	17	63.576	—	—	—

Table 5b- ANOVA Table for the interaction effect of tillage depth × forward speed on actual achieved depth (cm)

Source	df	SS	MS	F	p-value
Depth (A)	1	59.623	59.62	534.93	<.0001
Speed (B)	5	62.391	12.48	111.95	<.0001
A × B	-1	0	0	0	<.0001
Error (Residual)	10	1.11	—	—	—
Total	17	63.575	—	—	—

Table 5c- Mean actual depth for each treatment combination (cm)

(A×B)		Velocity km.h^{-1} (B)			(A)
		3	5	7	
Depth cm (A)	10	9.80c	9.58d	9.10d	9.49b
	15	13.70a	13.17a	12.54b	13.13
(B)		11.75a	11.37b	10.82c	

* High values indicate better performance.
* Similar letters indicate no significant difference at P < 0.05.

Conclusion

Based on the results of this study, the following conclusions can be made:

1. The study demonstrated that increasing forward speed and tillage depth elevates power loss due to slippage, thereby reducing field efficiency. Careful selection of suitable speed and depth is essential for optimal rotavator plough performance.
2. The highest fuel consumption was observed at 15 cm depth and 3 km·h^{-1}, whereas the lowest occurred at 10 cm depth and 7 km·h^{-1}, highlighting that balancing depth and operating speed is critical for improving energy efficiency.
3. The actual achieved tillage depth decreased with higher speeds, especially at greater nominal depths, due to vibration and reduced implement stability, emphasising the need to maintain equipment stability at increased speeds.
4. Based on these findings, operating at moderate speeds (around 5 km·h^{-1}) and medium tillage depths (10 cm) is recommended to achieve a good balance between fuel consumption, field efficiency, and actual tillage depth.
5. These results provide practical guidance for agricultural engineers and farmers to enhance rotavator plough performance in semi-arid soils, minimising energy and time losses during tillage operations.
6. This study confirms that physical soil properties, including clay-silty texture, high penetration resistance, and elevated bulk density, play a crucial role in rotavator plough performance.

Future work

1. It is recommended to operate the rotavator plough at moderate tillage depths (10 cm) and medium forward speeds (5 km·h^{-1}) to balance fuel consumption, field efficiency, and actual tillage depth, especially in clay-silty soils with high resistance.
2. Future studies should evaluate the plough performance under varying soil moisture conditions to ensure operational efficiency

across diverse environments.

3. A comparative assessment between the rotavator plough and other conventional tillage systems is suggested to examine their effects on soil physical properties, crop emergence, and yield.
4. It is advisable to design and test alternative plough share geometries and conduct computational simulations (using advanced computational simulation methods) to validate field results and enhance implement performance while reducing extensive field trials.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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Authors Contribution

Mahmood Shaker Al-totonjy: Supervision, Conceptualization, Methodology, Data Acquisition, Validation, Scientific Review and Editing. He provided overall supervision of the study, developed the main concept and research methodology, participated in field data collection, ensured the validity of procedures and results, and performed the scientific review and final editing of the manuscript.

Yahya Y. Mohsin: Technical Advice, Data Pre- and Post-Processing, Statistical Analysis, Visualization. He provided technical support during the experimental work, conducted data preprocessing and post-processing, performed statistical analyses, and prepared the visual representation of the results including charts and graphical outputs.

Jarullah Maher: Supporting Methodology, Field Experiment Execution, Software Services, Draft Writing. He contributed to the experimental design implementation, managed the required software services for analysis, participated in executing the field experiments, and prepared the initial draft of the manuscript.

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مقاله کوتاه

تأثیر عمق شخم و سرعت پیشروی بر عملکرد روتیواتور در شرایط نیمه‌خشک

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چکیده

مکانیزاسیون برای افزایش بهره‌وری کشاورزی و راندمان عملیاتی، به‌ویژه در مناطق نیمه‌خشک، بسیار مهم است. این مطالعه عملکرد یک تراکتور دو چرخ محرک CLAAS Talos 220 مجهز به روتیواتور برند Shaktiman را در دو عمق شخم ۱۰ و ۱۵ سانتی‌متر و سرعت‌های پیشروی ۳، ۵ و ۷ کیلومتر بر ساعت در شمال عراق در طی فصل زراعی ۲۰۲۴-۲۰۲۳ ارزیابی کرد. نتایج نشان داد که افزایش عمق و سرعت پیشروی منجر به تلفات بیشتر توان ناشی از لغزش چرخ، افزایش مصرف سوخت و کاهش راندمان مزرعه و عمق واقعی شخم می‌شود. بیشترین میزان افت توان (۶/۹۶ اسب بخار) و کمترین راندمان (۶۶/۶۰ ٪) در عمق ۱۵ سانتی‌متر و سرعت ۷ کیلومتر بر ساعت ثبت شد، در حالی‌که کمترین میزان افت توان (۰/۰۳۱ اسب بخار) و بیشترین راندمان (۸۰/۴۲ ٪) در عمق ۱۰ سانتی‌متر و سرعت ۳ کیلومتر بر ساعت ثبت شد. همچنین نتایج نشان داد که مصرف سوخت با عمق افزایش می‌یابد، اما در سرعت‌های بالاتر کاهش می‌یابد و عمق واقعی شخم به دلیل ارتعاشات کاهش می‌یابد. نتایج نشان می‌دهد که انجام عملیات در عمق متوسط تقریبا ۱۰ سانتی‌متر و با سرعت متوسط حدود ۵ کیلومتر بر ساعت، انتخاب بهینه از نقطه نظر مصرف انرژی، بهبود عملکرد مزرعه و افزایش حفاظت از خاک است.

واژه‌های کلیدی: خاک‌های نیمه‌خشک، راندمان مزرعه، روتیواتور، سرعت پیشروی، عمق شخم، لغزش چرخ، مصرف سوخت

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