Investigated of disc plow during tow tractor speeds and depths

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ABSTRACT

Factorial experiment was conducted in Telkaif District, located northeast of the city of Mosul, Nineveh Governorate, during the agricultural season (2025 – 2026). The study aimed to investigate the effects of tow speeds and tillage depths on bulk density, porosity, wheel slip, and the number of soil clods. And determine the optimal operational combination that achieves the highest tillage quality and enhances agricultural productivity. The results revealed significant differences for the studied factors and their interactions across all measured parameters. Tillage speed showed a statistically significant effect on bulk density, where the speed of 2.08 Km.hr^{-1} recorded the lowest value 0.93 g.cm^{-3}, compared to 6.17 Km.hr^{-1}, which recorded the highest value 1.05 g.cm^{-3}. The interaction between operating speed and tillage depth indicated that the best bulk density 0.91 g.cm^{-3} was obtained at a depth of 10 – 15 cm and a speed of 2.08 km.hr^{-1}. Regarding porosity, the speed of 2.08 km.hr^{-1} achieved the value 65.33%. Similarly, the interaction between speed and depth produced the best porosity value 66.0% at 2.08 km.hr^{-1} and depth of 10 – 15 cm. For wheel slip, the results demonstrated a significant effect of both speed and tillage depth. Slip increased from 11.40% at a depth of 10 – 15 cm to 23.65% at 15 – 20 cm. The speed of 2.08 Km.hr^{-1} resulted in the lowest slip value 8.50%, whereas the highest slip 28.55% was recorded at 6.17 km.hr^{-1}. The interaction between the two factors showed that the highest slip 37.50% occurred at 6.17 Km.hr^{-1} and a depth of 15 – 20 cm, while the lowest value 8.20% was observed at 2.08 km.hr^{-1} and a depth of 10 – 15 cm. As for the number of soil clods (tillage quality indicator). The results indicated a significant effect of both speed and depth. The interaction between two factors produced the best tillage quality (lowest number of clods), reaching 3.66 clods.m^{-2} at a speed of 2.08 Km.hr^{-1} and a depth of 15 – 20 cm, compared with the higher speed 6.17 Km.hr^{-1}. All interactions among the factors were significant difference. Concluded the tractor speeds were more effectively on the characteristics of the study comparing with the depth of tillage.

Keywords: Tillage, Fragmentation, Porosity, Slippage, Bulk density.

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INTRODUCTION

Tillage operations are considered among the fundamental pillars of agricultural production, as they are employed to improve the physical properties of soil and to create a favorable environment for plant growth. This is achieved through soil fragmentation, reduction of soil cohesion, and enhancement of porosity, aeration, and water permeability, which collectively have a positive impact on root development and nutrient uptake efficiency. Tillage is defined as the mechanical manipulation of soil aimed at preparing it for cultivation and enhancing plant growth **[16]**. This process is influenced by several factors, including soil properties and texture, type of plow, operating conditions, and soil moisture content. It directly influences the degree of soil aggregate fragmentation, energy requirements, and wheel slip. The selection of an appropriate plow type exerts a significant role in determining tillage quality, as it contributes to improving soil properties and increasing crop productivity **[4, 8]**. The disc plow is regarded as one of the most widely used tillage implements due to its high ability to penetrate the soil and operate efficiently under difficult conditions. In additions, it reduced clogging with crop residues owing to the nature of its sharp, concave discs, which cut and invert the soil progressively during rotation **[21].** The concave design of the discs also facilitates the mixing of soil with crop residues, achieving better homogeneity, which contributes to improved seedbed conditions and enhanced soil surface appearance. Tillage quality is commonly assessed using soil surface condition as a key indicator, an increased number of large soil clods indicates poor fragmentation, whereas a lower number reflects better soil uniformity and higher seed germination efficiency **[1]**. Increasing depth results in a larger volume of soil being cut and inverted, due to higher cohesion in the lower soil layers compared to the upper layers, thereby increasing the draft force required and impacting tractor performance **[18]**. Increasing tillage depth may also lead to higher bulk density and reduced porosity due to soil compaction **[14].** Tillage speed is another critical factor in determining soil fragmentation quality, high speeds may decrease tillage efficiency by reducing the interaction time between the soil and the implement **[17].** However, high speeds can also increase soil compaction and reduce porosity compared to lower speeds **[22, 3].**Bulk density is an important indicator reflecting the degree of soil cohesion, where high values indicate compacted soil with low porosity, while low values represent loose soil with high porosity. Therefore, effective tillage operations aim to

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reduce bulk density by increasing the inter-particle voids within the soil **[36]**. Wheel slip is also a key parameter for evaluating tractor performance and is defined as the difference between the theoretical and actual speed of the tractor **[5].** On the other hand slip is regarded as a key indicators for evaluating the performance of the mechanized unit and its value should not exceed 15% **[20].** In addition slip value should remain within an optimal range of 8-12% to achieve maximum power transfer efficiency. Exceeding this range results in a loose of traction and increased fuel consumption, whereas very low values (< 6-7%) indicate underutilization of the available power **[28, 9].** Several studies have indicated that the use of disc plows contributes to improved soil particle distribution and a reduction in soil clods, particularly when operating parameters are properly adjusted **[32,27].** Additionally, some studies have shown that reducing tillage speed decreases bulk density and increases porosity, whereas increasing tillage depth produces the opposite effects **[13].** Proper control of operating parameters such as tillage speed and depth contributes to improving soil particle distribution and reducing clod formation, thereby enhancing soil pulverization efficiency and improving seedbed quality **[2]**.

The aims of this experiment to evaluate the effects of tractor speeds and depth of tillage on the disc plow by measured bulk density, porosity, wheel slip, and the number of soil clods.

MATERIAL AND METHODS

A field experiment was conducted in Talkaif District, which belongs to the city of Mosul, during the agricultural season (2025 - 2026). The field topography was characterized by flatness. The soil moisture content was 14.5% at the time of tillage. The soil type was clay loam. Random soil samples were collected and analyzed to determine their characteristics based on soil texture, as shown in Table (1).

Table 1. Soil texture.

Soil textures (clay loam)		
silt	sand	clay
40%	32%	28%

This study examined two main factors: tillage speed and tillage depth. The experiment was carried out using a disc plow, as shown in Figure (1), and a Massey Ferguson 285s tractor, according to the specifications listed in Table (2) and (3).

Experiment Design

A factorial experiment was conducted using Randomized

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Complete Block Design (RCBD). Each factor was tested at two levels: Tillage speed (2.08 $km.hr^{-1}$ and 6.17 $km.hr^{-1}$) and tillage depth (10 – 15 cm and 15 – 20 cm), with three replications. The length of each experimental unit was 30 m. Data were analyzed using (SPSS) software (Version 23) **[30].** Analysis of variance (ANOVA) was performed on the collected data, and the significance of differences among treatment was tested using Duncan's multiple range test at a 5% probability.

1- Bulk Density ($g.cm^{-3}$).

It is defined as the ratio of the mass of dry soil to its total volume. Bulk density was determined by collecting random soil samples after tillage for each depth and for each treatment, with three replicates, using the core sample method (cylindrical soil sampling method). The samples were weighed before drying, then oven-dried at a temperature of 105 C°. Bulk density was calculated using Equation **[13].**

$$Pb = \frac{Ms}{Vt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

When Pb: Bulk Density ($g.cm^{-3}$). MS: Solid particle mass (g), and Vt: The total volume of soil (cm^3).

2- Soil Porosity (%).

Soil porosity refers to the proportion of the total soil volume occupied by pore spaces it was determined assuming a particle density of 2.65 g.cm-3 according to Equation **[13].**

$$F = 1 - \frac{Pb}{Ps} \text{ x } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

When F: Total porosity (%). Pb: Bulk density ($g.cm^{-3}$), and Ps: is Particle density ($g.cm^{-3}$).

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Figure 1. Shows the disc plow

3- Wheel Slip (%).

Slip percentage is defined as the relative difference between the theoretical speed of the tractor (without load) and its actual speed during field operation under the effect of soil resistance and the tillage implement. It is calculated according to Equation **[34].**

$$S = 1 - \frac{Va}{Vt} \text{ x } 100\ \% \ldots\ldots\ldots\ldots..(3)$$

When S: Slip Ratio (%), Va: is the actual velocity of the wheel, *Vt:* is the theoretical velocity of the wheel.

4- Number of soil clods (clods.m^{-2}).

This parameter is an important indicator for evaluating tillage quality and soil surface condition after tillage. It represents the number of soil clods remaining unit area, measured by taking three random 1m2 samples from each treatment and counting clods greater than (5cm) in diameter **[7].**

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Table 2. Specifications of the disc plow.

Specifications of the disc plow	
Disc plow	Type of plow
3	Number of disc
5cm	Disc thickness
60cm	Disc diameter
70cm	Plough beam
42°	Disc angle
22°	Disc tilt angle
315kg	Plough weight
120cm	Theoretical working width
170cm	Effective working width
30-35cm	Design tillage depth
Specifications of the agricultural tractor	

Table 3. Specifications of the agricultural tractor.

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Massey Ferguson 285s	**Tractor type**
Two-wheel drive (2WD)	**Model**
31KN	Total tractor weight
Four-stroke diesel engine with direct fuel injection (2WD)	**Engine type**
4	**Number of cylinders**
17.5:1	**Compression ratio**
56.6	**Rated engine power (kW)**
2200 ± 25 rpm	**Maximum crankshaft speed under load (rpm)**
2310 ± 25 rpm	**Maximum crankshaft speed at no-load (rpm)**
(4 standard and 4 low-range)	**Number of forward gears: Eight**
(1 standard and 1 low-range)	**Number of reverse gears: Two**
30-18.4 **inch**	**Rear tire size**
16-17.5 **inch**	**Front tire size**

RESULTS AND DISCUSSION

Table (4) shows no significant differences in the effect of soil depth on bulk. In contrast significant differences were observed regarding the effect of speed on bulk density, where the speed of 2.08 km.hr^{-1} recorded the lowest value of 0.93 g.cm^{-3} compared to the speed of 6.17 km.hr^{-1} which recorded the highest value of 1.05 g.cm^{-3}. This is attributed to the fact that increasing speed leads to an increase in mechanical energy exerted on the soil during tillage, which consequently leads to the rearrangement of soil particles and increased pressure on soil pores. Consequently, this compaction increases bulk density as higher speed increase shear forces and friction between soil particles and the tillage implement **[10].** Furthermore, the table indicates significant differences for the two-way interaction between tillage speed and soil depth regarding bulk density. It is observed that as tillage speed increased from 2.08 km.hr^{-1} to 6.17 km.hr^{-1} bulk density increased for both depths. This is explained by the increase speed raises the kinetic energy transferred to the soil, leading to an increase in dynamic stress affecting the soil. This stress rearranges soil particles and reduces porosity, thereby significantly increasing bulk density in the surface layer at high speeds **[15].**However, at a depth of 15 – 20 cm and a speed of 6.17 km.hr^{-1} a portion of the mechanical energy is first consumed in penetrating the upper soil layer.

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Additionally, deeper layers typically have a higher initial density making them less susceptible to compaction compared to the surface soil layer **[11].**The result of the interaction between speed and depth also indicate that using a lower speed during tillage achieved the lowest bulk density value recorded at 0.91 $g.cm^{-3}$ at the depth of 10 – 15 cm with a speed of 2.08 $km.hr^{-1}$. The reason for this is attributed to the mechanical forces affecting the shallower (surface) layers are less intense and their distribution within the soil matrix is more regular and uniform. The response of bulk density to changes in speed varies with depth due to differences in compaction levels and soil structure composition from one layer to another. High operating speeds significantly affect bulk density and consequently the distribution of voids and soil compaction compared to lower speeds **[13].**

Table 4. Effect of speed and depth on bulk density ($g.cm^{-3}$).

Tillage speed $km.hr^{-1}$	Interference Between speed and Depth		
	15-20	10-15	
0.93 b	0.96ab	0.91 b	2.08 $km.hr^{-1}$
1.05 a	1.03ab	1.08 a	6.17 $km.hr^{-1}$
	0.993a	0.995 a	Tillage Depth cm

Table (5) indicates significant differences in the effect of tillage speed on soil porosity %, with values of 65.33% and 60.50% recorded for both speeds respectively. It was observed that increasing the speed from 2.08 $km.hr^{-1}$ to 6.17 $km.hr^{-1}$ resulted in a decrease in porosity. This can be attributed to the increased dynamic forces and vibrations generated by the movement of the tillage implement within the soil, which lead to the rearrangement and compaction of soil particles, thereby reducing pore volume and porosity **[33].**Conversely, the lower speed produced the highest porosity value 65.33%, likely because it allows the implement more time to penetrate and loosen the soil, enhancing particle disintegration and improving the distribution of pore spaces thus increasing porosity. The results also indicated that porosity was not significantly affected by tillage depth with values of 62.83% and 63.0% recorded for the both depth respectively. Regarding the interaction between tillage speed and depth, significant differences were observed. As speed increased porosity decreased particularly in the surface layer 10 – 15 cm, while the deeper layer 15 – 20 cm retained a slightly higher porosity 60.33% at the same speed. This is attributed to the fact that the surface layers are directly exposed to the mechanical impact of the disc blades causing greater compaction of large pores, whereas part of the energy dissipates before reaching deeper layer, reducing its effect **[19].**Furthermore, the results show that conducting tillage at a

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lower speed increased porosity achieving the highest value 66.0% at 2.08 km.hr^{-1} and depth of 10 – 15 cm, which was followed by 64.66% at a depth of 15 – 20 cm. This is explained by the reduced mechanical resistance of the soil at lower speeds, which enhances the efficiency of soil fragmentation and improves soil aeration **[25].**These results indicate that lower operating speeds achieved higher porosity compared to higher speeds at both depth, reflecting the interaction between tillage speed and depth and their combined effect on soil porosity **[6].**

Table 5. Effect of speed and depth on soil porosity (%).

Tillage speed km.hr^{-1}	Interference Between speed and Depth		
	15-20	10-15	
65.33a	64.66 ab	66.0 a	2.08 km.hr^{-1}
60.50b	60.33 ab	58.66 b	6.17 km.hr^{-1}
	63.0 a	62.83 a	Tillage Depth cm

Table (6) indicates significant differences regarding the impact of plowing depth on the slippage percentage %. It is observed that increasing the plowing depth from 10-15cm to15-20 cm led to an increase in the slip rate from 11.40% to 23.65%. This is attributed to the fact that greater plowing depth increases the volume of soil cut and inverted by the disc, which in turn increases soil resistance and the draft force required from the tractor. Consequently the load on the tractor tires increases leading to slippage on the soil surface. Furthermore, the increased contact area between the disc and the soil leads to higher friction and resistance forces thereby reducing the actual power transmission into forward motion, where a portion of the power appears as wheel slip **[35].**The data in the table also indicate a significant of plowing speed on slippage. Increasing the plowing speed from 2.08 km.hr^{-1} to 6.17 km.hr^{-1} resulted in an increase in slippage reaching a value of 28.55%. This is due to the increased rate of soil-disc impact and the higher energy rate required for cutting and inverting the soil, which increases the required draft force and subsequently the slip. The increase in tractor speed leads to higher dynamic friction and a loss of traction-cohesion between the wheels and the soil, resulting in greater power loss and higher slippage **[20].**In contrast, the table shows that the lower speed yielded the best slippage value at 8.50% implying that lower speeds allow for a longer contact time between the tire and the soil, which enhances tractive forces and reduces kinetic loss due to slip **[24].**Furthermore, the table explain a significant effect of the dual interaction between plowing speed and depth. The results indicate that the plowing speed of 6.17 km^{-1} led to an increase in slippage at both depths with the highest slip value recorded at the 15-20 cm

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depth reaching 37.50%. This is due to a compounded increase in soil resistance, where the friction forces resulting from depth combine with the impact forces of the disc resulting from speed. This creates operating conditions that require a tractive power for exceeding what the tractors transmission system can provide without slippage. Therefore, the soil mass flow rate increases significantly placing the plow and tractor under substantial mechanical stress leading to a loss of grip between the tractor wheels and the soil surface **[18].**On the other hand, the results show that the optimal slippage value was 8.20% at speed of 2.08 km.hr^{-1} and a depth of 10-15 cm. this is because the shear forces generated between the tractor wheels and the soil remain within the limits that the soil can resist maintaining better cohesion between the wheels and the soil surface, which in turn minimizes slippage.

Table 6. Effect of speed and depth on wheel slip (%).

Tillage speed km.hr^{-1}	Interference Between speed and Depth		
	15-20	10-15	
8.50 b	9.80 c	8.20 d	2.08 km.hr^{-1}
28.55 a	37.50 a	19.60 b	6.17 km.hr^{-1}
	23.65 a	11.40 b	Tillage Depth cm

Table (7) shows significant differences regarding the impact of plowing depth on number of soil clods (plowing appearance). It is observed that increasing the depth from 10-15 cm to 15-20cm led to a decrease in the number of soil clods from 5.70 clods.m^{-2} to 4.0 clods.m^{-2}. This is attributed to the fact that increasing the plowing depth enhances soil accumulation in front of the disc generating higher internal pressure that breaks the bonds between soil particles, thereby reducing the clod count. Additionally increasing the depth using a disc plow increases the volume of soil subjected to cutting and inversion, which intensifies the shear and compression forces within the soil fracturing clods into smaller fragments. Furthermore, greater plowing depth increases soil disturbance and movement during the passage of the disc, resulting in a higher degree of pulverization due to increased tool-soil mechanical interaction **[12, 23].**The table also explain that plowing speed significantly affected the number of soil clods. Results indicate that increasing the plowing speed from 2.08 km.hr^{-1} to 6.17 km.hr^{-1} led to an increase in the number of clods reaching 6.85 clods.m^{-2}. This is explained by the fact that when the disc moves at high speed it pushes the soil mass laterally as a single unit before sufficient time is available for internal cutting and fracturing as high speeds reduced the effective contact time between the disc edge and the soil. Therefore, high plowing speeds decrease pulverization efficiency due to the increased soil cohesive forces that

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resist instantaneous fragmentation **[29].**Regarding lower speed, a lower clod count of 4.12 clods.m^{-2} was recorded. This is due to the increased interaction time between the disc and the soil which enhances the impact of shear and friction forces on the soil thereby reducing clod number. This is reflected positively in the soil pulverization index increasing the degree of fragmentation and providing a better plowing appearance **[31].**As for the interaction between plowing speed and depth, the table shows a significant effect on the number of soil clods. The results indicate that the optimal value was recorded at a speed of 2.08 km.hr-1 and depth of 15-20 cm achieving 3.66 clods.m^{-2}. This can be explained by the synergistic effect of depth and low speed on soil fragmentation and plowing quality at greater depth the volume of effected soil in front of the disc increases leading to higher soil resistance and shear forces. When coupled with low speed the disc has more time to interact with the soil allowing stresses to transfer gradually within the soil mass helping to break inter-particle bonds and reduce clods. Thus the number of soil clods is considered a vital indicator in evaluating plowing quality, where a lower count signifies an improved plowing appearance which positively affects the soil pulverization index and leads to a more homogeneous soil structure **[26].**

Table 7. Effect of speed and depth on number of soil clods (clods.m^{-2}).

Tillage speed km.hr^{-1}	Interference Between speed and Depth		
	15-20	10-15	
4.12 b	3.66 b	4.22 b	2.08 km.hr^{-1}
6.85 a	6.52 a	7.10 a	6.17 km.hr^{-1}
	4.0 b	5.70 a	Tillage Depth cm

CONCLUSIONS

In conclusion, the forward speed and the tillage depth have significant impacts on the studied soil physical properties and mechanization performance of the disc plow in clay loam soil type. Specifically, the bulk density was reduced by approximately 12% when the forward speed was used at the lower level, whereas the porosity responded oppositely by ≈ 30% when the speed increased from 2.08 km.hr^{-1} to 6.17 km.hr^{-1}. This superiority of the lower speed was confirmed by the significant interaction between speed and depth, where the optimal bulk density and porosity were achieved at a lower speed and a shallow tillage depth. Regarding slippage percentage, both studied factors have significant effects on this particular indicator, as its value increased positively with forward speed and tillage depth by 70% and 52%

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respectively, compared to the lowest level of these factors. On the other hand, the number of soil clods responded negatively to forward speed and tillage depth, by approximately 40% and 30% respectively. Therefore, the disc plow was more efficient in clay loam soil when operated at lower tillage speeds due to its ability to keep the soil healthier, as well as reducing slippage and improving plowing appearance.

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