Field and Laboratory Assessment of Power and Fuel Consumption for Chisel Plow: A comparison Study

Najem Qasm Mttanish[1] Sameer K. Fayyadh[1]*

[1] Department of Agricultural Machines and Equipment, College of Agricultural Engineering Sciences,
University of Baghdad, Baghdad, IRAQ.

*Corresponding author: Sameer K. Fayyadh – email: samir.faiad@coagri.uobaghdad.edu.iq

Abstract:

A study of two experiments carries out to assess chisel plow power and fuel consumption. First experiment was conducted using 66-New Holland 80S Tractor, while the second using soil bin under control conditions .Both experiments studied the effect of two factors. First factor was the speed with three levels: 0.5, 1.0, and 1.5 m. sec^{-1}.Second factor was the penetration angle with two levels: º, 45º30 on power and fuel consumption. Experiments were conducted in sandy loam soil. Both experiments were performed using a chisel plow at a tillage depth of 100 mm. Field results showed that the lowest fuel consumption was at a speed of 1.5 m/s and a penetration angle of 30º, reaching 3.12 L/h, equivalent to 12360.83 W of power. In other hand, power in the soil bin at the same speed was 616.3 W, achieving a fuel equivalent of 0.2342 L/h. Increasing the penetration angle from 30° to 45° at the speed of 0.5 m/s in the field experiment resulted in increased fuel consumption from 4.03 to 4.19 liters / hour and an increase in the equivalent electrical power of the tractor fuel from 16557.11 to 16570.56 watts, while the increase in the angle from 30º to 45º in the soil bin led to an increase in the electrical power from 687.05 to 695.03 W, and consequently an increase in the equivalent fuel consumption from 0.2565 to 0.2594 I/h.

Keywords: soil bin, Field experiment, power, fuel consumption, New Holland Tractor, chesil plough.

1- Introduction

Agricultural development is the cornerstone of increasing production to meet the needs of a growing global population. Tillage is a key agricultural practice, and its development necessitates scientific and practical experimentation. While these experiments are typically conducted in the field, traditional field experiments using agricultural tractors face several challenges that limit their research efficiency. These challenges include high operational costs, lengthy implementation times, significant susceptibility to varying soil characteristics from one location to another, and difficulty controlling variable environmental factors such as humidity, temperature, and accompanying climatic conditions. This negatively impacts the accuracy, reproducibility, and scientific comparability of the results **(Fleming & Sawyer, 2023; Sandu et al., 2022)**. To overcome these limitations, researchers have developed new equipment known as soil bins, which provides controlled laboratory environments that simulate field conditions for testing tillage tools. These systems allow for precise control of experimental variables such as soil type, moisture, instrument movements, and operational factors like speed and depth, overcoming some field problems such as slippage. This enables reproducible and cost-effective experiments **(Al-Suhaibani et al., 2021; Fleming & Sawyer, 2023; SpringerLink, 2024)**.

Oliveira et al., 2022; Mardani et al., 2024, indicated that soil bin enables researchers to test agricultural implements in different soil types. Recent studies have confirmed that relying on soil bin provides a high level of statistical confidence and excellent reproducibility of results, making them a pivotal tool in developing more sustainable, efficient, and accurate agricultural machinery capable of meeting contemporary challenges in agricultural production (**Kaiser & Witz, 1924; Pawar et al. (2020).**

As **Ani et al. (2018)** demonstrated, soil bin, in addition to providing standardized testing environments for soil-machine interaction studies, contributes to reducing variability compared to field tests and enable high-precision measurement of mechanical forces and movements. In this context, **Chen et al. (2024)** stated that soil bin installations have become essential in soil mechanics research and their interaction with agricultural implements, due to the precise testing conditions they provide that mimic real-world field conditions. With technological advancements, soil bins have transformed from simple systems into advanced research platforms, relying on precision sensors, high-speed data collection systems, artificial intelligence techniques, and automated soil preparation and conditioning systems. Advanced analytical software is also used to predict performance and optimize the design of agricultural implements before field testing **(Escalante et al., 2024; Chen et al., 2025).** The circular soil bin features a ring or circular path that allows for continuous testing without the need to readjust the tillage implement after each pass. This provides high operational stability and minimizes unwanted variations in test conditions. Thus, the circular soil bin is an effective research tool for studying soil interaction with rotary machinery and evaluating its performance under standard operating conditions (**Bae et al., 2023; More et al., 2024).** Soil bin are typically used in the initial stages to evaluate design concepts and optimize operating parameters, while field tests are employed in later stages to assess overall performance under realistic agricultural production conditions (**Shinners et al., 2022; Sandu et al., 2022).** Power requirements refer to the amount of power needed to perform various tillage operations. These requirements are influenced by several key factors, most notably soil type, tillage implement design, and operating speed. Accurate estimation of power requirements is essential for selecting appropriate agricultural machinery, improving energy efficiency, and reducing fuel consumption and associated operating costs **(Soni & Salokhe, 2019). Moeenifar et al. (2022)** indicated that power requirements decrease slightly with increasing speed due to the loosening of more fragile soils, before increasing again at higher speeds due to accelerated soil movement and increased inertia.

Barr et al. (2022) confirmed that power requirements increase disproportionately due to the dynamic effects of the soil and increased resistance. On the other hand, the penetration angle plays a pivotal geometric role in determining the shape and size of the excavated soil section, and consequently, the amount of force required to overcome soil resistance. **Yisa et al. (2019)** demonstrated this large angle increase the volume of soil obstructing the weapon, which significantly increases the pulling force. **Desbiolles (2015**) indicated that increasing the penetration angle leads to higher vertical friction on the blade tip, increasing the force required to penetrate the soil and causing the engine to operate at higher power levels, particularly when large angles coincide with dry or highly compacted soils. Recent studies show that the effect of speed and penetration angle on power requirements does not occur independently, but rather exhibits a complex, nonlinear interaction. When high speeds are combined with large penetration angles, the pulling force and power consumption increase exponentially, as the implement encounters a larger volume of soil and greater forces. Experiments have confirmed that this interaction represents the highest mechanical load on the plow and tractor **(Desbiolles, 2015).** Fuel consumption, on the other hand, refers to the amount of fuel used per unit area during tillage operations and is an important indicator of operational and economic efficiency in evaluating the effectiveness of a tractor system. This indicator is affected by several operational factors, such as operating speed and penetration angle, making it a pivotal metric in sustainable **agriculture (Janulevičius et al., 2019). Janulevičius et al. (2019)** demonstrated a U-shaped relationship between tillage speed and fuel consumption per hectare. **Williams et al. (2021)** also noted that fuel consumption per unit area increases significantly at operating speeds exceeding 3.0 m/s due to increased drag and the dynamic effects of movement.

Godwin et al. (2023) showed that integrated implement designs that optimize penetration angle and adjust tillage depth can reduce fuel consumption by 18–22% compared to conventional designs.

Furthermore, **Al-Zubaidi and Al-Rajbo (2020)** confirmed that smaller penetration angles contribute to reduced fuel consumption and slippage compared to larger angles, due to lower soil resistance and generated drag forces. Fuel consumption is directly related to both tillage speed and penetration angle, as these play a key role in determining traction force and torque load on the engine (**Grisso et al., 2014**).

Grisso et al. (2014) demonstrated that increasing the operating speed from 4 to 6 km/h can lead to a 20-30% increase in fuel consumption due to the increased mechanical load and energy required for cutting and displacing the soil. **Oluwole and Ogunlowo (2012**) also indicated that higher speeds cause a decrease in engine thermal efficiency, resulting in a relatively larger increase in fuel consumption than the increase in speed itself. **Adewoyin and Olatunji (2018)** showed that increasing the penetration angle by 10 degrees leads to a 25-40% increase in traction force, which directly translates to increased fuel consumption during tillage operations. This study aims to fabricate a soil bin and evaluate some performance indicators, comparing them to field performance using a conventional tractor.

2- Materials and methods

2-1- plough blades

The blades were sourced locally and are made of carbon steel (figure 1). The blade dimensions are 320 mm length, 70 mm width, and 6 mm thickness. The blade is double-sided, with an effective length of 120 mm on each side. Rockwell Hardness was tested using the HRBW system, and the alloy's chemical composition was analyzed at the General Company for Engineering Inspection and Qualification. The test results showed the blade's hardness to be 92 HRBW, while Table (1) shows the chemical composition of the blade alloy.

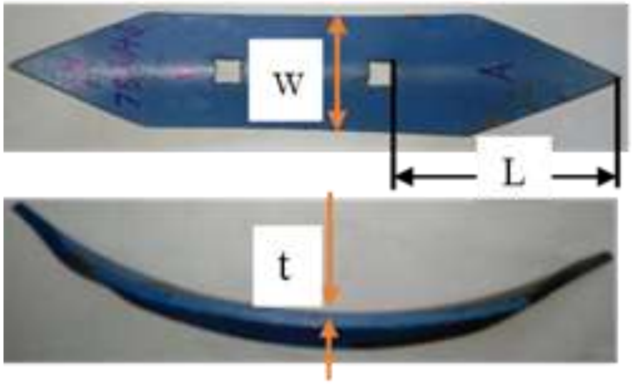

Figure (1) chesil plough blade

Table (1) Chemical composition of the blade alloy

Elements	C%	Si%	Mn%	P%	S%	Cr%	Ni%	Al%	Cu%	Fe%
Value %	0.228	0.259	0.523	0.023	0.029	0.083	0.086	0.058	0.183	Bal.

2-2 Soil bin manufacturing

Given the existence of two main types of soil bins, the linear bin and the circular bin, the circular bin was chosen for this study due to its operational and structural characteristics that align with the research objectives. This type is characterized by its relatively small size, requiring less space compared to linear soil bins, ease of transport from one location to another, and low manufacturing and operating costs. Furthermore, its ability to provide continuous operation makes it suitable for laboratory and educational applications.

A prototype circular soil bin was manufactured for laboratory testing in the engineering workshop of the Department of Agricultural Machinery and Equipment at the College of Agricultural Engineering Sciences, University of Baghdad. The soil bin manufacturing process included the following components:

2-2-1 Soil bin container

The soil bin container is the main part that houses all the bin's components. A hollow cylinder was welded to the center of the container. The drive shaft from the power unit passes through this cylinder to the horizontal arms that support the plowshares. This design ensures the shaft's straightness and stability during operation. A U-channel support column above the container level, was also welded. It was perforated in the center to secure both the drive shaft and the height control lever, as shown in Figure (2).

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2-2-2 Central shaft

The central shaft is one of the key components in the transmission system of the circular soil bin. This shaft is used to transfer the motion from the pulley connected to the electric motor to the horizontal arms carrying the plow shanks, through a metal ring (Flange) that is capable of vertical movement in both directions, which allows adjusting the position of the tool according to the required plowing depth. At the bottom, it is secured within a hollow cylinder mounted in the center of the hopper using ball bearings, ensuring smooth rotation and reducing friction and mechanical stress. The central shaft is connected to the power unit via a pulley and belt, providing consistent power transmission while absorbing vibrations and minimizing slippage during operation.

3-2-3 horizontal arms

It consists of three U-channel steel arms, they are fixed to the central shaft by a metal flange, ensuring balanced distribution of load and dynamic stability during operation. The horizontal arms are mechanically connected to the central shaft, allowing for highly efficient transmission of rotational motion to the arms, as well as enabling vertical movement in both directions for adjusting the tillage depth. This design enables precise control of the tool's linear speed according to experimental requirements. Additionally, the levelling lever and tamping cylinder are mounted on the horizontal arms to level and compact the soil after the plough passes over it, enhancing the integration of the mechanical system and increasing its operational flexibility during various tests. The rotary unit is connected to the power generation and transmission unit, which consists of a 5 kW three-phase electric motor connected to a control panel and power and operating time measurement. The motor is connected to a gear set to control the required speed. The motion is transferred from the gears to the rotary unit shaft using pulleys and a transmission belt.

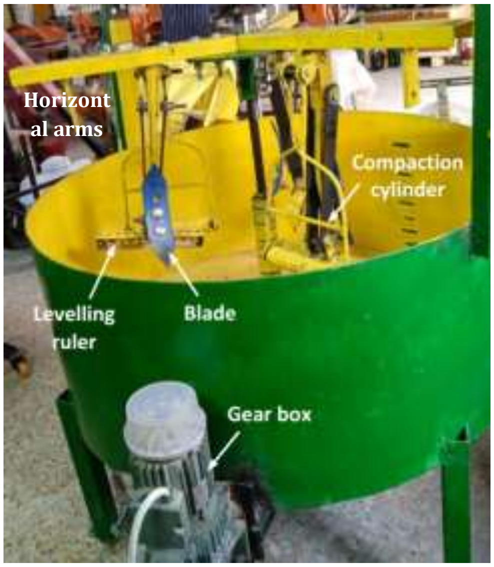

Figure (2) General shape of soilbincontainer

-3-2 66-New Holland 80S Tractor

In this study, the New Holland 80-66S two-wheel drive (2WD) tractor with 80 horsepower of Turkish origin, model 665 (Figure 3), was used to pull the chisel plow.

66-Figure (3) New Holland 80S tractor

The digger plow 4-2

A locally made chisel plough with a working width of 213 cm was used. The plough consists of ten stalks arranged in three rows: three stalks in the first row, four in the second, and three in the third. These stalks are alternately arranged as shown in Figure 4. This arrangement aims to improve soil penetration and reduce interference between the stalks, resulting in higher ploughing efficiency and more uniform soil breaking.

(Figure (4 chisel plough

Methodology

This study was conducted using two types of experiments:

1- Field Experiments

The field experiments were carried out using a New Holland 80-66S two-wheel drive (2WD) tractor with 80 horsepower of Turkish origin, model 665, at one of the research stations of the College of Agricultural Engineering Sciences, University of Baghdad, in the Jadriya area, during the 2025 growing season. Soil analysis was performed in the soil laboratory of the Department of Soil and Water Resources at the College of Agricultural Engineering Sciences. Based on the results of the histological analysis, the field soil was classified as sandy loam, with fractions of 372, 168, and 460 g/kg for sand, clay, and silt, respectively (Table 2).

Table (2) Soil Analysis

Unity	Reading	The attribute
g/kg	372	sand
g/kg	168	clay
g/kg	460	silt
	Sandy loam	Soil classification
%	11.12	moisture content
^{3}g/cm	2.63	True density
^{3}g/cm	1.64	apparent density
Desi Siemens/M	1.3	Electrical conductivity(EC)
pH	7.25	pH

To calculate speed, the tractor was driven unloaded for a predetermined distance of 50 meters across the field. This distance served as the standard for calculating speed at all operating levels. An additional 10-meter gap was left at the beginning of the path to allow for acceleration and a near-steady speed, and a similar gap was left at the end of the path for the tractor to stop and for recording the time (in seconds) required to cover the predetermined distance. Three cultivator legs were then attached, with one blade in the first row and two in the second, in an alternating arrangement to ensure even load distribution and minimize interference between the legs. After each pass, the time taken to cover the predetermined distance was measured. Additionally, the amount of fuel consumed during the operation was measured using a 1000 ml transparent graduated cylinder. The tractor's fuel tank was filled to the maximum level before each trial run. Upon reaching the designated endpoint, the engine was immediately switched off, and the fuel tank was refilled using the graduated cylinder to the same initial level as before the run. The difference in the volume of fuel added represents the amount of fuel consumed during that treatment. Thus, the amount of fuel consumed could be accurately determined based on the direct reading of the graduated cylinder. Fuel consumption was then converted to liters per hour. This process was repeated in all experiments, and based on the fuel consumption, the equivalent power was calculated using the following equation (Grisso, 2010):

$$P_{PTO} = \left(\frac{V_f}{t} \times 3600 \times \rho_f \times LHV\right) \times \eta_c \times \eta_{th} \times \eta_{mech} \ldots\ldots (1)$$

- :where

W	Power at the rearPTO shaft	
L	Fuel consumption	V_f
s	Time taken to cover the distance	t
kg/L	Diesel density(≈ 0.84 kg/L)	ρ_f
J/kg	Minimum calorific value of diesel(≈ 42.5 MJ/kg)	LHV
—	Combustion efficiency(≈ 0.98)	η_c
—	Engine thermal efficiency(0.30 – 0.40)	η_{th}
—	Mechanical efficiency of power transfer from engine toPTO (0.85 – 0.90)	η_{mech}

2- Laboratory Experiments

Laboratory experiments were conducted using a soil bin in the engineering workshop of the Department of Agricultural Machinery and Equipment at the College of Agricultural Engineering Sciences, under controlled conditions simulating natural field conditions. The same field soil used in the field experiments was employed to ensure uniformity of soil properties and minimize sources of variation. the effective diameter of the tool's rotation during operation is500 mm. The soil bin operated at different speeds and penetration angles to obtain the required linear speeds for the test. The rotational speed was converted to the linear speed using equation 2.

$$V=\pi DN/60 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

:where

V:Linear speed m/s

D:(Diameter of rotation (mm

N: Rotational speed (RPM), (measured practically using a tachometer).

Power is measured directly from the electric motor's the equivalent ,control panel. Based on this power fuel consumption is calculated using the following equation(Grisso, 2010) :

$$\dot{V}_{fuel} = \frac{P_{soil}}{\eta_{mech} \times \eta_{th} \times \eta_{c}} \times \frac{1}{LHV} \times \frac{3600}{\rho_{f}}$$

:where

$P_{soil:}$ Measured capacity on a soil bin W

research plan included studying the effect of The both the plowing speed at three levels (0.5 , 1.0 , and 1.5 m / s) and the penetration angleat two levels (30° and 45°) on power and fuel consumption All experiments (field and laboratory) were . . t a constant plowing depth of 100 mmconducted a

3- :Results and discussion

Figure 5 illustrates the effects of both speed and penetration angle on electrical power consumption (W) when utilizing a soil bin. The results show a significant effect of speed on power consumption, as the third speed at the first angle achieved the lowest power consumption, reaching 627.59 W, while the highest power value was recorded at the second speed and the second angle. This is because increasing speed leads to an increase in current and thus an increase in power consumption. As the speed increases, the required power increases up to a certain point, after which it stabilises and becomes almost constant. Beyond this point, the torque available to accelerate the rotating shaft decreases, and the current drawn from the source decreases, leading to a decrease in power consumption despite the increase in speed.

On the other hand, the results showed a significant effect of the penetration angle on power consumption when working in a soil bin. Increasing the penetration angle from A1 to A2 at the first speed resulted in a clear increase in electrical power consumption, whereas this effect was reversed at the second and third speeds. Although a larger angle requires greater penetration force to overcome soil resistance, up to a certain speed, the effect of speed is greater than that of the angle due to the decrease in torque with increasing speed. Based on the above, the effect of speed is greater than that of the angle. It is also evident that power consumption in a soil bin is affected by a combined effect of speed and penetration angle, and that optimal operating conditions are achieved when speed and torque are balanced, thus ensuring reduced current consumption and increased electrical performance of the system.

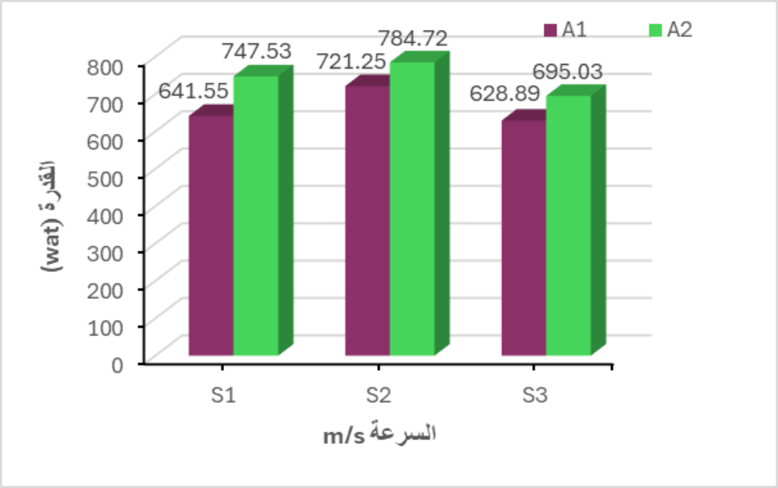

Figure (5) the effect of speed and penetration angle on power

Figure 6 shows the effect of speed and penetration angle on the equivalent power (W) resulting from fuel consumption (L/hr.) when using a tractor. The results show a significant effect of both speed and penetration angle. Speed S3 recorded the lowest equivalent power value at 12360.83 W at the first angle, while Speed S2 achieved the highest value, reaching 21071.67 W at the second angle. It was also observed that increasing the speed from S1 to S2 resulted in an increase in equivalent power from 16,259.00 W to 21,071.67 W. However, continuing to increase the speed to S3 caused the power to decrease to 12360.83 W. Since equivalent power is calculated based on fuel consumption, the change in power reflects the change in fuel consumption resulting from the operating factors (speed and angle). At medium speeds (S2), the engine load increases and fuel consumption increases due to increased soil resistance and power requirements, which is reflected in the higher equivalent power. Conversely, at high speeds (S3), fuel consumption decreases due to a change in the engine's operating pattern, resulting in a decrease in calculated equivalent power, despite the increased speed.

On the other hand, the results showed a significant effect of the penetration angle factor on the equivalent power resulting from fuel consumption. Increasing the penetration angle from A1 to A2 resulted in a slight increase in equivalent power, from 16557.11 to 16570.56 W. This is attributed to the fact that larger angles require more power to overcome soil resistance, leading to increased fuel consumption, which in turn is reflected in an increase in the calculated equivalent power. Therefore, the equivalent power resulting from fuel consumption is directly affected by both speed and penetration angle, and the relationship between these factors and fuel consumption is linear. This underscores the importance of selecting optimal operating values for speed and angle to reduce fuel consumption and improve the mechanical and energy efficiency of the tractor. This behaviour is the same as the general behaviour of power consumption when working on the soil bin, noting the difference in values. Figure 7 shows the comparison of power consumed in both the soil bin and the equivalent power consumption of fuel in the field experiment. The significant difference in values is noted, as the soil bin achieved a significant decrease in power consumption compared to the equivalent power consumption of fuel when using the tractor in the field experiment. This reflects the lower energy requirements in the laboratory experiment compared to field conditions. This difference is attributed to the fact that work in the soil bin is carried out under controlled operating conditions and is free from many of the problems associated with field work that cause an increase in power consumption, such as slippage, tractor resistance, surface irregularity, in addition to losses resulting from vibrations and changes in soil properties along the tillage path. In contrast, field operations require more energy due to the need to move the entire tractor system. Therefore, using a soil bin in such studies is economically advantageous, offering a significant reduction in energy consumption and operating costs. Furthermore, it allows for many repeated experiments in less time and at a lower cost compared to field trials using agricultural tractors. This underscores the important role of soil bines as effective research tools for evaluating and improving the performance of tillage equipment before proceeding to large-scale field tests.

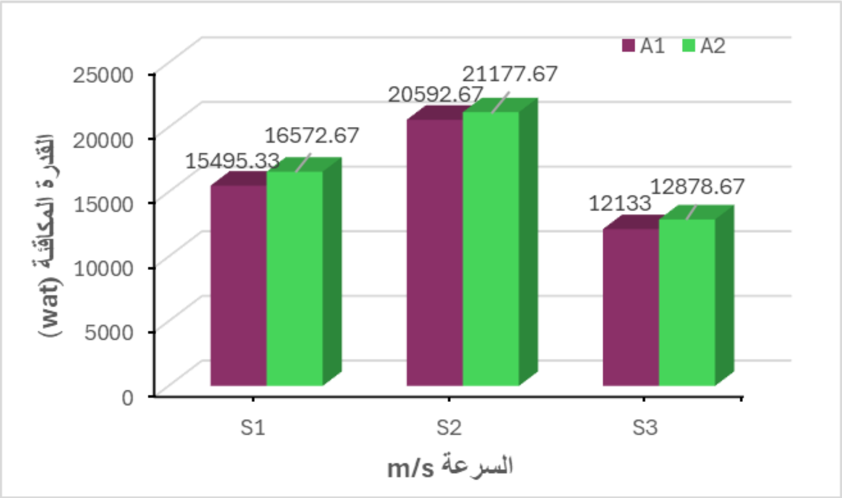

Figure (6) the effect of speed and penetration angle on equivalent power

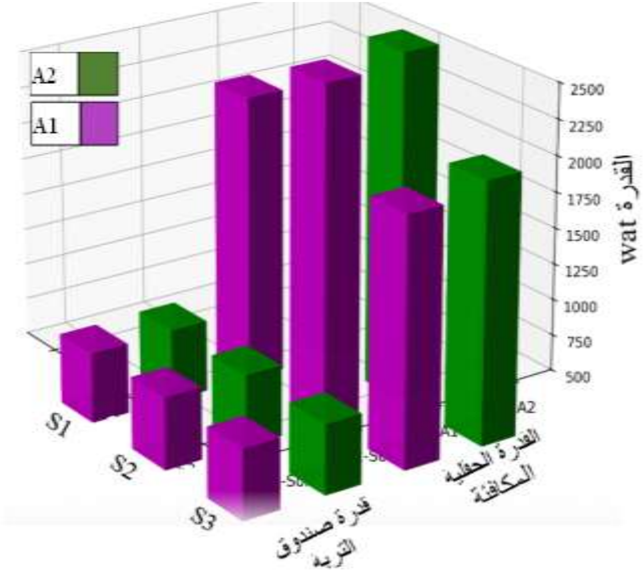

Figure (7) Comparison between the power consumed in the soil bin and the equivalent power in the field

On the other hand, Figure 8 shows the effect of tractor speed and penetration angle on fuel consumption (liters/hour) during field work using a cultivator. The results show a significant effect of both tractor speed and penetration angle on fuel consumption. Speed S3 recorded the lowest fuel consumption at 3.12 liters/hour, while Speed S2 recorded the highest at 5.33 liters/hour. It was also observed that increasing the speed from S1 to S2 led to an increase in fuel consumption from 4.11 to 5.33 liters/hour, but continuing to increase the speed to S3 resulted in a decrease in consumption to 3.12 liters/hour. The reason for this was previously explained when discussing the equivalent power resulting from fuel consumption.

The results also showed a significant effect of the penetration angle on fuel consumption. Increasing the penetration angle from A1 to A2 resulted in a slight increase in fuel consumption, from 4.18 to 4.19 liters/hour. This increase is attributed to the increased drag and soil resistance at larger angles, requiring more power from the tractor engine, thus leading to higher fuel consumption. These results are consistent with what was indicated by Mekhi (2012), who explained that increased drag leads to higher fuel consumption in tillage operations. Therefore, selecting optimal values for these two factors contributes to reducing fuel consumption and improving the energy efficiency of the tractor system. On the other hand, Figure 9 shows the effect of speed and penetration angle on the estimated equivalent fuel (liters/hour) calculated based on the electrical power consumed when using the soil bin. Therefore, it reflects the effect of speed and angle factors on the power consumed by the soil bin. Considering the advanced results, and when comparing the actual fuel consumption in the field experiment using the agricultural tractor with the equivalent fuel values calculated based on the electrical power consumed when using the soil bin Figure 10, a significant difference can be observed between the readings for both methods. This difference represents the amount of fuel saved by the soil bin. This means cost savings equivalent to the difference between the fuel costs consumed in the field experiment and the electricity costs in the experiment using the soil bin. This difference is attributed to the operating nature of the soil bin, which relies on an electric motor that offers higher efficiency and greater operational stability, as well as the absence of losses associated with slippage, load unevenness, and the additional resistances that accompany tractor operation in the field. Consequently, the soil bin provides a controlled testing environment that enables mechanical experiments to be conducted at a lower operating cost, while reducing overall energy consumption compared to traditional field experiments. Furthermore, the reduced fossil fuel consumption associated with using the soil bin has a positive environmental impact by limiting harmful gas emissions from diesel fuel combustion, such as carbon dioxide and nitrogen oxides, which are major contributors to air pollution. Therefore, using the soil bin is not only an economic option but also an environmentally friendly research tool that contributes to supporting sustainable agriculture and reducing the environmental impact of mechanised agricultural experiments.

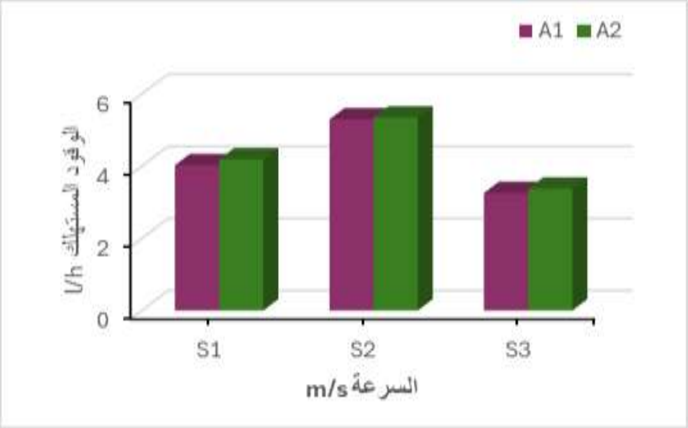

Figure (8) the effect of speed and angle one fuel

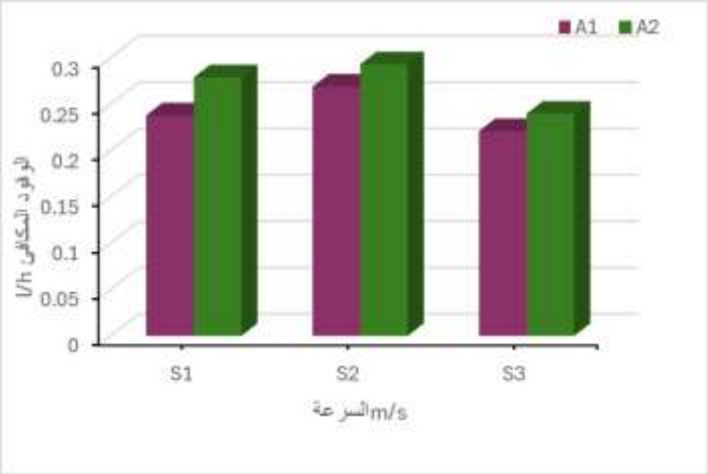

Figure (9) the effect of speed and angle one fuel equivalent

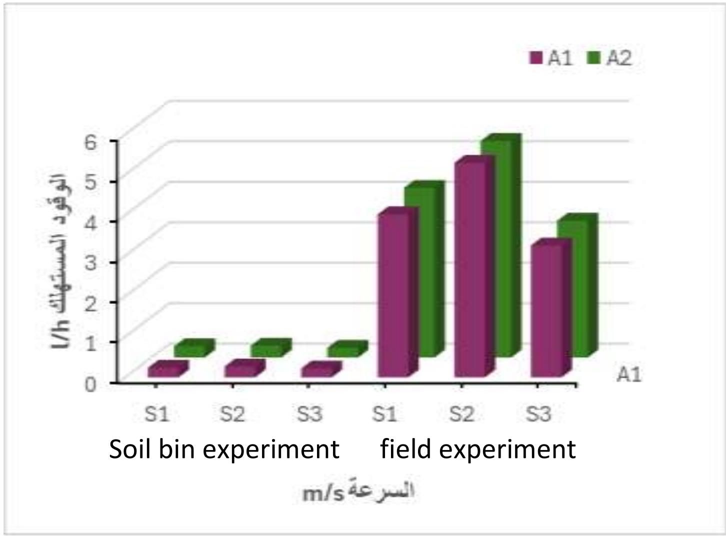

Figure (10) Comparison between the fuel consumed in the soil bin and the equivalent fuel in the field

Conclusion

The study demonstrated

-1the effectiveness of using a soil bin and its superiority over using an agricultural tractor in conducting ploughing experiments with a chisel plough regarding power requirements and fuel consumption, as the soil bin achieved the lowest value for both power (616 watts) and fuel equivalent (0.221 l/h) at the third speed and first corner.

-2In the field test, the third speed achieved the lowest fuel consumption value (3.26 l/h) at the first angle.

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