Effect of Adding Wings to the Shallow Tines on the Performance of Subsoiler Plow in the Soil Disturbed Area, Soil Pulverization Index & Equivalent Energy of Pulverization

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Abstract: The experiment was performed using locally manufactured subsoiler plow provided with wings on the outside of shallow tines feet to study the impact of adding the wings and depth of tillage on the disturbance area of soil, soil pulverization index (mean weight diameter, MWD) and the equivalent energy of soil pulverization (Eq EP) in clay soil. This experiment was done in Randomized Complete Block Design (RCBD), with three replications having a factorial experiment. Three tillage depths (40, 50, and 60cm) with and without wings on the feet of shallow tines were used. The results showed that the impact of adding wings and tillage depths had a significant effect on the disturbance area, soil pulverization index and the equivalent energy of soil pulverization ($p < 0.05$). The treatment of adding wings on shallow tines (S+shw) has pre-eminence in studied factors. The disturbed area increased by 11.11, 14.29 and 9.80%, the MWD decreased by 27.33, 32.31 and 19.38% and the Eq EP increased by 43.19, 53.03 and 25.13% when the depth of tillage increased from 40, 50 and 60cm respectively.

Keywords: subsoiler plow, wings, disturbed area, means weight diameter, equivalent energy.

Introduction

The tillage considered one of the main steps to create the seed cradle. Therefore the plowing tools take out the energy into the soil to produce desired effects such as cutting, breaking, inversion, and movement of soil. Soil is thus, transformed from the solid initial condition to the desired final condition by this process, (Ros *et al*., 1995). Frequent conventional tillage on the same depths during soil preparation, it leads to increase soil compaction. Also, soil compaction increases during processes of the break up the soil which that require passage the tractor in the field for more than once in the heavy soils as well as increase crush soil to micro granules. Basrah located in the southern Iraq, where the soil structure is heavy and the processes may be lead to soil degradation which affects both of the growth vegetative and yield of the crops as a result of the compact layers, increasing in bulk density and penetration resistance, thereby that lead to reduce water movement in the soil (Lal, 1997;

Melesse *et al.*, 2009; Jabro *et al.*, 2010; Aday *et al.*, 2011a). Therefore, there are alternative methods of the tillage and soil management should be used to reduce the traversing of the tractor in the field (Gill, 1969; Botta *et al.*, 2006; Kadhim & Subr, 2012). Using the subsoiler plow is an especial common technique used to tear down hardpans; therefore it required a high draft force (Godwin *et al.*, 1981; Raper & Sharma, 2002; Desale *et al.*, 2012). Some modifications have been made, such as adding wings and shallow tines to improve the performance and profits from the available power (Kasisira & du Plassis, 2006).

The disturbed soil can be defined as the crumble, move, and mixing that leads to a decrease in bulk density and change in the location of the loosening soil for three directions, particularly in the vertical direction of soil. These changes were caused by a tool passing through the soil. Consequently, the tool must be designed optimally to the soil disturbance parameters composition which includes: push back the critical depth, rake angle, shallow tines, and adding wings. Moreover, adding wings lead to change the soil failure to crescent shape for three dimensional (forward, lateral and vertical) soil movements (Godwin & Spoor, 1977; Aday *et al.*, 2011b; Barr *et al.*, 2018). Also, affected the form of the furrow, soil throw on the side and blended the layers vertically by adding the wings (Sharifat, 1999; Desbiolles & Saunders, 2006; Solhjou *et al.*, 2012; Hasimu & Chen, 2014).

Dogra *et al.* (2014) showed that the mean weight diameter of the clods size increased with an increase in blade width. Mean weight diameter varied between 2.22 to 12.15mm at different width blade. Minimum weight diameter (MWD) was observed for 10cm

wide blade and 4.62 Hz spading frequency. Maximum weight diameter (MWD) was observed for blade 15cm wide and 1.85 Hz spading frequency. The soil was crumbled when used the forwarding bent-winged tine plow more than the backward one plow. The reason for that the conventional winged tine is the removal of soil from down to the surface, but the bent-winged tool cut the soil in the subsurface and moved it vertically during it moved forward; therefore, the soil has teardown into small pieces. (Askari *et al.*, 2019).

One of the most approaches to reduce the requirements of energy can be achieved by increasing the efficiency of tillage. The required energy to operate a tillage tool in the soil is used to overcome the mechanical strength of the soil and to cause displacement, which results in break-up the soil (Muhsin, 2017; Almaliki, 2018; Almaliki *et al.*, 2019). According to what indicated it Tisdall & Oades (1982), macro aggregates was larger than 200µm, so it was more affected compared to the micro aggregate (2-200µm). The action of the direct plowing tools and equipment probably does not result in the important dismantling of soil. Therefore the macro aggregate and the agglomerate soil have partly shredded by the plowing tools (Balesdent *et al.*, 2000). Soil pulverization requires more energy for breaking the soil to small pieces which decrease the soil mean weight diameter and increases the pulverization (Khadr, 2008).

A few researchers studied the effect of wings in the subsoiler on soil fragmentation and disassemble, which reflect on knowledge of farmers about using the tine's wings and their benefit in soil tilling. Most of previous studies confirm that adding wings with subsoiler and tines was significant in the

performance of the subsoiler. However, the studies about effects of wings on soil fragmentation were specific and rare. The published researches of such literature show that the used wings can be included the rake angle and the attack angle which consider very important in the efficiency of the subsoiler performance. However, there is no comprehensive study of this respect. The objective of this study is to reach the cognition of the impact of adding wings to shallow tines in the subsoiler plow in the soil mean weight diameter and equivalent energy for pulverization. The main goal of the research is to determine the mean weight diameter of the plowing soil area, which was scrutinized in terms of the suitability of the loosened area for direct seed implants.

Materials & Methods

Characteristics of subsoiler plow

The subsoiler plow was designed and manufactured in the Department of Agricultural Machines and Equipment, College of Agriculture, University of Basrah (Fig. 1). It consists of the frame attached to the leg forward angle (rake angle) of 60°. The foot was fixed at the end of the subsoiler leg. The penetration angle of the front of the foot is 35°. The foot was provided two wings fixed on both sides at the inclination angle of 25°. The width of the foot together with the wings is 30cm. The subsoiler plow was provided with two shallow tines at a distance of 36cm forward of the subsoiler plow. The lateral distance (distance between shallow tines) can be changed. Each foot of shallow tines provided with wing fixed on the outside. The width of the foot together with a wing is 20cm.
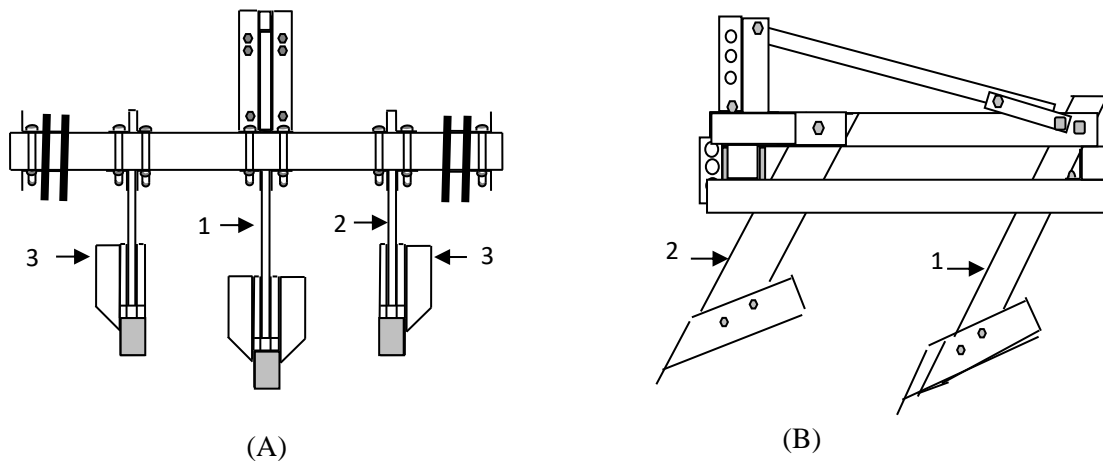

(A)   (B)

Fig. (1): The schematic subsoiler (A) Front view, (B) Side view

1= subsoiler plow, 2= shallow tines, 3= wings

Soil properties

The field experiments were carried out in Research Station farm of Agriculture College of university Basrah in soil clay texture; their limits of consistency were shown in table (1). The soil samples were taken before

experiment execution to estimate the moisture content and bulk density (Black *et al.*, 1965). The penetration resistance, cohesion, and adhesion strength were measured from 10 to 60 cm (Gill & Vanden Berg, 1968). The results of soil analysis were presented in table (2).

Table (1): Soil texture and consistency limits

Sand g Kg⁻¹	Silt g Kg⁻¹	Clay g kg⁻¹	Liquid limit %	plastic limit %
Sand g Kg^{-1}	Silt g Kg^{-1}	Clay g kg^{-1}	Liquid limit %	plastic limit %
70.60	325.40	604.00	48.66	26.83

Table (2): The physical and mechanical properties of experiment soil.

Depth cm	Moisture content %	Bulk density Mg. m^{-3}	Cone index kN. m^{-2}	Cohesion kN. m^{-2}
0-10	14.40 ±0.66	1.20 ±0.03	1266.56 ±9.27	13.30 ±0.60
10-20	20.70 ±0.75	1.23 ±0.10	1241.24 ±6.46	14.89 ±0.44
20-30	21.07 ±0.96	1.15 ±0.08	1241.24 ±3.98	16.54 ±0.41
30-40	21.98 ±0.57	1.36 ±0.04	1551.55 ±5.88	19.22 ±0.57
40-50	22.53 ±0.61	1.40 ±0.05	1681.68 ±5.10	21.34 ±0.88
50-60	25.29 ±0.64	1.30 ±0.09	1480.00 ±7.00	18.79 ±0.47

Data collection

The tillage was carried out on long lines of 15 m by using Massy-Ferguson tractor, (2680, 4WD). The rated power of the tractor is 96.98 kW, at a forward speed of 0.34 m sec⁻¹. After the tillage process, the soil was left to dry in the field. The disturbed soil was removed by hand for a length of 50 cm and to width of soil disturbed for each line at all tillage depths beyond the trench and the undisturbed soil profile exposed was measured by measuring the dimensions of the trench, then convert it to a geometric shape (Fig. 2), and calculating the area by the equation (1).

$$A = \frac{(L1 + L2)}{2} * d \quad ... (1)$$

A= disturbed area, L1= soil surface disturbed, L2 = the bottom of ditch, d = depth of tillage.

The soil out of the trench was collected for all tillage depths. Then it was passed through a series of different sizes of sieves with diameters (120, 90, 50, 30, 10 and 2 mm). The clods of the diameter greater than 120 mm were measured by using the measuring

tape. The mean weight diameter (MWD) was calculated by using equation (2).

$$Xi = \sum_{i=1}^{n} \frac{Wi * M}{W} \quad .... (2)$$

Where Xi : is the mean weight diameter (mm), Wi : is the mass of soil on each sieve (kg), M : is the average sieve size (mm), W : is the mass of soil sample (kg).

Different soil samples were randomly collected from each tillage depth at moisture content about 4.90%. After that, the samples were separately weighted, for three replicates. The pulverization energy was calculated from a break up the soil clods by a crash drop from a height 0.80 m according to Gill & McCreery (1960) using the following formula (3).

$$Q = M * g * Z * n \quad .... (3)$$

Where:

Q : is the pulverization energy (kJ), M : is the mass of sample (kg), g: is the acceleration (m sec⁻²), Z : is the vertical distance of fall
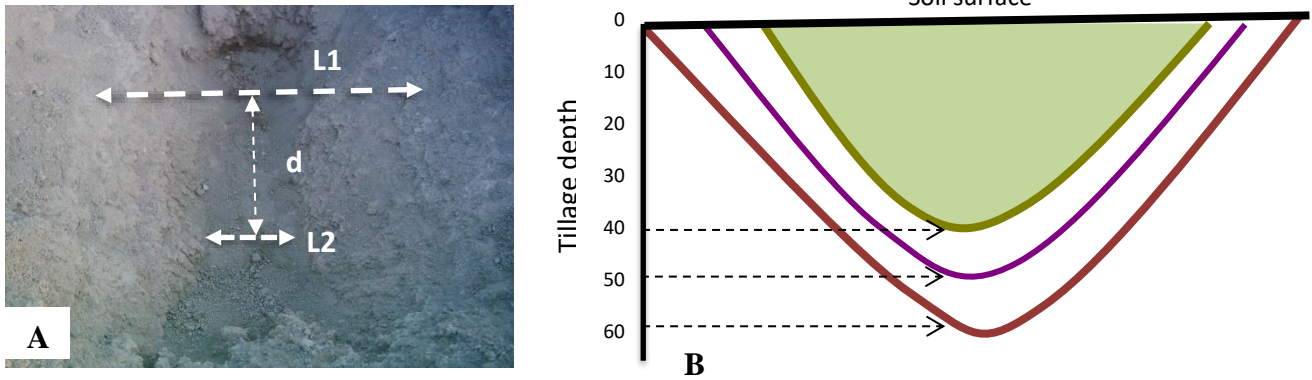
Fig. (2): A- Actual shape, B- Soil geometric shape as a consequence of the subsoiler plow action.

down (0.80 m), and n : is the times number of the fall down.

The MWD for the obtained small pieces of the soil after a number of dropping were calculated by using the same sieves who using in calculation the MWD in the field. The relationship between the MWD and the pulverization energy was determined by using a logarithmic scale of the axis X (fig. 3). The pulverization energy of the disturbed soil by the subsoiler plow was calculated per each plowing depth by using equation (4) consequent from the graph to determine the amount of energy used for the pulverization.

$$\cdot y = -23.17 * Ln(x) + 112 \quad (4)$$

Where y: is the mean weight diameter (mm), x: is the energy required for the pulverization (kJ.Mg^{-1}).

The equivalent energy for pulverizing (kJ. Mg^{-3}) was calculated by multiplying the pulverization energy required and soil bulk density at different depths. The experience was performed using a complete randomized block design (RCBD) with three replications and the data were analysed using Genstat. The differences between averages were compared using LSD at a level of 0.05 (Table 4).
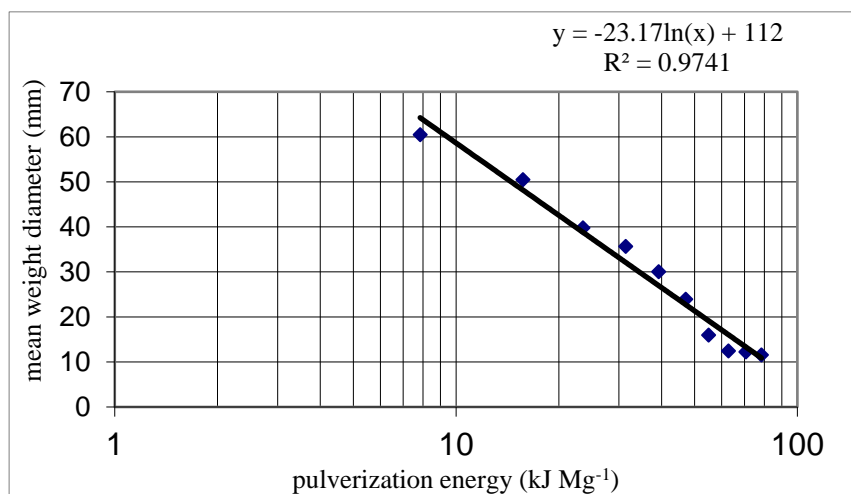
Fig. (3): Correlation between energy required and mean weight diameter.

Results & Discussion

The disturbed area of soil

The results in the table (3) showed that the effect of wings and tillage depth in the disturbance area was significant differences at (P< 0.05). Increasing of the disturbed area (27.59 and 23.24%) when the depth increment from 40 to 50 and then 60cm sequentially while the increment was 10.53% when adding the wings.

With increasing tillage depth and adding wings, the disturbance soil was increased, the results displayed in table (3). This goes back to during movement of the plow in the soil, it is cut off the soil and send it to the sides of the plow. The edge of the furrow of the disturbance soil generated was observed beyond the plowing line of the trench similar to an isosceles triangle. This result was compatible with that reported by Liu &

Kushwaha (2006). Adding the wings on the feet of the shallow tines was substantial effect on the soil disturbance parameters as they all incremented when the plowing depth increment. This could be returned to control parameters nature of soil failure or disturbance is the (depth/width ratio). Moreover, the rake angle leads to increase the forward rupture distance and lateral cracks. Then it's led to the crescent failure formation of the soil (Godwin & Spoor, 1977; McKyes, 1985).

The interaction between the depth of tillage and adding the wings on the feet of shallow tines in the disturbance area was significant effect (p< 0.05). The disturbance area increased by 11.11, 14.29 and 9.80% for the adding wings treatment (S + shw) compared with without wings treatment (S + sh) when increase tillage depth from 40 to 50 and 60cm respectively (Table 3).

Table (3): Effect depths of tillage and adding wings to shallow tines in disturbed area (m²)

	Depth of tillage (cm) (D)			
	40	50	60	Mean
S+sh	$0.27^a \pm 0.03$	$0.35^c \pm 0.04$	$0.51^e \pm 0.01$	0.38^a
S+shw	$0.30^b \pm 0.02$	$0.40^d \pm 0.02$	$0.56^f \pm 0.03$	0.42^b
Mean	0.29^a	0.37^b	0.53^c	

S+sh= Subsoiler + shallow tines, S+shw= Subsoiler + shallow tines + wings, D= depth of tillage. Values are means ± SE Obtained from three replications. The means with the different letters had significant effect at a probability level of 0.05.

It noticed the percentage of the increase in the soil disturbance increased when increasing the depth from 40 to 50 and then decreased at the depth 60cm. this is because of the shallow tines with wings are working at the front of the subsoiler plow and at different soil in the properties such as moisture content, bulk

density and penetration resistance at the depth at 50cm (Table 2). This caused an increase in a crescent failure zone and reduced the pressure of soil on the foot of the subsoiler plow. Then, it's led to an increase in the lateral cracks of soil by the subsoiler plow.

Table (4): Statistical analysis of the test (F) of the values of area, MWD, and the Eq EP.

Source	df	Area	MWD	Eq EP
D	2	2086.95*	5141.21**	403.53*
W	1	215.12*	24609.13**	2787.36*
D x w	2	9.88*	684.74**	60.83*

D=depth of tillage, W= wings, * = significant differences at level 0.05, ** at level 0.01

Mean weight diameter (Pulverization index)

As shown in the table (5), the results showed significant effect at (P<0.05) of the tillage depth in the Mean weight diameter (MWD). The MWD decreased 3.70% and 15.45% when the depth increased 40 to 60cm respectively. The reason of this increases maybe due to the increase in the volume of the soil loosing with increase of the tillage depth, which leads to increase the collisions between the soil clods. The MWD decreased in a greater rate when the depth increased from 50 to 60cm compare with increase the depth from 40 to 50cm. This is because the depth of the shallow tines relative to the depth of the subsoiler, where they are working in depth of soil which is different in the bulk density and moisture content in both depths (Table 2).

When adding the wings to the shallow tines, they significantly effected in the MWD. The MWD decreased 26.54% in comparison to without adding wings as shown in the table (5).

This may be due to the adding of the wings to the shallow tines led to increase the contact area with soil, as well as increasing the volume of soil loosing and thus increase the movement of the clods and collision soil clods with each to other (Aday *et al.*, 2011a).

In the context of interaction between the depth of plow and adding the wings was significantly affected (p< 0.05) in the MWD. The treatment of adding wings overcome shallow tines (S+shw) in decreased the MWD by 27.33, 32.31 and 19.38% when increase the depth of tillage from 40, 50 and 60cm respectively. The depth of tillage 50cm gave the high rate in the decrease of the MWD comparative with other depths. This is because the shallow tines work at depth of soil that bulk density is 1.15 Mg.m^{-3} and moisture content 20.07% which is nearly from friable status. Also, adding the wings on the feet lead to increase contact area with soil and then increase the acceleration of clods, causing increase the fragmentation.

Table (5): Effect depths of tillage and adding wings to shallow tines in MWD (mm)

	Depth of tillage (cm) (D)			
	40	**50**	**60**	**Mean**
S+sh	38.62^a ±0.98	37.88^b ±0.85	31.35^c ±0.71	35.95^a
S+shw	30.33^d ±0.99	28.63^e ±0.68	26.26^f ±0.79	28.41^b
Mean	34.48^a	33.25^b	28.80^c	

S+sh= Subsoiler + shallow tines, S+shw= Subsoiler + shallow tines + wings, D= depth of tillage. Values are means ± SE Obtained from three replications. The means with the different letters had significant effect at a probability level of 0.05.

Equivalent energy

The depth of plow had a significant effect on the equivalent energy for the pulverization (Eq EP). An increasing in Eq EP (7.84% and 11.60%) when the depth of tillage increased from 40 to 60cm respectively (Table 6). These increases may be returned to an increase in the depth of tillage that leads to an increase in the cracks of the soil. Moreover, the moisture content of the soil also close to the friable status thus increased the volume of the soil loosening when the depth of plow increased, which reduced the energy required to penetrate and cut the soil, that's made the subsoiler plow exploits of the energy available in fragmentation of the soil. This result is agreement with Panwar & Siemens (1972) and Aday *et al*. (2001).

Adding of the wings to the feet of shallow tines led to a significant increasing (p<0.05) in the Eq EP. It's increased by 39.20% because to increase the area of contact between the soil and wings, that's led to utilize of the energy available in the soil fragmentation as shown in table (6). The interaction between the depth of tillage and the wings in the Eq Ep significantly increased (p< 0.01) when increasing the depth and adding the wings. Its increased by 43.19, 53.03 and 25.13% for (S + shw) compared with (S + sh) when increase the tillage depth from 40 to 50 and 60cm, respectively. The maximum and minimum percentages of increase in the Eq EP was at the depth tillage 50 and 60cm respectively. The reason of this maybe to the depth of the shallow tines and depth of the subsoiler plow were worked at different soil in the properties of the soil such as moisture content, bulk density and penetration resistance at the depth of 50cm (Table 2). As well as the volume of the soil loosening lead to exploiting part of the energy available in fragmentation soil.

Table (6): Effect depths of tillage and adding wings in Eq EP (kJ m^{-3}).

	Depth of tillage (cm) (D)			
	40	**50**	**60**	**Mean**
S+sh	$32.21^a \pm 0.89$	$33.38^b \pm 1.00$	$41.87^c \pm 1.02$	$35.82^{\underline{a}}$
S+shw	$46.12^d \pm 0.99$	$51.08^e \pm 0.98$	$52.39^f \pm 1.07$	$49.86^{\underline{b}}$
Mean	39.16^a	42.23^b	47.13^c	

S+sh= Subsoiler + shallow tines, S+shw= Subsoiler + shallow tines + wings, D= depth of tillage. Values are means ± SE
Obtained from three replications. The means with the different letters are different significantly at a probability level of 0.05.

Conclusions

This experiment showed that adding the wings to the shallow tines as well as increase depth of subsoiler plow lead to an increase in soil disturbance area, improve the soil pulverization (reduce mean weight diameter). Moreover, led to improving the performance of the subsoiler plow in using the equivalent energy for pulverization in clay soil under conditions of implementation of the experiment. The increase percentage of the studied properties is affected by increase in the depth of subsoiler plow and the change in soil characteristics, such as soil moisture and bulk density.

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تأثير اضافة الاجنحة الى المحاريث الضحلة في اداء المحراث تحت سطح التربة في مساحة التربة المفككة،
دليل التفتيت والطاقة المكافئة للتفتيت

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الخلاصة: نفذت التجربة باستخدام محراث تحت سطح التربة مصنع محلياً مزود بأجنحة على أقدام المحاريث الضحلة من الجهة الخارجية بهدف دراسة تأثير إضافة الأجنحة وعمق الحراثة على مساحة التربة المفككة ودليل تفتيت التربة. (معدل القطر الموزون MWD ، والطاقة المكافئة للتفتيت (Eq EP) في التربة الطينية، بتصميم القطاعات العشوائية الكاملة، لثلاثة مكررات بتطبيق تجربة عاملية. تم استخدام ثلاثة أعماق للحراثة 40 و 50 و 60 سم مع وبدون اضافة الأجنحة على أقدام المحاريث الضحلة كعوامل للبحث. أظهرت النتائج وجود تأثير معنوي (0.05> p) لجميع المعاملات. اظهرت معاملة إضافة الأجنحة على المحاريث الضحلة (shw + S) تفوقا معنويا في عوامل الدراسة حيث زادت المساحة المفككة بنسبة 11.11 و 14.29 و 9.80٪ ، وانخفض MWD بنسبة 27.33 و 32.31 و 19.38٪ وزادت Eq EP بنسبة 43.19 و 53.03 و 25.13٪ عند زيادة عمق الحراثة من 40 و 50 و 60 سم على التوالي.

كلمات مفتاحية: محراث تحت سطح التربة، الاجنحة، المساحة المفككة، معدل القطر الموزن، الطاقة المكافئة للتفتيت.