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An experimental investigation on the influence of enhancers fuel and some performance indicators on a two-leg subsoiler plow

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Abstract: The research was implemented in Al-Hamdaniya District, one of the districts of Nineveh Governorate in northern Iraq, located southeast of Mosul. The soil texture of the field is Clay loam. In the present study, fuel consumption, vibration in the driver's seat, noise, and exhaust gas temperature were investigated during 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°. Two plowing depths of 35 and 45 cm were considered. The results indicated that fuel consumption and exhaust gas temperature recorded a significantly negative loss with diesel fuel without improved additives, reflecting the economic loss and the efficiency performance. The results showed the positive superiority of diesel fuel with improved additives in the fuel consumption, vibration in the driver's seat, noise, and exhaust gas temperature, except diesel with Max-Tane and diesel with Power Max enhancers achieved a negative effect increase in vibration in the driver's seat and noise, respectively. However, the values remained within the measurements approved by European Parliament Directive 2003/10/EC. Moreover, increasing the angle of penetration and plowing depths increases fuel consumption, vibration in the driver's seat, noise, and exhaust gas temperature. Finally, the results indicate the superiority of the fuel-improved additives and angle of penetration with plowing depths achieved the best results in the studied trait except for the vibration in the driver's seat at the intersection diesel with Max-Tane with a penetration angle of 55o and plowing depth of 45 cm.
Keywords: *Enhancer's fuel, Noise, Plowing depth, Penetration angle, Penetration angle.*

1. Introduction

Multifunctional agricultural equipment designed to streamline various operations in a single pass is prevalent. This equipment offers economic advantages, such as expediting tasks, minimizing operational time, and reducing the need for multiple tractors and equipment to traverse the soil surface. However, this practice can lead to the formation of a soil "hard pan," hindering the penetration of irrigation water (Altahan et al.,2015). The tractor is pivotal in agricultural machinery, significantly enhancing agricultural productivity. As an energy provider in the fields, tractors operate diverse Implementations, contributing to advancing agricultural practices (Kareem and Sve, 2019). In the evolving landscape of agriculture, the development and enhancement of tillage machines are crucial for efficient farming, particularly since agriculture has transitioned into a trade. Efficient management is critical to success in the agricultural business (Zhao et al., 2021).

Agricultural tractors play a vital role as agricultural power machines, furnished with various implements designed for plowing, tillage, land preparation, sowing, and weeding. They contribute to

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the multifunctionality of modern farming equipment and transport. Consequently, there is a rising interest in representing a sustainable and eco-conscious approach to agricultural machinery by tractors designed to be energy-efficient and environmentally friendly, representing a sustainable and eco-conscious approach to agrarian machinery (Lang et al., 2018; Moinfar et al., 2020). Agricultural tractors heavily rely on fossil fuels, constituting the importance of their energy sources, primarily diesel, gasoline, and liquefied petroleum gas (Roschat et al., 2024). Previous studies and reports suggest that introducing additives to fuel generally leads to reduced emissions and improved overall performance. Although there may be a slight increase in fuel consumption, the benefits include enhanced engine efficiency.

A study was conducted to evaluate the effect of alternative fuel on a diesel hand tractor using a combination of handle grip and engine mount. The alternative fuel addition method succeeded in reducing the vibration of the operator's hand arm by 59.27% (Yap et al., 2016).

The heightened soil resistance and increased soil volume have been linked to escalated fuel consumption; the finding aligns with their observation of a significant upsurge in fuel consumption corresponding to an increase in plowing depth, as noted in the research by Adewoyin and Ajav (2013). Prem et al., 2016 highlighted the positive impacts of combined machines on energy consumption, field operation costs, and soil properties. The performance of tractors during plowing operations is contingent upon factors such as plowing depth, forward speed, tractor type... etc. However, to optimize fuel consumption and minimize costs, the appropriate plowing depth should be determined based on the depth of crop roots. Fuel costs significantly impact agriculture production input expenses, particularly in primary tillage, and are influenced by various parameters, including plow types, plowing depths, and many other factors (Min et al. 2023; Li et al.,2024).

Noise is a pertinent risk factor in agriculture, particularly when assessing the health and safety of workers. Even with advancements in agricultural equipment technology, the constant noise levels generated during farm tractor and equipment operations remain a significant source of discomfort for operators (Baesso et al., 2017). Factors such as engine speed and fuel type play statistically significant in noise pollution (Seifi et al., 2016; Ghaderi et al., 2019; Lakhani et al., 2020). Drivers are especially susceptible to fatigue and reduced productivity due to vibration direction (Krajnak, 2018). Vibration in agricultural tractor driver seats has been associated with various health issues, including musculoskeletal, cardiovascular, and neurological disorders (Singh et al., 2023; Prakash et al., 2023).

Research on incorporating fuel improvers into diesel fuel for agricultural applications remains relatively scarce. Most existing studies have been conducted under controlled laboratory conditions, often overlooking real-world factors such as climate variations and soil characteristics. Moreover, investigations into tillage equipment have not provided specific recommendations regarding the optimal quantity of improvers, noise levels, and vibration rates experienced by tractor operators. Noise and vibration are recognized as significant hazards with potential adverse effects on the well-being of tractor drivers. Currently, limited studies have established definitive values for these parameters within acceptable global limits, and there are no standardized recommendations for agricultural practices in Iraq (Awwad et al., 2023). Therefore, the research aimed to investigate the performance of tractors by estimating fuel consumption noise and vibrations in the driver's seat. It will be achieved by examining (1) The impact of traditional diesel fuel and improved diesel fuel on fuel consumption, vibration in the driver's seat, noise, and exhaust gas temperature (2) Exploring the effect of the interaction between fuel type, plowing depth, and the angle of penetration of the subsoiler plow on the studied characteristics.

2. 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

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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.

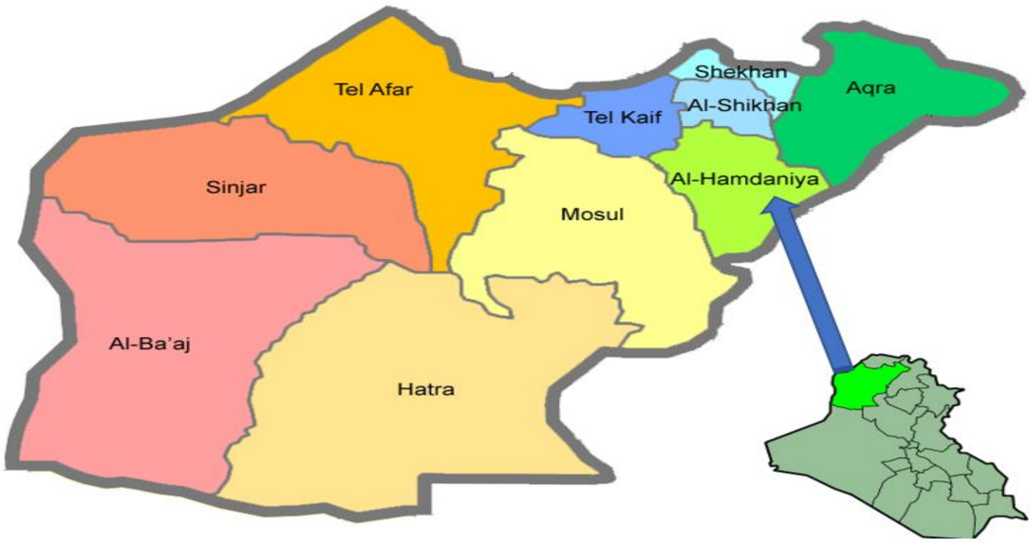

Figure 1.
Experiment field in Al-Hamdaniya District.

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.

2.1. *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/cm³	Unavailable	0.95 g / cm³
Degree of toxicity	Acute toxicity 4	Acute toxicity 4	Toxic and contains carcinogenic substances
Increased cetane number	5 points	5 points	8 points
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	**Specification's diesel fuel without addition**	**Specification's diesel fuel with an addition (Power - Max)**	**Specification's diesel fuel with an addition (Bardhal)**	**Specification's 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:

2.1.1. Fuel Consumption

Fuel consumption per unit time (liters/hour) = (amount of fuel consumed (ml)/actual time to complete the transaction (seconds)) *3.6. (Awwad et al.,2023)

2.1.2. Vibration in the Driver's Seat

The vibration was measured using a Uni-TUT315A device. The device above consists of a vibration sensor, which contains in front of it a magnet through which it is attached to the driver's seat to measure its vibration. A wire connects the sensor to a measuring device that contains a digital screen that shows vibration. Vibration in the driver's seat was measured when the subsoiler plow passed a distance of 100 meters for each experimental unit (Hilal et al., 2021).

2.1.3. Noise

The noise was measured using an Extech 407750 device. The device above consists of a noise sensor installed near the driver's seat to measure the noise when the subsoiler plow passes a distance of 100 meters for each experimental unit (Taha et al., 2022).

2.1.4. The Engine Exhaust Temperature

A wireless infrared engine body temperature gauge measured the engine exhaust temperature. It was estimated by pointing the thermometer at the object to be measured and holding the trigger. An infrared body thermometer measures the surface temperature of an object. The optical detector can sense the energy emanating from the body at different wavelengths. This energy is collected and focused on the detector. The electronic system then converts the information into a temperature reading that appears on the unit. For increased ease and accuracy, a guided laser makes aiming more precise.

2.2. 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. The length of each plot was 100 meters.

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

S.O.V	DF	Fuel consumption	Vibration in driver's seat	Noise	Exhaust gas temperature
Fuel types (a)	3	4.83183544 **	0.0676533**	4.06735475**	2844.187302**
Block	2	0.43913794 NS	0.00005677 NS	0.15712608 NS	1165.858871 NS
Error	6	0.18649821	0.00003872	0.17496342	180.36627
Angle of penetration (b)	1	14.26613306**	0.01452552**	0.03111008 NS	52.091667 NS
a*b	3	0.47984003**	0.00553108**	0.49673408 NS	120.583126 NS
Error	8	0.03894391	0.00024844	0.16190708	56.907684
Plowing depth (c)	1	12.6105691**	0.03547969**	0.23604075 NS	2.787888 NS
a*c	3	0.33600478 NS	0.02744635**	1.06507764**	208.923036 NS
b*c	1	0.00329923 NS	0.00394219*	0.05617008 NS	528.039867*

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a*b*c	3	0.00405833 NS	0.00446719**	1.48611097**	333.122226*
Error	16	0.12920608	0.00049687	0.19301758	67.687941

3. Results and Discussion

3.1. The Effect of the Diesel Fuel and Improved Additives on the Studied Traits

Table 5 shows the effect of diesel fuel and improved additives on fuel consumption, vibration in the driver's seat, noise, and exhaust gas temperature during plowing by a two-armed subsoiler plow, respectively. The effect of diesel fuel with improved additives showed statistically significant differences in all the studied traits. The fuel consumption recorded the highest considerable loss with diesel fuel without improved additives, negatively reflected in the economic loss and the efficiency performance. The lowest fuel consumption was achieved at a diesel with Bardahl (9.939 L.ha-1). The superiority of the improved additives with the lowest fuel consumption over the diesel fuel is due to the improved engine performance, and diesel fuel with improved additives function significantly influences percentage consumption, as presented in Table 5. These results are consistent with (Taha et al., 2022; Awwad et al.,2023).

The vibration in the driver's seat recorded the highest significant values with diesel fuel with Max-Tane and the second highest value at diesel fuel (0.306 m.s-2) while the lowest value at diesel fuel with Bardahl (0.248 m.s-2). Many researchers have developed different theories to explain the vibration in the driver's seat; for example, the intricate working conditions of tractors generate substantial vibrations (Brunetti et al., 2021), impacting the long-term health of drivers both physically and mentally (Han et al., 2022). Vibrations are inherent in tractor operations, primarily arising from the entire tractor's vibration due to uneven road surfaces (Li et al., 2021). Additional sources include vibrations induced by sudden tractor maneuvers such as fuel types, acceleration, braking, and steering while on the road (Jung et al., 2021), as well as those resulting from the coupling of the engine and transmission mechanism (Huang et al., 2021), with uneven road surfaces being the predominant cause. Enhancing influences various aspects of tractor performance (Desai et al., 2021). Given the intricate operational conditions faced by tractors, particular attention must be given to improving the vibration attenuation of seat suspension (Zhu et al., 2022).

The noise and exhaust gas temperature showed a significant difference between the diesel fuel and improved additives in the tillage operation. The use of diesel fuel with Max-Tane provided the lowest loss value of noise, with 81.608 dB (Table 5). All noise readings recorded for fuel types were at a level of less than 85 dB; therefore, noise is a significant risk factor in agriculture, necessitating careful consideration to ensure workers' health and safety. The operation of tractors, in particular, introduces a substantial source of discomfort for workers, predominantly due to the accompanying noise. Excessive noise is a widespread occupational health concern, contributing to significant social and physiological consequences, such as Noise-Induced Hearing Loss (NIHL). European Parliament Directive 2003/10/EC addresses the minimum health and safety requirements related to workers' exposure to physical agents, specifically noise. The directive establishes an average upper limit of 85 dB(A) for noise exposure during an eight-hour shift, aiming to prevent hearing impairments among workers. This standard aligns with the guidelines set by the International Labour Organization, as indicated in its code of practice (Vallone et al., 2016).

Table 5 shows that the interaction between diesel fuel and improved additives has a significant effect on exhaust gas temperature. Diesel fuel without improved additives recorded a lower rate of exhaust gas temperature (140.630 °C), and diesel fuel with Bardahl additive recorded a higher rate of exhaust gas temperature (175.415 °C). Fuel additives impact diesel fuel combustion and are considered to be of growing prominence in controlling the formation of fuel deposits that can have detrimental effects on combustion and exhaust gas temperature. The build-up of lacquer and carbonaceous deposits on injector tips can affect the amount of fuel injected and the spray pattern, causing problems with reduced power, exhaust gas temperature, and higher smoke emissions (Gupta et al., 2024).

Table 5.
The effect of diesel fuel and improved additives on fuel consumption, vibration in the driver's seat, noise and exhaust gas temperature.

Fuel types	Fuel consumption $L.hr^{-1}$	Vibration in driver's seat $m.s^{-2}$	Noise db	Exhaust gas temperature °C
Diesel	11.399 A	0.306 B	82.597 A	140.630 B
Diesel with Power max	10.259 B	0.255 C	82.947 A	163.868 A
Diesel with Bardahl	9.939 B	0.248 D	82.646 A	175.415 A
Diesel with Max – Tane	10.335 B	0.410 A	81.608 B	170.508 A

3.2. The Effect of the Penetration Angle of a Subsoiler Plow on the Studied Traits

Table 6 shows the effect of the penetration angle of a subsoiler plow on fuel consumption, vibration in the driver's seat, noise, and exhaust gas temperature, respectively. The impact of the angle of penetration showed statistically significant differences in fuel consumption and vibration in the driver's seat. The fuel consumption and vibration in the driver's seat recorded the highest considerable loss with increased angles. The lowest fuel consumption and vibration in the driver's seat were achieved at 45 angles (9.937 $L.ha^{-1}$ and 0.287 $m.sec^{-2}$). The results showed that the effect of the penetration angle has insignificant differences in the noise and exhaust gas temperature (Table 6). The noise and exhaust gas temperature recorded the highest insignificant values with increased penetration angle. A penetration angle of 45^0 is superior in having the lowest noise and exhaust gas temperature rate compared to a penetration angle of 55^0. The reason is that increasing the angle leads to an increase in the volume of soil pushed forward and leads to the collision of the pushed soil with the cultivated soil, which works to collect a larger volume of soil in front of the plow and causes increased resistance to parts of subsoiler plow. It also increases friction on the plow parts, which is reflected in the performance of the tractor.

Table 6.
The effect of the penetration angle of a subsoiler plow on fuel consumption, vibration in the driver's seat, noise and exhaust gas temperature.

Angle of penetration (Degree)	Fuel consumption $L.hr^{-1}$	Vibration in driver's seat $m.s^{-2}$	Noise db	Exhaust gas temperature °C
45	9.937 B	0.287 B	82.424	161.563
55	11.028 A	0.322 A	82.475	163.647

3.3. The Effect of the Plowing Depth of a Subsoiler Plow on the Studied Traits

The fuel consumption and vibration in the driver's seat showed a significant difference between increasing plowing depth in the tillage operation. The use of the 35 cm depth provided the lowest fuel consumption and vibration in the driver's seat values, with values of 9. 970$L.ha^{-1}$ and 0.277 m. s^{-2}, respectively (Table 7). Fuel consumption is influenced by factors such as plowing depth, speed, and soil conditions, which are critical variables in agricultural operations (Nassir, 2022), while (Himoud., 2018) reported that fuel consumption rose from 3.44 to 5.40 kg/hr increase in tillage depth from 2.5 to 7.5 cm. Almaliki et al. (2021) linked increased plow depth to wheel slippage, which contributes to elevated fuel consumption and diminished field efficiency. Nadykto et al. (2024) explained that the relationship between depth, fuel consumption, and vibration is inverse as a result of increased soil compaction with increasing depth. Despite the high value of noise, it was within the permissible natural limits according to the European Parliament Directive 2003/10/EC. The results show 45 cm plowing depth superiority by producing a low exhaust gas temperature of 162.364 °C with a high production value for the noise of 82.52 dB.

Table 7.
The effect of the plowing depth of a subsoiler plow on fuel consumption, vibration in the driver's seat, noise and exhaust gas temperature.

Plowing depth (cm)	Fuel consumption $L.hr^{-1}$	Vibration in driver's seat $m.s^{-2}$	Noise db	Exhaust gas temperature °C
35	9.970 B	0.277 B	82.379	162.846
45	10.995 A	0.332 A	82.52	162.364

3.4. The Influence of Interference Between the Fuel Types and Penetration Angle on the Studied Traits

Table 8 indicates significant differences in fuel consumption and vibration in the driver's seat and no significant differences in noise and exhaust gas temperature. The highest fuel consumption value was recorded when the diesel fuel interfered with the penetration angle of a subsoiler plow of 55o and reached 11.854 $L.ha^{-1}$. The lowest fuel consumption value was recorded when the diesel fuel with Max-Tane improved additive interfered with the penetrated angle of 45 o and reached 9.495 $L.ha^{-1}$. Fuel consumption and vibration in the driver's seat decreased as the penetrated angles of a subsoiler plow were decreased, so obtaining the lowest fuel consumption and vibration at a set of tractors with a less penetrated angle should be used. These results differ from Hilal et al. (2021), who concluded that increasing the angle leads to decreased vibration on the tractor driver's seat.

For instance, they were decreasing the penetrated angle from 55° to 45° leads to a decrease in the fuel consumption and vibration in the driver's seat values by 7.67, 9.09, 7.69, and 15.02 % fuel consumption and by 9.06, 4.98, 3.87and 21.13% for vibration in the driver's seat at diesel, diesel with Power Max, diesel with Bardahl and diesel with Max-Tane, respectively. The results also showed that the lowest vibration in the driver's seat was recorded when the diesel with Power Max and diesel with Bardahl improved additives and the penetrated angle 45°, while the highest vibration value at the diesel without improved additives and diesel with Max-Tane at both angles 45° and 55°. In a comprehensive investigation, seat vibrations were scrutinized across a sample of 100 vehicles, with a meticulous comparison based on Adhering to the BS 6841 and ISO 2631 standard criteria, as extensively documented, adopted a nuanced approach by considering varied body postures during the assessment of Whole-Body Vibration (WBV). Their findings underscored that a seated operator exhibits heightened sensitivity and susceptibility. Seated operators tend to be more sensitive to fore-aft and lateral vibrations, whereas a standing operator responds more acutely to vibrations in the vertical direction (Shibata, 2015). Moreover, Nawayseh's exploration delved into the influence of sitting conditions. Shibata (2015) observed the impact of seat design and body posture on vibration transmissibility via the driver's seat. His findings indicated that an increased backrest angle amplified the Vibration Dose Value (VDV) along the x-direction while reducing it along the z-direction. Remarkably, the total VDV at the backrest exceeded that on the seat surface with an elevated backrest angle. However, VDV values remained largely unaffected by foot position and headrest contact variations, a significant insight gleaned from (Nawayseh., 2015).

Exposure to mechanical vibration poses a significant risk to individuals in the agricultural sector, especially tractor operators (Kogler et al., 2015). This risk has gained prominence in Europe, particularly in industrialized nations, necessitating the development of regulations and targeted interventions to mitigate it. In this regard, European Directive 2002/44/EC addresses the minimum health and safety requirements concerning workers' exposure to vibrations physical agents, specifically vibration. The directive aims to enforce protective measures for preventing vibration-related risks in the workplace, explicitly addressing WBV, which stands out as a prominent ergonomic factor affecting agricultural operators' health and work efficiency. While numerous studies have investigated WBV in the context of wheel tractor drivers, research on track-laying tractors remains scarce. (Vallone et al., 2016).

Table 8 shows insignificant noise and exhaust gas temperature differences at all treatment interactions. The diesel with Max-Tane interfered, and the penetrated angles 45° and 55° recorded the best noise results compared to the treatments. The highest noise value reached 83.211 dB with diesel with Power Max and the penetrated angle 45°. Although the noise value is high, it is still within acceptable limits, as shown in European Parliament Directive 2003/10/EC, which addresses the minimum health and safety requirements related to workers' exposure to physical agents, specifically noise. The directive establishes an average upper limit of 85 dB(A) for noise exposure during an eight-hour shift, aiming to prevent hearing impairments among workers. This standard aligns with the guidelines the International Labour Organization (ILO) set, as indicated in its code of practice (Vallone et al., 2016). While exhaust gas temperature increases with improved additives at both penetrated angles, the reason for increasing combustion efficiency is that fuel improvers contain alcohol and substances that enhance engine performance.

Table 8.
The influence of the fuel types and penetration angle on fuel consumption, vibration in the driver's seat, noise and exhaust gas temperature.

Fuel types	Angle of penetration (Degree)	Fuel consumption $L.hr^{-1}$	Vibration in driver's seat $m.s^{-2}$	Noise db	Exhaust gas temperature °C
Diesel	45	10.944 CB	0.291 D	82.443	138.633
	55	11.854 A	0.32 C	82.751	142.627
Diesel with Power max	45	9.77 E	0.248 E	83.211	158.879
	55	10.747 C	0.261 E	82.683	168.856
Diesel with Bardahl	45	9.541 EF	0.248 E	82.614	177.729
	55	10.336 D	0.258 E	82.678	173.101
Diesel with Max - Tane	45	9.495 F	0.362 B	81.428	171.013
	55	11.174 B	0.459 A	81.788	170.003

3.5. The Influence of Interference Between the Fuel Types and the Plowing Depth of a Subsoiler Plow on the Studied Traits

Table 9 shows the influence interaction of the fuel types and plowing depth on the fuel consumption, vibration in the driver's seat, noise, and exhaust gas temperature during plowing by a two-armed subsoiler plow, respectively. Fuel consumption and exhaust gas temperature indicated an insignificant difference, while vibration in the driver's seat and noise showed significant differences at all treatments. The highest fuel consumption value was recorded when the diesel fuel interfered with the plowing depth of a subsoiler plow of 45 cm and reached 11.946 $L.ha^{-1}$. The lowest fuel consumption value was recorded when the diesel fuel with Bardahl improved additive interfered with the plowing depth of 35 cm and reached 9.301 $L.ha^{-1}$. Fuel consumption and vibration in the driver's seat increased as the plowing depth

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of a subsoiler plow was increased, so obtaining the lowest fuel consumption at a plowing depth of 35 cm was 10.853, 9.661, 9.301, and 10.067 L. ha^{-1} for diesel without improved additives, diesel with Power Max, diesel with Bardahl and diesel with Max-Tane, respectively.

Table 9 shows significant differences in vibration in the driver's seat and noise at all treatment interactions. The diesel with Bardahl interfered, and the plowing depths of 35 and 45 cm recorded the best vibration in the driver's seat results compared to the treatments. The highest vibration in the driver's seat value reached 0.509 m. s^{-2} with diesel with Max-Tane improved additive and the plowing depths of 45 cm. The diesel with Max-Tane improved additive interfered, and the plowing depths of 35 and 45 cm recorded the best noise results compared to the treatments, which were 81.591 and 81.625 dB, respectively. The highest exhaust gas temperature value was recorded when the diesel with Bardahl improved additive interfered with the plowing depth of a subsoiler plow of 45 cm and reached 176.675 ^{o}C. The lowest exhaust gas temperature value was recorded when the diesel fuel without improved additives interfered with the plowing depth of 45 cm and reached 135.673 ^{o}C.

Table 9.
The influence of the fuel types and the plowing depth of a subsoiler plow on fuel consumption, vibration in the driver's seat, noise and exhaust gas temperature.

Fuel types	Plowing depth (cm)	Fuel consumption L.hr^{-1}	Vibration in driver's seat m.s^{-2}	Noise db	Exhaust gas temperature ^{o}C
Diesel	35	10.853	0.294 B	82.139 DC	145.587
	45	11.946	0.318 B	83.055 BA	135.673
Diesel with Power max	35	9.661	0.256 C	83.213 A	165.86
	45	10.857	0.253 C	82.681 BAC	161.875
Diesel with Bardahl	35	9.301	0.248 C	82.575 BC	174.155
	45	10.576	0.248 C	82.718 BAC	176.675
Diesel with max – Tane	35	10.067	0.312 B	81.591 D	165.782
	45	10.602	0.509 A	81.625 D	175.234

3.6. The Influence of Interference Between the Penetration Angle and Plowing Depth of a Subsoiler Plow on the Studied Traits

Table 10 shows statistically significant differences in the effect of the interaction between the angle of penetration and plowing depth in vibration in the driver's seat and exhaust gas temperature. Fuel consumption, vibration in the driver's seat, and noise recorded the highest essential values with the interaction between the penetration angle of 55^{o} and plowing depth of 45 cm. The penetration angle of 45^{o} and plowing depth of 35 cm had the lowest fuel consumption value of 9.433 L. ha^{-1}, while it had the highest vibration in the driver's seat and exhaust gas temperature. For example, it recorded 0.269 m.s^{-2} and 158.488 ^{o}C for vibration in the driver's seat and exhaust gas temperature values, as presented in Table 10 . However, the highest fuel consumption of 11.549 L. ha^{-1} was at a penetration angle of 55^{o} and plowing depth of 45 cm. It indicates that the angle increases with increasing plowing depth, which leads to an increase in the resistance and friction of the soil, which increases the energy needed to overcome this resistance and friction. The results showed that the influence of penetration angle was closely different for each plowing depth.

Table 10.
The influence of penetration angle and plowing depth of a subsoiler plow on fuel consumption, vibration in the driver's seat, noise and exhaust gas temperature.

Angle of penetration (Degree)	Plowing depth (cm)	Fuel consumption L.hr^{-1}	Vibration in driver's seat m.s^{-2}	Noise db	Exhaust gas temperature °C
45	35	9.433	0.269 C	82.388	158.488 B
	45	10.442	0.305 B	82.46	164.639 BA
55	35	10.507	0.286 C	82.371	167.205 A
	45	11.549	0.358 A	82.579	160.089 BA

3.7. The Effect of the Triple Interaction of Study Factors on the Studied Traits

Figures 2,3,4 and 5 show that the fuel-improved additives and angle of penetration with plowing depths achieved the best results in the studied trait except for the vibration in the driver's seat at the intersection diesel with Max-Tane with a penetration angle of 55o and plowing depth of 45 cm. As illustrated in Figure 2, fuel consumption increases negatively with diesel fuel without improved additives, significantly affecting fuel consumption. Meanwhile, when diesel fuel was used with improved additives, fuel consumption decreased significantly. In the current study, the main sources of high values on fuel consumption are diesel fuel, the increased penetration angle of a subsoiler plow, and plowing depth. Diesel fuel without improved additives can strongly condition the values of fuel consumption to which they are hitched. The effective interaction of the diesel fuel without improved additives, penetration angle of 55o, and plowing depth of 45 cm achieved the highest fuel consumption and reached 12.396 L.ha-1. However, the fuel consumption recorded minimal with the interaction of diesel with a Bardahl, penetration angle of 45o, and plowing depth of 35 cm.

Figure 3 shows the influence of the fuel types, penetration angle, and plowing depth on the vibration in driver's seat. The results indicated that values were influenced significantly by the treatments. The values at the fuel-improved additives and angle of penetration with plowing depths were considerably lower than that of diesel fuel without improved additives with all treatments except for the vibration in the driver's seat at the intersection diesel fuel with Max-Tane with a penetration angle of 55° and plowing depth of 45 cm, however the value remained within the measurements previously approved from ISO 2631-5 (2004) and European Parliament and Council Directive 2002/44/EC (Hilal et al., 2021).

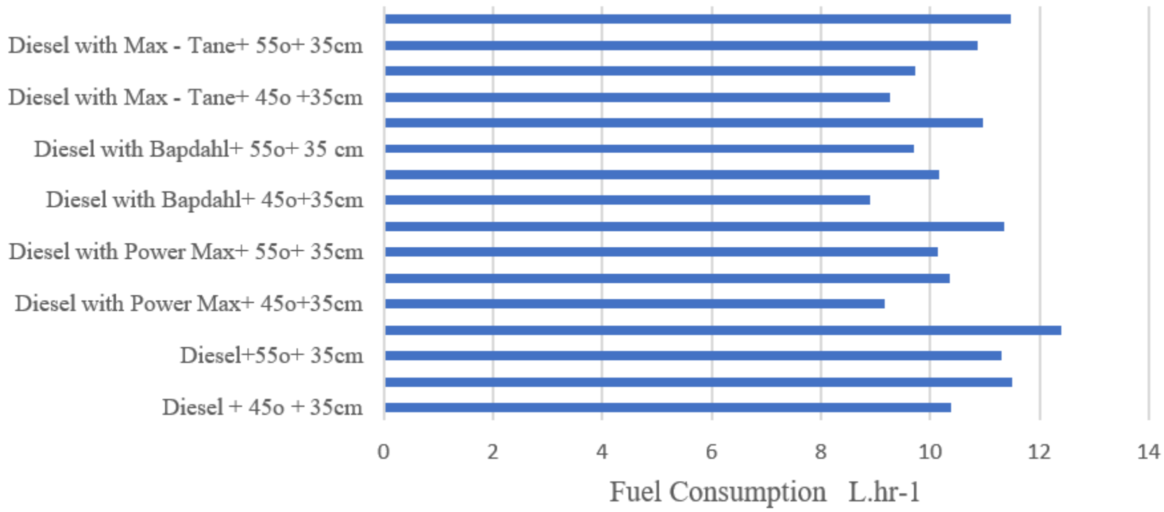

Figure 2.
The influence of fuel types, penetration angle and plowing depth of a subsoiler plow on fuel consumption.

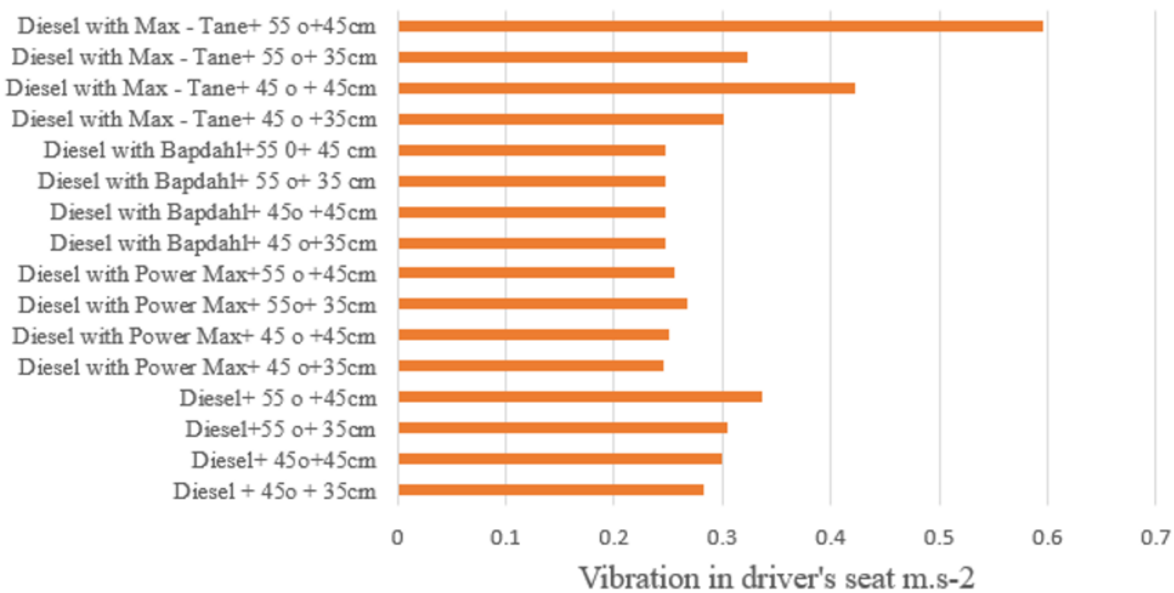

Figure 3.
The influence of fuel types, penetration angle and plowing depth of a subsoiler plow on vibration in the driver's seat.

According to Figure 4, noise is increased negatively with diesel fuel without improved additives, indicating that diesel fuel without improved additives significantly affects noise. The effective interaction of diesel fuel and a penetration angle 55° at a plowing depth of 45 cm was recorded as the highest noise. The results also showed the lowest noise in the diesel with Max - Tane improved additive and a penetration angle of 45°, at a plowing depth of 35 cm, reached 81.113 dB. The second lowest value was recorded at the interaction between the diesel with Max - Tane improved additive and a penetration angle of 55°, at a plowing depth of 45 cm, reached 81.506 dB.

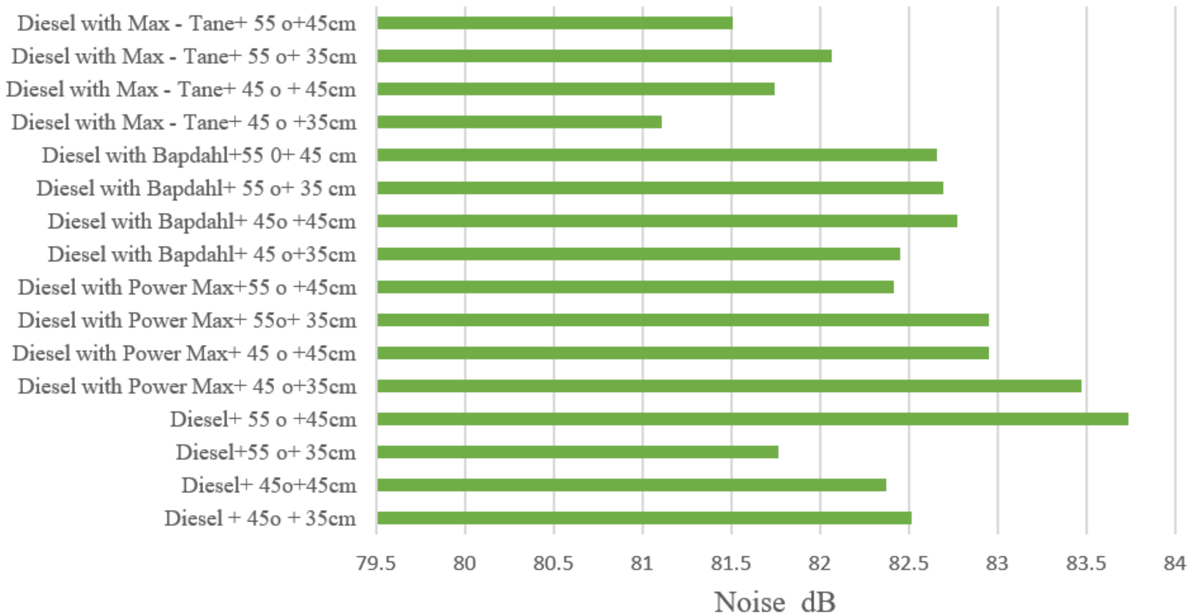

Figure 4.
The influence of fuel types, penetration angle and plowing depth of a subsoiler plow on noise.

As illustrated in Figure 5, The effective interaction of the diesel with Bardahl improved additives, penetration angle of 45o, and plowing depth of 45 cm achieved the highest exhaust gas temperature and reached 183.925 °C. The second highest value in exhaust gas temperature was recorded at the interaction of the diesel with Max-Tane additives, penetration angle of 45o, and plowing depth of 45 cm. However, the exhaust gas temperature was recorded as minimal with the interaction of diesel fuel without improved additives, penetration angle of 55o, and plowing depth of 45 cm. Fuel additives impact diesel fuel combustion and are considered to be of growing prominence in controlling the formation of fuel deposits that can have detrimental effects on combustion and exhaust gas temperature (Gupta et al., 2024).

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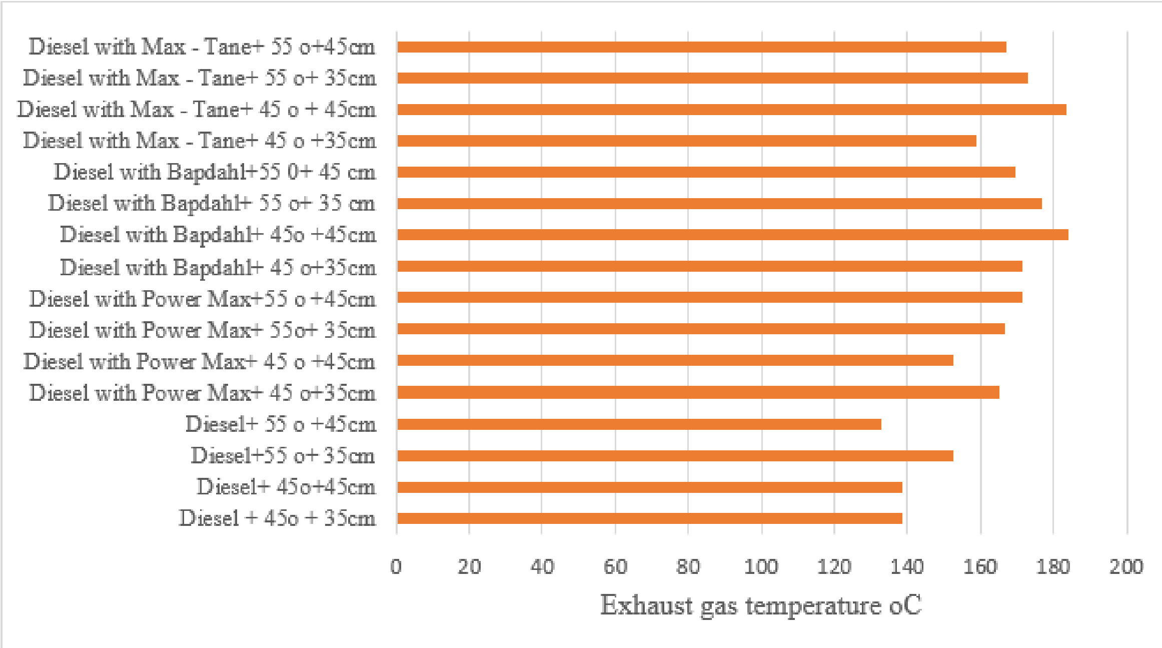

Figure 5.
The influence of fuel types, penetration angle and plowing depth of a subsoiler plow on exhaust gas temperature.

4. Conclusions

The following conclusions can be drawn from the results: diesel fuel with improved additives is superior in fuel consumption, vibration in the driver's seat, noise, and exhaust gas temperature. The diesel with Max-Tane and diesel with Power Max enhancers have negatively affected vibration and noise in the driver's seat. However, the values remained within the measurements approved by European Parliament Directive 2003/10/EC. The angle of penetration and plowing depths increase fuel consumption, vibration in the driver's seat, noise, and exhaust gas temperature. The results indicate the superiority of the fuel-improved additives and angle of penetration with plowing depths, which achieved the best results in the studied trait. The researchers suggest studying the power spent during the farm operation for future work.

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