The impact of the traffic systems on soil physical properties

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Abstract

The field experiment was conducted during the winter growing season of 2024–2025 in an agricultural field located in Al-Ghammas District, within the province of Al-Diwaniyah, Iraq. Wheat (Triticum aestivum) was sown on November 15, 2024, and harvested on May 9, 2025. The soil at the experimental site was classified as clayey in texture.

The experimental design followed a Split Plot Layout within a Randomized Complete Block Design (RCBD) framework to evaluate the influence of two main factors. The first factor was the agricultural traffic system, consisting of two levels: Random Traffic Farming (RTF) and Controlled Traffic Farming (CTF), which were assigned to the main plots. The second factor included three levels of tillage systems: Conventional Tillage (CT), Reduced Tillage (RT), and Zero Tillage (ZT), allocated to the sub-plots. The total number of experimental units was 18.

Several physical and productive factors related to soil were assessed. These included: bulk density ($g.cm^{-3}$), gravimetric soil moisture (%), and cone penetration resistance (kPa). The main findings can be summarized as follows: The CTF system outperformed the RTF system across most of the traits studied. Soil moisture content under CTF reached 19.5%, compared to RTF. Bulk density was reduced dropping from 1.643 $g.cm^{-3}$ in RTF to 1.604 $g.cm^{-3}$ in CTF. Cone penetration resistance also declined, from 1403.89 kPa in RTF to 1202.11 kPa in CTF .

Keywords: Soil Physical Properties.

Introduction

Despite wars, disasters, and famines occurring around the world, the global population continues to grow rapidly and alarmingly [3], with projections estimating it will reach nearly 10 billion by 2050 [10]. This anticipated growth has prompted a global call to action for effective solutions aimed at increasing agricultural production to bridge the gap in food and feed supplies and to meet energy demands [6]. Enhancing agricultural productivity requires improving the efficiency of input use in agricultural operations, thereby increasing the yield per unit area of cultivated land [7،11.[

The importance of increasing agricultural output extends beyond feeding the world's population; it also plays a central role in national economic development, particularly in emerging countries [9]. The adoption of intensive continuous cropping systems and the use of large, heavy farm machinery are among the strategies employed to enhance the productivity of arable soils [13]. However,

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while these approaches have boosted short-term agricultural output, they have also led to a decline in soil efficiency due to increased mechanical stress and resultant soil compaction. This issue has been formally recognized as a major concern by the European Union [7 ،11.[

Soil compaction is considered one of the most critical factors affecting both the physical and chemical properties of the soil. It reduces pore space, thereby decreasing soil aeration and water availability, which negatively affects root nutrient uptake [6]. Moreover, compacted soils emit higher levels of greenhouse gases such as carbon dioxide and nitrous oxides due to reduced microbial activity and oxygen availability [5]. Hydraulic conductivity, water retention capacity, soil strength, and mechanical resistance to root penetration are also adversely affected by excessive soil compaction within the root zone [19.[

Studies indicate that over 80% of fields under conventional farming systems are managed in ways that contribute to increased soil compaction [20]. This leads to the deterioration of soil structure, heightened environmental challenges such as erosion and reduced fertility, and ultimately results in decreased crop yields over time. These concerns necessitate a reevaluation of current agricultural management practices to achieve greater sustainability [6.[

Globally, soil compaction may represent the most serious threat facing agricultural soils today due to its long-term detrimental impact on sustainable productivity. Its influence extends beyond food production to include the soil's critical role in mitigating the effects of climate change [17]. It is also a primary driver of rainfall-induced erosion due to reduced vertical water infiltration caused by mechanical stress, which leads to pore size heterogeneity and enhances surface runoff and erosion intensity [18.[

Soil physical properties and greenhouse gas emissions are influenced by agricultural practices such as tillage, cropping systems, and fertilization. Therefore, there is a pressing need to conduct further research to evaluate various tillage methods and develop innovative cropping systems that enhance crop productivity, contribute to food security, and support a future of self-sufficient agricultural development [6.[

Materials and Methods:

The experiment was conducted in one of the agricultural fields in Al-Ghammas District, Al-Diwaniyah Governorate, during the winter season of 2024–2025. The soil of the field was clay in texture, and its physical and chemical properties are presented in Table 1. The study aimed to evaluate the effects of tillage systems and agricultural traffic patterns on selected soil physical properties, namely: dry bulk density, percentage of soil moisture content, and soil penetration resistance (cone index.(

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Table 1 Some chemical and physical properties of the soil used in the research

The attribute		value	Unit of measurement
PH		8.6	–
Electrical conductivity ECe		2.28	Decision^{-1}
Cation exchange capacity (CEC)		28.34	centimole+kg^{-1} soil
carbonate minerals		32.87	Kg^{-1} soil
Organic matter OM		6.9	Kg^{-1} soil
Available Nitrogen		15.00	mg kg^{-1} soil
Available Phosphorus		10.24	mg kg^{-1} soil
Available Potassium		250.00	mg kg^{-1} soil
Bulk Density		1.68	Megagram m^{-3}
Soil separators	Sand	39	gm.kg^{-1}
	Clay	43	
	Silt	18	
clayey soil texture		clayey	

A New Holland (TD-80) agricultural tractor was used in the experiment, with the following specifications: 80 mechanical horsepower, four-stroke diesel engine, front tire size 11.2 R24, and rear tire size 16.9 R30, of Turkish manufacture.

The following soil physical properties were studied: dry bulk density, percentage of soil moisture content, and soil penetration resistance (cone index.(

The experimental field was divided into two main plots representing the Controlled Traffic Farming (CTF) and Random Traffic Farming (RTF) systems. Each main plot was further divided into three sub-plots corresponding to the tillage systems: Conventional Tillage System (CT), Reduced Tillage System (RT), and Zero Tillage System (ZT). The experiment included three replications, resulting in a total of 18 experimental units (2 × 3 × 3). Each experimental unit had an area of 120 m² (3 m × 40 m), with a 1-meter buffer zone between units to avoid treatment interference. To ensure tractor stability during the experiment, a 10-meter buffer zone was left at the beginning of each plot.

In the setup of this experiment, the soil within the wheel tracks represented the RTF system, while the soil adjacent to the wheel tracks represented the CTF syste [2.[

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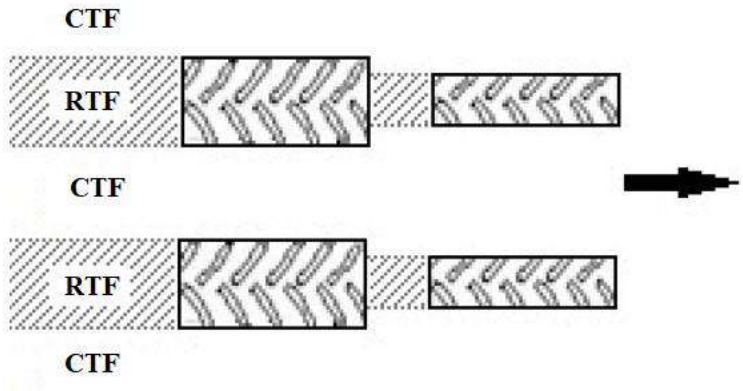

Figure 2-3 Position of RTF and CTF system soil in experimental design [2[

The experiment was conducted using a Split Plot Design within a Randomized Complete Block Design (RCBD). The collected data were statistically analyzed using the Statistical Analysis System (SAS, 2018), and the Least Significant Difference (LSD) test was applied to compare the means of the treatments. [21[

The following properties were studied:

-1Dry bulk density (g•cm^{-3}:(

It was calculated using the core sample method, by collecting soil samples with cylindrical cores of known diameter and height. These cylinders were inserted into the soil to a depth of 30 cm. The soil contained within each core was carefully extracted, placed into labeled bags, and weighed immediately in the field. The samples were then left in place until the entire sampling process was completed.

In the laboratory, the soil samples were oven-dried at 105 °C for 24 hours [4], and then weighed again. The dry bulk density was calculated using the following equation:

fb = MS/Vt …… Equation (1–3(

Where:

fb = dry bulk density of the soil on a dry weight basis (g•cm^{-3}(

Ms = mass of the oven-dried soil sample (g(

Vt = total volume of the soil in its original structure (cm³(

-2 Soil moisture content (or soil water content:(

Soil moisture content was determined gravimetrically using the weighing method according to the

following equation [8:[

PW = (MSW- MS/MS) *100% ……. Equation (3–3(

Where:

PW = gravimetric moisture content percentage (%)

MSW = mass of the wet soil sample (g(

MS = mass of the dry soil sample (g(

-3Soil penetration resistance (kPa:(

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Soil penetration resistance readings were taken using the digital Cone Penetrometer 300 (CP300), manufactured by RIMIK Workshop, Toowoomba, Queensland, Australia. The device was set to record measurements up to a depth of 30 cm. The cone was inserted at eight random locations within each experimental unit, resulting in a total of 144 readings (8 × 18), with an average of 24 insertions per treatment. This procedure complies with the recommendations of [9.[

Figure 3–10: Soil Penetration Resistance Measuring Device in the Field

- 1Dry apparent soil density:

-4Results and Discussion:

Table (1-4): Effect of Tillage Systems, Agricultural Traffic Systems, and Their Interaction on Soil Dry Bulk Density (g•cm⁻ ³(

Tillage systems	Traffic system		Average
	RTF	CTF	
Conv.Til.	1.623	1.590	1.606
Redu. Til	1.652	1.620	1.636
Zero.Til.	1.653	1.603	1.628
Average	1.643	1.604	---
L.S.D.	Traffic system ، * 0.0207 :Tillage systems : ، * 0.0254 Interference. * 0.0315 :		
(*P≤0.05.)			

The effect of tillage systems, agricultural traffic systems, and their interaction on dry bulk density is presented in Table (4-1). The agricultural traffic system had a significant effect on dry bulk density, as the shift from the Random Traffic Farming (RTF) system to the Controlled Traffic Farming (CTF) system resulted in a reduction of dry bulk density from 1.643 g•cm^{-3} to 1.604 g•cm^{-3}, representing a decrease of 2.37%. This reduction is likely due to the fact that the random traffic system caused soil compaction as a result of heavy machinery movement, which increases soil bulk density. These findings are consistent with those reported by [15]. Meanwhile, the use of the Controlled Traffic Farming (CTF) system led to a reduction in soil bulk density [16.[

As shown in the table, tillage systems also significantly affected soil dry bulk density. The shift from Conventional Tillage to the other tillage systems (Reduced Tillage and Zero Tillage) resulted in an increase in bulk density from 1.606 g•cm^{-3} to 1.636 and 1.628 g•cm^{-3}, respectively. This increase may be attributed to the fact that soils tilled with moldboard plowing followed by smoothing with disc harrows tend to have lower bulk density compared to soils managed under Reduced and Zero Tillage systems. These findings are consistent with those reported by [18.[

The interaction between tillage systems and agricultural traffic systems had a significant effect on soil dry bulk density. The combination of Zero Tillage and Random Traffic Farming (RTF) resulted in the highest soil bulk density (1.653 g•cm^{-3}), whereas the lowest bulk density (1.509 g•cm^{-3}) was observed under the interaction of Conventional Tillage with the Controlled Traffic Farming (CTF) system.

-2Soil Moisture Content (Soil Water Content:(

Table (2-4): Effect of Tillage Systems, Agricultural Traffic Systems, and Their Interaction on Soil Moisture Content(%)

Tillage systems	Traffic system		Average
	RTF	CTF	
Conv.Til.	0.183	0.225	0.204
Redu. Til	0.167	0.186	0.177
Zero.Til.	0.144	0.173	0.159
Average	0.165	0.195	---
L.S.D.	Traffic system ، * 0.0158 :Tillage systems :		
(*P≤0.05.)			

The effect of tillage systems, agricultural traffic systems, and their interaction on soil moisture content (or soil water content) is presented in Table (2-4). The agricultural traffic system had a significant effect on soil moisture content, where the shift from the Random Traffic Farming (RTF) system to the Controlled Traffic Farming (CTF) system resulted in an increase in soil moisture content from 0.165 to 0.195, representing an 18% increase. This improvement is attributed to the increased total soil porosity under the CTF

system, which enhances the soil's water retention capacity. These findings are consistent with the results reported by [12.[

The table also shows the effect of tillage systems on the percentage of soil moisture content, where the Conventional Tillage, Reduced Tillage, and Zero Tillage systems recorded decreasing values of soil moisture content at 0.204, 0.177, and 0.159, respectively. This decrease may be attributed to the reduction in soil porosity, which consequently lowers the soil's capacity to retain water. These results are in agreement with [14.[

The interaction effect between tillage systems and agricultural traffic systems was also significant. The combination of Conventional Tillage with the Controlled Traffic Farming (CTF) system achieved the highest soil moisture content percentage (0.225), whereas the interaction between Zero Tillage and Random Traffic Farming (RTF) resulted in the lowest soil moisture content percentage (0.144 .(

-3Soil Penetration Resistance (kPa:(

Table (3-4): Effect of Agricultural Traffic System, Tillage Systems, and Their Interaction on Soil Penetration Resistance (kPa(

Tillage systems	Traffic system		Average
	RTF	CTF	
Conv.Til.	1305.00	1054.00	1179.50
Redu. Til	1523.67	1281.67	1402.67
Zero.Til.	1383.00	1270.67	1326.83
Average	1403.89	1202.11	---
L.S.D.	Traffic system ، * 96.13 :Tillage systems 117.74 : ، *Interference.* 146.44 :		
(*P≤0.05.)			

The effect of the agricultural traffic system, tillage systems, and their interaction on soil penetration resistance is shown in Table (3-4). The traffic system had a significant effect on soil penetration resistance, as the shift from the Random Traffic Farming (RTF) system to the Controlled Traffic Farming (CTF) system led to a decrease in soil penetration resistance from 1403.89 kPa to 1202.11 kPa, representing a reduction of 14.37%. This reduction is likely due to the random traffic in the RTF system causing increased compaction of soil layers, which resulted in higher bulk density and reduced macroporosity, thereby increasing resistance to penetration. In contrast, the compacted areas in the CTF system were confined to permanent fixed wheel tracks, leaving the remaining field soil uncompacted. These findings are consistent with the results reported by [1.[

The table shows a significant effect of tillage systems on soil penetration resistance, with resistance increasing from 1179.50 kPa to 1402.67 kPa and then to 1326.83 kPa under the Conventional Tillage, Reduced Tillage, and Zero Tillage systems, respectively.

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The interaction effect between tillage systems and agricultural traffic systems was significant for soil penetration resistance. The highest penetration resistance value (1523.67 kPa) was recorded under the interaction of Reduced Tillage and the Random Traffic Farming (RTF) system, while the lowest value (1054.00 kPa) resulted from the interaction of Conventional Tillage with the Controlled Traffic Farming (CTF) system.

5-1**Conclusions** :

-1

The Controlled Traffic Farming (CTF) system outperformed others by achieving the lowest dry bulk density (1.604 g•cm^{-3}), the lowest soil penetration resistance (1202.11 kPa), and an increase in soil moisture content percentage (0.195.(

-2The Conventional Tillage system excelled by achieving the highest soil moisture content percentage (0.204), the lowest soil dry bulk density (1.606 g•cm^{-3}), and the lowest average soil penetration resistance reading (1179.50 kPa.(

-3The interaction between Conventional Tillage and the Controlled Traffic Farming (CTF) system achieved the highest soil moisture content percentage (0.225), the lowest soil dry bulk density (1.509 g•cm^{-3}), and the lowest average soil penetration resistance (1054.00 kPa.(

5-2Recommendations:

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Under the conditions of this experiment, it is recommended to adopt the Conventional Tillage system combined with the Controlled Traffic Farming (CTF) system, as it achieved the best results for the studied soil properties.

-2It is recommended that Iraqi researchers further study the Controlled Traffic Farming (CTF) system within Iraq's environmental conditions and share their findings with farmers to encourage its adoption as a modern agricultural practice to address the challenges facing both the Iraqi and global agricultural sectors.

-3Further research is recommended to develop strategies aimed at reducing soil compaction and improving the condition of compacted soils, in order to support crop growth and enhance productivity under soil compaction-affected conditions.

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