The Effect of Adding Diesel Fuel Additives and Some Mechanical Indicators on The Energy Requirement of a Double Tines Subsoiler Plow

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Abstract

The current study evaluated the effect of three factors: the fuel type factor and four levels (diesel fuel without improver, diesel fuel with the German Power Max improver, diesel fuel with the Dutch Bardahl improver, and fuel with the American Max-Tane improver). The plow penetration angle factor at two levels (45º and 55º) and the plowing depth factor at two levels (35 and 45) cm, on each draft force, the area of loose soil, and the efficiency of energy utilization. The field's topography was flat, and the soil had a texture (Clay loam). An experiment was conducted with three factors, using a randomized complete block design (RCBD) and the split-split plot system. The averages were tested by Duncan's multiple range test at a probability level of 0.05. The following are the most important results reached: first, the effect of the improved fuel type by adding Bardahl achieved the best values, and there was a significant difference in draft force, loose soil area, and energy utilization efficiency, respectively, of 10.386 kN, 0.245 m^2, and 23.527 m^3. $M.J^{-1}$. Moreover, the effect of the plow penetration angle of 45 degrees achieved a significant difference through the best values recorded in draft force with 10.956 kN, loose soil area with 0.245 m2, and energy utilization efficiency was 22.486 m^3. MJ^{-1}. Finally, the effect of the plowing depth of 35 cm achieved a significant difference in draft force (10.625) kN. A 45 cm plowing depth recorded the best values for the loose soil area, which was 0.272 m^2, and the energy utilization efficiency was 22.722 m^3. MJ^{-1}.

Keywords: Diesel fuel; draft force; improver fuel; penetration angle; plowing depth

Introduction

In a tractor engine, the combustion of the air-fuel mixture occurs when the ignition conditions are ideal at the end of a certain period of ignition delay after fuel injection. The longer ignition delay period, which requires more time to complete the combustion process, leads to uncontrolled and imperfect combustion and increased air-fuel mixture taken into the engine cylinder (Ciniviz et al., 2017).

Increasing the area of loose soil and reducing the power requirements and pulling force required to pull the subsoiler plow increases agricultural energy utilization efficiency. It is considered one of the necessary tasks to increase the machine's productivity and increase the tractor's efficiency in completing the plowing process. This requires the development and selection of advanced technological means and materials that effectively increase the capacity of the tractor engine and improve the level of energy output to overcome the resistance of the soil. The draft force was spent between 20% and 55% of the tractor's capacity on agricultural processes (Rivero et al., 2022). The properties of diesel fuel depend on the exact composition of its composition. The percentage of paraffinic, naphthenic, and aromatic hydrocarbons is one of the most critical factors that make a difference between the types of diesel fuel. The high content of paraffinic hydrocarbons increases the quality of fuel ignition. Still, at the same time, it poses a problem in meeting the requirements of low temperatures, which is greatly reflected in the capacity of internal combustion engines (Gadhvi, 2019). The Cetane number is an essential indicator of fuel quality. A high Cetane number reduces the ignition time, which leads to a reduction in the interval between the start of fuel injection and self-ignition. The high Cetane number enhances fuel combustion and improves engine performance (Ali et al., 2018).

The Cetane number is also considered one of the vital fuel properties in diesel engine operation (Jbril and Mekonen, 2021). Cetane number improvers and enhancers are known as those compounds that easily decompose to form longitudinal chains of carbon atoms, which in turn improve and enhance the rate of combustion initiation time, which leads to improving the ignition properties of diesel fuel. Selected chemicals from alkyl nitrates, a portion of peroxides, tetrazoles, and thioldehydes can be suitable as Cetane number improvers. The low costs made alkyl nitrates play the most important role for this purpose, so 2-ethyl-hexyl nitrate is considered one of the most important and most used additives as Cetane number improvers, and its addition to diesel fuel at a concentration of 0.1% and 0.05%. It was noted that the Cetane number increased by 25% (Khudhair et al., 2017). The changes in chemical and physical properties such as density, viscosity, Cetane number, and flash point are among the most important focus of studies that are interested in improving additives to diesel fuel, due to their significant impact on the efficiency of engine performance, engine power, thermal efficiency and improving fuel consumption efficiency by improving the quality of the fuel combustion process and increasing torque to produce more energy (Fayyazbakhsh and Pirouzfar, 2017).

Ali et al. (2018) stated that their study aimed to improve diesel engine efficiency and emissions using fuel additives. Two levels of diesel fuel were adopted: conventional diesel fuel without additives and improved diesel fuel with the addition of 5% diethyl ether to know the effect of each on the diesel engine power. The study's results showed that the average increase in engine power when operating with improved diesel fuel with the addition of 5% diethyl ether reached 5.23% compared to conventional diesel fuel. The fuel test results showed that the cetane number of the improved diesel fuel with 5% diethyl ether increased by 6% compared to the Cetane number of conventional diesel fuel. Taha and Taha (2019) indicated that increasing the plowing depth leads to an increase in the pulling force with a significant effect at the 0.05 level, as the lowest plowing depth of 15 cm recorded the lowest value of the pulling force, which amounted to 4.534 kilonewtons while increasing the plowing depth by 10 cm from the lowest depth leads to an increase in the value of the pulling force to 5.547 kilonewtons. Meselhy (2020) concluded that working below the critical depth of the plow blade leads to an increase in the pulling force and that one of the essential indicators determining the energy required for the plowing equipment is the pulling force.

The study of Abdullah and Hilal (2014) indicated that the highest values recorded for the critical width and depth were 14.29 cm and 26.92 cm, respectively, at a penetration angle of 30 degrees, while the lowest values recorded for the critical width and depth of the loosened soil area were 11.34 cm and 23.68 cm, respectively, at a penetration angle of 50 degrees. The results of the study of Alfaris et al. (2020) also showed that the plowing depths of 40, 50, and 60 cm had a significant effect at the 5% level in increasing the loosened soil area by 27.59% and 23.24% when the operating depth increased from 40 to 50 and then 60 cm, respectively.

The reason for the increase in the area of loose soil when increasing from 40 cm to 50 cm and then its decrease at a depth of 60 cm is the difference in soil properties such as moisture content, apparent density, and soil resistance to penetration at both plowing depths of 50 cm and 60 cm. Al-Rajabo et al. (2021) indicated in their study to investigate the effect of the penetration angle at levels of 45 and 55 degrees on energy utilization efficiency, as its value for a subsoil plow reached 0.306 m^3. MJ^{-1}at a penetration angle of 55 degrees, while the energy utilization efficiency reached 0.396 m^3. MJ^{-1}at a penetration angle of 55 degrees, which is a result due to the decrease in energy requirements compared to the increase in the cross-sectional area of loose soil as the penetration angle of the plow blade into the soil decreases. Al-Hameed and Abd Al-Nabi (2023) concluded that increasing the plowing depth from 15 cm to 35 cm increased the area of loose soil by 179.34%. Increasing the plowing depth led to increased cracks in the soil and increased the soil masses stirred by the plow's shearing tool, which helped increase the area of loose soil. In the study of Aday et al. (2016) to evaluate the field performance of the partially curved double-arm subsoil plow at different levels of plowing depths, which were 30, 40, 50, and 60 cm, the researchers noted a significant decrease in the soil resistance (the reciprocal of energy utilization efficiency) at the 1% level from 92.30 kN/m2 to 69.33 kN/m2. This was when the operating depth increased from 30 to 60 cm, as this decrease in the soil resistance is associated with a significant increase in the stirred compared to the pulling force. Therefore, improving the performance of the subsoil plow requires using it at a greater operating depth, provided that there is sufficient traction force to pull it forward, which led to an increase in energy utilization efficiency from 5.90 to 9.68 m^3. MJ^{-1}. The study of Petrov et al. (2020) indicated that the energy utilization efficiency in the plowing unit depends on the extent to which the mechanical energy of the tractor engine is converted into mechanical work that is useful in stirring and loosening the soil, which is an important feature that the automated tractor units should distinguish. On this basis, the objectives of our study were to study the effect of adding improved materials to diesel fuel on the power consumed by the agricultural tractor loaded with the dual-arm subsoiler plow. Also, studying the impact of the interaction between the three types of additives added to diesel fuel and the two penetration angles of the two subsoiler plow arms and two depths of plowing on the power consumed through their effect on the pulling force, the area of loosened soil, and the efficiency of utilizing the tractor's energy.

Materials and Methods

Field Site and soil test: Experiments were carried out at the field of Al-Hamdaniya District, one of the districts of Nineveh Governorate in northern Iraq, located southeast of Mosul. The area of the Al-Hamdaniya district is 1,155 square kilometers; its population is 356,754 people, and its coordinates are 36.2714°N 43.3737°E, as displayed in Figure 1. Soil texture examination was conducted in the laboratories of the College of Engineering, University of Mosul, using the grain size analysis test method. The method used to estimate soil moisture content (M.C) and the soil bulk density is described in Black et al. 1983. The soil penetration index is evaluated as described by Gill and Vandenberg (1968) at depth levels 0-10, 10-20, 20-30, 30-40, and 40-50 cm at many field parts, with three replicates for each treatment. The soil test results are shown in Table 1.

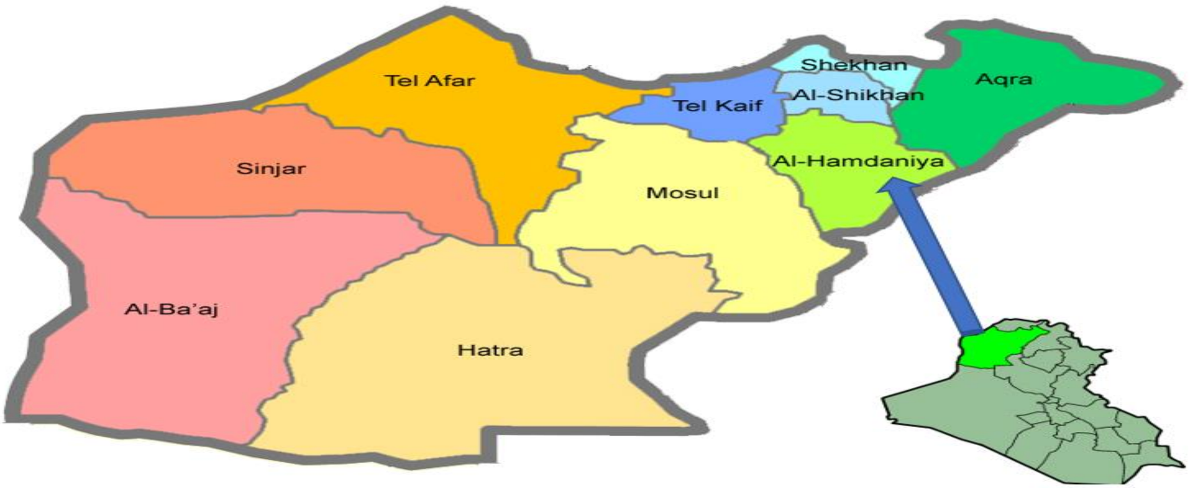

Figure 1. Experiment field in Al-Hamdaniya District

Table (1) Explains some of the physical and mechanical properties of the soil before implementation

Soil depth (poison)	Bulk density (g/cm3)	M.C (%)	Soil penetration index (kN/m2)
0 – 10	1.45	17.3	313.62

10 – 20	1.55	19.6	383.60
20 – 30	1.47	21.2	438.04
30 – 40	1.42	22.5	482.10
40 – 50	1.35	23.2	515.80
Soil texture	Clay	Silty	Sand
Clay loam	33.61	40.06	26.33

Tractor and implement: A Fiat 115 - 90 tractor was used in this research, and a tractor manufacture company, Fabbrica Italiana di Automobili Torino. The particular specifications of this tractor were Engine model and type (8065.05), 6 cylinders with turbocharging, Hydraulic pump capacity (50,8 L/min), and Maximum load of the 3-point hitch (5300/5700 kg). Hydro-type braking system control, PTO (540/1000 rpm), mechanical gearbox, driving speed and maximum (0.2-27.9 and 32.2 km.hr-1), and the total weight of the tractor (5740 kg). Overall height with cabin (290 cm), total length (450/462cm), total width(275/267 cm), front wheel (14,9-28), and rear wheel (18,4-38).
In the experiment, the subsoiler plow was used. General Company for Mechanical Industries manufactured the two-leg subsoiler plow in Alexandria, Iraq. Two-meter width between 2 legs, two serrated front discs, max working Depth 0.5meter, and in work was set at a 1-meter working width.

Specifications of diesel fuel improvers

Details of the specifications of the fuel improvers that were used in the experiment according to the specifications of the manufacturers and the mixing ratios with diesel fuel are shown in Table (2). An examination of the types of improvers and diesel fuel was carried out in the Qayyarah refinery laboratories, as shown in the table (3)

Table (2) shows specifications **of diesel fuel improvers**

	Power – Max	Pardahl	Max – Tane
Product classification	According to Regulation (EC) No. 1907/2006	According Regulation (EC) No. 1907/2006 REACH (as amended by Regulation (EU) 2015/830 Date of issue: 1	US regulations TSCA 8b
Producing country	Germany	Dordrecht – Netherlands	American United States
Physical condition	Liquid	Liquid	Liquid
Color	Transparent	Transparent	Purple
Components	Hydrocarbons13,C10-C, n-alkanes, isoalkanes, rings, <2% aromatics -2-ethylhexylnitrate	Hydrocarbons13,C10-C, n-alkanes, isoalkanes, rings > 2% aromatics, 2-ethylhexyl nitrate	2 Ethylhexyl nitrate, solvent is naphtha (petroleum), mild odor. Naphtha, a heavy-smelling solvent (petroleum). 1,2,4-trimethylbenzene naphthalene benzo[a]pyrene
Flash point	< 200°C	200°C	Unavailable
Relative density	0.83 – 0.84 g/cm^3	Unavailable	0.95 g / cm^3
Degree of toxicity	Acute toxicity 4	Acute toxicity 4	Toxic and contains carcinogenic substances
Increased cetane	5 points	5 points	8 points

number			
Addition ratio	300 milliliters: 60-80 litres	500 milliliters : 50 litres	29.574 milliliters: 7.57082 litres

Table (3) shows diesel fuel specifications with the additions cetane booster

TESTS	Specifications diesel fuel Without Addition	Specifications diesel fuel with an addition (Power - Max)	Specifications diesel fuel with an addition (Bardhal)	Specifications diesel fuel with an addition (Max – Tane)
Cetane number	47	48	48	48
Density @ 15 C°	0.8270	0.8250	0.8241	0.8240
flash point C°	76	74	73	73
Viscosity @ est 40 C°	2.3	2.0	1.8	1.8
the color	1.5	1.0	0.5	0.5
Sulfur content wt.%	0.863	0.854	0.835	0.834

The indicators studied, and the equations used to calculate them are:

Drag force (kN):-

The readings were taken directly from the digital dynamometer to measure the drag force, and were calculated using the equation:-

$$F_t = F_{pm} - F_{rm} \quad \text{……………………(1)}$$

F_t: Force required to pull the plow under the soil (kN).

F_{pm}: Force required to pull the rear tractor and the plow under the soil (kN).

F_{rm}: Force required to pull the rear tractor only (kN).

Area of loose soil (m^2):-

By using the dual-arm subsoil plow, we obtain two types of loosening; they are (Crescent Failure) and (Compressive Failure), as in Figure (3-3), where the crescent loosening is near the soil surface, and in it the soil moves forward, to the sides and upwards, and its porosity increases and its density decreases, while the compressive loosening occurs at depth, away from the soil surface, and the soil is compressed, and its density increases and its porosity decreases, and the soil moves forward and to the sides only Spoor and Godwin (1978).

Since the subsoil plough under trial is a two-armed plough, it is necessary to calculate the total area of loosened soil (A total) by applying the equation, Hilal (2007) for each of the two plough arms, so that we obtain:

$A = s \times dc + w \times d$……………… …..(2)

$s = \frac{b-w}{2}$ ……………………………………………(3)

……………. (4) $A_1 = s_1 \times dc_1 + w_1 \times d_1$

…………….(5) $A_2 = s_1 \times dc_2 + w_2 \times d_2$

………………… ….. ($A\,total = A1 + A2$ 6)

Where:

S: The loosened distance of the soil on one side of the plow stem (meters).

d: The depth of plowing (meters).

dc: The distance of the critical depth from the soil surface (meters).

b: The width of the loosened soil (meters).

W: The width of the plowed soil below the critical depth (meters).

From the geometric shape of the section: du: The distance of the critical depth from the bottom of the plowing furrow (meters).

Each of (dc, d, W, b) was measured using a solid measuring tape after digging trenches perpendicular to the plough lines under the soil, and then displacing the loose soil by hand and using a brush to clarify the features of the section.

Energy utilization efficiency (m^3. MJ^{-1}):-

It is the number of cubic meters of soil loosened by the plow under the soil for each megajoule of energy consumed. It is affected by several factors, including the depth of plowing, the design of the plow, and the condition of the soil. It was calculated based on the following equation: Mckyes (1985):

$$\eta = (1/S.R.)\times 1000$$

………………..(9)

Where:

ŋ: Energy utilization efficiency (m3/MJ).

S.R.: Specific resistance (kN/m2).

Specific resistance represents a part of the total resistance per unit area of the plowed section and its units are (kilonewton/m2) or (kg/cm2), and it was calculated from the following equation Gill and Vanden Berg (1986):

$$S.R. = F/A$$

……………………………(10)

Where:

F : Pulling force (kN).

A : Area of loosened soil (m^2).

The experiment factors and statistical design

The experiment was conducted with three factors; the subsoiler plow was tested in the field using four types of fuel that include diesel without enhancers fuel, diesel with Power Max enhancers fuel, diesel with Bardahl enhancers fuel, and diesel with Max-Tane enhancers fuel, and two angles of penetration were 45◦ and 55◦ at two plowing depths of 35 and 45 cm. The experiment was analyzed using a randomized complete block design with a split-plot design and Duncan's multiple range test at the 0.05% and 0.01% probability levels; the analysis of variance for the studied traits was presented in Table (4). The trial site was divided into 16 treatments with three replications.

Table (4) Analysis of variance for the studied traits (mean squares).

S.O.V	DF	Draft Force	Area Of Loose Soil	Energy utilization efficiency
Fuel types (a)	3	** 19.34572227	** 0.00090383	** 93.1018411
Block	2	NS 0.35343641	NS 0.00003616	NS 2.2041278
Error	6	0.83751061	0.00005065	3.2233379
Angle of penetration (b)	1	** 9.66366034	** 0.00277993	** 96.9037129
a*b	3	* 0.88300848	* 0.00005669	NS 0.2530909
Error	8	0.17632496	0.00000852	0.9010549
Plowing depth (c)	1	** 29.23982062	** 0.05721345	** 131.8697906
a*c	3	NS 0.02182501	** 0.00014854	NS 1.3308957
b*c	1	NS 0.72099141	** 0.00095667	** 17.2433552
a*b*c	3	NS 0.39866378	** 0.00011896	NS 1.7612315
Error	16	0.3637498	0.00001452	0.9611798

Results and discussion:

1- The effect of fuel type on draft force, area of loose soil, and energy utilization efficiency:

Table 5 shows that the fuel type significantly affects the draft force required to pull the plow under the dual-arm soil. The optimized fuel type with the addition of BARDAHL recorded the lowest draft force value at 10.386 kN, followed by the optimized fuel type with MAX-TANE at

10.884 kN, and then the optimized fuel type with the addition of Power Max at 11.094 kN. Meanwhile, diesel fuel without an additive recorded the highest draft force required to pull the plow at 13.257 kN. The reason for this is that adding the mentioned fuel additives led to a shorter time required for fuel ignition and thus improved the combustion process of the air-fuel mixture by fully utilizing the oxygen inside the combustion chamber. This increased temperature and pressure in the combustion chamber, producing greater force on the piston, increasing crankshaft torque, and consequently increasing the engine's power.

The type of fuel has a significant effect on the area of the loose soil. The fuel type optimized with the addition of BARDAHL recorded the highest value of 0.245 m^2 as the area of the loose soil, followed by the fuel type optimized with MAX-TANE additive, which recorded 0.243 m^2. Next, the fuel type optimized with the addition of Power Max recorded 0.235 m^2, while the fuel type without an additive recorded the lowest value for the area of the loose soil at 0.226 m^2. The reason for this is that the relationship between the specific resistance of the soil and the area of the loose soil is an inverse relationship. In contrast, its relationship with the draft force is centrifugal. Due to the decrease in draft force for each type of fuel, including the mentioned additives, its effect was to decrease the specific resistance of the soil, leading to an increase in the plow's ability to penetrate and create lateral cracks, resulting in an increase in the cross-sectional area of the soil and consequently increasing the area of the loose soil.

Similarly, the effect of fuel type was significant on energy utilization efficiency. The fuel type optimized with the addition of BARDAHL recorded the highest value for energy utilization efficiency at 23.527 m^3. MJ^{-1}, thus outperforming the fuel type optimized with the addition of MAX-TANE, which recorded 22.377 m^3. MJ^{-1}, followed by the fuel type optimized with the addition of Power Max, recording 21.224 m^3. MJ^{-1}. On the other hand, the fuel type without an additive recorded the lowest value for energy utilization efficiency at 17.132 m^3. MJ^{-1}. The reason for this lies in the significant effect of the fuel type on the decrease in the required draft force for the plow and its corresponding significant effect on increasing the area of the loose soil. Since energy utilization efficiency, in its mathematical concept, is the reciprocal of the specific resistance of the soil, which equals the draft force divided by the area of the loose soil, the increase in the area of the loose soil and the decrease in draft force were the main reasons for the significant effect of the fuel type optimized with the mentioned additives above in increasing energy utilization efficiency compared to the fuel type without an additive, aligning with Ali et al. (2018).

Table 5 : The effect of fuel types on draft force, area of loose soil and energy utilization efficiency.

Fuel types	Draft Force KN	Area Of Loose Soil m2	Energy utilization efficiency m^3. MJ^{-1}
Diesel	13.257 A	0.226 C	17.132 C
Diesel with Power max	11.094 B	0.235 B	21.224 B
Diesel with Bardahl	10.386 B	0.245 A	23.527 A
Diesel with Max – Tane	10.884 B	0.243 A	22.377 BA

2- The Effect of penetration angle of a subsoiler plow on draft force, area of loose soil, and energy utilization efficiency:

Table 6 observes the significant effect of increasing the penetration angle of a subsoiler plow on the required draft force. The 45-degree angle recorded the lowest draft force value at 10.956 kilonewtons, while the 55-degree angle recorded the highest draft force value at 11.854 kn. This is because increasing the penetration angle leads to an increase in the volume of soil pushed forward, resulting in the pushed soil colliding with the untilled soil. This leads to a large volume of soil buildup in front of the plow, increasing soil resistance to the plow penetration movement. Additionally, a large volume of soil being lifted upward increases the effective weight on the plow penetration, leading to increased friction with the soil.

Also, the penetration angles significantly affect the area of the loose soil. The 45-degree penetration angle recorded the highest value of 0.245 m² as the area of the loose soil, while the 55-degree penetration angle recorded the lowest value of 0.230 m². This result can be attributed to the fact that the increase in penetration angle decreased the critical depth below the soil surface and the width of disturbance at the soil surface. Additionally, the increase in the compression of the lifted soil against the plow penetrations with untilled soil, both on the sides and on the top, led to a decrease in the value of the area of the loose soil. This agrees with what was mentioned by (Al-zubaidi and Al-rajabo, 2022).

Similarly, the effect of penetration angles also showed significant differences in energy utilization efficiency. The 45-degree penetration angle outperformed with the highest value for energy utilization efficiency at 22.486 m^3. MJ^{-1}, while the 55-degree penetration angle recorded the lowest value at 19.644 m^3. MJ^{-1}. This result can be attributed to the fact that increasing the penetration angle of the plow penetrations led to an increase in the specific resistance of the soil to them by increasing the draft force relative to the area of the loose soil. This aligns with the findings of (Abdullah and Hilal , 2017) , who note that by applying the relationship above between the specific resistance of the soil and energy utilization efficiency, we find that an increase in the penetration angle led to a decrease in energy utilization efficiency.

Table 6 : The effect of the penetration angle of a subsoiler plow on draft force, area of loose soil and energy utilization efficiency.

Angle of penetration (Degree)	Draft Force KN	Area Of Loose Soil m2	Energy utilization efficiency m^3. MJ^{-1}
45	10.956 B	0.245 A	22.486 A
55	11.854 A	0.23 B	19.644 B

3- The effect of plowing depth of a subsoiler plow on draft force, area of loose soil, and energy utilization efficiency:

Table 7 shows that the increase in plowing depth with the plow under the dual-arm soil had a significant effect on draft force. The plowing depth of 35 cm surpassed others, recording the lowest draft force value at 10.625 kN, while the depth of 45 cm ranked second, recording the highest draft force value at 12.186 kN. The reason for this is that increasing the plowing depth led to an increase in draft force due to the increased load on the plow, thereby increasing the resistance encountered by the plow. Consequently, the required draft force increased.

The effect of plowing depth on the area of the loose soil with the plow penetrations under the soil appeared to be significant. The plowing depth of 45 cm showed superiority by recording the highest value of 0.272 m² as the area of the loose soil, while the depth of 35 cm recorded the lowest value at 0.203 m². This is because increasing the plowing depth led to an increase in the cross-sectional area of the soil exposed to the plow penetrations' effects, increasing the volume of soil cut. Additionally, the critical depth is pushed further away from the soil surface downwards, along with increased lateral effects due to cracks occurring in adjacent soil. This aligns with the findings of (Hilal, 2007).

The significant effect of plowing is noticeable on energy utilization. The plowing depth of 45 cm surpassed the highest value at 22.722 m^3. MJ^{-1}, compared to the depth of 35 cm, which recorded 19.407 m^3. MJ^{-1}. This is because increasing the plowing depth led to a decrease in the specific resistance of the soil due to the increase in the area of the loose soil relative to the draft force. This necessitates improving the plow's performance under the soil by operating it at a greater depth, provided there is sufficient draft force to pull it forward. Consequently, there is an increase in energy utilization efficiency due to the larger volume of loose soil compared to the lower energy requirements. This aligns with the findings of (Aday et al. , 2016).

Table 7 : The effect of the plowing depth of a subsoiler plow on draft force, area of loose soil and energy utilization efficiency.

Plowing depth (cm)	Draft Force KN	Area Of Loose Soil m2	Energy utilization efficiency m^3. MJ^{-1}
35	10.625 B	0.203 B	19.407 B
45	12.186 A	0.272 A	22.722 A

4- The effect of fuel type and plowing angle interaction on draft force, area of loose soil, and energy utilization efficiency:

Table 8 illustrates that the dual interaction of fuel type with plowing angles did not significantly affect draft force. The interaction of the fuel type enhanced with BARDAHL addition with a 45-degree plowing angle recorded the lowest draft force value at 10.120 kN. In comparison, the interaction of the fuel type without an additive with a 55-degree plowing angle recorded the highest draft force value at 14.044 kN.

The interaction effect of fuel type with plowing angles was insignificant concerning energy utilization efficiency. The interaction of the fuel type enhanced with BARDAHL addition with a 45-degree plowing angle recorded the highest value for energy utilization efficiency at 24.783 m3. MJ^{-1}, while the interaction with the lowest value at 15.640 m3. MJ^{-1} was the fuel type without an additive with a 55-degree plowing angle.

Moreover, the interaction effect of fuel type with plowing angles was significant on the area of the loose soil. The fuel type enhanced with MAX – TANE addition with a 45-degree plowing angle recorded the highest value at 0.254 m², followed by the fuel type enhanced with BARDAHL addition with a 45-degree plowing angle at 0.252 m². The fuel type is enhanced with power max addition with a 45-degree plowing angle at 0.241 m². Lastly, the interaction of the fuel type without an additive with a 45-degree plowing angle recorded the lowest value at 0.233 m² as the area of the loose soil. This result can be attributed to the fact that fuel additives led to an increase in engine power by improving the combustion process inside the combustion chambers, resulting in an increase in the amount of cetane for the fuel and the full utilization of oxygen in the combustion chambers, thus obtaining a greater energy output due to the increased power strokes for the engine. Additionally, the interaction of this effect with the fuel type with a 45-degree plowing angle, which affected the reduction of soil resistance to the plow penetrations' movement and the reduction of soil pressure on them, all led to an increase in the area of the loose soil.

Table 8 : The influence of the fuel types and penetration angle on draft force, area of loose soil and energy utilization efficiency.

Fuel types	Angle of penetration (Degree)	Draft Force KN	Area of Loose Soil M^2	Energy utilization efficiency $m^3. MJ^{-1}$
Diesel	45	12.469	0.233 C	18.624
	55	14.044	0.219 E	15.64
Diesel with Power max	45	10.549	0.241 B	22.807
	55	11.638	0.229 D	19.641
Diesel with Bardahl	45	10.12	0.252 A	24.783
	55	10.652	0.238 B	22.271
Diesel with Max - Tane	45	10.688	0.254 A	23.729
	55	11.081	0.233 DC	21.025

5- The effect of fuel type and plowing depth interaction of a subsoiler plow on draft force, area of loose soil, and energy utilization efficiency:

Table 9 shows that there was no significant effect of the dual interaction of fuel type with plowing depth on draft force. The interaction of the fuel type enhanced with BARDAHL addition with a plowing depth of 35 cm recorded the lowest draft force value at 9.617 kN. In comparison, the interaction of the fuel type without an additive with a plowing depth of 45 cm recorded the highest draft force value at 14.092 kN.

Similarly, the same table indicates that the interaction of fuel type with plowing depth did not significantly affect energy utilization efficiency. The interaction of the fuel type enhanced with BARDAHL addition with a plowing depth of 45 cm recorded the highest value at 25.487 m3. MJ^{-1}, while the interaction of the fuel type without an additive with a plowing depth of 35 cm recorded the lowest value at 15.689 m3. MJ^{-1} for energy utilization efficiency in this dual interaction. However, the interaction of fuel type with plowing depth significantly affected the area of the loose soil. The interaction of the fuel type enhanced with BARDAHL addition with a plowing depth of 45 cm recorded the highest value at 0.283 m^2 as the area of the loose soil, followed by the interaction of the fuel type enhanced with MAX – TANE addition with a plowing depth of 45 cm at 0.274 m^2. Next was the interaction of the fuel type enhanced with power max addition, recording 0.271 m^2 as the area of the loose soil. Lastly, the interaction of the fuel type without an additive with a plowing depth of 45 cm recorded the lowest value at 0.259 m^2 as the area of the loose soil. This effect resulted from the increase in engine power output when fuel additives were added to the fuel, as explained in the previous paragraph, in addition to the rise in the area of the soil section exposed to both plow penetrations when increasing the plowing depth. This led to an increase in the area of loose soil, consistent with the findings of (Hilal, 2007) and (Alfaris, 2022).

Table 9: The influence of the fuel types and the plowing depth of a subsoiler plow on draft force, area of loose soil and energy utilization efficiency.

Fuel types	Plowing depth (cm)	Draft Force KN	Area of Loose Soil M^2	Energy utilization efficiency $m^3. MJ^{-1}$
Diesel	35	12.422	0.193 G	15.689
	45	14.092	0.259 C	18.575
Diesel with Power max	35	10.308	0.198 F	19.301
	45	11.88	0.271 B	23.147
Diesel with Bardahl	35	9.617	0.206 E	21.567
	45	11.155	0.283 A	25.487
Diesel with Max - Tane	35	10.152	0.213 D	21.073
	45	11.616	0.274 B	23.681

6- The effect of the interaction between plowing penetration angle and plowing depth on draft force, loose soil area, and energy utilization efficiency:

Table 10 demonstrates that the dual interaction between plowing penetration angles and plowing depth did not significantly affect draft force. The interaction of a plowing penetration angle of 45° with a plowing depth of 35 cm recorded the lowest draft force value at 10.299 kN. In comparison, the interaction of a plowing penetration angle of 55° with a plowing depth of 45 cm recorded the highest draft force value at 12.757 kN. Furthermore, the interaction between plowing penetration angles and plowing depth significantly affected the loose soil area. The interaction of a plowing penetration angle of 45° with a plowing depth of 45 cm recorded the highest value at 0.284 m². In comparison, the interaction of a plowing penetration angle of 55° with a plowing depth of 35 cm recorded the lowest value at 0.200 m² for the loose soil area. This result is attributed to the decrease in the pressure of the soil section on the plow penetrations due to their penetration into the soil at a 45° angle, in addition to the increase in the soil section area and side cracks resulting from increasing the depth from 35 cm to 45 cm, consistent with the findings of Ogbeche et al. (2018) and Alfaris et al. (2020). Moreover, this interaction had a significant effect on energy utilization efficiency. The interaction of a plowing penetration angle of 45° with a plowing depth of 45 cm recorded the highest energy utilization efficiency value at 24.743 $m^3. MJ^{-1}$. It was followed by the interaction of a plowing penetration angle of 55° with a plowing depth of 45 cm at 20.702 $m^3. MJ^{-1}$. Then, the interaction of a plowing penetration angle of 45° with a plowing depth of 35 cm was recorded at 20.229 $m^3. MJ^{-1}$. Lastly, the interaction of a plowing penetration angle of 55° with a plowing depth of 35 cm recorded the lowest energy utilization efficiency value at 18.586 $m^3. MJ^{-1}$. This decrease in the plowing penetration angle under the soil with an increase in plowing depth led to a decrease in the soil's specific resistance due to the increase in the loose soil area compared to draft force, thus increasing energy utilization efficiency resulting from loosening a larger volume of soil for lower energy requirements.

Table 10 : The influence of penetration angle and plowing depth of a subsoiler plow on draft force, area of loose soil and energy utilization efficiency.

Angle of penetration (Degree)	Plowing depth (cm)	Draft Force KN	Area Of Loose Soil M^2	Energy utilization efficiency $m^3. MJ^{-1}$
45	35	10.299	0.206 C	20.229 B
	45	11.614	0.284 A	24.743 A
55	35	10.951	0.2 D	18.586 C
	45	12.757	0.26 B	20.702 B

7- The effect of the triple interaction between fuel type, plowing penetration angle, and plowing depth on draft force, loose soil area, and energy utilization efficiency

Table 11 shows that the triple interaction between fuel type, plowing penetration angle, and plowing depth was not statistically significant. The interaction of the fuel type with the addition of BARDAHL, plowing penetration angle of 45°, and plowing depth of 35 cm recorded the lowest draft force value at 9.355 kN. In contrast, the interaction of the fuel type without the additive, plowing penetration angle of 55°, and plowing depth of 45 cm recorded the highest draft force value at 14.947 kN. Similarly, the triple interaction between fuel type, plowing penetration angle, and plowing depth did not significantly affect energy utilization efficiency. The highest value was recorded due to the interaction of the fuel type with the addition of BARDAHL, plowing penetration angle of 45°, and plowing depth of 45 cm at 26.892 m3. MJ^{-1}, while the lowest value was recorded for the interaction of the fuel type without the additive, plowing penetration angle of 55°, and plowing depth of 35 cm at 14.627 m3. MJ^{-1}. Additionally, this interaction had a significant effect on the loose soil area. The highest value was observed through the interaction of the fuel type with the addition of MAX-TANE, plowing penetration angle of 45°, and plowing depth of 45 cm at 0.293 m², followed closely by the interaction of the fuel type with the addition of BARDAHL, plowing penetration angle of 45°, and plowing depth of 45 cm at 0.292 m². The third in the ranking was the interaction of the fuel type with the addition of Power Max, plowing penetration angle of 45°, and plowing depth of 45 cm, recording 0.280 m². Notably, the interaction of the fuel type without the additive, plowing penetration angle of 45°, and plowing depth of 45 cm recorded the lowest value at 0.270 m², indicating its least effect on the loose soil area. The results of this interaction can be attributed to factors elucidated in previous paragraphs by Alfaris et al. (2020) and Alrajabo et al. (2021).

Table 1 : The influence of fuel types, penetration angle and plowing depth of a subsoiler plow on draft force, area of loose soil and energy utilization efficiency.

Fuel types	Angle of penetration (Degree)	Plowing depth (cm)	Draft Force KN	Area of Loose Soil m^2	Energy utilization efficiency $m^3. MJ^{-1}$
Diesel		35	11.703	0.195 HG	16.751

	45	45	13.236	0.27 C	20.497
	55	35	13.142	0.19 H	14.627
		45	14.947	0.248 E	16.653
Diesel with Power max	45	35	10.156	0.201 G	19.884
		45	10.942	0.28 B	25.73
	55	35	10.459	0.195 HG	18.718
		45	12.817	0.262 D	20.564
Diesel with Bardahl	45	35	9.355	0.212 F	22.675
		45	10.884	0.292 A	26.892
	55	35	9.878	0.201 G	20.46
		45	11.426	0.274 CB	24.082
Diesel with Max - Tane	45	35	9.98	0.215 F	21.606
		45	11.395	0.293 A	25.852
	55	35	10.325	0.211 F	20.539
		45	11.837	0.254 E	21.511

Conclusions

The study is considered one of the few studies that estimated the impact of enhancers in experiments and reached the following conclusion: the results of the study revealed the superiority of the improved fuel type with the addition of Bardahl by recording the best values for each of the studied characteristics, which are the draft force, the area of loose soil, and the efficiency of energy utilization. The penetration angle of the two plow blades of 45 degrees documented the best values in each of the characteristics of draft force, the area of loose soil, and the efficiency of energy utilization. The plowing depth of 35 cm reached the best values on the characteristics. Researchers believe more field experiments should be conducted in the future.

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