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Effect of Tillage Depth and Lateral Distance of Shallow Plows on the Mean Weight Diameter and the Energy of Soil Fragmentation by Using Locally Manufactured Subsoiler Plow

Murtadha A. A. Alfaris[1] **and Salim Almaliki**[2]

[1,2] Department of Agriculture Machines and Equipment, College of Agriculture, University of Basrah, Iraq.

[1]E-mail: murtadha130@gmail.com

Abstract. The field experiments were carried out in Basrah province, to study the effect of the distance between the shallow plows (0.40, 0.50, 0.60m), and adding wings on the foot of the subsoiler plow, at tillage depth (0.30, 0.40, 0.50, 0.60m) on the Mean Weight Diameter (MWD) and equivalent energy of the soil fragmentation in clay soil. The results showed that the increase in the plowing depth to 0.60m by the subsoiler without wings on the foot and shallow plows gave largest of the MWD (102.28mm). While the increased the lateral distance of the shallow plows to 0.60 m gave MWD (67.13mm). The interaction effect of adding wings and tillage depth led to decrease MWD by 30% when adding wings compared to the no addition treatment. The MWD decreased by more than half with adding wings and shallow plows. The equivalent energy increased by 30.58% when increasing plowing depth from 0.30 to 0.60m compared to 9.09% for the no winged plow. Moreover, the equivalent energy of fragmentation decreased when increases lateral distance of the shallow plows. The equivalent energy increased by 36.29% when increasing the depth of tillage from 0.30 to 0.60m at lateral distance 0.60m compared to 9.09% for the plow without wings.

Keywords. Subsoiler plow, Wings, Shallow plows, MWD, Equivalent energy.

1. Introduction

The soils of southeastern Iraq, especially Basra Province, are classified as heavy soils in which clay minerals are predominant, which is characterized by the formation of solid, compact layers that hinder the spread of plant roots, as well as, it is distinguished by the waterlogging of the soil, the high level of groundwater and the spread of salts on the soil surface [1,2]. [3] explained that a successful plowing operation should include the broken of hardpan soil which is determined from the bulk density of the soil and the penetration resistance. The primary use of the subsoiler plow is to dismantle the compact layers with the high bulk density that is created in heavy textured soils [4].

Assessment and improvement of ploughs performance and their power requirements during tillage operation has been a large interesting to manufacturers, designers and farmers as these have direct and indirect results on the effectiveness of tillage operations[5]. A subsoiler plow is widely used by farmers as a primary tillage tool for manipulating the compaction of soil. Its performance evaluation is essential in order to improving soil properties [6,7]. Immoderate subsoil compaction led to diminishing soil fertility and permeability, which reflect on productivity, soil corrosion risks, waterlogging and nitrogen absorption [8]. Soil compaction rises the draft force requirement to break up the soil and in turn increases the machine's working resistance which reflects on fuel consumption and the economic advantage of conservation tillage [9,10]. Subsoiler plough used to break up hardpan down to 0.60m depth and more [11,12]. Many research has indicated several factors that affect the performance of the subsoiler plow, including number of shank, working speed, depth of tillage, soil moisture content and soil type [13,14]. Soil characteristics that effect on power requirement are moisture content, bulk density, and soil texture and soil strength. The most important indicators which the subsoiler plow must be work at it are draft reduction, optimum energy exploitation and produced soil disturbed and pulverization [15]. Hence, some researchers have investigated various subsoilers and parameters to minimize draught force and total power requirements with considerable increase in soil pulverization. Consideration should be given to the design of shanks shape of subsoiler, as they are very important to the efficiency and effectiveness of subsoiling. Thus, variation in power requirements depends on subsoiling depth, soil water conditions and the amount of compaction [16,17].

The equivalent energy of soil fragmentation is the energy required to pulverize the soil only which regarded as useful energy. The tillage operations consume 60% of the energy spent on various agricultural operations [18]. The field energy is the energy required to cut, move overturn and pulverize the soil. It depends on soil type, moisture content, the plowing depth, forward speed and on the plow design [19]. [20] found that the increased depth from 10 to 20 cm led to decreased energy equivalent from 90.20 to 63.39 kJ.m^{-3} for compound chisel plow when the plow.

Many studies have been accomplished to investigate different computational techniques for simulating agricultural equipment performance, and they are analytical, empirical, and numerical methods [21,22]. [23] produced a mathematical model, with a stepwise regression algorithm to simulate draft requirements of disk plow. The importance achieved of this point led to development of several mathematical models for prediction of the performance of implements during tillage operations. Mathematical models are an effective tool for designers and researchers in the field of agricultural equipment [24]. [25] developed an artificial neural network (ANN) model, with a back propagation learning algorithm to predict draft requirements of two winged share tillage tools in a loam soil. The developed programs can support manufacturers, designers and operators in agricultural field to evolve performance of agricultural machinery by analyzing the many factors involved in the software. The objective of this paper is to study the effect of adding shallow plows and the wings to the subsoiler plow on the mean weight diameter (MWD) and equivalent energy of the soil fragmentation. Moreover, to produce mathematical model for predicting MWD and equivalent energy b using Design Expert.

2. Materials and Methods

2.1. Study Site

The field experiments were carried out Basrah province located in (19′′ 30′ 33° N 54′′ 47′ 44° E, Basrah province, Iraq). The soil at the experimental site has clay texture (543.4 clay, 385 silt, and 71.6 sand g.kg^{-1}). Before carrying out the experiment, for measuring soil moisture content and bulk density, several soil samples from experiment location at various levels of depth from 0 to 0.60 m at different zones of the field were taken using a cylindrical core sampler. Collected samples were immediately put in plastic cases to avoid moisture loss during arrival to the laboratory. Samples were weighted before and after drying in oven at 105°C to reach the constant weight. Moisture content and bulk density were calculated as stated in [26]. Cone index values were acquired by taking penetrometer readings at various tillage depths at several sites of the field using a cone penetrometer according to ASABE Standards S313.2 with a cone base area of 130 mm^2 and 30º [27]. The soil properties of the soil depths 0-0.60 m as shown in table 1.

Table 1. Some soil properties for the field experiments whither done.

Depth (m)	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**
Soil moisture (%)	13.44	15.45	18.81	22.65	26.87	28.45
Bulk density (Mg m^{-3})	1.26	1.29	1.30	1.35	1.48	1.29
Con index (kN m^{-2})	1576.44	1664.76	1687.76	1876.89	2546.19	1914.63

2.2. Tractor and Implement

The tractor was Massey Ferguson 2680 (96.97 kW, 4WD) which was employed for mounting the subsoiler plow. The modified subsoiler plow was used in this study which manufactured in the Department of Agricultural Machinery-College of Agriculture - University of Basrah. The modified subsoiler plow comprises a frame connected with an inclined leg at an angle of 60° equipped with a foot of 0.38m length. The foot is equipped with wings (width of wings with the foot is 0.30m) and an angle of inclination of the foot 120°. The frame of subsoiler plow was provided with two shallow plows at a distance of 0.36m forward of the subsoiler plow, the horizontal distance (distance between shallow plows) can be changed (Fig.1).

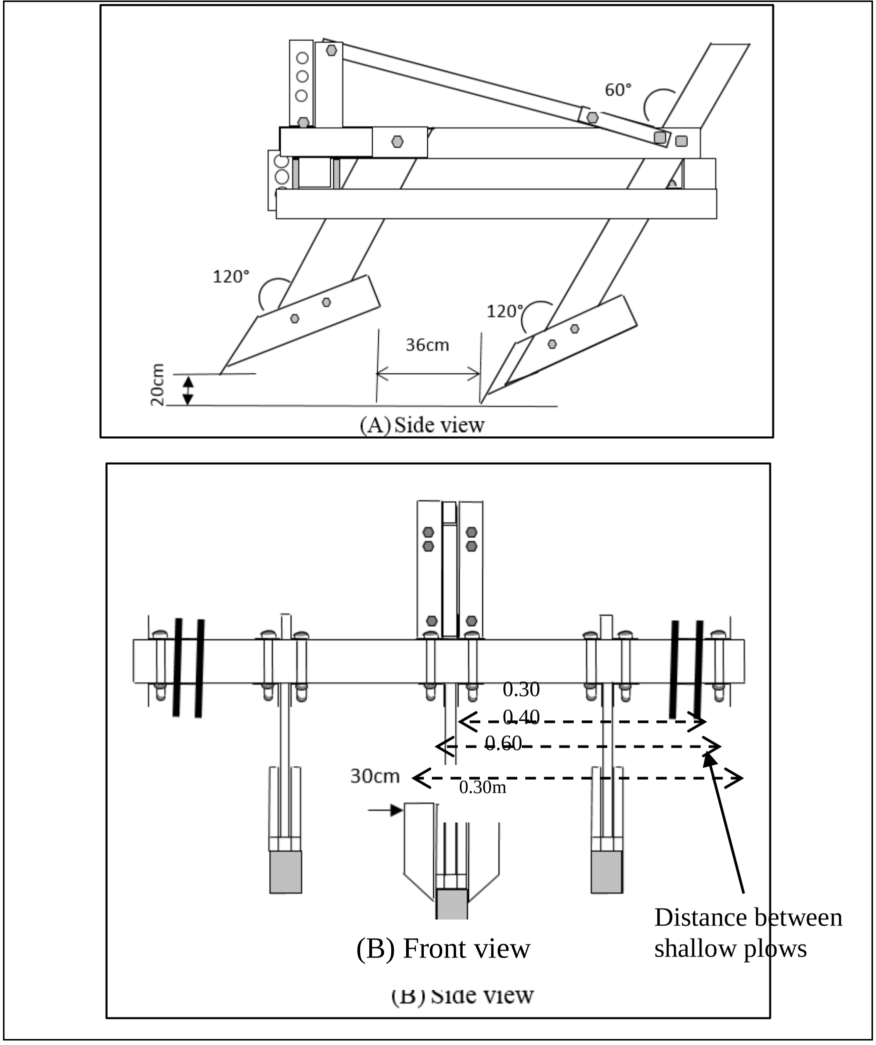

Figure 1. (A) Side view and (B) Front view of modified subsoiler plow.

The field experiments were conducted by using subsoiler plow only in the initially and then use with shallow plows at three lateral distances (0.40, 0.50, 0.60m), with and without the wings on the foot of the subsoiler plow at tillage depth (0.30, 0.40, 0.50, 0.60m). The longitudinal distances of 15m assigned to each test. The selected forward speed of tests was 0.34 m/sec. After the tillage operation is over. The soil was allowed to dry in the field naturally, to obtain the actual dimensions of the disturbed soil profile; the ruptured soil was removed manually, 0.50m length for each tillage experiment, with three replications. 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 fiberglass tape. The mean weight diameter (MWD) was calculated by using equation (1).

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

Where Xi: MWD (mm),
Wi: Soil on each sieve (kg),
M: Average size of sieves (mm),
W: Mass of sample the soil (kg).

The fragmentation energy was calculated from a break up the soil clods by a crash drop from height 0.80 m according to [28] as in equation (2).

$$Q = M * g * Z * n \quad (2)$$

Q = the energy of fragmentation (kJ),
M = the mass of soil sample (kg),
g = acceleration (m sec^{-2})
Z = the vertical distance of fall down (0.80 m),
n = number of the fall down times

The obtained small pieces of the soil after a number of dropping have calculated the MWD for them, using the same sieves who using in calculate the MWD in the field. The relationship between the MWD and the energy of fragmentation was determined using a logarithmic scale of the X axis as figure (2). The energy of fragmentation which used by the subsoiler plow was calculated using equation (3) consequent from the graph to determine the amount of energy used for the fragmentation soil.

$$X = EXP\left\{\frac{y-243.06}{-46.95}\right\}\rho p \quad (3)$$

x= required energy for soil fragmentation (kJ Mg^{-1}),
y= MWD (mm),
(ρp) soil bulk density for each tillage depth.

The Equivalent energy for fragmentation soil was extracted from the mathematical functions in Excel program.

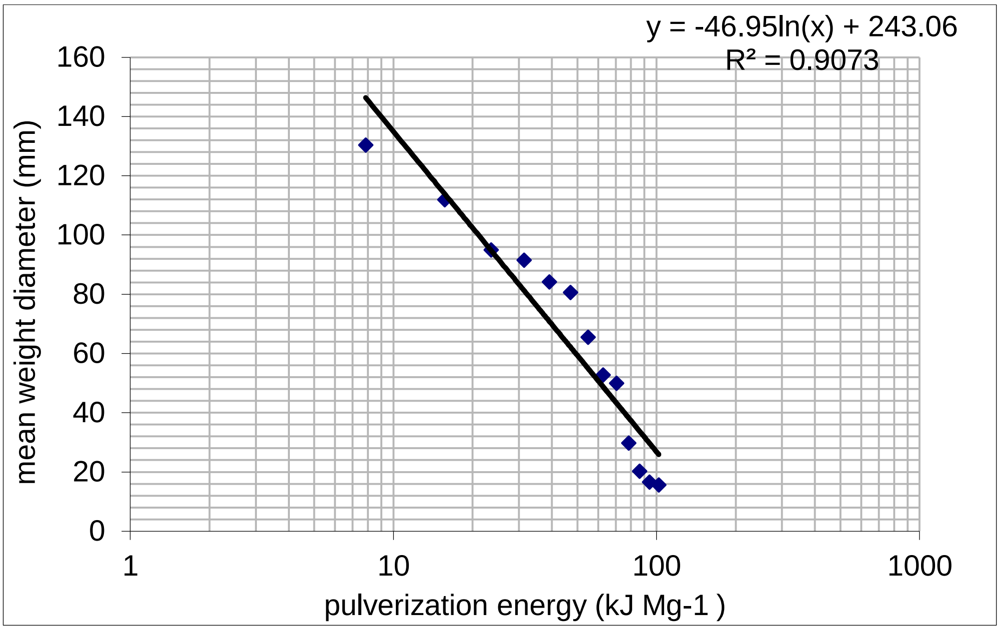

Figure 2. The relationship between required energy and mean weight diameter.

2.3. Mathematical Model

A total of 96 experiments were performed to obtain appropriate models for weighted diameter rate and friability of the modified subsoil plow under various field conditions. Three independent field parameters, including wing width (0 ad 0.30m), lateral distance (0.00, 0.40, 0.50 and 0.60m) and tillage depth (0.30, 0.40, 0.50, and 0.60m). To choose more accurate and reliable models after averaging the processors, a set of different polynomial models were analyzed using Design Expert software (Version: 8.0.6.1). The ANOVA table was applied to evaluate the significance of the studied parameters and their interaction on the MWD and equivalent energy. An ANOVA table was applied to assess the significance of the studied parameters and their interaction on MWD and equivalent energy. Moreover, produce mathematical formulas to predict MWD and equivalent energy of plow under modified soil.

Table 2. Summary of statistics of MWD and equivalent energy.

	MWD	**Equivalent energy**
Std. Dev.	4.911E-003	0.014
R-Squared	0.8993	0.5314
Mean	0.14	1.24
Adj R-Squared	0.8925	0.4796
C.V. %	3.51	7.52
Pred R-Squared	0.8853	0.547
PRESS	2.445E-003	0.120
Adeq Precision	38.774	16.927

3. Results and Discussion

MWD and equivalent energy significantly affected with adding wings, lateral distance and tillage depth (Table 3).

Table 3. Analysis of variance of MWD and Equivalent energy.

Source	**MWD**				**Equivalent Energy**			
	Sum of Squares	**df**	**F Value**	**p-value Prob > F**	**Sum of Squares**	**df**	**F Value**	**p-value Prob > F**
Model	0.019	6	132.50	< 0.0001	122.47	6	4.47	0.0005
A-wing	9.708E-003	1	402.46	< 0.0001	37.42	1	8.19	0.0053
B-Lateral Distance	6.837E-004	1	28.34	< 0.0001	2.33	1	0.51	0.04774
C-Depth	4.500E-003	1	186.57	< 0.0001	53.20	1	11.64	0.0010
AB	4.345E-005	1	1.80	0.0430	5.783E-003	1	1.266E-003	0.0217
AC	2.718E-003	1	112.66	< 0.0001	8.82	1	1.93	0.0481
BC	6.145E-004	1	25.47	< 0.0001	2.42	1	0.53	0.0391
Residual	2.147E-003	89	-	-	406.72	89	-	-
Lack of Fit	2.140E-003	25	800.83	< 0.0001	406.70	25	49816.46	< 0.0001
Pure Error	6.841E-006	64	-	-	0.021	64	-	-
Cor Total	0.021	95	-	-	529.19	95	-	-
Std. Dev.	4.911E-003	-	-	-		-	-	-

Fig. 3. Illustrates the interaction effect between the lateral distance and the tillage depth in the MWD values. The maximum of the MWD value recorded at tillage depth 0.60m and lateral distance zero (without shallow plows). The increase in the plowing depth by the subsoiler without wings on the foot and shallow plows, led to an increase in the MWD (increase of clods size), as it increased from 48.38 mm to 102.28 mm when increasing the depth of tillage from 0.30 to 0.60m. This happened as a result agitating the soil by the subsoiler plow. The plow directs the available energy into the soil which led to lateral cracks in the vertical direction in the soil and at the front area of the plow leg, and according to the type of soil in which the experiment was conducted (clay soil) as well as its moisture content, earthen clusters of different sizes were formed in the line of work of the plow. The results are corresponding to finding by [29].

When adding shallow plows, it notice from fig. 3 a decrease in the MWD compared to the subsoiler plow only (without additions) at all the depths of plowing. The MWD increased with the increase in the lateral distance of the shallow plows. The lateral distance 0.40m of the shallow plows has recorded lower MWD for all tillage depths. The MWD was 44.78, 54.58, 60.63, and 67.13 mm for depths of 0.30, 0.40, 0.50, and 0.60m, respectively. This was due to the passage of soil clods through the distance between the shallow plows and from the outer sides of the shallow plows. While in the lateral distance 0.40m for shallow plows and as a result of an increase in the volume of the loosened soil, which led to the collision of the clods with the shank of the shallow plows and with each other. Thus increasing the fragmentation of the soil clods.

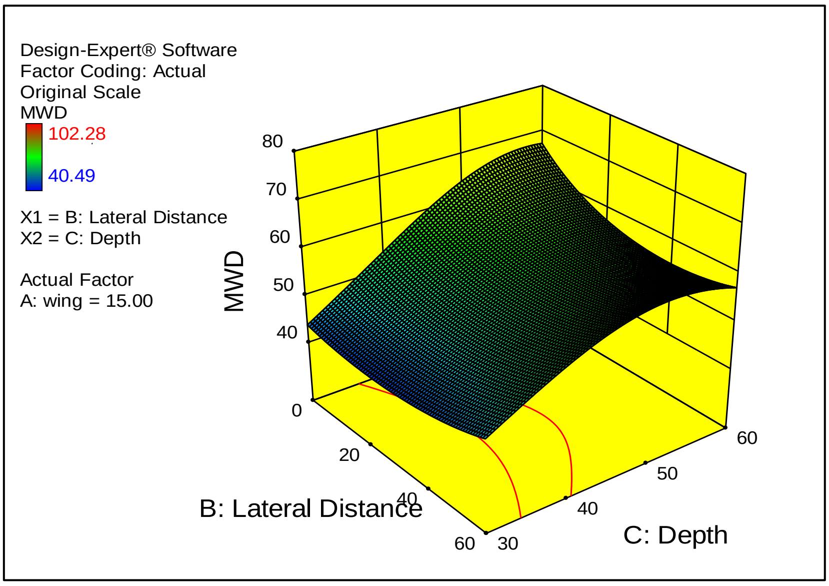

Figure 3. The effect of lateral distance and tillage depth on MWD.

Fig. 4. Shows the impact of plowing depth and adding wings on MWD. The MWD increased with increasing tillage depth until 0.50m. After that the MWD decreased with increasing tillage depth at 0.60m. The interaction effect of adding wings and tillage depth led to decreasing MWD. The MWD recorded a maximum value of 68.48 mm at a tillage depth of 0.60m with no adding wings. Furthermore, the minimum value of MWD recorded at tillage depth 0.30m with adding wings on the subsoiler foot. The reason for this is due to the role of the wings which worked to increase the area contact and friction with the soil. Moreover, the cutting edge of wings led to increase the tearing of the soil clods as well as the volume of the raised of soil. Thus increase the collision of the soil clods with each other. The results are in agreement with result of [30].

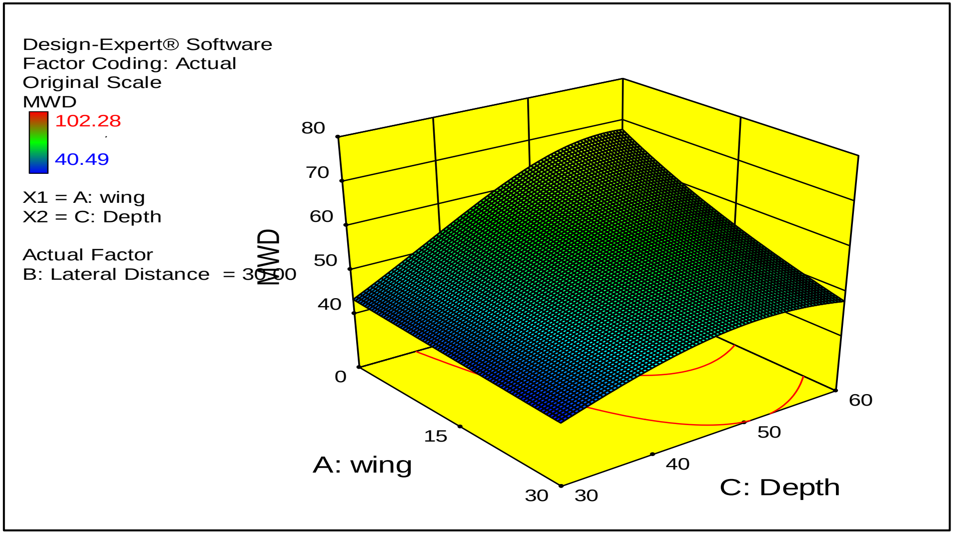

Figure 4. The effect of wings width and tillage depth on MWD.

From fig. 5, it noticed that the adding wings on the foot of subsoiler plow its led to decrease MWD. The MWD decreased by 30% when adding wings compared to the no addition treatment. The lateral distance between the shallow plows (0.40) m was recorded as the lowest MWD by 50.43 mm. This indicates that the addition of wings to the subsoiler foot and utilizing shallow plows in front of subsoiler plow led up to the improvement of the plow performance. Hence, the MWD decreased by more than half with adding wings and shallow plows. This goes back to increase volume of loose soil due to the increased collision of soil particles with wings and shallow plows.[31,32].

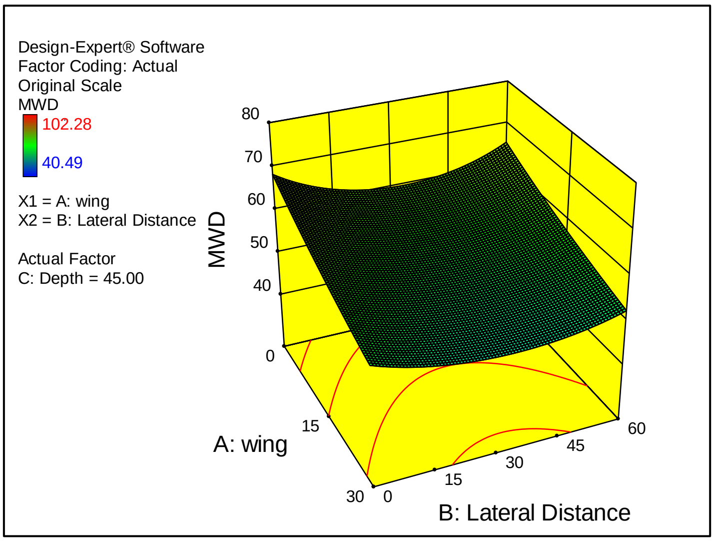

Figure 5. The effect of wings width and lateral distance on MWD.

From the figure, it notice that the addition of the wings and the shallow plows had a clear effect on the reduction of the MWD compared to the non-addition. Although the MWD increased when increasing the plowing depth, the increase was less than that of the no addition treatment. The lateral distance of the shallow plows of 0.40m recorded the lowest values of the MWD for the depths of 0.30, 0.40 and 0.50 m, as the values for the three depths reached 40.49, 50.59 and 48.37 mm, respectively. On the other hand, when the depth was increased to 0.60m, the treatment of the lateral distance 0.60m was recorded, the lowest value of the MWD reached 45.45 mm, with a reduction of 55.56% compared to the subsoiler without addition, while the MWD of the lateral distance of the shallow plows was 46.45 and 46.28 mm (0.40 and 0.50m) respectively. This indicates that the addition of wings to the foot of the subsoiler plow and the shallow plows in front of it led to improvement of the plow work and the reduction of the MWD by more than half. The reason may be due to the presence of shallow plows and wings that increased the volume of the loose soil at a depth of 0.60 m, which increased the friction and collision of the soil with the wings and shallow plows as well as the soil moisture content that helped increase Fragmentation of the soil.

The model for MWD prediction is presented by following equation:

$$
\begin{gathered}
1/\mathrm{Sqrt}(\mathrm{MWD}) = +0.18984-7.80882\mathrm{E}{-004} * \text{wing} \\
-3.59445\mathrm{E}{-004} * \text{Lateral Distance} \\
-1.41868\mathrm{E}{-003} * \text{Depth} \\
+1.96915\mathrm{E}{-006} * \text{wing} * \text{Lateral Distance} \\
+3.17253\mathrm{E}{-005} * \text{wing} * \text{Depth} \\
+9.93514\mathrm{E}{-006} * \text{Lateral Distance} * \text{Depth}
\end{gathered}
$$

From the figure (6) it notice an increase in the equivalent energy of fragmentation for the subsoiler plow, with an increase in the depth and the highest value was at the depth of 0.50m, then the equivalent energy decreased at the depth of 0.60m, and the reason may be due to the nature of the soil condition in terms of moisture content and soil bulk density with which the plow works below the soil surface as well as the depth of the plows Shallow this results are agreement with [33].

The equivalent energy of fragmentation decreased when increases lateral distance of the shallow plows, however the equivalent energy increased by 36.29% when increasing the depth of tillage from 0.30 to 0.60m at lateral distance 0.60m compared to 9.09% for the plow without wings for the same increase in the depth of plowing, this happened as a result of the increase in the large soil volume as a result of the increase in soil fissures, which increased the collision of the soil masses With each other, thus increasing their fragmentation, as well as the contact area between the soil and the surface of the wings, which enabled the plow to exploit the available energy to increase the fragmentation.

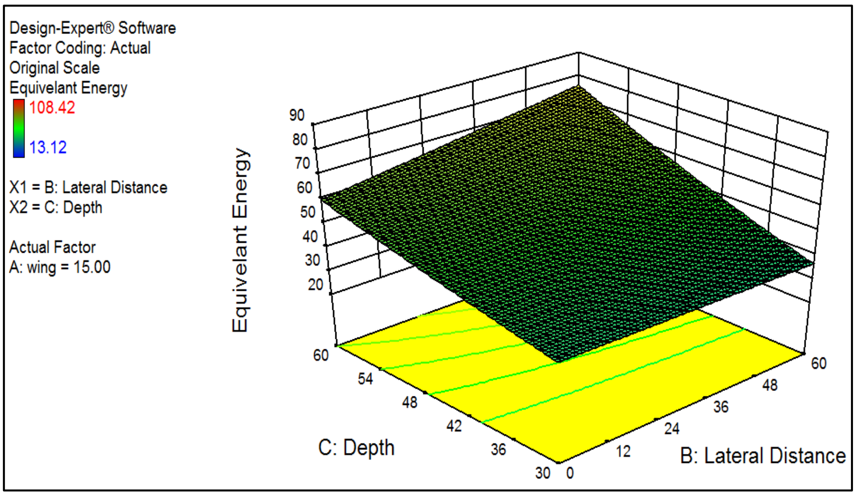

Figure 6. The effect of lateral distance and tillage depth on Equivalent energy.

From the figure (7), it notice an increase in the equivalent energy with increasing tillage depth. The highest value was at the depth 0.50m, then the equivalent energy decreased at a depth of 0.60m. The reason may be due to the nature of the soil condition in terms of the moisture content and the bulk density of the soil as well as the depth of the plows are shallow as the plow directs the available energy to overcome the strength of the soil.

As for the effect of adding wings, the equivalent energy increased by 30.58% when increasing the depth of plowing from 0.30 to 0.60m compared to 9.09% for the no winged plow with the same increase in the depth of plowing. The reason of this due to increase soil volume as a result of increased acceleration caused by the wings in the soil. Which led to increase the collision of soil masses with each other. Hence, increase their fragmentation and contact area between the soil and the wings. Which enabled the plow to exploit the available energy to increase fragmentation [34,35].

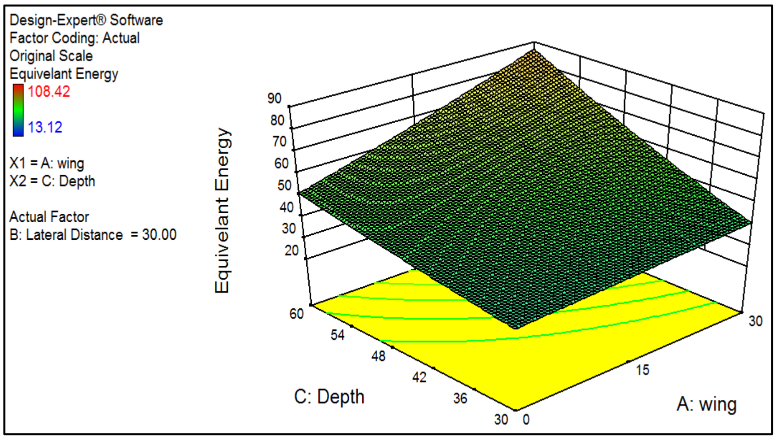

Figure 7. The effect of wings width and tillage depth on Equivalent energy.

In general, the equivalent energy was decreased with the increase in the lateral distance of the shallow plows, but the addition the wings led to an increase in the equivalent energy compared to the no addition of all study parameters, as shown in the figure (8), as it was the lowest equivalent energy at the depth of 0.30m for the subsoiler plow only (without wings and shallow plows). While when the shallow plows were added, the lateral distance of 0.40m recorded the highest equivalent energy compared to other lateral distances, before adding wings. When adding wings, the equivalent energy of the subsoiler plow increased compared with no addition, but it decreased with increasing the lateral distance of the shallow plows. The results showed that the equivalent energy of subsoiler plow with shallow plows at 0.60m lateral distance and wings increased by 3.55% compared to subsoiler plow with only shallow plows when the depth increased from 0.30 cm to 0.60m, while the percentage increase when adding wings is only by 21.49% for the same increase in the depth of tillage.

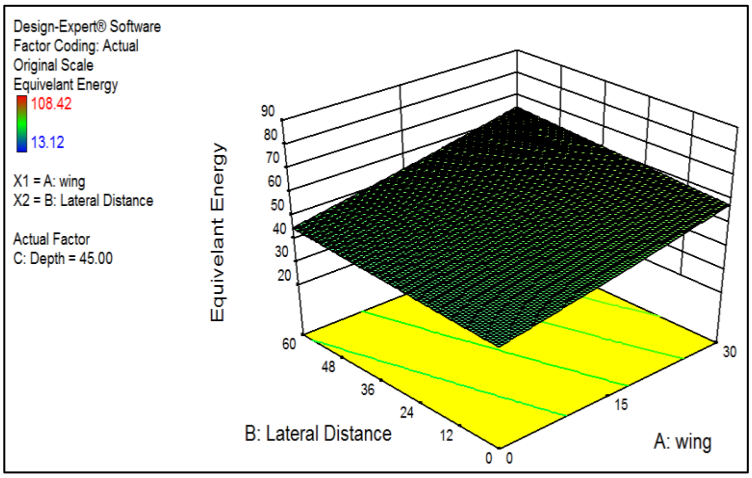

Figure 8. The effect of wings width and lateral distance on Equivalent energy.

The appropriate model for the equivalent energy is represented in following equation, in which the coefficients are in the coded unit form.

Final Equation in Terms of Actual Factors:

$$\begin{gathered}\text{Sqrt (Equivalent Energy)} = +5.24534-0.038213 * \text{wing} \\ -0.021538 * \text{Lateral Distance} \\ +0.024295 * \text{Depth} \\ +2.27190\text{E-}005 * \text{wing} * \text{Lateral Distance} \\ +1.80786\text{E-}003 * \text{wing} * \text{Depth} \\ +6.22950\text{E-}004 * \text{Lateral Distance} * \text{Depth}\end{gathered}$$

Conclusions

The MWD increased with the increase in the depth of tillage for the subsoiler plow. However, the MWD decreased when addition the wings on the foot of the subsoiler plow. Increasing the lateral distance of the shallow plows led to increasing the MWD, but increasing the depth and adding the wings led to a decrease in the MWD.

Increasing the plowing depth led to increasing the equivalent energy of fragmentation at a depth of 0.50m, and then decreased at a depth of 0.60m while increasing the lateral distance of shallow plows reduced the equivalent energy for fragmentation.

The addition of wings increased the equivalent energy of fragmentation.

The interaction between the depth of plowing, the addition of wings, and shallow plows led to increasing the equivalent energy of fragmentation.

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