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The Effect of Moldboard Plowing Speed on The Physical Properties of The Topsoil and Subsoil layers

Dheyaa S. Ashour*, **Hussain A. Safi & Ahmad A. Al-Mothefer**

Department of Agricultural Machines and Equipment, College of Agriculture, University of Basrah, Iraq

***Corresponding author email**: dheyaa.ashour@uobasrah.edu.iq; **H.A.S.**: Hussainsafi71@gmail.com; **A.A.A.**: ahmad.mohammed@uobasrah.edu.iq

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Abstract: The soil compaction of moldboard plowing appears as a plow pan, which causes many problems such as resisting root growth, lowering drainage and degrading of soil structure. This study was carried out to determine the effect of surface tillage via using the moldboard plow of 30 cm depth under three operational speeds {S_1=0.49, S_2 =0.74, and S_3 =1.05 m.s^{-1}} on the soil bulk density (ρ_b), total porosity (*f*) and penetration resistance (P.R). Soil property of three depths with intervals 10 cm were measured for two positions: {topsoil depth (Td) which represent 0-10, 10-20, and 20-30 cm and subsoil depth (Sd) which represent 30-40, 40-50 and 50-60 cm}. The study results indicated that the lowest values for ρ_b (0.86 and 0.69 Mg.m^{-3}) and P.R (983.61 and 118.44 kN.m^{-2}), and the highest values for *f* (67.52% and 74.05%), were recorded under the treatments of S_3, and Td, respectively. The soil depth has a significant effect on the P.R only; the D_1 reached the lowest value (861.47 kN.m^{-2}). The overlapping of S_3×Td has recorded the lowest values for ρ_b (0.51 Mg.m^{-3}) and P.R (106.42 kN.m^{-2}) and the highest value for *f* (80.82%). The moldboard plow disturbed the topsoil aggregates so that the Td was more homogeneous forces (no significant differences between its depths). However, the weights of the soil depths of 0-10, 10-20, 20-30, 30-40 and 40-50 cm were accumulate on the (50-60cm) which get the highest value of ρ_b (1.34 Mg.m^{-3}) and P.R (2561.78 kN.m^{-2}), and the lowest value of *f* (49.46%). The triple interaction was significant with regard to ρ_b and *f* only. The treatment S_3TdD_3 recorded the lowest value for ρ_b (66.67%) and the highest value for *f* (82.48%) compared the treatment of S_2SdD_3, which reached the highest ρ_b and the lowest *f*.

Keywords: Bulk density, Moldboard plow, Penetration resistance, Plow pan, Porosity, Soil compaction.

Introduction

Soil compaction is one of the major problems facing modern agriculture which mainly resulted on the overuse of heavy machinery (Obour & Ugart, 2021; Shaheb *et al.*, 2021). It forms in two soil layers: soil tillage layer and below tillage layer, the surface soil compaction takes place until a depth of 0.3 m or in the topsoil (soil tillage layer) and subsoil compaction takes place to depth under soil tillage layer. Soil compaction in cropping systems affects mostly the upper layer of soil (topsoil compaction) but it is also observed at certain depth (subsoil compaction) (Nawaz *et al.*, 2013). Additional that, other types of compaction, such as sidewall and surface skin compaction, can drastically lower yield under certain circumstances, they typically present less management challenges because they typically do not persist long in the soil and can be handled in a variety of ways, and alternatives are available to either prevent or lessen their impact (Abisuwa *et al*., 2023). Tillage beds and subsoil compaction are two more types of compaction that can last for many years and are significantly more challenging to manage. Several agricultural practices can result in agricultural soil compaction. The deep tillage is conceder one of processes to soil compaction mitigation strategies (Nassir *et al*., 2024).

Any overuse of agricultural machinery on soil that is already deep tilled then plowed cause a majorly reduced soil surface bearing capacity of compacted factors (Soane *et al*., 1986). Tillage is one of the agricultural processes that is necessary provide the appropriate conditions for plants to grow and give higher crop yield (Boone, 1988). It is practiced to address and change the physical, chemical and biological features of soil and enhance suitable conditions to get good plant growth and yield (Morris *et al*., 2010).

Always plowing the soil at the same depth leads to compacting the soil. The compacted soil is distinguished by a high bulk density, which could reduce the movement and growth of plant roots, decrease water infiltration, and limit water movement in the soil (Sommer & Zach, 1992). The compacted soil can occur by the pressure of the tilled soil, the side tractor wheels, blade pressure, and smearing (skidding of plow shears through tillage) on the base of the plow passing of the tillage line particularly if the soil is wet. So that the compacted layer due to plowing is formed directly under the tilled layer (Morris *et al*., 2010). Mallory *et al*. (2011) identified that the compacting of the soil layer takes place through a plow pan, produced by plowing in continuous soil prepare in a cropping system. Raheb & Heidari (2023) obtained that the plow pan boundary from 16 to 64 cm under the surface, which was characterized with by an increase in the bulk density from 5%-14% and a decrease in the total porosity from 7%-19% compared with the other layers.

The moldboard plow is characterized by its ability to bury crop residues and weed control (Håkansson *et al*., 1998). Additionally, it has a high capability to pulverize the soil, and decrease its penetration resistance, and soil bulk density and increases its total soil porosity regarding. It considered a popular primary tillage in many countries. The plow pulverizes the soil by collecting and embracing it in front of the plow shears which lift and turn the soil caused distributes soil aggregate. This process requires from the plow to be rest on the soil beneath it and this leads to compacting the soil under tillage lines for this plow. It can also cause many problems for the soil, such as resisting root growth, reducing water infiltration, lowering the drainage ability, oligotrophic problem, anoxia and degradation of soil properties (Jeřábek *et al*., 2017; Peng *et al*., 2019; Erzamaev *et al*., 2021; Hao *et al*., 2021; Lu *et al*., 2021).

The plow pan (plow layer or plow sole) is a negative indicator of the tillage. However, the moldboard plow performance must consider the comparative improvements in soil properties of the upper tillage depth (topsoil depth) and the degradation of soil properties under the tillage depth (subsoil depth). The soil compaction can be determined by studying some soil properties such as bulk density, penetrometer resistance and total porosity (Morad *et al*., 2007). In addition, these properties are considered indicators of how the tillage operation was efficient in relieving the compaction (Nassir, 2018). Several of studies reported some effects of the moldboard plow on the soil properties of the tilled layer (Morris *et al.*, 2010; Mallory *et al.*, 2011; Raheb & Heidari, 2023). However, few studies have addressed the effect of different factors on the properties of plow pans.

The current study aims to: (1) learn about investigate the moldboard plow effect on topsoil and subsoil (plow pan), (2) determine the positive effect on the tilled layer under three operation speeds, and (3) evaluate the advantages and disadvantages of the moldboard plowing.

Materials & Methods

The study was conducted in a field of the College of Agriculture, University of Basrah at summer 2023. The soil properties of the target soil are shown in table (1). The tillage was achieved by a moldboard plow at three operation speeds of 0.49 (S_1), 0.74 (S_2) and 1.05 (S_3) m.s^{-1}, at 30 cm depth. Two zones of soil block were targeted during this study (which soil samples were taken), topsoil depth (Td) which represent the tilled soil that divided into three depths (D_1=0-10, D_2=10-20, and D_3=20-30 cm) while the subsoil (Sd) or plow pan which represented the soil bellow the tilled soil and also divided into three depths (D_1=30-40, D_2=40-50, and D_3=50-60cm cm from the soil surface). The bulk density (ρ_b), total soil porosity (*f*) and penetration resistance (P.R) were measured during this study.

The operation speed was measured by limited two land point which the distance between them was 10 m. The tractor moved between these points with measured the time on three gearboxes G_1, G_2, and G_3 at engine speed 1500 rpm which gave three operation speeds 0.49, 0.74, and 1.05 m.s^{-1}, respectively.

The recorded data was analyzed statically by SPSS program using Randomized Complete Block Design (RCBD) in factorial arrangements with three same importance factors. The ANOVA table of the statistical analysis is shown in table (2). The means of the operating speeds and soil sample depths were compared by the revised least significant differences test (RLSD P>0.05) while the soil position of sample means were compared by t-test.

Table (1): Physical properties of the soil.

Depth (cm)	ρ_b (Mg.m^{-3})	M.C (%)	*f* (%)	P.R (kN.m^{-2})	Soil Particles (g.kg^{-1})			Texture
					Sand	Silt	Clay	
0-10	1.15	11	56.60	1430.06	35.30	546.66	418.04	silty clay
10-20	1.18	12	55.47	1450.83	38.60	650.88	310.52	Silty clay loam
20-30	1.19	15	55.09	1509.50	36.85	683.30	279.85	Silty clay loam
30-40	1.21	18	54.34	1586.67	13.53	693.72	292.75	Silty clay loam
40-50	1.24	21	53.21	1790.22	9.22	711.37	279.41	Silty clay loam
50-60	1.32	23	50.19	2200.00	9.24	665.31	325.45	Silty clay loam
Average	1.22	16.67	54.15	1661.21	23.79	658.54	317.67	Silty clay loam

Pulverization index after tillage (mm)		
(S_1=0.49)	(S_2=0.74)	(S_3=1.05)
20.23	37.82	9.13

Soil bulk density was determined before and after tillage practice [topsoil (tillage layer) and subsoil (under tillage depth)] by the Core Sampler Method and calculated from equation 1 (Ashour *et al.*, 2022).

$\rho_b = \frac{M_s}{V_t}$ ....(1)

Where:

ρ_b: soil dry bulk density ($Mg.m^{-3}$).

M_s: mass of dry soil (Mg).

V_t: total volume of soil (m^3).

Total soil porosity was calculated before and after tillage (upper and under tillage depth) using equation 2 (Vomocil method) (Ashour *et al.*, 2022).

$f = \{1 - \frac{\rho_b}{\rho_s}\} \times 100$ ....(2)

Where:

f: total soil porosity (%).

ρ_b: dry soil bulk density ($Mg.m^{-3}$).

ρ_s: soil particle density (2.65 $Mg.m^{-3}$).

Soil penetration resistance was measured by a penetroloagger which measuring penetration resistance at each 1 cm depth from the soil surface. This devise is an internal digital recorder data and transfer it to computer by cable. The cone of a 30° penetrating angle, and a base area of 1 cm^2 was used before tillage and under tillage depth, while the cone of a 60° penetrating angle and a base area of 3.3 cm^2 was used with the soil-tilled layer (Ashour *et al.*, 2022).

Results & Discussion

Effect of the operation speed (S) on ρ_b, f and P.R.

The results in table (2) indicated that theρ_b, f and P.R were significantly affected by the operating speed. Table (3) showed that the ρ_b and P.R increased by 3.70% and 12.73% then decreased by 25.58% and 20.52%, while the f was lowered by 2.89% and then increased by 12.37% when the operating speed increased from S_1 to S_2 and S_3 respectively. The soil collected in front of the plow shears with S_2 was a higher than the pressure which imposed of this speed leaded to produced bigger clods caused to increase the soil strength due to decrease soil fragmented, and increase ρ_b and P.R which in return decrease *f*. The reverse case occurred with S_3 had major pressure with more soil pulverized to give the lowest values for ρ_b and P.R and a higher f (Table 1; Isaak *et al.*, 2024).

Table (2): Statistical analysis of F for P.R, ρ_b and f data.

Source of Variation (S.O.V.)	d.f	ρ_b	f	P.R
Block	2	$0.273^{n.s}$	$0.261^{n.s}$	$2.514^{n.s}$
A	2	131.804^{**}	133.879^{**}	7.272^{**}
B	1	2695.552^{**}	2428.663^{**}	1784.686^{**}
C	2	$1.270^{n.s}$	$1.815^{n.s}$	41.544^{**}
A×B	2	24.513^{**}	29.923^{**}	8.046^{**}
A×C	4	$0.109^{n.s}$	$0.105^{n.s}$	$2.052^{n.s}$
B×C	2	31.573^{**}	28.430^{**}	38.341^{**}
A×B×C	4	6.89^{**}	5.504^{**}	$2.426^{n.s}$

A: operating speed, B: position of the sample, C: soil depth, *: significant, **: high significant, n.s: non-significant.

Table (3): Effect of the operating speed (S) on ρ_b, f and P.R.

Operating speed (m.s^{-1})	ρ_b (Mg.m^{-3})	F (%)	P.R (kN. m^{-2})
0.49 (S_1)	1.04^b ±0.287	60.88^b ±6.003	1034.47^a ±965.348
0.74 (S_2)	1.08^c ±0.333	59.17^a ±7.382	1185.43^b ±1183.972
1.05 (S_3)	0.86^a ±0.365	67.52^c ±8.628	983.61^a ±948.943

Effect of the position of soil sample (Td and Sd) on ρ_b, f and P.R.

The results of table (4) indicate that the position of the soil sample had a highly significant effect on theρ_b, f and P.R. moving from the topsoil (Td) to the subsoil (Sd) has led to increase the ρ_b and P.R by 48.46 and 94.13%, and decreased the f by 45.20% (Table 4). The tillage by the moldboard plow resulted in a weak pulverized soil at topsoil depth (Table 1) and formed a plow pan at subsoil depth at the same time. The plow pan represents compacted soil under the tillage layer become compacted, due to the skid pressure of the plow that acts on the separation of the surface between the tilled and nontilled layer (Yang *et al.*, 2021).

Table (4): Effect of the position of soil sample (Td and Sd) on the ρ_b, f and P.R.

The position of soil sample	ρ_b (Mg.m^{-3})	f (%)	P.R (kN.m^{-2})
Td (0-30 cm)	0.69^a ±0.332	74.05^b ±2.021	118.44^a ±34.713
Sd (30-60 cm)	1.30^b ±0.934	51.00^a ±3.790	2017.24^b ±506.613

Effect of the soil depth (D) on ρ_b, f and P.R.

Table (5), explain the soil depth significantly affected the P.R only. The P.R values increased with increasing soil depth (Table 5), The D_3 reached the highest value of 36.05% when compared with D_1. Weights of upper soil layers will compress on the D_3, which causes an increase in the P.R. (Medina *et al.*, 2012).

Table (5): Effect of the soil depth (D) on the ρ_b, f and P.R.

soil depth (cm)	P.R (kN.m^{-2})
0-10 (D_1)	861.47^a ±768.737
10-20 (D_2)	994.95^b ±916.808
20-30 (D_3)	1347.10^c ±1301.046

Effects of the interaction between the operation speed (S) and the position of soil simple (Td and Sd) on the ρ_b, f and P.R.

The results in table (6) showed that the interaction between the operation speed and the position of the soil sample (Td and Sd) has a significantly affect the ρ_b, f and P.R. From Table 6, the treatment S_3Td has a lower ρ_b and P.R, and a higher f of 63.31%, 95.30%, and 70.43%, respectively, compared with the treatment of S_2Sd. The high pressure of the speed S_3, it increased the soil pulverizing of the tilled layer (Td). Conversely, decreasing the operating speed to S_2 distributed the plow pressure on the soil under the tilled depth and produced the highest plow pan (Sd).

The soil penetration resistance of S_2Sd was higher than the compacted soil (plow pan). It exceeds the value that was specified by Martino & Shaykewich (1994) and De Moraes *et al*. (2014) who considered 2000 kN.m^{-2} as the critical value to limit the growth of the root.

Table (6): Effects of the interaction between the operation speed (S) and the position of the soil sample (Td and Sd) on the ρ_b, f, and P.R.

Operation speed (m.s^{-1})	The position of the soil sample	ρ_b (Mg.m^{-3})	f (%)	P.R (kN.m^{-2})
0.49 (S_1)	Td	0.79^{b} ±0.085	70.40^{d} ±2.013	139.97^{a} ±54.450
	Sd	1.29^{d} ±0.038	51.35^{b} ±0.833	1928.98^{b} ±420.724
0.74 (S_2)	Td	0.77^{b} ±0.102	70.92^{e} ±2.323	108.93^{a} ±12.052
	Sd	1.39^{e} ±0.086	47.42^{a} ±1.856	2261.93^{c} ±609.293
0.49 (S_3)	Td	0.51^{a} ±0.048	80.82^{f} ±1.338	106.42^{a} ±5.235
	Sd	1.21^{c} ±0.034	54.22^{c} ±0.732	1860.80^{b} ±426.887

Effect of the interaction between the position of soil sample (Td and Sd) and the soil depth (D) on ρ_b, f and P.R.

The results in table (7) indicated that the ρ_b, f and P.R. were significantly affected by the interaction of the position of soil simple and the soil depth. Table 7 showed that there were no significant differences in the P.R among the TdD_1, TdD_2 and TdD_3. However, they achieved to the lowest values for the ρ_b and P.R, and the highest value for *f*. On the other hand, the treatment SdD_3 recorded the highest values for ρ_b and P.R, with the lowest value for *f*. The moldboard plow works by lifting, turning and mixing the soil aggregates so that the soil depths in Td (soil tilled layer) were homogeneous. However, the weights of the soil depths of TdD_1, TdD_2, TdD_3, SdD_1 and SdD_2 were applied on the deep depth of SdD_3. In addition, the pressure of the moldboard plowing was distributed to SdD_3.

The P.R data clarified that the compacted soil (plow pan) formed in SdD_3. This treatment reached 2561.78 kN.m^{-2}, which represents a high resistance to root growth (Martino & Shaykewich 1994; De Moraes *et al*., 2014).

Table (7): Effect of the interaction between the position of the soil sample (Td an Sd) and the soil depth (D) on the ρ_b, f and P.R.

The position of the soil sample	Soil Depth (cm)	ρ_b (Mg.m^{-3})	f (%)	P.R (kN.m^{-2})
Td	0-10 (D_1)	0.77^{b} ±0.172	71.13^{d} ±4.221	117.60^{a} ±16.595
	10-20 (D_2)	0.65^{a} ±0.145	75.33^{e} ±3.663	105.30^{a} ±1.756
	20-30 (D_3)	0.64^{a} ±0.118	75.69^{e} ±3.122	132.43^{a} ±56.829
Sd	0-10 (D_1)	1.25^{c} ±0.037	53.00^{c} ±0.797	1605.33^{b} ±102.459
	10-20 (D_2)	1.31^{d} ±0.102	50.54^{b} ±2.200	1884.60^{c} ±72.900
	20-30 (D_3)	1.34^{e} ±0.106	49.46^{a} ±2.318	2561.78^{d} ±523.516

Effect of the interaction between the operation speed (S), the position of the soil sample (Td and Sd), and the soil depth (D) on the ρ_b, f and P.R.

The interaction between the operation speed (S), the position of the soil sample (Td and Sd), and the soil depth (D) had a highly significant effect on the ρ_b and f, while it did not affect the P.R (Table 8). The treatment S_3TdD_3 presented the lowest value (66.67%) for ρ_b and the highest value (82.48%) for the f compared the treatment of S_2SdD_3 that recorded the highest ρ_b and the lowest f (Table 8). The highest operation speed (S_3) imposes high pressure on the soil block causing more pulverization to the surface soil. One important foundation for the moldboard plowing is turning the soil (burying the soil surface with the strong deep soil) so that the deep tilled soil (D_3) is weaker than its surface. The S_2 caused a collection of the tilled soil in front of the plow higher than the other treatments, and this increased the compacting pressure that is imposed on the soil under tillage depth and this pressure is being on the deep depth (D_3). (Medina *et al*., 2012; Yang *et al*., 2021; Isaak *et al.*, 2024).

Table (8): Effect of the interaction between the operation speed (S), the position of soil the sample (Td and Sd) and the operation depth (D) on ρ_b, f and P.R.

Operation speed ($m.s^{-1}$)	The position of the soil sample	Soil Depth (cm)	ρ_b ($Mg.m^{-3}$)	f (%)
0.49 (S_1)	Td	0-10 (D_1)	0.85^{d} ±0.002	67.91^{h} ±1.002
		10-20 (D_2)	0.76^{c} ±0.140	71.51^{i} ±3.256
		20-30 (D_3)	0.75^{bc} ±0.013	71.78^{i} ±0.981
	Sd	0-10 (D_1)	1.26^{ef} ±0.010	52.62^{d} ±0.734
		10-20 (D_2)	1.28^{fg} ±0.417	51.60^{c} ±0.895
		20-30 (D_3)	1.33^{g} ±0.007	49.84^{b} ±0.551
0.74 (S_2)	Td	0-10 (D_1)	0.91^{d} ±0.004	65.78^{g} ±0.928
		10-20 (D_2)	0.71^{bc} ±0.011	73.16^{j} ±0.789
		20-30 (D_3)	0.69^{b} ±0.023	73.83^{j} ±1.013
	Sd	0-10 (D_1)	1.28^{fg} ±0.153	51.64^{c} ±0.315
		10-20 (D_2)	1.43^{h} ±0.005	45.98^{a} ±0.467
		20-30 (D_3)	1.47^{h} ±0.029	44.64^{a} ±0.331
0.49 (S_3)	Td	0-10 (D_1)	0.54^{a} ±0.018	79.69^{l} ±1.499
		10-20 (D_2)	0.50^{a} ±0.078	81.31^{m} ±2.134
		20-30 (D_3)	0.49^{a} ±0.035	81.46^{m} ±1.011
	Sd	0-10 (D_1)	1.20^{e} ±0.051	54.74^{f} ±2.006
		10-20 (D_2)	1.22^{ef} ±0.064	54.03^{e} ±1.397
		20-30 (D_3)	1.22^{ef} ±0.49	53.89^{e} ±0.877

Conclusions

The results clarified that:

1-The operation speed S_2 and the soil depth D_3 had the highest values for ρ_b and P.R. and the lowest value for f. Meanwhile, S_3 and D_1 had the lowest values for ρ_b and P.R and highest value for f.

2-The moldboard plowing formed a soil compacted layer (plow pan) under the tillage depth, especially in the soil deep depth (D_3) which is 50-60 cm from the soil surface.

However, its value was higher before the tillage. Corresponding to that, a great decrease in ρ_b and P.R and an increase in f were achieved.

3-This study displayed that the moldboard plowing for one time may be form plow pan on deep depth. However, this plow pan may be development to deep near of soil surface depending on tillage factors as, operation speed, deep tillage,… etc. This result is a difference with previous researchers how find the plow pan occur by continues tillage for many years.

4-The parameter ρ_b was very high in D_2 and D_3 with the operation speed of S_2 so that decreased the f values. However, the other operation speeds gave lower values.

5-The experimental results indicated that planting after moldboard plowing is possible with no need for other harrowing operations if similar conditions to this study are granted.

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Contributions of authors

D.S.A.: Presented idea of the article, collected the data, performed the analysis, wrote the paper and revised the manuscript.

H.A.S. and A.A.A.: Assist in carrying out the experiment and collecting

ORCID

D.S. A,: https://orcid.org/0000-0003-2699-6697
H.A. S.: https://orcid.org/0000-0002-9019-1757

A.A.A.: https://orcid.org/0000-0002-2257-2646

Conflicts of interest

As for the requirements of the publishing policy, there is no potential conflict of interest for the authors

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تاثير الحراثة بالمحراث المطرحي القلاب في صفات التربة الفيزيائية لطبقتي التربة السطحية وتحت السطحية

ضياء سباهي عاشور وحسين عبد الكريم صافي واحمد عبد الكاظم المظفر

قسم المكائن والآلات الزراعية، كلية الزراعة، جامعة البصرة، جمهورية العراق

المستخلص: تنتج الحراثة بالمحراث المطرحي القلاب طبقة صلبة مكبوسة تسمى بحوض المحراث (او طبقة المحراث او طبقة الحرث) وتسبب العديد من المشاكل كأعاقة نمو الجذور وانخفاض قابلية البزل وتدهور خصائص التربة. لذا نفذت هذه الدراسة لتقدير تأثير الحراثة بالمحراث المطرحي القلاب على عمق 30 سم بثلاث سرع امامية {S_1=0.49 وS_2=0.74 وS_3=1.05 م.ثا$^{-1}$} على الكثافة الظاهرية للتربة (ρ_b) والمسامية الكلية (f) ومقاومة الاختراق (P.R). حيث تم قياس تلك الصفات لثلاثة اعماق {0−10 (D_1) و10−20 (D_2) و20−30 (D3)} ولموقعين {فوق عمق الحراثة (Td) وتحت عمق الحراثة (Sd)، والتي تمثل الاعماق 30−40 و40−50 و50−60 سم من سطح التربة}. تشير نتائج الدراسة الى ان معاملتي السرعة الامامية S_3 وموقع اخذ العينة Td سجلتا اقل ρ_b (0.86 و0.69 ميكاغرام.م$^{-3}$) وP.R (983.61 و118.44 كيلونيوتن.م$^{-2}$) على التوالي، وقابل ذلك ارتفاع في قيم f والتي كانت 67.52 و74.05% للمعاملتين السابقتين على التوالي. كما تظهر النتائج ان تأثير عمق التربة كان معنوياً في صفة P.R فقط، اذ سجل العمق D_1 اقل قيمة P.R بلغت 861.47 كيلونيوتن.م$^{-2}$. وتبين النتائج ان المعاملة S_3Td سجلت اقل القيم لـρ_b وP.R واعلى f، فقد كانت القيم 0.51 ميكاغرام.م$^{-3}$ و106.42 كيلونيوتن.م$^{-2}$ و80.82% على التوالي. ان الحراثة بالمحراث المطرحي القلاب تؤدي الى خلط تجمعات التربة لذا فان اعماق التربة للموقع Td كانت متجانسة القوى اذ لم تظهر اختلافات معنوية بين تلك الاعماق، لكن تركز وزن التربة للاعماق TdD_1 وTdD_2 وTdD_3 وSdD_1 وSdD_2 على العمق السفلي SdD_3 ادى الى تسجيله اعلى القيم لـρ_b (1.34 ميكاغرام.م$^{-3}$) وP.R (2561.78 كيلونيوتن.م$^{-2}$) واقل قيمة لـ f (49.46%). كما تشير النتائج ان للتداخل الثلاثي بين المعاملات المدروسة تاثيراً معنوياً على ρ_b وf فقط. حيث اعطت المعاملة S_3TdD_3 اقل ρ_b واعلى f بنسب 66.67% و82.48% على التوالي مقارنة بالمعاملة S_2SdD_3 التي سجلت اعلى قيمة لـρ_b واقل f.

الكلمات المفتاحية: الكثافة الظاهرية، المحراث المطرحي القلاب، مقاومة الاختراق، حوض المحراث، المسامية، كبس التربة.