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Evaluation of field performance indicators of subterranean ploughs for breaking hard layers at different depths and speeds

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ABSTRACT

The experiment was conducted in the spring season of the year 2023, at the beginning of May, in the Al-Rajaiba area, Al-Jadid Al-Gharbi district, Karbala Governorate, Iraq. The land area is 1/2 hectare, 44 m wide x 114 m long. To evaluate the performance of a subsoil plough for breaking the hard layer with different ploughing depths and speeds in some field performance indicators in the soil. The soil texture of the experimental field is clay. The research included a statement of the effect of different ploughing depths and speeds on some technical indicators of field performance under two levels of speed (3.71 and 5.21) km/h and three levels of depths of 40 cm, 50 cm and 60 cm, with three reparations. The least significant difference test under the confidence level of 0.05 was used to compare the averages of the parameters. The studied characteristics were cohesion strength, bulk density, theoretical productivity, actual productivity, and total porosity. The results showed that the speed of 5.21 km/h was significantly superior to that of 3.71 km/h in all the studied characteristics of the soil ploughed with a subsoil plough compared to the unploughed soil. Using a subsoil plough decreased the bulk density and cohesive strength by 1.31 g/cm^3 at the speed of 3.71 km/h, at a depth of 40 cm and 48.65 kN/m^2, at the same depth and speed, respectively. The use of the plough also led to an increase in the total porosity, actual productivity, and theoretical productivity by a value of 50.322 g/cm^3 at a speed of 3.71 km/h and a depth of 40 cm, 10.758 ha/h and 15.369 ha/h at a speed of 5.21 km/h and a depth of 40 cm, respectively. That led to improving field performance indicators and soil physical properties. The results also showed an increase in bulk density and soil cohesion with increasing ploughing depth and with increasing live service or use of the land. It is recommended to do this process frequently.

Keywords: Subsoil, speed, depth, plough, hard layer.

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INTRODUCTION

The increase in repetitive ploughing operations, especially with traditional ploughs and at almost constant depths, is a major reason for the occurrence of the hard layer, especially in depths that cannot be reached by plough knives. The impermeable layer has a negative impact on the fundamental qualities and properties of the soil, including its physical and chemical properties, water conductivity, and overall porosity. This will reduce water movement within the soil, decreasing washing efficiency and causing salt accumulation, as well as deteriorating air conditions within the soil. The lack of oxygen is necessary for root cell division and the inactivity of soil microorganisms. The ploughing process is considered one of the main processes for preparing the soil and creating a suitable bed for the seeds. That works to increase the area exposed to direct sunlight and facilitate the movement of air and water deeper into the soil, which leads to improving the physical properties of the soil and combating pests, weeds and diseases. Thus, the soil transforms from a primitive, solid state to the desired final state suitable for cultivation (Ros et al., 1995). The regularity of traditional ploughing at the same depths along with preparing the soil can lead to increased soil compaction and reduced aeration. Soil compaction also increases during soil ploughing operations, which require the tractor to pass through the field several times. The soil of almost all agricultural lands in Iraq is characterized by a heavy structure and repeated agricultural operations may lead to the deterioration of the soil properties, which affects the growth of vegetative and root plants due to these cohesive layers (Lal, 1997). The qualitative characteristics of ploughing depend on the practical speed of ploughing, the depths of ploughing, and the nature of the treated soil. Choosing the right agricultural equipment is crucial for preserving the quality and physical characteristics of the soil. Failure to do so can affect the soil and make it unsuitable for plant growth. Additionally, choosing the wrong type of machine and lacking the necessary skills can result in increased fuel consumption, which is not cost-effective. These machines play a crucial role in agricultural mechanization, with ploughs accounting for 21.58% of all agricultural machinery in Iraq (Central Bureau of Statistics, 1995). Ploughs have been used for centuries as the first step in preparing seed beds (Bell, 1996).

According to Hilal et al. (2018), the soil cohesion increases by 88% with depth, specifically from 25 cm to 45 cm. Due to the increase in soil moisture and bulk density with increasing depth, there is a significant relationship between cohesion and bulk density. However, using a subsoil plough resulted in a decrease in cohesion between soil particles at all depths. Specifically, it decreased by 5,650, 11,120, 9,760, and 11.36 kN/m^2 at depths of 25, 35, 45, and 55 cm, respectively, compared to after using the plough. They justified the reason for dismantling and crushing soil aggregates and the decrease in bulk density when using the subsoil plough.

This machine, known as a subsoil plough, is used to break up consolidated layers to improve the physical characteristics of the field, enhance fertility, and increase soil aeration and water conductivity (Al-Banna, 1990). This type of plough is highly efficient in reconstructing and recomposing the soil to achieve proper aeration, porosity, cohesion, and fertility for seed germination and plant root growth. Additionally, it opens channels in the soil to facilitate drainage of excess water (Aday and Hillal, 2004). The tractor speed is a crucial factor in evaluating the performance of agricultural machinery, such as a subsurface plough. Increasing the speed can lead to higher slippage, which depends on the physical and mechanical characteristics of the soil and the type of plough used (Al-Ani, 2000).

The flip plough, also known as a rail plough, has been widely used in Iraq for several decades despite some disadvantages when used in certain local soils. One of the most significant issues is the creation of a hard sub-layer, as mentioned by Al-Sabbagh (1990). According to Al-Hadithi (2019), increasing the machine speed from 3.21 to 3.71 km/h resulted in a significant increase in slippage percentage from 11.86 to 14.42%, practical productivity from 0.21 to 0.42 ha/h, and the volume of soil raised from 367.10 to 438.00 m3/h, with a significant decrease in specific fuel consumption from 70.8 to 69.40 litres/ha, respectively. Furthermore, increasing the depth of the agricultural machine from 10 to 20 to 30 cm led to a significant increase in both the percentage of slippage from 5.01 to 13.21 to 21.19% and the specific fuel consumption per unit area from 66.10 to 71.30 to 72.90 litres/ha. Additionally, the volume of soil raised increased from 222.50 to 402.30 to 582.80 m^3/h, with a significant decrease in practical productivity from 0.25 to 0.22 to 0.21 ha/h, respectively.

The load on the tractor's axle increases with greater depth of ploughing and higher tractor speed when it is connected to heavy equipment or machinery. This increased load generates pressure on the soil, leading to higher soil compaction and reduced porosity.

The overall bulk density increases, causing the soil to exhibit physical characteristics unsuitable for production. This also leads to increased operating expenses for the machinery, including higher fuel consumption, reduced capacity, and slippage (DeJong-Hughes et al., 2001).

The research concerns the compaction, cohesion, and merging of soil layers due to repeated passage of agricultural machinery during ploughing, especially in hard-to-reach depths, known as the hard sub-layer. This study aims to investigate how the depth of plough knives below the soil surface and varying speeds affect field performance indicators, as well as certain physical properties of the soil, such as surface density, total porosity, and cohesion strength. Also, investigate the moral outcomes of different depths of knife entry into the soil and the speed at which the work is completed, particularly in eliminating hard sublayers. Find the optimal combination of tractor speed and ploughing depth by testing two speeds and three depths to determine field performance indicators.

MATERIALS AND METHODS

The experiment took place in the spring of 2023, at the beginning of May, in the Al-Rajaiba area, Al-Jadid Al-Gharbi District, Karbala Governorate, Iraq. It was conducted on a land area of 1/2 hectare, measuring 44 meters wide and 114 meters long. The purpose was to evaluate the performance of a subsurface plough in breaking the hard layer at different ploughing depths and speeds, focusing on various field performance indicators. The land has not been ploughed for subsoiling in over 10 agricultural seasons. The soil texture of the experimental field is clay. Soil samples were taken for texture analysis at the General Agriculture Laboratory of the Karbala Agriculture Directorate, Iraqi Ministry of Agriculture (Table 1).

Table 1. Analyses of soil texture.

Soil texture	Soil separators		
Clay soil	Silt	Sand	Clay
Moisture content (13%-15%)	5%	7%	88%

Design of experiment

The experiment was carried out as a factorial with two factors and a randomized complete block design (RCBD) according to split panels (Al-Rawi Khalafallah 1981 and Al-Sahuki and Wahib 1990), where a sample of the experimental land was excavated to an amount of (2*2*1=2 m^3) so that we could obtain knowledge of the depth of the deep layer and the characteristics of the soil.

A sample of the experimental land was excavated to a volume of 2 m^3 to understand the depth of the deep layer and the soil characteristics. Soil samples were taken at depths 0-20, 20-40 and 40-60 cm. A sieve with a 2 mm opening diameter was used to filter the soil and determine some of its physical characteristics.

After analyzing the initial samples (Table 2), the experimental land was leveled and modified using a leveling machine to prepare it for the three sectors. One sector was divided into six panels (experimental units) with a length of 40 meters for each line of work. A distance of 5 meters was left between the sectors and 2 meters between each experimental unit to enable rotation of the tractor, to gain stability and for the tug to meet its estimated speed while working. When the soil was ready to apply the treatments, it was ploughed (using a subsoil plough). The treatments were applied at the depths and speeds mentioned in the experiment design Table 3, and readings were taken for the studied characteristics as follows:

1- Main plot: Forward speed factor, Velocity, at two levels:
Note that the fuel level for each level is fixed at a certain amount
• V1 gearbox on number 1 heavy = 3.71 km/h
• V2 gearbox on number 2 heavy = 5.21 km/h

2- The secondary factor (Sub plot) is the depth factor of ploughing at three depths:
• d1 minimum depth 40 cm
• d2 average depth 50 cm
• d3 top depth 60 cm

The parameters were randomly distributed, and the data collected from the experiment was analyzed based on the design used. The differences between the parameters were tested using the LSD method at a 5% probability level in the GenStat program. An electronic computer was used to test the significance of the differences and the averages of the various parameters.

Table 2. Field experiment chart table.

Front speed (km/hr)	Depth (cm)	R1	R2	R3
	D1 - 40	V1D1R1	V1D1R2	V1D1R3
V1 - 3.71	D2 - 50	V1D2R1	V1D2R2	V1D2R3
	D3 - 60	V1D3R1	V1D3R2	V1D3R3
	D1 - 40	V2D1R1	V2D1R2	V2D1R3
V2 - 5.21	D2 - 50	V2D2R1	V2D2R2	V2D2R3
	D3 - 60	V2D3R1	V2D3R2	V2D3R3

Studied aspects

Cohesion strength: The Annulus ring device was utilized to measure the cohesive strength of the soil at different depths. These measurements were taken to assess the impact of varying depths and speeds.

Practical density of the soil: This refers to the density of solid particles, which remains relatively constant.

Soil bulk density: This is the mass of the soil particles divided by the bulk volume. Bulk volume is the total volume the particles occupy, including the particle's volume, inter-particle void volume, and internal pore volume. Soil samples were collected from the field at a rate of 3 samples for each treatment using a soil core

Table 3. Table of preliminary analysis for the first irrigation at all depths of the soil of the experimental land.

Chemical and physical properties			Depth of Soil (cm)		
			0-20	0-40	0-60
Sand		Soil g/kg[1]	89.4	71.9	60.4
Silt			312.6	345.4	366
Clay			598.3	606.2	601.1
texture			Clay	Clay	Clay
The moisture content of the first irrigation %			0.228	0.241	0.286
Bulk density (Mg/m^3)			1.39	1.41	1.45
Particle density (Mg/m^3)			2.637	2.640	2.642
Total porosity (%)			47.288	46.590	45.117
ph			7.43	7.41	7.49
Total carbonate (g/kg)			446.25	394.54	375.65
Organic matter (g/kg)			2.45	1.62	1.19
ECe ds/m[1]			19.23	17.24	12.33
Melted ions	Ca^{++}	m/mol[1]	30.56	28.35	24.36
	Mg^{++}		22.65	18.24	12.69
	Na^{+}		83.65	70.25	51.66
	k^{+}		3.52	3.69	3.59
	HCO_3^{-1}		4.63	4.49	4.36
	SO_4^{-}		26.83	25.91	25.12
	Cl^{-}		104.95	102.11	98.95
	Co_3^{-}		0.00	0.00	0.00
Irrigation water		EC	3 - 3.3		
		ph	7.1 – 7.3		

sampler with a height and diameter of 5 cm. The samples were then dried in an oven at 105 degrees Celsius for 24 hours, following the method described in (Blake and Hartge, 1986).

These measurements were conducted in the Soil Department laboratory at the College of Agriculture, Al-Qasim Green University, Babylon, Iraq.

$$B.D. = ms/vf \quad (1)$$

B.D.: The bulk density of the soil is estimated in g/cm^3
ms: the mass of solid soil particles, estimated in grams
vf: the volume of pores in the soil, estimated in cm^3.

Total Porosity: The total porosity indicates the proportion of pores within the soil mass relative to the total volume. The total porosity was calculated for all treatments using the following equation (Hassan, 1990):

$$F= 1-(FB/FS)*100 \quad (2)$$

F: pores present in the soil mass relative to the total volume of soil (%)
FB: indicate of soil (g/cm3)
FS: basic soil value (g/cm3).

Theoretical productivity (Pt): Theoretical productivity was measured using the method of (Russel, 1980 and Al-Tahan, 1991).

$$Pt = 0.1*Bt*Vt \quad (3)$$

Pt: theoretical productivity
Bt: working width 30 cm
Vt: Theoretical speed of tractor.

Actual productivity: This was calculated according to Russel, 1980 and Al-Tahan, 1991.

$$P_p = 0.1 \times B_p \times V_p \times ST_p \quad (4)$$

P_p: Actual productivity (ha/h)
B_p: Actual working width (m)
ST_p: Time utilization factor. We used this factor as 0.70 (70%) with reference to Al-Khafaf et al. (1991).

RESULTS AND DISCUSSION

Soil cohesion strength

The study showed a relationship between speed coefficients, soil depths, and soil cohesion (kN/m^2). It revealed that soil cohesion increased with greater soil depth across all treatments involving ploughing below the soil surface. Treatment V2D3 had the highest recorded value of 100.751 kN/m^2, followed by V1D3. The two parameters with the highest values are 96,840 kN/m^2 for V1D1 and 67,885 kN/m^2 for V2D2. These parameters are superior because they have the highest cohesion values due to their cohesive and compact layers (the hard layer). This increases the hardness and cohesion of the soil, which is the focus of the research problem, as well as increasing the density values (Hill, 1990).

Bulk density

The results presented in the table (bulk density) indicate that using a subsoil plough significantly reduces the soil's bulk density as depth increases, compared to not using it. The bulk density was reduced by 1.31, 1.346, 1.45, 1.406, 1.445, and 1.52 at depths of 40, 50, and 60.

This decrease when using a plough is due to the soil being loosened and its porosity increased, as supported by Carter et al. (1996). The data from the table indicates that increasing the speed has a significant effect on raising the apparent density. The V1 speed achieved the lowest density value of 1.31 g/cm3 at a depth of 40 cm, while the V2 speed achieved the highest value of 1.52 g/cm3 at a depth of 60 cm. These results are consistent with those obtained by Hilal et al. (2018). The soil cohesion increases with depth due to a rise in soil moisture and bulk density. There is a significant relationship between cohesion and bulk density. However, using a plough to till the soil led to reduced cohesion among soil particles at all depths. This is attributed to the dismantling and cracking of soil aggregates and the decrease in bulk density when using the plough under the soil. The results of Table 4 revealed an interaction between ploughing depth and speed. The indicators of this characteristic increased with all ploughing speeds. The ploughing depth (40 cm) and speed V1 achieved the lowest value, amounting to 1.31 g/cm³, while depth (60 cm) and speed V2 gave the highest value of 1.51 g/cm³.

Table 4. The interaction of speed coefficients and soil depths in bulk density (g/cm3).

Tractor speed (km/h)	Depth (cm)	R1	R2	R3	Recurrence rate
	D1 - 40	1.31	1.30	1.32	1.31
V1 - 3.71	D2 - 50	1.33	1.34	1.37	1.346
	D3 - 60	1.41	1.45	1.49	1.45
	D1 - 40	1.39	1.40	1.43	1.406
V2 - 5.21	D2 - 50	1.435	1.44	1.46	1.445
	D3 - 60	1.49	1.51	1.56	1.52

Total porosity

Table 5 shows the significant impact of increasing ploughing depths on the total porosity. At a ploughing depth of 40 cm and a speed of 3.71 km/h (V1), the total porosity reached its highest value of 50.322, while the lowest value of 42.467 was achieved at a ploughing depth of 60 cm and a speed of 5.21 km/h (V2). Table 5 also shows that the decrease in porosity is directly proportional to the increase in all speeds. Speed V1 achieved the highest value for this characteristic at 50.322, while speed V2 achieved the lowest value at 42.467. These results were consistent with the findings of Muhammad (2008).

The increase in speed leads to the destruction of the structure of soil fine aggregates, as well as the weight of the tiller's bodies and the weight of the rear axle for penetration. This results in increased soil compaction and decreased overall porosity.

Table 5. Overlap of front speed of tractor and depth of soil and it porosity.

Front speed (km/h)	Depth (cm)	Porosity	R1	R2	R3	Frequency
	D1 - 40	2.637	50.322	50.701	49.943	50.322
V1 - 3.71	D2 - 50	2.640	49.621	49.242	48.106	48.989
	D3 - 60	2.642	46.631	45.117	43.603	45.117
	D1 - 40	2.637	47.288	46.909	45.771	46.656
V2 - 5.21	D2 - 50	2.640	45.643	45.454	44.696	45.264
	D3 - 60	2.642	43.603	42.846	40.953	42.467

Actual productivity

It is evident from Table 6 that the type of plough, ploughing depth, and speed has a significant impact on practical productivity. For instance, ploughing at a depth of 40 cm and using the second speed resulted in a practical productivity of 10.758 ha/h, which significantly outperformed the productivity of ploughing at a depth of 60 cm and using the first speed, which amounted to 5.367 ha/h. The highest productivity was achieved at a depth of 40 cm and speed V2, while the lowest productivity was observed at a depth of 60 cm. This highlights the importance of speed in determining machine productivity, and increasing speed can lead to

Table 6. Overlap of speed coefficients and soil depths in theoretical productivity hectare/hour.

Front speed (km/h)	Depth (cm)	Working width (cm)	R1	R2	R3	Frequency
	D1 - 40	29 - 31	10.759	11.13	11.501	11.13
V1 - 3.71	D2 - 50	24 -26	8.904	9.275	9.646	9.275
	D3 - 60	19 - 22	7.049	7.791	8.162	7.667
	D1 - 40	29 - 31	15.63	14.588	15.890	15.369
V2 - 5.21	D2 - 50	24 -26	12.504	13.025	13.546	13.025
	D3 - 60	19 - 22	9.899	10.42	11.462	10.593

higher process productivity. These findings are shown in Table 7 and are in line with Akbarnia and Alimardani (2010).

It is evident from the table that increasing ploughing depths has a significant effect on productivity for both ploughs, with productivity being inversely proportional to ploughing depth. The highest productivity value is achieved when the ploughing depth exceeds 40, while the lowest value is achieved at a ploughing depth of 60 cm.

Table7. Overlap of speed coefficients and soil depths in actual productivity hectare/hour.

Front speed (km/h)	Depth (cm)	Working width (cm)	R1	R2	R3	Frequency
	D1 - 40	29 - 31	7.5313	7.7910	8.0507	7.7910
V1 - 3.71	D2 - 50	24 -26	6.2328	6.4925	6.7522	6.4925
	D3 - 60	19 - 22	4.9343	5.4537	5.7134	5.367
	D1 - 40	29 - 31	10.941	10.2116	11.123	10.758
V2 - 5.21	D2 - 50	24 -26	8.7528	9.1175	9.4822	9.1175
	D3 - 60	19 - 22	6.9293	7.2940	8.0234	7.4155

Table 8. Overlap of speed coefficients and soil depths in soil cohesion (kN/m^2).

Tractor speed (km/h)	Depth (cm)	R1	R2	R3	Frequency
	D1 - 40	45.878	47.171	51.146	48.65
V1 - 3.71	D2 - 50	59.622	63.172	65.365	62.719
	D3 - 60	96.502	94.848	99.172	96.840
	D1 - 40	51.131	49.318	52.341	50.930
V2 - 5.21	D2 - 50	65.780	66.365	71.511	67.885
	D3 - 60	97.602	98.115	106.536	100.751

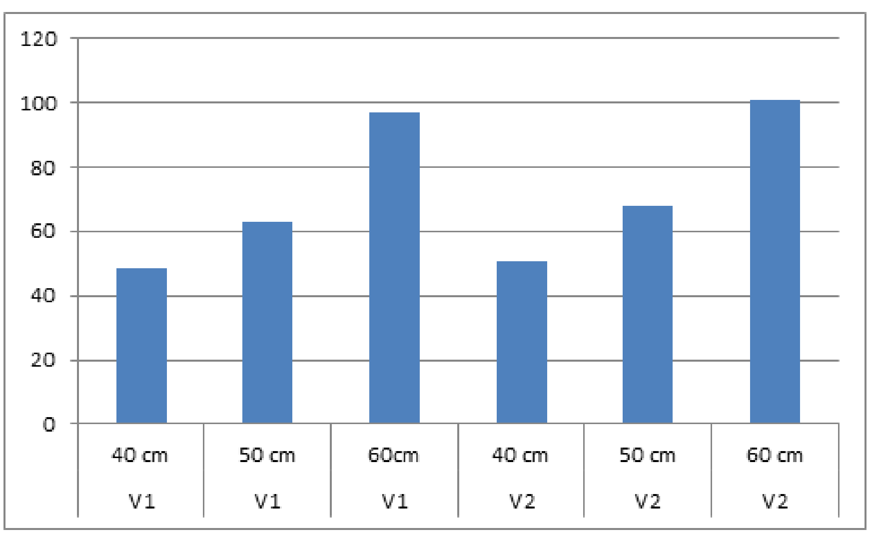

Figure 1. Cohesion strength.

CONCLUSION AND RECOMMENDATION

Based on the findings, it can be concluded that using the plough below the soil surface at a depth of 40 cm (V1D1 48.65) resulted in reduced cohesion values compared to other treatments as shown in Table 8. It can also be inferred that cohesion values increase with greater depth. Therefore, ploughing beneath the soil surface helps reduce soil cohesion and compaction strength, particularly in the hard layer.

Based on the results obtained, we recommend using a subsoil plough in the experimental conditions to achieve the best technical indicators for field performance and physical soil characteristics. Additionally, we suggest adopting a forward speed (V1 = 3.71 km/hr) and a ploughing depth of 40cm to further enhance the technical indicators for field performance and physical soil characteristics within the experimental conditions seen in Figure 1. Finally, we recommend analyzing the impact of these factors on the growth and production of various crops.

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