

Effect of depth and speed factors on draft force and some physical characteristics

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Abstract:

A field experiment was conducted at Al-Ra'ed Station in Abu Ghraib region to estimate the performance of a locally assembled machine and everyone was appreciated drawbar pull (kgf), power lost to slippage (hp), actual productivity (ha/hr), and total soil porosity (%). The experiment included two factors: operational speed at three levels (3.05, 4.36, and 5.22 km·h⁻¹), the second working depth at three levels (10, 20, and 30 cm). The split-plot design was employed in a randomized complete block design (RCBD) with three replications, and treatment means were compared using the least significant difference (LSD) test. The results showed that the first operational speed of 3.05 km·h⁻¹ achieved the lowest drawbar pull (850.6 kgf), the lowest power lost to slippage (1.975 hp), the lowest actual productivity (0.696 ha/hr), and the highest total soil porosity (64.47%). In contrast, the third speed level gave contrasting outcomes. The first depth level attained the least drawbar pull (860.8 kgf), the lowest power lost to slippage (1.981 hp), the highest actual productivity (0.812 ha/hr), and the highest total soil porosity (63.95%), while the third depth level gave opposite results.

Keywords: drawbar pull, power lost to slippage, actual productivity, total soil porosity.

Introduction:

Combined machine with a single operation pass in the field are of great importance and is an efficient role in saving effort, time and costs from harming soil compaction risk to ensure better service for agricultural crops. At the global level, the efficiency assessment of combined machines and the effects of their working conditions on soil and energy are among recent research interests which aim to achieve a trade-off between productivity and sustainability [1, 2, 3].

Several published studies have studied the influence of plowing depth and working speed on mechanical behavior of agricultural machines and properties of soil. Ketena et al., [4] concluded that plowing depth has a significant impact on draft force and is more pronounced in medium-textured

soils, while Kim et al., [5] reported high forward speed results in increased draft force requirement. Based on their experimental results, Al-Aradi [6] concluded that an increase in forward speed leads to a corresponding increase in draft force. Several other latter studies also supported this finding that an increase in plowing speed and depth leads to higher draft force and energy requirements [7, 8]. Also, Al-Suhaibani and Ghaly, [9] concluded in his experiment conducted on a chisel plow in sandy loam soil that increasing the plowing depth led to a corresponding increase in draft force. Al-Qazzaz [10] Concluded during an experiment he conducted on a locally manufactured chisel plow with a Massey

Ferguson MF650 tractor that that increasing the operating speed led to a significant increase in power lost due to slippage. Similarly, increasing the plowing depth also resulted in a significant rise in power lost due to slippage, which is consistent with the results of contemporary research that found that slippage and power loss are significantly affected by the depth and speed combination [11, 12]. Porosity is defined as the percentage of interstitial voids to the total soil volume.

Jassim and Qasim [13] showed that increasing speed significantly decreases the soil's total porosity. More recent studies interpreted this by stating that higher speeds lead to greater breakdown of soil clods and drift of fine particles, which increases bulk density and decreases porosity [14]. Al-Talabani *et al.*, [15] concluded in an experiment conducted in the Abu Ghraib area on silty clay loam soil that increasing

Materials and Methods:

The trial was implemented in the fields belonging to Al-Raed Research Station in the Akr Kuf area on the Abu Ghraib road. The soil was prepared, and then the experiment field was flooded with water after surrounding the field with earth embankments to obtain the suitable moisture content for facilitating the plowing process at a rate of (16-18) %. Afterwards, the final leveling process of the field was carried out, and points were taken from the center and edges of the field using a level device. The field was partitioned into experimental units by positioning markers to show the start and end of each experimental unit. The experiment field's area measured 4.08 dunams, measuring 170 meters in length and 60 meters in width. Three random samples were taken from three different depths using a hand auger.

the depth led to a decrease in total porosity. This is a trend confirmed by contemporary research linking the increased soil pressure at greater depths and decreased porosity [12]. Field productivity is defined as the rate of actual performance in the field, meaning the actual area accomplished by the machine in a specific time, and it depends on the actual working width and practical speed [16]. Al-Janabi, [17] found that speed has a direct impact on practical productivity during an experiment he conducted, that higher operating speeds lead to an increase in practical productivity. Research however reveals that the productivity gain due to greater depth might be compensated by a rise in soil resistance and slippage; hence interaction effect of both should be analyzed together so as to work out an efficient operation [18]. Research shows that setting the plowing speed and depth is particularly important in order to obtain an acceptable tillage effectiveness together with preservation of soil physical properties.

The soil texture was determined by analysis, and it was concluded that the soil texture is (silty clay loam).

The trial was conducted using a Split Plot arrangement within RCBD with 3 replicates. Plowing depth with three levels allocated to the main plot, while the sub-plots represented the practical speed of the mechanized unit with three levels., bringing the total number of experimental units to (27). The experimental unit was (30) meters in length, with (20) meters of space left before each unit for the tractor and implement to stabilize.

Two agricultural tractors were employed to carry out the experiment: the first tractor, model (FALTRA), with power rating of (120) horsepower (HP), and the second tractor, type (MASSEY-FERGUSON), with a horsepower of (85) HP.

The combined implement was used - a set of implements connected to a single

frame, designed to improve the soil and prepare it for creating a good seedbed. It is a mechanized assembly unit that includes plowing, smoothing, and leveling. In the plowing stage, the type of plow was a subsoller chisel plow with a working width of (1.8) meters, featuring flexible shanks in a single row containing four shanks with a

distance of (56 cm) between them and a shank length of 45 cm. Following the plow is the rotary smoother with a design working width of (2.2) meters. The third and final part of the combined implement, representing the leveling stage, is a spiked-tooth harrow with a working width of (2.1) meters.

Studied Traits and Methods of Calculation:

1. Draft force pull (kgf)

$$FT = FPU - FRM.....(1)$$

- FT = Draft force (kN)
- FPU = Tractive force of the rear wheels of the front tractor (kN)
- FRM = Rolling resistance of the wheels barely touching the ground (kN)

The drawbar pull readings were recorded in kilonewtons (kN) and converted to kilogram-force (kgf) using the following equation [19]:

$$kgf = \frac{kN \text{ reading} \times 1000}{9.81}(2)$$

2. Power Lost Due to Slippage (hp)

Calculated using the following equation

$$Ps = FPU (VT-VP)/270.....(3)$$

Where:

- Ps: Power lost due to slippage (hp)
- FPU: Total thrust force (kN)
- VT: Theoretical speed (km·h⁻¹)
- VP: Actual (field) speed (km·h⁻¹)

VT is calculated as:

$$VT = (d / Tt) \times 3.6 (4)$$

Where:

- d: Distance traveled (m)
- Tt: Theoretical time (seconds)

VP is calculated as:

$$VP = (d / Tp) \times 3.6 (5)$$

Where:

- Tp: Actual (field) time (seconds)

3. Actual (Field) Productivity (hectare h⁻¹)

Theoretical field capacity was calculated using the following equation [20]:

$$EFC = 0.1 \times Wp \times Vp \times Ft (6)$$

Where:

- EFC: Actual field capacity of the combined implement (ha·h⁻¹)
- Wp: Effective working width of the combined implement (m)
- Vp: Actual operating speed of the implement (km·h⁻¹)
- Ft: Field time efficiency factor, defined as the ratio of actual working time to total field time, expressed as a percentage. Total time includes actual working time plus turning time at the end of each pass [20], and was calculated as follows:

$$TC = (Tp / Tt) \times 100 (\%) (7)$$

Where:

- TC: Field time efficiency (%)
- Tp: Actual working time (seconds)
- Tt: Total field time (seconds)

4. Total Soil Porosity (%)

Total soil porosity was estimated mathematically from bulk density and

particle density values using the following equation [21]:

$$PO = [1 - (Pb / Ps)] \times 100 \dots\dots\dots (8)$$

Where:

- PO: Total porosity (%)
- Pb: Bulk density (g·cm⁻³)
- Ps: Particle density, assumed constant at 2.65 g·cm⁻³

Results and Discussion

Draft Force: (kgf)

Draft force was significantly affected by both the depth of tillage and operating speed, and its interaction was non-significant. The force increased gradually from 860.8 kgf at a depth of 10 cm to 1013.7 kgf at 30 cm depth. It is also found that the average draft force increased from 850.6 kgf to 980.9 kgf as speed was increase from 3.05 km/h to 5.22 km/h respectively.

These results were consistent with existing literature. The higher increase with depth should be due to the large mass of soil being split and moved away which conform

to Al-Suhaibani and Ghaly [9] as well as Al-Janabi & Al-Mallah, 21 who found a about 35% increase in force from 10-30 cm deep. The advantage of moving up the speed is attributed to larger amount of forward momentum and a faster rate of particulate strain rate imparted onto the soil which results in increased dynamic resistance, as confirmed by Khalid et al. [22].

In summary, both depth of operation and speed of travel are important but independent in determining draft force requirements; there is a considerably higher power input required for deeper and faster operations.

Table 1. The influence of operational depth and practical speed, as well as their interactive effect, on draft force.

Depth (cm) (D)	Practical speed (V) Km/hr			Mean depth
	3.05	4.36	5.22	
10	781.5	897.0	903.8	860.8
20	859.7	961.6	978.6	933.3
30	910.6	1070.3	1060.1	1013.7
Mean Speed	850.6	976.3	980.9	
LSD 0.05	D	V	D*V	
	80.8	62.6	NS	

Power Lost Due to Slippage (hp):

Slip power loss was strongly influenced by the tillage depth and operating speed (Table 2). The power yield increased continuously from 1.981 hp at a depth of 10 cm up to 3.224 hp at a depth of 30 cm. Likewise, power loss augmented from 1.975 hp to 3.300 hp by raising speed from 3.05 km/h up to the maximum of 5.22 km/h. the highest depth and velocity led to power lost due to slippage to 3.968 hp.

Such results are in accordance with data from other authors. The higher with depth, can be explained by a higher draught force required therefore more wheel torque and thus a greater tendency of slip. This is in agreement with Askari & Khalil [23], who connected the growing depth to 25% increase in slippage. Moreover, a non-significant interaction effect was found, indicating that the product of depth and speed is an important factor affecting power transmission efficiency -which has also been observed by Aikins et al. [12] and Al-

Qazzaz, [10]. The faster speed cause shorter tire-soil contact time generally worsening slippage, particularly in heavy load condition and with deeper penetration of a tire.

In conclusion, operational depth and speed turn out to be two important but independent in determining power lost due to slippage, where deeper and faster operations predominantly cause a significant loss of tractive performance.

Table 2. The influence of operational depth and practical speed, as well as their interactive effect, on power lost due to slippage (hp)

Depth (cm) (D)	Practical speed (V) Km/hr			Mean depth
	3.05	4.36	5.22	
10	1.463	1.916	2.563	1.981
20	1.949	2.626	3.371	2.649
30	2.513	3.19	3.968	3.224
Mean Speed	1.975	2.577	3.300	
LSD 0.05	D	V	D*V	
	0.211	0.269	0.405	

Actual productivity: (hectare/hour)

Actual productivity was influenced highly by working speed and depth, even though their interaction effect was not found significant. Travel speed enhanced productivity, increasing from the lowest (0.696 ha/h at 3.05 km/h) to highest (0.944 ha/h at 5.22 km/h); on the other hand, higher maximum depth of tillage had a minimal significant adverse effect with average productivity reduced from 0.812 ha/hr at 10 cm to 0.773 ha/hr at 30 cm. The maximum value of the productivity (0.971 ha/hr) was observed in the shallowest depth and highest speed.

These findings support the current theory. More speed means more distance covered in a given time. The decrease with depth is probably caused by a higher draught that can reduce operational speed or require more time to traverse an area. This speed-depth trade-off for the best performance echoed that borne out by Soni & Salokhe [18] when shallow depth was moved faster results in optimal mix of productivity and soil conservation. Gürsoy & Li, [1] also indicated that improvements in productivity should not come at the expense of the soil's physical properties.

Table 3. The influence of operational depth and practical speed, as well as their interactive effect, on Actual Productivity: (ha/hr)

Depth (cm) (D)	Practical speed (V) Km/hr			Mean depth
	3.05	4.36	5.22	
10	0.707	0.759	0.971	0.812
20	0.698	0.747	0.946	0.797
30	0.682	0.723	0.915	0.773
Mean Speed	0.696	0.743	0.944	
LSD 0.05	D	V	D*V	
	0.012	0.0414	NS	

Total Soil Porosity

Tillage depth and operating speed affected significantly total soil porosity, with the interaction between them being not significant. Porosity declined from 63.95% depth of 10 cm to 58.88% at the depth of 30 cm. Likewise, at the lower speed of 3.05 km/h, porosity decreased from a mean of 64.47% to 58.70%, with the minimum value (57.44%) obtained at the highest depth and speed (Table 4).

This decline is attributed to greater soil compaction. Faster travel speeds add to the dynamic theatres, which may disintegrate aggregates and depth provides more pressure on pores to force particles away from the soil. These findings are supported by Chen et al. [14], who linked high speeds to the fragmentation of soil clods and filling of voids, and Aikins et al. [12], who identified subsurface pressure as a primary cause of porosity reduction.

Table 4. The influence of operational depth and practical speed, as well as their interactive effect, on total soil porosity (%)

Depth (cm) (D)	Practical speed (V) Km/hr			Mean depth
	3.05	4.36	5.22	
10	69.09	62.51	60.26	63.95
20	63.27	60.40	58.39	60.69
30	61.06	58.13	57.44	58.88
Mean Speed	64.47	60.34	58.70	
LSD 0.05	D	V	D*V	
	1.63	3.91	NS	

Despite the presence of a significant individual effect of depth and speed, their interaction was not significant in most of the studied characteristics. This aligns with what Zhao et al. (2024) stated in their study

on modeling the performance of tillage implements, where they indicated that the effect of individual factors may be more pronounced than their interaction under certain conditions.

Conclusions:

1. An increase in pulling force occurs with higher tillage depth and speed, where the third depth recorded the highest draft force rate (1013.7 kgf).
2. An increase in power lost with increasing tillage depth and speed, as power lost due to slippage increased significantly with depth and speed, reaching the highest value (3.968 hp).

3. The highest actual productivity (0.971 ha/hr) was achieved at the first depth and third speed.
4. Total soil porosity decreased significantly with increasing depth and speed, with the third depth and third speed recording the lowest value (57.44%).

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