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The Effect of Traffic Farming System and Sowing Speed on Tractor' Power and Fuel Requirements and Field Soil Strength

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Abstract

An experiment was conducted in a field with sandy loam soil of Agricultural Engineering Science College, University of Baghdad. The effect of three different speeds (5.68, 7.70, and 10.23 km. h^{-1}) on the performance of two agricultural systems: the random traffic system (RTF) and the controlled traffic system (CTF). The field experiment was carried out with split-plots arrangement using the random traffic design (RCBD) system. The traits studied in this experiment were soil resistance to penetration, fuel consumption and the power requirements per unit area. The superior results of the CTF system over the RTF system were demonstrated in all the studied methods. The CTF system achieved a lower average energy consumption per unit area, which was 18.20 kW.ha.h^{-1} compared to 34.01 kWh. ha. h^{-1} in the RTF system. The average fuel consumption rate was also reduced by 38%, from 7.97 L. h^{-1} in the RTF system to 4.94 L. h^{-1} in the CTF system.

As for the penetration resistance system, the CTF system recorded 31.25%, with a total of 1260.33 kPa compared to 1833.11 kPa in the RTF. On the other hand, increasing the seeding speed resulted in a decrease in energy consumption per unit, as well as fuel consumption rate. The interaction between the studied factors had a significant effect on the best treatments

Keywords: CTF, RTF, soil penetration resistance, fuel consumption, energy requirements per unit area

Introduction

Agricultural departments are striving to achieve a higher profitability by employing advanced and wide mechanical units. As a result of this endeavor, the soil pressure resulting from the movement of these advanced and heavy wide units has become widespread to cover most of the cultivated field area. [1] stated that the use of modern technology since the early 1970 has achieved the desired goal of increasing agricultural production and filling the food gap resulting from population growth. However, the researcher indicated that studies on soil compaction increased by 50% between 1970 and 2010. [2] indicated that soil compaction will cause significant and serious damage to global food production. Therefore, efforts must be intensified to contribute effectively to finding effective solutions to mitigate this real problem.

Finding practical and documented solutions will have a significant impact on improving the properties of compacted soil, such as improving its drainage, increasing its water storage, breaking up the layers and aerating them, thus reducing its resistance to root penetration. These solutions will also improve the productivity of the cultivated crop by increasing the density of the roots, their elongation, and their deep penetration into the soil to reach water reservoirs and nutrients during times of scarcity, which leads to increasing and improving crop productivity. [3] defined soil compaction as a change in the volume of the soil as a result of the rearrangement of its particles due to an applied vertical weight, thus reducing the area of interstitial spaces and the particles become in closer contact with each other, and thus the apparent density increases. The compaction rate is also affected by the percentage of soil clay, as the soil is easier to compact the higher the percentage of clay in it [4] In a field experiment conducted by [5] In Romania, it was found that clay soils are affected by compaction, which causes a change in the apparent density of the soil by 1 g. cm^{3-1} due to the movement of vehicle tires, which led to a decrease in the yield of the crop by approximately 18%.

Stated that one of the main causes of soil compaction is the movement of machinery and equipment wheels on the surface of the field soil. In addition to the presentation of pressure, its limits will extend as the size and weight of agricultural equipment increases [6]. Therefore, many researchers have confirmed that the pressure generated by the movement of traditional tractor tires is less when compared to the movement of the tires of those advanced and large mechanical units [7].

Indicated that The system of movement of the machinery and equipment within the field have a major impact on the compaction of the layers of cultivated soil within the root activity zone and below [8]. showed that soil compaction due to the movement of heavy machinery may reduce crop productivity by half or even more, and the reduction depends on the size and severity of soil compaction [9].

The random traffic system of machines and equipment, or what is called Random Traffic Farming (RTF), is the prevailing system for the smallest and large holdings around the world. Within this system, the traffic paths are random for various equipment and machines relating to all agricultural operations in the field, and then a large area of the field is exposed to tire pressure every time a crop is served, which leads to the creation of soil with high density, low relative porosity, and high penetration resistance, which negatively affects the soil properties and its ability to retain water. In Iraq, this system is still the prevailing and adopted by farmers, and therefore it may be the main reason for the decline in Iraqi agricultural production in addition to climate change and global warming [10].

In developed and advanced countries, since the early eighties of the twentieth century, steps have begun towards adopting the regular traffic farming system (CTF) as a modern technology to fill the shortage of food and food. In this system, pressure is confined to the smallest possible areas within the field within permanent passageways for machines and equipment year after year, while the field soil designated for crop cultivation remains uncompacted [4]. [8] indicated that the soil allocated from the CTF field for permanent passage of equipment and tractors represents approximately (20%) of the field area, while the remaining area of approximately (80%) will be uncompacted soil designated for crop cultivation. This system has received the attention of many researchers and has proven its efficiency as a successful technique to reduce the negative impact of soil compaction.

The superiority of the CTF system was evident in sugar beet planting, as it reduced soil compaction and increased root depth, and the increase in the productivity of beet of the CTF system was higher than that of beet of the RTF system by 10% [7]. The researchers attributed this to the fact that in the CTF system, the machines never get out of their designated paths, and thus the cultivated surface soil is not affected, so that the crop grows in a suitable environment to increase production. [11] showed that in the CTF system, all machines have the same path width, so that field traffic can be confined to the smallest possible area of permanent traffic lanes, thus improving the productivity of crops of non-compacted soil, which allows the plant to absorb fertilizers and water efficiently. The CTF system also provides the possibility of reducing the need for tillage, increasing the retention of organic matter in the soil, increasing soil porosity from approximately 5% to 70%, and improving water infiltration and saturated hydraulic conductivity, which enhances crop growth [8]. [2] recommended that farmers avoid planting crops in soils with cone index (CI) higher than 1500 kPa to avoid the negative effects of soil compaction [2]. One of the reasons for the low productivity of RTF crops is the high density of the crop soil affected by the traffic and hence greater resistance to root growth and elongation. The measurement of soil resistance to penetration is a function of the actual pressure experienced by the plant root when it grows in the measured soil. The extent of soil compaction can be identified by using the cone penetrometer (Cone Index) [2]. Cl readings depend on the type of soil texture, its apparent density, and its moisture content [4]. Also, soil moisture, cohesion strength, and soil adhesion strength are factors that affect penetrometer readings [12].

It is known that the time to complete any agricultural operation depends on the rate of speed of the operation. Increasing the speed may reduce the efficiency of the operation. However, both fuel consumption and power requirements per unit area will decrease with increasing speed of the agricultural operation. [13] observed that changing the seeding speed from 6.28 to 7.61 then to 11.43 km. h^{-1} resulted in a reduction in the amount of fuel consumed from 19.165 to 12.576 then to 8.111 L. ha^{-1}, it also reduced the energy requirements per unit area from 69.18 to 45.40 then to 29.40 kW .h. ha^{-1}.

Reducing soil compaction leads to increased crop productivity and crop quality and reducing compaction also reduces the energy consumed for agricultural operations thus reduces fuel consumption [12]. Also, [14] noted that the energy requirements in no-till soil increase by approximately 14% compared to the energy requirements required in plowed soil, which reflects the effect of soil resistance to penetration by the working parts of agricultural equipment on the value of energy required per unit area. In a study conducted in the southern United States by [15] to calculate the costs of soil preparation, the researchers found that compacted (unqualified) soils consumed fuel at an estimated 25% of the total cost value, while the percentage was 16% for uncompacted soils prepared for planting.

Found that the energy of the agricultural process decreases with increasing speed, the reason was attributed to the decrease in fuel consumption, whereby the researchers stated that by increasing the tractor's practical speed from 5.28 to 7.76 then to 8.30 km. h^{-1}, fuel consumption decreased from 34.25 to 30.24 then to 23.45 L. ha^{-1}, respectively. Since soil strength has a clear effect on the amount of tractor consumed fuel and thus the energy requirements, this search was conducted to study the effect of traffic farming system and sowing speed on tractors' power and fuel requirements and field soil strength. [14]

Materials and Methods

Experiment Site:

The experiment was conducted in one of the fields of the College of Agricultural Engineering Sciences - University of Baghdad in Al-Jadriya (33°16'04 "N) (44°22'26 "E) during the fall season of 2023 until the spring season of 2024. The field soil was classified as sandy loam with soil separates of 88, 492 and 420 g/kg for each of clay, sand and silt, respectively. The Jinma JM- 754 four-wheel drive agricultural tractor, Chinese origin, 2012 model, was used to implement the experiment.

Soil Resistance to Penetration

The soil resistance to standard cone penetration was measured in the study field soil in all experimental units using the Rimik CP300 cone penetrometer which consists of a 0.8 m long column, a cone with a base area of 130 mm², a diameter of 12.83 mm, apex angle of 30˚ and an integrated data logger and a depth sensor [4] (ASABE, 2014). The data were extracted by inserting the device and expressing the resistivity automatically in the soil and using the data at a depth of 0.30 m. The field measurements were uploaded for further analysis on a computer using the Rimik CP 40 II Retrieval 6.0 software (Rimik, 2004) in units of kPa.

Figure 1: Rimik CP300 on site

Fuel consumption

Fuel consumption was measured using the 1000 ml graduated cylinder method. When the tractor reached the beginning of the tractor stability zone before the experimental unit, the engine stopped, and the tractor fuel tank was filled with fuel. At the end of the distance, the engine was stopped and the amount of fuel consumed was measured by refilling the tractor fuel tank using the graduated cylinder above, and then calculating the fuel added to the tank to fill it, which represented the amount of fuel consumed. This scenario was applied to all 18 experimental units. The equation below was used to calculate fuel consumption [13].

$$Fu.\ C = Qd \times 10000 / Wp \times D \times 1000 \quad \text{……………... (1)}$$

Where:

Fu. C: Amount of fuel consumed per unit area (liters/ha),

Qd: Amount of fuel consumed during treatment (ml),

Wp: Practical working width (170 cm = 1.7 m),

D: Distance traveled during treatment (meters).

Power requirements per unit area

To quantify the power requirements per unit area, equation 2 was applied to calculate the power requirements per unit area that proposed by [16] and [13]

$$EP = EFC \times ER \quad \text{……………… (2)}$$

Where:

ER: Power Requirement (kW. h. ha^{-1}),

EP: Engine Power (kW),

EFC: Actual Field Capacity (ha. h^{-1}).

The engine power was calculated using Equation (3) which proposed by [13]

$$EP = 3.16\ Fu.\ C \quad \text{……………. (3)}$$

Where:

EP: Engine power (kW),

Fu. C: Fuel consumption (L. h^{-1}),

After that, the below equation was applied to calculate the actual field capacity which proposed by [13].

$$EFC = 0.1 \times Vp \times Wp \times FE \quad \text{………. (4)}$$

Where:

EFC = Actual field capacity (ha. h^{-1}),

Vp = Practical speed (km. h^{-1}),

Wp = Practical working width (m).

Statistical Analysis

The statistical program SAS - Statistical Analysis System (2018) was used to analyze the data to study the effect of speed along with traffic system and their interaction on the studied traits according to the randomized complete block design (RCBD). The significant differences between the averages were compared using the Least Significant Difference (LSD) test.

Results and Discussion

Soil resistance to penetration

The effect of the traffic system and sowing speed on the soil penetration resistance and the interaction between them is shown in Table 1. The traffic system had a significant effect on soil resistance to penetration, as the transition from the RTF system to the CTF system led to a decrease in the soil resistance to cone penetration from 1833.11 kPa to 1260.33 kPa recording a reduction percentage of 31.25%. This may be due to the fact that the soil of the RTF system was exposed to random passes, which increased the compaction of its layers, thus its densities increased and its porosities decreased, which in turn increased its resistance to the cone penetration of the penetrometer (CP300), so the readings were large, while the compacted areas were limited within the permanent fixed passes of the CTF system, while the field soil remained uncompacted, and this was reflected in the penetrometer readings, and this is consistent with what was mentioned by [4].

From Table 1, it’s evident that there is no significant effect of sowing speed on the soil resistance to penetration. The effect of the interaction between seeding speed and the passage system was significant in this trait. The highest soil resistance value of (1897.33 kPa) was obtained from the combination of 5.68 km. h^{-1} speed and RTF system, while the lowest value of 1212.00 kPa, which was obtained from the combination of 10.23 km/h speed and CTF system.

Table 1: the effect of sowing speed, traffic system, and their interaction on soil resistance to penetration (kPa)

Speed (km. h^{-1})	Interaction between forward speed and traffic system		Av. Speed
	Traffic system		
	CTF	RTF	
S_1: 5.68	1299.00	1897.33	1598.17
S_2: 7.70	1270.00	1816.00	1543.00
S_3: 10.23	1212.00	1786.00	1499.00
Av. Traffic System	1260.33	1833.11	---
L.S.D value	Speed(S)113.88 NS, Traffic system (TF):92.983*,Interaction (TF×S): 161.05*		
NS = Not Significant, * = Significant (P≤0.05)			

Fuel consumption

Table 2: the effect of sowing speed, traffic system, and their interaction on fuel consumption (L. h^{-1})

Speed (km. h^{-1})	Interaction between forward speed and traffic system		Av. Speed
	Traffic system		
	CTF	RTF	
S_1: 5.68	5.19	9.02	7.11
S_2: 7.70	5.02	8.04	6.53
S_3: 10.23	4.61	6.86	5.73

Av. Traffic System	4.94	7.97	---
L.S.D value	Speed(S) 0.243* , Traffic system (TF): 0.199* , Interaction (TF×S): 0.344*		
NS = Not Significant, * = Significant ($P \leq 0.05$)			

Table 2: shows that fuel consumption decreases with increasing practical speed. As the forward speed increased from 5.68 to 7.70 then to 10.23 km. h^{-1}, the fuel consumption decreased from 7.11 to 6.53 and then to 5.73 L. h^{-1}, respectively. This can be explained by the fact that increasing speed reduces the time taken to complete the agricultural operation, which leads to a decrease in fuel consumption. This explanation is consistent with what was indicated by [13] and [17]. The table also illustrates that the agricultural traffic system has a significant effect on fuel consumption. Switching from the random traffic system (RTF) to the controlled traffic system (CTF) led to a decrease in fuel consumption from 7.97 to 4.94 L. h^{-1} by a decrease of 38%. This is due to the reduction in tractor wheel slippage in the control traffic system (CTF) compared to the random traffic system (RTF), where significant slippage causes greater time and fuel consumption. This is consistent with the results of both [6] and [4].

The effect of the interaction between sowing speeds and agricultural traffic system was significant on the number of liters of fuel consumed per hour. The highest fuel consumption (9.02 L. h^{-1}) was recorded when the first speed (5.68 km. h^{-1}) interacted with the random traffic system (RTF). In contrast, the lowest fuel consumption (4.61 L. h^{-1}) was achieved from interaction of the third speed (10.23 km. h^{-1}) and the controlled traffic system (CTF).

Power requirements per unit area

Table 3: the effect of sowing speed, traffic system, and their interaction on power requirements (kW. h. ha^{-1})

Speed (km .h^{-1})	Interaction between forward speed and traffic system		Av. Speed
	Trafficking system		
	CTF	RTF	
S_1: 5.68	25.17	47.52	36.35
S_2: 7.70	17.89	32.29	25.09
S_3: 10.23	11.55	22.23	16.88
Av. Traffic System	18.20	34.01	---
L.S.D value	Speed(S) 0.420 * , Traffic system (TF): 0.343* , Interaction (TF×S): 0.594*		

NS = Not Significant, ⁎ = Significant ($P \leq 0.05$)

The effect of traffic system, sowing speed and their interaction on power requirements per unit area is shown in Table 3, the aforementioned shows the significant effect of traffic system ($P \leq 0.05$) on the power requirements per unit area. Whereas the traffic system (CTF) consumed a lower rate of power of (18.20 kw. ha. h^{-1}) outperforming the random traffic system (RTF), which consumed a higher rate of power of (34.01 kw. ha. h^{-1}). The reason may be due to the low slippage rate due to the presence of fixed compacted paths, which reduces the required energy rates hence reduces fuel consumption; this is in consistent with [6]. The results of the statistical analysis of the table also indicated that opeartion speeds had a significant effect on the power requirements per unit area. Obviously from the table it is clear that with increasing speed, energy expenditure decreased, as the first speed was (36.35 kw. ha. h^{-1}) and the second average speed were (25.09 kw. ha. h^{-1}) while it reached (16.88 kw. ha. h^{-1}) at the third high speed, the reason may be that the higher speed reduces fuel consumption as well shorter time to complete the operation and thus lower the power requirements, this is consistent with both [13].

And from the cultivation system, the two interactions with sowing speeds had a significant effect; the highest rate of power requirements recorded (47.52 kw. ha. h^{-1}) resulted from the interaction of the first speed (5.68 km. h^{-1}) with the RTF system, while the lowest rate of power requirements was (11.55 kw. ha. h^{-1}) from the third speed (10.23 km. h^{-1}) and the CTF system.

Conclusion:

Developed countries have embraced the CTF system to preserve soil structure, a healthy environment, and the long-term sustainability of agricultural production. The research indicates that switching from the RTF system to the CTF system has significantly reduced field soil strength, fuel usage, and the energy needs of the mobile power source in the field. These improvements undoubtedly resulted in increased agricultural yield and reduced agricultural operations costs. To address the challenges of achieving sustainable agricultural production in Iraq, especially in maintaining Iraqi agricultural soil, and globally, we recommend conducting further research on the CTF system in relation to the country’s environmental conditions and soil types. This will, in turn, enhance the chances of Iraqi farmers adopting the system.

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