Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal, 2025, 19(3), 381–388
https://doi.org/10.12913/22998624/199797
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Received: 2024.12.03
Accepted: 2025.01.15
Published: 2025.02.01

Evaluation of performance efficiency of a locally made electronic device for measuring fuel consumption in agricultural tractors

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ABSTRACT

The experiment was conducted to measure the efficiency of a locally made electronic device used to measure the fuel consumption of the mechanical unit and compare it with the traditional measurement method. On the other hand, to study the effect of operating factors on some mechanical properties. The experiment included three operating factors, including measurement method (electronic and traditional), forward speed (2.236 and 3.488 km·h^{-1}), and tillage depth (10–15 and 20–25 cm). Field efficiency, fuel consumption, slippage percentage, and draft force were measured. The following results were reached no significant differences in fuel consumption, field efficiency, slippage, and draft force due to the measurement method. The results also demonstrated that the second forward speed (3.49 km·h^{-1}) achieved the minimum amount of fuel consumed was 30.60 L·ha^{-1}, the highest slippage percentage was 7.74%, the highest field efficiency was 60.83%, and the highest draft force was 7.57 kN, compared to the first forward speed (2.24 km·h^{-1}). Additionally, the results indicated that the 10–15 cm tillage depth achieved the lowest fuel consumption at 33.60 L·ha^{-1}, the lowest slippage percentage at 6.53%, the lowest draft force at 6.05 kN, and the highest field efficiency at 61.18%. The correlation coefficient between the measurements of the electronic device and the traditional method was 93.7%. The results confirmed the success of the electronic device in measuring fuel consumption with high efficiency.

Keywords: slippage percentage, electronic device, fuel consumption, field efficiency, tillage depth.

INTRODUCTION

Improving the performance of agricultural tractors can significantly reduce energy losses in agricultural operations this can be achieved by enhancing the tractor's design or using precise measurement technologies. For instance, installing modern methods to accurately measure fuel consumption helps identify and address influencing factors. Additionally, adopting advanced technologies based on sensors and performance monitoring can enhance operational efficiency and minimize energy loss [1, 2]. Studies have shown that approximately 20–55% of tractor power is lost due to the interaction between the soil surface beneath the tractor wheels and the tractor wheels themselves, which increases fuel consumption. Therefore, enhancing tractor performance and efficiency is essential [3, 4]. Fuel consumption measurement is considered an indicator of the power required for agricultural operations, and accurately measuring fuel consumption for different agricultural machines is a critical step. Many agricultural factors affect fuel consumption in tractors, such as soil type, texture, moisture, and density, as well as the type of tractor (two-wheel or four-wheel drive), tractor size, and the interaction between the tractor and the implement used. Consequently, fuel consumption values for a tractor measured by different methods are not constant and vary from one test to another [5].

Estimating tractor fuel consumption helps improve the operational efficiency of agricultural equipment and select the best operating practices that reduce fuel consumption, minimize wear and stress on the equipment, and ultimately extend its lifespan while maintaining it in good condition [6, 7]. There are several methods for measuring fuel consumption, both traditional and modern. Traditional methods have several drawbacks, requiring considerable effort and time, while modern methods are accurate, quick, and require minimal effort. There are direct measurement methods that involve using sensors installed on fuel lines to measure the amount of fuel flowing to the engine over a specific period another method is measurement via the fuel tank determining the amount of fuel added or consumed by comparing the fuel level in the tank before and after operation. A third method involves measurement through software analysis, where the tractor is connected to analytical software that collects precise consumption data using advanced sensors to analyze performance and efficiency [8]. The operational speed of the mechanical unit affects fuel consumption; as speed increases, fuel consumption per unit area decreases [9, 10]. Additionally, the relationship between speed and field efficiency is directly proportional, meaning that as speed increases, field efficiency also increases [11]. Moreover, the percentage of slippage and draft force also rises with increasing speed [12, 13]. Depth has a significant impact on certain performance characteristics of the mechanical unit [14]. As the depth increases, fuel consumption, slippage percentage, draft force, and field efficiency all increase [15, 16, 17]. The study aimed to manufacture an electronic device to measure the fuel consumption of the mechanical unit, test its efficiency, and compare it with the traditional method under different operating conditions. On the other hand, to study the effect of operating factors on some mechanical properties.

MATERIALS AND METHODS

The experiment was conducted at the fields of the College of Agricultural Engineering Sciences, University of Baghdad, located in Al-Jadriya at latitude 33°16′12″N and longitude 44°22′54″E. The dimensions of the experimental field were 80 m long and 30 m wide. To evaluate the efficiency of a locally made electronic device for measuring fuel consumption and was compared to a traditional method. The study examined the effects of three factors: measurement method (electronic and traditional), forward speed (2.236 and 3.488 km·h^{-1}), and tillage depth (10–15 and 20–25 cm). Field efficiency, fuel consumption, slippage percentage, and draft force were measured in this experiment.

The ground testing was made using a nested design under a randomized complete block design (RCBD). The experiment was conducted with three replicates, and means were compared at a probability level of P<0.05. Two types of tractors were used in the experiment: JINMA Four-wheel drive (4WD) with a capacity of 75 horsepower, Chinese origin and NEW HOLLAND Dual-wheel drive (2WD), 80 horsepower, two-wheel drive (66S), Turkish origin, along with a three-bottom moldboard plow industrialization by the public association for a trade of Mechanical in Alexandria. An electronic device was made consisting of two flow sensors mounted on an Arduino UNO board

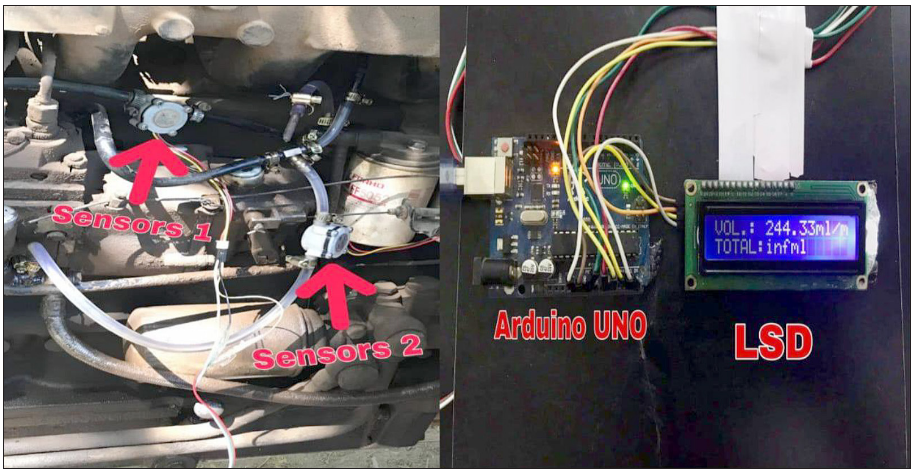

Figure 1. The electronic device that was manufactured

(Figure 1). The flow sensor is Sea YF-S401 mechanical type. The working range is 0.3–6 L·min^{-1} flow rate and 0.8 MPa pressure. The first sensor was used to measure the fuel flow entering the injector pump, while the second sensor measured the fuel returning from the injectors and injection pump back to the tank. Fuel consumption was calculated as the difference between the values recorded by the first and second sensors.

The traditional method consists of a graduated cylinder with a capacity of 1000 ml. The cylinder is filled with fuel, and then the tractor's fuel tank is filled to its maximum level. The fuel valve located beneath the graduated cylinder is then closed, before starting the process open the control valve located beneath the graduated cylinder and close the valve of the tractor's fuel tank at the end of the process close the valve of the graduated cylinder and open the valve of the tractor's fuel tank. Figure 2 shows a diagram of the traditional method.

The method was calibrated both in the laboratory and in the field the correlation coefficient was 93.7%. Figure 3 shows the relationship between the traditional method and the electronic device.

Studied traits

Fuel consumption rate

The fuel consumption rate was calculated using the following equation [18]:

$$V_{CO} = \frac{Q \times 10000}{TL \times WP \times 1000} \quad (1)$$

where: V_{CO} – fuel consumed per hectare (L·h^{-1}), Q – fuel consumed in the treatment (mL), TL – treatment length (m), WP – effective working width (m).

Slippage percentage

The slippage percentage was calculated using the equation [4]:

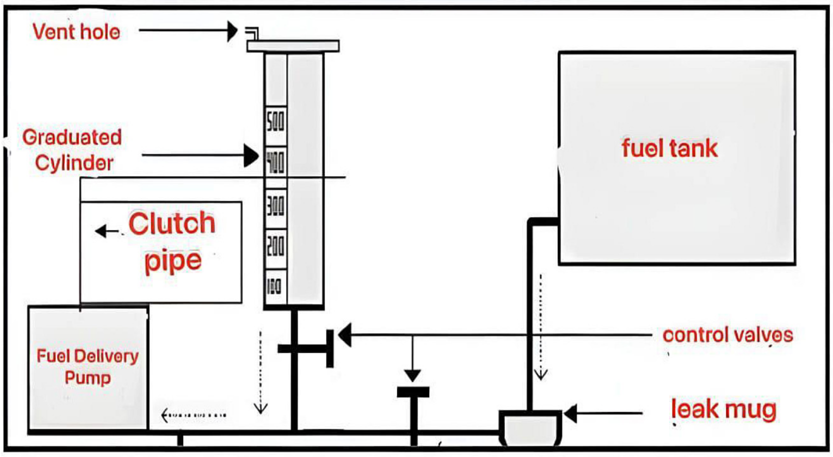

Figure 2. The diagram of the traditional method

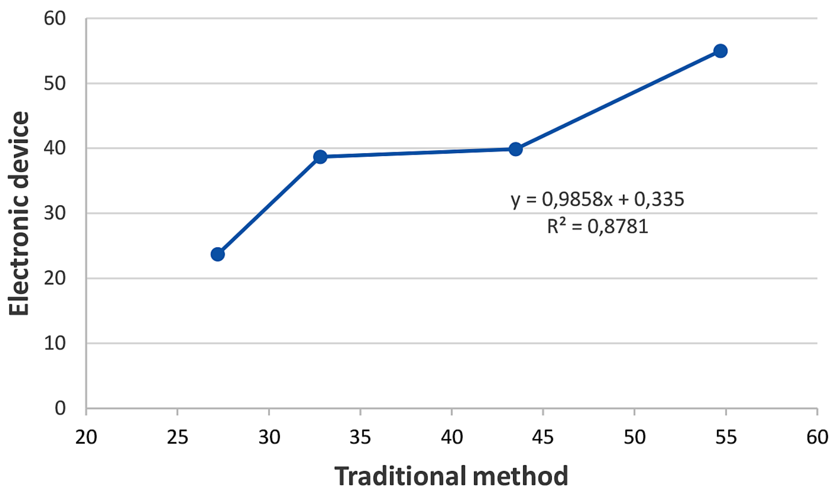

Figure 3. The relationship between the traditional method and the electronic device

$$S = \frac{Vt - Vp}{Vt} \times 100 \quad (2)$$

where: S – slippage percentage (%), Vt – theoretical forward speed (km·h^{-1}), Vp – effective working forward (km·h^{-1}).

Draft force

The draft force was calculated using the following equation [19]:

$$F_t = F_{pu} - F_{rr} \quad (3)$$

where: F_t – draft force (kN), F_{pu} – total pulling force during plowing (kN), F_{rr} – rolling resistance force when the plow barely touches the ground (kN).

Field efficiency

Field efficiency was calculated using the following equation [20].

$$Fe = \frac{EFC}{TFC} \times 100\% \quad (4)$$

where: Fe – field efficiency (%), EFC – effective field capacity (ha·h^{-1}), TFC – theoretical field capacity (ha·h^{-1}).

RESULTS AND DISCUSSION

Fuel consumption rate

Figure 4 shows the effect of the measurement method, forward speed of the mechanized unit, tillage depth, and their interactions on the fuel consumption rate of the agricultural tractor. It shows no significant differences in fuel consumption based on the measurement method used. However, the figure indicates a significant difference in fuel consumption rate related to tractor speed. When the speed increased from 2.24 to 3.49 km·h^{-1}, the fuel consumption rate decreased from 48.30 to 30.60 L·ha^{-1}. This reduction in fuel consumption may be attributed to the improved use of the tractor's available power with increased speed, reducing the time required to complete field operations. These findings align with those reported by [21, 22]. Figure 4 also shows a significant effect of tillage depth on fuel consumption. When the tillage depth increased from 10–15 to 20–25 cm, fuel consumption increased from 33.60 to 45.30 L·ha^{-1}. This increase can be attributed to the greater volume of soil tilled at greater depths, which increases the work required and, consequently, the fuel consumption. These results are consistent with those obtained by [14]. The figure reveals a significant interaction between measurement method and forward speed. The electronic method at a speed of 3.49 km·h^{-1} achieved the lowest fuel consumption, recorded at 30 L·ha^{-1}. Additionally, in the interaction between the measurement method and tillage depth, the electronic method at a depth of 10–15 cm revealed the slightest fuel consumption of 31.80 L·ha^{-1}. Moreover, a significant interaction was observed between forward speed and tillage depth, with 3.49 km·h^{-1} acceleration and 10–15 cm lowness resulting in the lowest fuel consumption of 24.45 L·ha^{-1}. In the three-way interaction between measurement method, forward, and tillage depth, the electronic method at a speed of 3.49 km·h^{-1} and a depth of 10–15 cm revealed the slightest fuel consumption of 23.70 L·ha^{-1}.

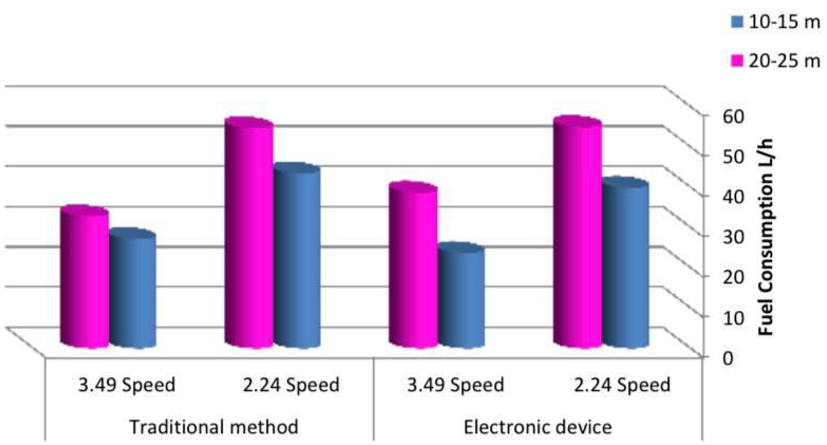

Figure 4. The effect of measurement method, forward speed, and tillage depth on fuel consumption

Slippage percentage

Figure 5 shows the effect of the measurement method, the forward speed of the mechanized unit, tillage depth, and their interactions on slippage percentage. It shows no significant differences in slippage percentage based on the measurement method. However, it indicates significant differences related to tractor speed. Increasing speed from 2.24 to 3.49 km·h^{-1} caused an expansion in slippage percentage from 6.15% to 7.74%. This increase in slippage may be due to higher draft resistance and reduced wheel-soil contact as speed increases, causing more slippage. These results align with those reported by [23, 24]. Figure 5 also shows a significant effect of tillage depth on slippage percentage. When the tillage depth increased from 10–15 to 20–25 cm, slippage increased from 6.53 to 7.37%. This is likely due to the greater load on the implement blades as the volume of soil facing the blades increases, resulting in higher slippage. The results are symmetrical with [25, 26]. Figure 5 also highlights a significant interaction between measurement method and forward speed. The electronic device at 2.24 km.h^{-1} acceleration recorded the smallest slippage percentage of 6.10%. Similarly, in the interaction between the measurement method and tillage depth, the electronic device at 10-15 cm lowness achieved the smallest slippage percentage of 6.51%.

Additionally, a significant interaction was observed between forward speed and tillage depth, with 2.24 km·h^{-1} acceleration and 10–15 cm lowness resulting in the lowest slippage percentage of 5.65%. In the three-way interaction between measurement method, forward speed, and tillage depth, the electronic device at 2.24 km·h^{-1} acceleration and a 10–15 cm lowness achieved the smallest slippage percentage of 5.42%.

Draft force

Figure 6 shows the effect of the measurement method, the forward speed of the mechanized unit, tillage depth, and their interactions with the draft force. The figure indicates no significant differences in Draft force based on the type of method used. However, significant differences are observed in the draft force related to the forward speed of the tractor. When speed increased from 2.24 to 3.49 km·h^{-1}, draft force increased from 6.38 to 7.07 kN. This increase in draft force is due to the higher load on the plow. As speed increases, a greater force is required to displace the soil during tillage, which leads to the development of resistance faced by the tillage and, consequently, higher draft force. These results align with findings by [9, 16]. Figure 6 also reveals a significant effect of tillage depth on the draft force. When tillage depth increased from 10–15 to 20–25 cm, draft force increased from 6.05 to 7.90 kN. This is attributed to the greater depth requiring more effort to plow the soil, which increases the resistance encountered by the plow and, in turn, increases the draft force. These findings are consistent with those of [15, 27]. Additionally, the figure shows a significant interaction between the measurement method and forward speed. The electronic device at 2.24 km·h^{-1} recorded the lowest draft force of 6.22 kN. In the interaction between the measurement method and tillage depth, the electronic device at 10–15 cm lowness resulted in the smallest draft force of 6.01 kN. Furthermore,

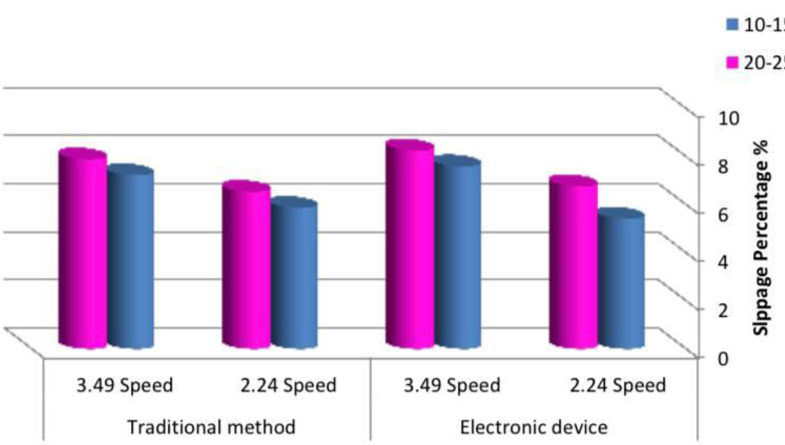

Figure 5. The effect of the measurement method, forward speed, and tillage depth on slippage percentage

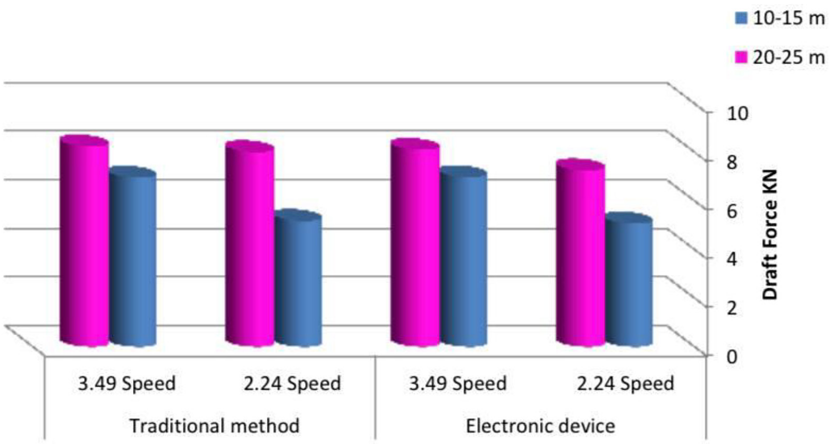

Figure 6. The effect of the measurement method, forward speed, and tillage depth on draft force

the interaction between forward speed and tillage depth was significant, with 2.24 km·h^{-1} acceleration and a 10–15 cm tillage lowness yielding the lowest draft force of 5.12 kN. In the three-way interaction between measurement method, forward speed, and tillage depth, the electronic device at a speed of 2.24 km·h^{-1} and a 10–15 cm tillage lowness showed the smallest draft force of 5.07 kN.

Field efficiency

Figure 7 shows the effect of the measurement method, forward speed, tillage depth, and their interactions on field efficiency. Figure 7 shows no significant differences in field efficiency based on the type of method used. However, significant differences are observed in field efficiency based on the forward speed of the tractor. When the forward speed increased from 2.24 to 3.49 km·h^{-1}, field efficiency increased from 58.22 to 60.83%. This increase is attributed to the fact that higher forward speed led to improved field efficiency due to the positive relationship between forward speed and efficiency. As actual productivity approached theoretical productivity, field efficiency improved. These results are in line with those of [11, 13]. Figure 7 also indicates a significant effect of tillage depth on field efficiency. When tillage depth increased from 10–15 to 20–25 cm, field efficiency decreased from 61.18% to 57.86%. This decline is due to increased soil resistance to penetration as the operating depth increases, which leads to more slippage and a reduction in efficiency. These outcomes are compatible with [4,6]. Additionally, figure 7 shows a significant interaction between the measurement method and forward speed. The electronic device at a speed of 3.49 km·h^{-1} recorded the highest field efficiency of 61.62%. In the interaction between the measurement method and tillage depth, the electronic device at a depth of 10–15 cm showed the biggest field efficiency of 61.66%. Moreover, the interaction between forward speed and tillage depth was significant, with an acceleration of 3.49 km·h^{-1} and a tillage depth

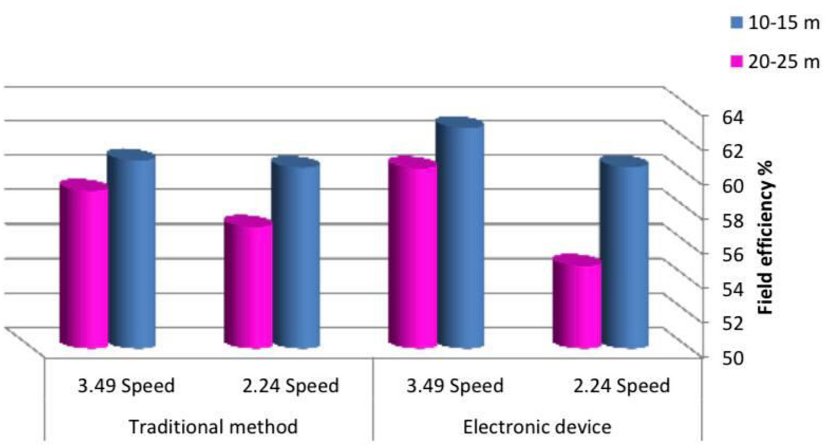

Figure 7. The effect of the measurement method, forward speed, and tillage depth on field efficiency

of 10–15 cm resulting in the biggest field efficiency of 61.85%. In the three-way interaction between measurement method, forward speed, and tillage depth, the electronic device at 3.49 km·h^{-1} and a tillage lowness of 10–15 cm showed the biggest field efficiency of 62.79%.

CONCLUSIONS

The results obtained show that the forward speed of 3.49 km·h^{-1} and the tillage depth of 10–15 cm gave the best results for the studied characteristics when using the electronic device. Also, increasing the speed led to a decrease in fuel consumption and an increase in field efficiency, draft force, and slippage percentage. Increasing the tillage depth led to an increase in fuel consumption, slippage percentage, and draft force while decreasing field efficiency. Therefore, it is recommended to use the electronic device to measure fuel consumption in agricultural tractors because it provides higher measurement efficiency.

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