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A Field Study of Soil Pulverization Energy by using Different Moldboards Types Under Various Operating Condition

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Abstract: A field experiment was conducted in the experiment field of Agricultural College, Basrah University, to study the effect of three types of moldboards i.e. helical, general purpose and digger moldboard, three tillage depths (15, 20 and 25 cm) and three forward speeds (4.37, 6.11 and 7.03 km h^{-1}) on the draft force (DF), soil pulverization index (SPI), the specific energy (SE), the energy equivalent (EQE), and soil pulverization efficiency (SPE). Split-split plot with complete randomized block design with three replications were used in this study, and Least significant differences (LSD) was used to compare the means of treatments at 0.05 levels. The results showed there was a significant effect for moldboard types, plowing depths, plowing speeds and the interaction on all studied parameters. Whereas the digger moldboard type achieved the lower values of DF and SPI compared with the general purpose and helical moldboard types by percentage of 12.13 and 19.49% respectively and 16.37 and 50.61% respectively. However, the digger moldboard gave the highest value of SPE of 80%. The results Also, indicated to that the plowing depth and plowing speed had a significant effect on studied parameters when increasing the plowing depth by percentage 67% the DF and SPI increased by 137.27% and 30.46%, while the SE, the EQE and SPE reduced by 18.19, 17.80 and 2.70 % respectively. However, increasing the plowing speed by a percentage of 61%, the DF, SE, EQE, and SPE increased by 25.98, 45.11, 8.18 and 35.59% respectively, while the SPI decreased by 29.15%.

Key words: Moldboards types, Plowing depth, Plowing speed, SPI and Soil pulverization efficiency.

Introduction

The moldboard plow is one of the most important primary soil preparation equipment. moldboard plow can achieve all plowing goals through cut the soil and overturning it, which helps to pulverize the soil, thereby provide the suitable cradle for seed germination and growth, (Abdallah *et al.*, 2016). The preparation of soil to agriculture and the provision of a suitable seedbed requires more than 60% of the energy consumed in all agricultural operations (Jacobs & Harrol, 1983). Therefore, part of the energy that spent in tillage operations can be reduced through the use of different designs of shares or moldboards because of their direct effect in the process of cutting the soil and its overturn. The requirements of the draft force of the plow are based on the geometric design of the moldboards (Maky & Desir, 1984). Draft force is an essential indicator for evaluating plows performance. (Nassir, 2016) found that the draft force of the moldboard plow increases linearly with the increase width of the moldboard, Aday & Al-Edan (2004) noted that the draft force of the moldboard plow with a serrated moldboard - type reduced the draft force by 17.5 and 22.5%, compared with the deep digger moldboard plow type in moist and fragile soil respectively. The depth of tillage and forward speed had an effect on the energy requirements of the plow. Al- Hadithi (2015) confirmed that the draft force increased from 9 to 13.5 kN when the plowing depth is increased from 10 to 20 cm for the normal plow. while using the modified moldboard plow by added vertical fins led to increasing the draft force from 10.8 to 31.5 kN. Also Nassir *et al.* (2016) found that the draft force increased significantly with the increase of the speed of the plowing. The tillage practices of all types of moldboard plows aim to break up the soil blocks. This will help in the preparation of a good seedbed facilitated to germination the seeds thereby spreading the roots in the soil to take sufficient water, air and nutrients so it is important to study the soil pulverization index (SPI) (Mean Weight Diameter) which are a standard for the degree of soil pulverization. In study conducted by Nassir (2018) on three different body types of moldboard plow he found that general-purpose plow had maximum value of the soil pulverizing percentage was 60%, while semi digger plow and helical plow had minimum values of the soil pulverizing percentage of 53 and 40% respectively. Nassir (2017) found that the increase in forward speed from 0.8 to 1.62 m sec^{-1} decreased the soil pulverization index (SPI) from 88.02 to 61.83 mm while the soil pulverization index increased from 79.34 to 81.5 mm when the plowing depth increased from 22 to 23 cm. The reduction of the soil pulverization index (SPI) values should be performed by the lowest energy requirements and this achieved by increasing the plow efficiency on soil pulverization. The field energy (specific energy) is the energy used in the field to overcome the forces of cohesion and friction among the soil blocks in order to break up the soil and its fragmentation. Aday & Al-Edan (2004) found that the specific energy of the plow was reduced with increasing depth due to the increase in the size of the plowed soil more than the increase in the energy requirements, while the specific energy increased with the increase of the plowing speed due to increase energy requirements with a decrease in the distribution area. The field energy (specific energy) is the energy required by plowing implement to cutting, breaking down soil, and fragmentation the soil. Nassir (2016) found that the modified moldboard plow had lower specific energy compared to deep digger moldboard plow type by percentage of 25.36%. Khader (2008) noted that the specific energy of moldboard plow increased with increasing plowing speed, it increased from 79.51 to 108.02 kJ.m^{-3}, when the plowing speed increased from 0.89 to 1.92 m sec^{-1}. The equivalent energy is the energy required to fragmentation the soil only. It had been estimated in the laboratory (Nassir, 2014). The energy efficiency of the plow is increases with the convergence of the specific energy (field energy) and the equivalent energy (laboratory). The energy efficiency of the plow is equal to the equivalent energy divided by the specific energy. The closer the two energies, the plow becomes more efficient (Nassir *et al.*, 2016). The aim of this study to compare among three different bodies of the moldboard plow in term the energy pulverization requirements including the soil pulverization index (SPI), the specific energy, the energy equivalent, and energy pulverization efficiency at different plowing depths and plowing speeds in clay loamy soil.

Materials & Methods

Description of moldboard plows:

Three types of moldboard plow were utilized i.e. general-purpose moldboard, semi-helical moldboard, and digger moldboard. Specification of three moldboard types are illustrated in table (1).

Tractors used

Two different tractors were used in this study. The specifications were demonstrated in table (2).

Measure the draft force:

Load cell (250 kN) was used to evaluate the draft force of the plow. The load cell was attached between the Massey-Ferguson 440 axtra tractor and the Massey-Ferguson 285s tractor loaded of plow by a flexible cable. The gearbox of Massey-Ferguson 285s tractor was putted in idle gear position. This tractor onlycontrols on plowing depth by the hydraulic system in order to keep plowing depth at the required depth. Whereas draft force was recorded for all the plowing depth and plowing speed by a portable computer connected with load cell by USB. In the same way, the rolling resistance is measured but the plow outside of the soil surface and is portable on the tractor (Massey-Ferguson 285s), and the draft force was calculated from the following equation (Aday & Al-Edan, 2004):

$$F = F_{total} - R \ldots\ldots\ldots\ldots\ldots (1)$$

Where: : Draft force (kN); F_{total} : Total draft force (kN); R : Rolling resistance (kN).

Soil pulverization index

Random samples were taken from the experiment field after the plowing operating for all treatments. After sampling from the field. The samples were passed the sieving device shown in Fig. (2). The sieves had meshed of (100-70, 70-50, 50-30, 30- 20, 20-5.0, 5.0- 2.0, 2.0-1.7 mm) where the pulverization index of soil was calculated from the following equation (2), according to the method mentioned in Hillel (1980).

$$PI = \frac{\sum Wi * \bar{d}i}{W_{total}} \ldots\ldots\ldots\ldots (2)$$

Where: PI: Pulverization index; Wi = The weight of the clods of soil found between two sieves di and di+1; W_{total} = The weight of the total mass; n = The number of sieves; In Eq. 2, di was calculated using the following equation:$\overline{di} = \frac{1}{2}(d_i + d_{i+1}) \ldots\ldots\ldots\ldots\ldots (3)$

Table (1): Specification of three types bodies of moldboard.

Moldboard type	θ_s (deg)	θ_i (deg)	W_S (mm)	L_L (mm)	L_0 (mm)
General-purpose	35	27	275	180	800
Helical	37	30	290	250	1105
Digger	33	28	260	150	900

L_L= landslide length. *Lo* = overall length of bottom W_S = share culling width perpendicular to the direction of travel.
θ_i = share wing angle. θ_s= l+ateral directional moldboard tail angle.

Fig. (1): Measurement device of draft force

Abbreviation: 1-Load cell. 2- laptop. 3- USB connection. 4- Two rings to fixation of the load cell. 5- program recorded and saved data of draft force.

Energy required to soil pulverization: Samples of the experiment field were collected randomly for each plowing depths (15, 20, and 25cm) and forward speeds (0.46, 0.73 and 1.18 m.sec^{-1}). The blocks of soil left to dry in the lab for two weeks. Each soil block was weighted after that soil blocks were dropped from an altitude of 80 cm on hard ground many times. The pulverization index (mentioned previously) was estimated for each time had been soil block dropped, until the soil blocks become the small size and unbreaking. The energy required to soil pulverization for each dropping process of the

Soil properties and soil texture

It is summarized in table (3). The methods of measurements mounted in Black *et al*. (1993).

Energy required to soil pulverization

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Soil block was calculated from the following equation (Aday *et al*., 2004):

$$ESP = (m * g * z) * n \dots\dots\dots\dots\dots\dots (4)$$

were dropped from an altitude of 80 cm on hard ground many times. The pulverization index (mentioned previously) was estimated Where: ESP: Potential energy (kJ); m: mass of soil blocks (kg); g: gravitational force (m.sec^{-2}); z: dropping height of soil block (m); n: number times dropping of soil block.

Table (2): Tractor specifications.

Parameters	Massey- Ferguson 440 xtra	Massey-Ferguson 285s
Max Hp (kW) power	82 (61.1)	77 (65.6)
Engine speed (rpm)	2200	2000
Engine type	Perkins (diesel)	Perkins (diesel)
Engine capacity (litter)	4.40	4.06
No. of cylinder	4	4
Compression ratio	18.5:1	17.5:1
Thrust generation	MFWD	2WD

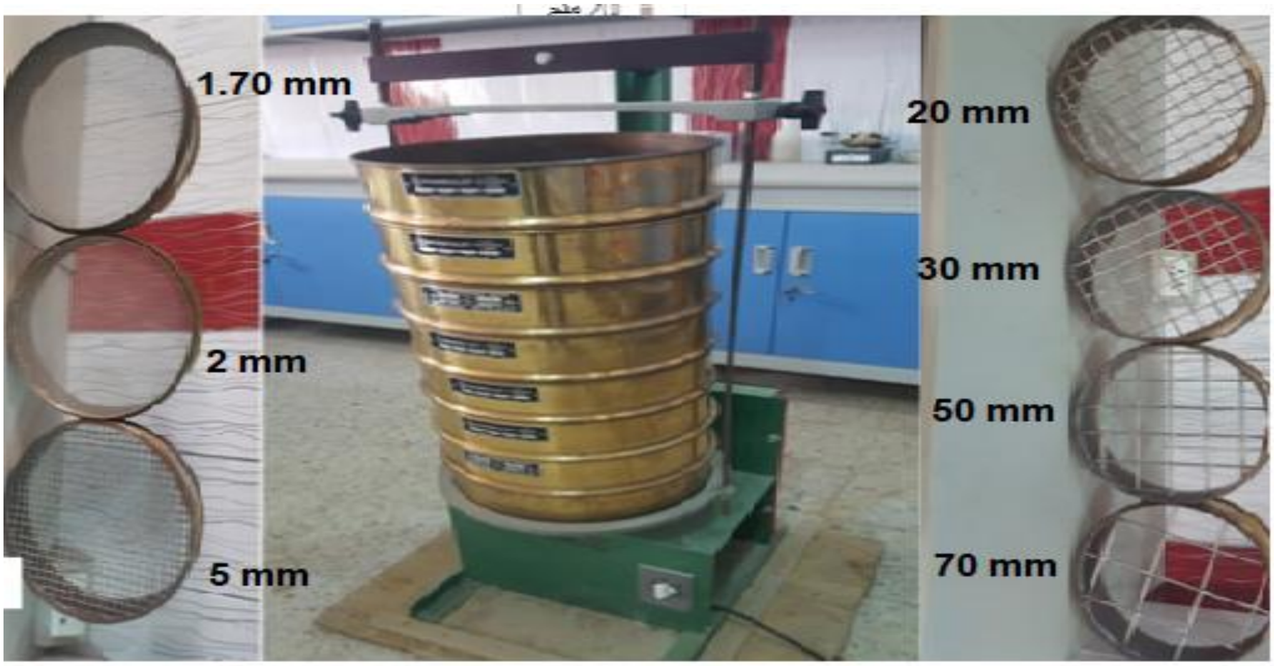

Fig. (2): The sieve device and sieves used.

Equivalent energy

Its estimated from fig. (3), which consider Logarithmic relationship between soil pulverization energy and pulverization index (PI). Where equivalent energy was estimated by dropping the pulverization Index (PI) which was determined in the field on the relationship between pulverization Index (PI) (Y-axis) and the energy required to soil Pulverization (X-axis). To obtain the equivalent energy values were multiplied the mean of soil bulk density values by the energy of pulverization for each treatment. Equivalent energy calculated by the following equation (Black *et al.*, 1993).

$$EqE = (m * g * z) * \rho b \dots\dots\dots\dots\dots\dots (5)$$

Where:

EqE: Equivalent energy (kJ m^{-3}).
ρb: bulk density (Mg m^{-3}).

The specific energy

It is calculated as follows equation (Aday, 1997)

$$SpE = \frac{F}{A} * \frac{m}{m} \dots\dots\dots\dots\dots (6)$$

Where:

SpE= specific energy (kJ.m^{-3}).

F: draft force (kN).

A: cross-section width of the plowed soil by the plow (m^2).

m: one meter of soil plowed along the operating path (m).

The pulverization efficiency

It is calculated as follows equation. (Aday (3))

$$\eta = \frac{EqE}{SpE} * 100 \dots\dots\dots\dots\dots\dots (7)$$

Where: η = Pulverization energy efficiency (%)

Table (3): Soil properties and soil texture.

Plowing depth (cm)	Moisture content (%)	Bulk density ($g.cm^{-3}$)	Soil penetration resistance ($kN.m^{-2}$)
10-0	10.30	1.25	1545.32
15-10	15.50	1.30	1989.86
25-15	18.20	1.48	2502.86
Soil texture	Sand ($gm.kg^{-1}$)	Silt ($gm.kg^{-1}$)	clay ($gm.kg^{-1}$)
Silty loam	276.73	552.45	170.82

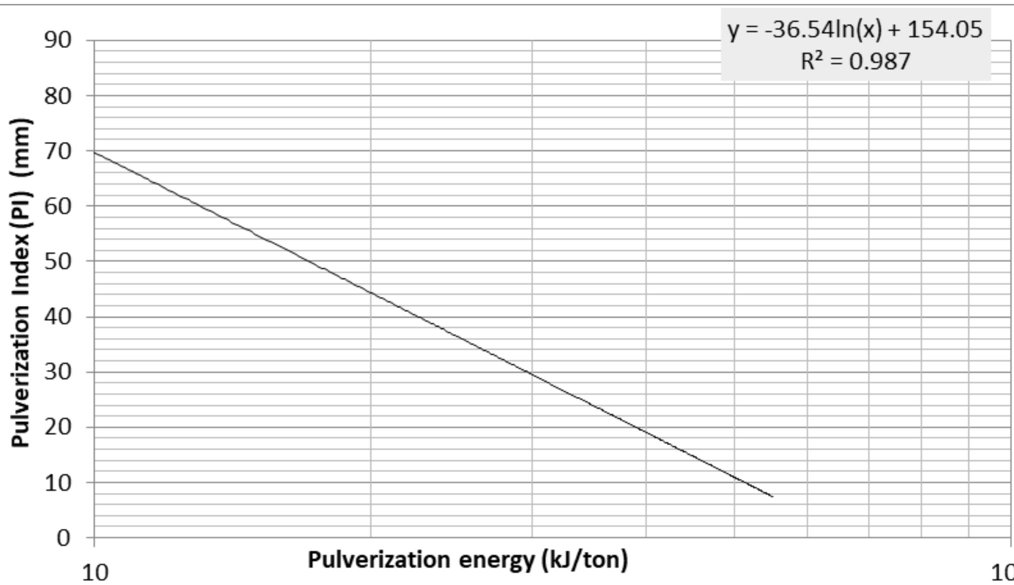

Fig. (3): The realitonshipe between the Pulverizatin energy and the Plverization Index

Result & Discussion

Draft force:

Table (4) explained that there was a significant effect of moldboard types on draft force. The results showed that the plowing by digger moldboard reduced the draft force required to pull the plow by percentage of 0.12% and 0.19% respectively, compared to the general-purpose and helical moldboard. The reason is that the variation in the design of the moldboard. The big geometric dimensions of the helical moldboard recorded a higher draft force of 13.80 kN. This is in accordance with the results notified by Naderloo *et al.* (2009).

The plowing depth had significant effect in draft force (table 4). The results showed that increasing the plowing depth where increasing plowing depth from 15 to 20 cm increased draft force from 7.38 to12.68 kN by increasing percentage of 72%. Furthermore, increasing the plowing depth to 25 cm recorded the highest the draft force value of 17.51 kN by increasing percentage of 38%. This was because of the increase in the weight of the soil which needs additional draft force to overcome the considerable weight which results from increasing the plowing depth. This results agree with the results reported by Nassir (2016).

The draft force significantly affects in plowing speed (table 4). Whereas increasing the plowing speed from 4.37 to 6.11 km h^{-1} draft force increased from 11.16 to 12.34 kN also, increasing plowing speed from 6.11 to 7.03 km h^{-1} draft force increased from 12.34 to 14.06 kN. This is due to the increasing acceleration of the soil blocks and gives it a kinetic energy to overcome the strength of cohesion between soil particles and the strength of friction between the blocks of soil, which causes an increase in the draft force. Similar findings reported by Naderloo *et al.* (2009) and Jasim & Mankhi (2012).

Table (4): Effect of moldboard type, plowing depth, and forward speed in draft force.

Forward speed	4.37 km h^{-1}	5.51 km h^{-1}	6.76 km h^{-1}
	11.16	12.34	14.06
Moldboard types	Helical	General-purpose	Digger
	13.80	12.67	11.11
Plowing depth	15 cm	20 cm	25 cm
	7.38	12.68	17.51
L.S.D.$_{(0.05)}$	Type = 0.45	Depth = 0.503	Speed = 0.520

The results of interaction among plowing types, plowing depth and plowing speed were shown in table (5). The results of interaction among moldboard type, plowing depth, and speed had significant effect on draft force. The helical moldboard type recorded the highest value of draft force (20.67 kN) when using its in deep plowing of 25cm and high plowing speed of 7.03 $km.h^{-1}$. While the digger moldboard types recorded the lowest value of draft force (5.49 kN) when using its in shallow depth of 15 cm and low plowing speed of 4.37 $km.h^{-1}$. Similar findings reported by Taniguchi *et al.* (1999), Sahu & Raheman (2006) and Al-Hashimy (2012).

Table (5): Effect of interaction among moldboard type, plowing depth, and forward speed in draft force.

	Forward speed ($km\ h^{-1}$)				
	Depth	4.37	5.51	6.76	Means
Helical	15	6.06	9.06	10.23	8.45
	20	12.48	13.47	16.02	13.99
	25	17.61	18.63	20.67	18.97
	Means	12.05	13.72	15.64	13.80
General	15	5.85	7.23	9.00	7.36
	20	11.67	12.03	15.03	12.91
	25	17.31	17.55	18.33	17.73
	Means	11.61	12.27	14.12	12.67
Digger	15	5.49	6.00	7.5	6.33
	20	9.45	11.31	12.69	11.15
	25	14.55	15.81	17.1	15.82
	Means	9.83	11.04	12.43	11.1
	$L.S.D._{(0.05)}$	Type*Depth* Speed= 0.804			

Soil pulverization index (SPI)

Soil pulverization index was significantly ($p \leq 0.05$) affected by moldboard types. The results in table (6), referred that helical moldboard type recorded the highest soil pulverization index values of 25 mm compared with general purpose and digger which recorded 15.02 and 12.56 mm respectively. The results in table (6), referred that helical moldboard type recorded the highest soil pulverization index values of 25 mm compared with general purpose and digger which recorded 15.02 and 12.56 mm, respectively. These results could be attributed to increasing soil volume which was cut and overturned by helical moldboard type due to its a great edge width of the helical moldboard, leading to increasing the soil pulverization index, while the digger moldboard plow had small edge width and this allowed to pulverization of soil considerably greater than overturning soil blocks. Similar results were also reported by Nassir (2018).

Plowing depth had a significant effect ($p \leq 0.05$) in soil pulverization index (table, 6).

When increasing the plowing depth from 15 to 20 and 25 cm increased the soil pulverization index from 14.88, 18.73 and 21.44 mm respectively, by increasing percentage of 43.8% and 16%. This increasing of soil pulverization index could be attributed to the increasing volume of the plowed soil with increasing depth where the soil has a high strength due to the increased strength of soil adhesion and its cohesion thus making soil pulverization reduced his is in conformity with Rashidi & Keshavarzpour (2007) and Muhsin (2017b).

Plowing speed had a significant effect on soil pulverization index (table 6). Whereas when increasing plowing speed from 4.37 to 6.11 km h^{-1} the soil pulverization index decreased from 21.23 to 17.74 mm by percentage 16.44%. However, Increasing plowing speed from 4.37 to 7.03 km. h^{-1}. The results showed that the pulverization index (SPI) decreased with increasing the plowing speed. This could be attributed to an increase in acceleration of the soil blocks and collision it each to other led to break up the soil blocks to small sizes which decrease the soil pulverization index (SPI) thereby increasing the soil pulverization. These results agree with Aday (1997), Nassir (2017) and Muhsin (2017a).

Table (6): Effect of interaction among moldboard type, plowing depth, and forward speed in soil pulverization index

		Forward speed (km h^{-1})			
	Depth	4.37	5.51	6.76	Means
Helical	15	24.66	21.00	15.23	20.30
	20	30.23	24.80	20.90	25.31
	25	35.23	29.66	27.13	30.67
	Means	30.04	25.15	21.09	25.43
General purpose	15	15.90	13.00	10.16	13.02
	20	17.63	14.26	12.66	14.85
	25	20.50	15.27	15.76	17.18
	Means	18.01	14.18	12.86	15.02
Digger	15	13.12	11.68	9.16	11.32
	20	15.16	12.89	11.05	13.03
	25	18.63	17.08	13.30	16.34
	Means	15.64	13.88	11.17	13.56

The interaction among moldboard type, depth, and speed had significant effect ($p \le 0.05$) in soil pulverization Index (table 7). The helical moldboard type operating at plowing depth of 25cm and low speed of 4.37 km. h^{-1} achieved the highest value of soil pulverization index (35.23 mm), while digger moldboard type achieved the lowest value of soil pulverization index (9.16mm).

Table (7): Effect of moldboard type, plowing depth, and forward speed in pulverization index.

Forward speed	4.37 km h^{-1}	5.51 km h^{-1}	6.76 km h^{-1}
	21.23	17.74	15.04
Moldboard types	Helical	General-purpose	Digger
	25.43	15.05	12.56
Plowing depth	15 cm	20 cm	25 cm
	14.88	17.73	21.40
L.S.D.$_{(0.05)}$	Type = 0.883	Depth = 1.073	Speed = 0.980

Equivalent energy (EQE)

The effect of moldboard types on equivalent energy was shown in table (8). Digger moldboard type resulted in significant ($p \leq 0.05$) higher values of equivalent energy than helical moldboard type and general purpose moldboard type by percentage of 18.18% and 56.49 % respectively. This attributed to depending the equivalent energy on values of soil pulverization index which estimated from fig (3), where the equivalent energy increased with reducing the soil pulverization index. The effect of plowing depth had a significant effect ($p \leq 0.05$) on equivalent energy it as shown in table (8). Whereas the plowing depth of 15 cm recorded the highest value of equivalent energy was 135.91kJ m^{-3} and more than plowing depths of 20 and 25 cm by an amounted of 13.01 and 24.20 kJ m^{-3} respectively. This was because of the equivalent energy which determined experimentally depending on the soil pulverization index (SPI). where the equivalent energy had been related by an inverted relationship with pulverization index (SPI) as is illustrated in (Fig. 3). Where low value pulverization index (SPI) need high equivalent energy thereby increasing the equivalent energy when reduction plowing depth. The effects of plowing depth on the equivalent energy are similar to the results obtained by Nassir (2017) and equivalent energy affected significantly ($p<0.05$) by plowing speed (table 8). When increasing the plowing speed from 4.37 to 7.03 km h^{-1} the equivalent energy increased from 97.71 to 141.79 kJ m^{-3} (45.11%).

Table (8): Effect of moldboard type, plowing depth, and forward speed in equivalent energy.

Moldboard types	Helical	General-purpose	Digger
	111.71	122.90	168.4
Plowing depth	15 cm	20 cm	25 cm
	125.91	126.17	149.12
Forward speed	4.37 km h^{-1}	5.51 km h^{-1}	6.76 km h^{-1}
	97.71	131.07	141.79
L.S.D.$_{(0.05)}$	Type = 3.21	Depth = 4.41	Speed = 3.87

The interaction among moldboard type, plowing depth and speed had effect significant effect ($p \leq 0.05$) in equivalent energy (table 9). The maximum value of equivalent energy was

188.16 kJ. m^{-3} when using the digger moldboard type at plowing depth of 20 cm and plowing speed of 7.03 km. h^{-1} while the minimum value of equivalent energy was 55.68 kJ m^{-3} when using the digger moldboard type at plowing depth of 25 cm and plowing speed of 4.37 km h^{-1}.

Table (9): Effect of interaction among moldboard type, plowing depth, and forward speed in equivalent energy.

	Forward speed (km h^{-1})				
	Depth	4.37	5.51	6.76	Means
Helical	15	68.76	115.80	126.72	103.76
	20	60.45	122.61	82.98	88.68
	25	55.68	96.51	128.07	93.42
	Means	61.63	111.64	112.59	95.29
General purpose	15	105.66	135.87	156.24	132.59
	20	101.34	141.69	164.25	135.76
	25	86.88	115.86	127.77	110.17
	Means	97.96	131.14	149.42	126.17
Digger	15	163.11	172.68	178.35	171.38
	20	106.80	137.85	188.16	144.27
	25	130.74	140.79	123.60	131.71
	Means	133.55	150.44	163.37	149.12
L.S.D.(0.05)		Type*Depth* Speed= 6.24			

Specific energy (SE)

Helical mouldboard had the lowest value of specific energy compared with moldboard types of the digger and general purpose by an amount of 10.77 and 11.84 kJ. m^{-3} respectively (table 10). This was because of the increasing the distributed area more than increasing in draft force for helical moldboard, therefore recorded the lowest value of specific energy (157.27 kJ m^{-3}) according to equation (6). This is in accordance with Kader (2008) and Arvidsson *et al*. (2004). There were no significant differences between the values of specific energy for digger moldboard type and general purpose moldboard type. The effect of plowing depth had a significant effect ($p<0.05$) on specific energy it as shown in table (10). Whereas the plowing depth of 15 cm recorded the highest value of specific energy (182.76 kJ m^{-3}). The lowest value of specific energy recorded by plowing depth of 25cm. It was 154.63 kJ. m^{-3}. This was because of increasing the soil distribution area greater than increasing in draft force when increasing the plowing depth. are similar to the results obtained by Nassir (2017) and Aday & Al-Edan (2004). It can be observed from table (10), there were no significant differences between plowing speed of 6.11 and 7.03 km. h^{-1} on specific energy. The increasing the specific energy with increasing plowing speed could be attributed to increasing the draft force requirements considerably with increasing the plowing speed. These results agree with the results conducted by Nassir (2014).

Table (10): Effect of moldboard type, plowing depth, and forward speed in specific en

Forward speed	4.37 km h^{-1}	5.51 km h^{-1}	6.76 km h^{-1}
	161.77	174.09	175.01
Moldboard types	Helical	General-purpose	Digger
	157.27	169.11	168.4
Plowing depth	15 cm	20 cm	25 cm
	154.63	175.03	182.76
L.S.D.$_{(0.05)}$	Type = 3.74	Depth = 4.42	Speed = 3.88

The interaction among moldboard type, plowing depth and speed had effect significant in specific energy (table 11). The Digger moldboard type operating at plowing depth of 15cm and low speed of 4.37 km h^{-1} give the highest value of specific energy (210.99 kJ. m^{-3}), while Helical moldboard achieved the lowest value of specific energy (114.30 kJ. m^{-3}) when operating at plowing depth of 25 cm and plowing speed of 4.37 km. h^{-1}. These results attributed to the increasing the draft force requirements. This trend accords with Nassir (2017) and Kader (2008).

Table (11): Effect of interaction among moldboard type, plowing depth, and forward speed in specific energy.

	Forward speed (km h^{-1})				
	Depth	4.37	5.51	6.76	Means
Helical	15	170.94	165.33	162	166.09
	20	135.3	176.1	184.29	165.23
	25	114.3	142.74	164.4	140.48
	Means	140.18	161.39	170.23	157.2667
General-purpose	15	181.86	175.62	175.8	177.76
	20	146.7	192.99	190.86	176.85
	25	143.19	160.11	154.83	152.71
	Means	157.25	176.24	173.83	169.1067
Digger	15	210.99	205.77	196.50	204.42
	20	163.80	171.12	200.08	178.33
	25	188.82	177.00	146.31	170.71
	Means	187.87	184.63	180.96	184.49
	L.S.D.$_{(0.05)}$	Type*Depth* Speed= 7.03			

Soil pulverization efficiency (SPE)

It can be noted from data of table (12) that there were significant ($p \leq 0.05$) differences among types of moldboard in terms of values of soil pulverization efficiency. The digger moldboard achieved the highest value of Soil pulverization efficiency (0.80) compared with general-purpose moldboard type which achieved the second highest value of soil pulverization efficiency was 0.74, while the lowest value of soil pulverization efficiency achieved by helical moldboard (0.60). This because the soil pulverization efficiency mainly depended on pulverization index where increasing soil pulverization led to increasing soil pulverization efficiency. Similar results were reported by Aday (1997). The plowing depth had significant effect in soil pulverization efficiency (table 12). The results revealed reducing the soil pulverization efficiency from 0.74 to 0.70 when the plowing depth increasing from 15 to 20 cm. However, increasing the plowing depth to 25 cm the soil pulverization efficiency recorded the second lowest value of 0.72. This was due to that the shallow depth needing low energy to pulverization of soil and this made the equivalent energy close from the specific energy thereby increasing soil pulverization efficiency according the equation (7). These results agree with results reported by Aday et al. (2001) and Nassir (2017). Effect of forward speed on soil pulverization efficiency are shown in table (12). There is a trend that the soil pulverization efficiency increased with the increase in plowing speed from 4.37 to 7.03 km h^{-1} led to increase the soil pulverization efficiency from 0.59 to 0.80. This could be attributed to decreasing the soil pulverization index related to the soil pulverization and this led to increasing in the equivalent energy which occurred when a higher plowing speed which played important rule in increasing the specific energy thereby the equivalent energy close from specific energy, consequently the soil pulverization efficiency increased according to equation (7). Similar results were reported by Nasser (2016).

Table (12): Effect of moldboard type, plowing depth, and forward speed in soil pulverization energy.

Moldboard types	Helical	General-purpose	Digger
	0.60	0.74	0.80
Plowing depth	15 cm	20 cm	25 cm
	0.74	0.70	0.72
Forward speed	4.37 km. h^{-1}	5.51 km. h^{-1}	6.76 km. h^{-1}
	0.59	0.75	0.80
L.S.D.$_{(0.05)}$	Type = 0.002	Depth = 0.001	Speed = 0.003

The results of the interaction among type x depth x speed were shown in table (13). The interaction had effect significant in soil pulverization efficiency. The digger moldboard type recorded the highest value of soil pulverization efficiency was 0.91 when operating at plowing depth of 15 cm and plowing speed of 7.03 km h^{-1}. While the helical moldboard type operating at plowing depth of 15 cm and low speed of 4.37 km h^{-1} recorded the lowest value of soil pulverization efficiency

.**Table (13): Effect of interaction among moldboard type, plowing depth, and forward speed in soil pulverization energy.**

		Forward speed (km h^{-1})			
	Depth	4.37	5.51	6.76	Means
Helical	15	0.40	0.70	0.78	0.63
	20	0.45	0.70	0.45	0.53
	25	0.49	0.68	0.78	0.65
	Means	0.45	0.69	0.67	0.60
General-purpose	15	0.58	0.77	0.89	0.75
	20	0.69	0.73	0.86	0.76
	25	0.61	0.72	0.83	0.72
	Means	0.63	0.74	0.86	0.74
Digger	15	0.77	0.84	0.91	0.84
	20	0.65	0.81	0.88	0.78
	25	0.69	0.80	0.84	0.78
	Means	0.40	0.70	0.78	0.63
	L.S.D.$_{(0.05)}$	Type*Depth* Speed= 6.24			

(0.40). This trend accords with Aday & Al-Edan (2004) and Nassir (2016).

Conclusions

force compared to the general-purpose and helical moldboard types by the percentage of 12.13 and 19.49% respectively and the lowest value of soil pulverization index (high soil pulverization) by percentage 16.37 and 50.61% respectively. the DF and SPI increased significantly by 137.27% and 30.46% while the SE, the EQE, and SPE reduced by 18.19, 17.80 and 2.70 % respectively when increasing plowing depth from 15 to 25 cm. Plowing speed had a significant effect on studied parameters when increasing plowing speed from 4.37 to 7.03 km h^{-1} the DF, SE, EQE, and SPE increased by 25.98, 45.11, 8.18 and 35.59% respectively, while the SPI decreased by 29.15%. The best performance was for the digger moldboard at high plowing speed (7.03 km. h^{-1}) and low plowing depth (15 cm).

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