ISSN: 2073-9524
eISSN: 2310-8746

Short-Term Investigation into the Effect of the Traffic Farming Systems on the Soil Physical Behavior of an Arable Land

Kasem M. M. AL-Halfi[1*], **John McL. Bennett**[2,3]

[1]Department of Agricultural Machines and Equipment, College of Agricultural Engineering Sciences, University of Baghdad, Iraq.
[2]School of Business, Charles Sturt University, Wagga Wagga, New South Wales, Australia.
[3]Soil Insights, Toowoomba, Queensland, Australia.
[*]Corresponding author: kasem.m@coagri.uobaghdad.edu.iq

Article history:
Received: 19 September 2024
Accepted: 4 December 2024
Published: 30 December 2024

Keywords: *Controlled traffic farming, Random traffic farming, Bulk density, Cone index.*

Abstract

The field experiment was carried out in clay loam soil to monitor the dry soil bulk density (BD), moisture content (dry base) (MC), and cone index (CI) till the depth of 0-60 cm under two farming systems, namely the controlled traffic farming system (CTF) and the random traffic farming system (RTF) from 1/02 - 30/04/2023. During the trial period, the RTF system soil's BD increased from 1.45 g cm^{-3} to 1.48 g cm^{-3} with an increase of 2 %, while the increase in the CTF system soil's BD was 0.7 % (from 1.36 g cm^{-3} to 1.37 g cm^{-3}), the MC also increased from 27.7 % to 28.08 % (1.37 %) in the RTF soil and from 36.16 % to 37.64 % (4.09 %) in the CTF system soil. While the CI increased from 2438 kPa to 2499 kPa with an increase of 2.26 % for the RTF system soil, however, it became 2018 kPa after it was 2096 kPa for the CTF soil with a decrease of 3.72 %. The results showed that switching from the RTF system to the CTF system reduced the soil' BD by 6.85 %, reduced the soil CI by 16.55 % and increased the soil MC by 32.31 %. Finally, the graphic curves reflected the stability and consistency of the CTF system soil's physical behavior with increasing depth compared to the RTF system soil's physical behavior which fluctuated and disturbed for the same studied depth and under the same climatic conditions and traditional farming practices.

https://dx.doi.org/10.52951/dasj.24160213

Introduction

To deal with the rapid population growth and meet its needs for food, feed, and energy, the agricultural sector has adopted a strategy of increasing the same agricultural soils' productivity through the adoption of modern and advanced technologies rather than the strategy of adding new lands to the agricultural plan (Cesco *et al.*, 2023). Agriculture production has increased dramatically as a result of modern technology adoption, including the introduction of large, heavy, and productive machines and equipment (Jasim *et al.*, 2023). Nevertheless, in recent years, the global agricultural sector has seen a marked decline in agricultural soil productivity (Jebur *et al.*, 2024). According to Ali *et al.* (2024), the use of agricultural land for intensive and continuous cultivation has depleted the soil's organic matter, making it easy to compact under the weight of heavy tractors and other agricultural machinery, resulting in deterioration in the soil's structure and physical properties. In addition to the frequency of intensive cultivation and the decline in soil fertility, the traditional farm traffic system, also known as the random traffic farming system (RTF), is one of the most significant contributors to the deterioration of the agricultural soil's structure, physical properties, and fertility, which in turn results in a decrease in soil productivity (Bennett *et al.*, 2019). Tullberg *et al.* (2007), Tamirat *et al.* (2022), and Macák *et al.* (2023) have all found that under the RTF system, 80 – 100 % of field soil will be impacted by tractor and machinery tires and tracks with traditional tillage, while with conservation tillage like minimum or zero tillage, only 30 – 60 % of field soil will be affected by tires and tracks' passage in one season.

Globally, the RTF system covers substantial areas, with approximately 4, 33, 10 and 18 million hectares found in Australia, Europe, Asia, and Africa, respectively (AL-Halfi, 2021). Abdulkareem *et al.* (2023) demonstrated that continuous and random machinery traffic will result in soil particles becoming closer together, reducing spacing and increasing bulk density, with a more pronounced effect if the soil had been disturbed prior. The random traffic of tractors and heavy machinery, along with frequent tillage, can cause the soil's physical properties to degrade due to compaction, potentially exceeding traditional tillage depth levels (Bangale, 2023). AL-Halfi (2021) stated that equipment weighing over 30 tons may cause deterioration up to 40 cm in deep; whereas Bennett *et al.* (2017) have mentioned that traditionally tilled soils under heavy loads could experience physical degradation up to 60 cm in deep.

The compaction of arable land soils slows down the infiltration of rainwater or irrigation water to the lower layers (Jebur *et al.*, 2024), leading to a higher risk of water erosion due to increased runoff (Godwin *et al.*, 2019) causing a reduction in soil organic matter, fertility, and water content (Bennett *et al.*, 2019). Furthermore, soil compaction also results in a decrease in soil nitrogen, causing the main crop plants to experience a shortage of this essential nutrient, ultimately reducing their vegetative growth (Issaka *et al.*, 2019). Because of the evidence mentioned above and various studies demonstrating the negative effects of soil compaction on crop yield production due to the use of heavy, and bulky mechanization for food, feed, and energy production, efforts are being made to find solutions to maintain soil structure and sustain agricultural production (Jebur and AL-Halfi, 2022).

Deep tillage (AL-Halfi, 2021) coupled with the addition of soil amendments like lime, gypsum, or organic matter (Henry *et al.*, 2018), minimizing machinery passes or adjusting their timing on the soil surface within the optimal moisture content (Chamen *et al.*, 2015), reducing vertical stresses of machinery units contact points (Moinfar *et al.*, 2021), or combining various of above techniques (Jasim and Madlol, 2011; Hachim and Jebur, 2022), are common approaches to alleviate soil compaction effects on agricultural soil structure and productivity. Yet, the controlled traffic farming system (CTF) is a highly successful and effective technology for mitigating soil compaction (AL-Halfi, 2021; Hussein *et al.*, 2021).

The CTF system is a contemporary technology designed to confine the field compacted areas into permanent and narrow pathways utilized for the agricultural machinery tires and tracks' movement year after year (Tullberg *et al.*, 2007). In this system, the majority of the field soil, around 80 - 85 %, will be non-compacted for planting and growing crops. The remaining 20 – 15 % is compacted for farm machinery and equipment to pass through (Macák *et al.*, 2023). Hence, this technique will offer two different types of soils within the same field - one densely compacted for tire and track traffic and another non-compacted for the main crop growing (Hussein *et al.*, 2023). Numerous global studies have shown that this system is effective in enhancing soil quality, environmental health, and crop yield.

Tullberg (2010) found that the CTF system has led to a 25 % rise in crop yield, while under dry season conditions; it maintained a stable crop production rate (Rataj, 2022). The absence of soil tillage and the low slippage and resistance of the tractor wheels and tracks' motion in this system have significantly decreased energy, fuel, and expenses (Antille *et al.,* 2015). Decreasing field traffic reduces exhaust emissions, helping to maintain a healthy environment by lowering the greenhouse gases released, which have a major impact on climate change (Hussein *et al.*, 2021). The problem of soil erosion and loss caused by floods (runoff) and winds is a serious concern in agriculture today (AL-Halfi, 2021). Wang et al. (2008) found that the soil in China's CTF system has seen a notable decrease in floods (28 – 42 %) due to its higher water penetrability, resulting in a reduced runoff rate. The introduction of a GPS-guided automatic tractor driving system will elevate the CTF system as a promising technology in precision farming systems (Tamirat *et al.*, 2022). According to AL-Halfi (2021), integrating the CTF system with deep tillage systems can greatly enhance efficiency in preserving soil structure and ensuring long-lasting impact. If CTF is paired with conservation tillage systems, the expected advantage will grow due to fewer passes and zero tillage practice (Godwin *et al.,* 2022). Overall, many researchers like AL-Halfi (2021), and Bangale (2023), have concluded that the CTF system significantly improves the soil's preparedness for farming by decreasing bulk density and root penetration resistance while increasing water content when compared to the RTF system.

Millington *et al.* (2017) conducted an experiment at Harper Adams University - UK to study the effects of the CTF system (soil not impacted by tire passage) against the RTF system (tire tread impacting soil surface). They found out that switching from RTF to CTF resulted in a 6 % decrease in soil bulk density within the root zone (0 - 25 cm), leading to a 19 % decrease in soil strength at the same depth boundary (2290 kPa for CTF vs. 2960 kPa for RTF). Antille *et al.* (2019) also pointed out that a low cone index (CI) value of arable land soil can improve fertilizer use efficiency by promoting root growth and elongation. Bingham *et al.* (2010) suggest that root growth is impeded when soil CI values exceed 1800 kPa, while Martino and Shaykewich (1994) have observed that roots are stunted when soil strength reaches 2000 kPa. Busscher *et al.* (1986) found that at 2500 kPa, soil compaction will hinder crop root growth, while Atwell (1993) stated that roots will struggle to grow if soil reaches 3000 kPa or higher.

Although the benefits of the CTF system are well-documented, its application is limited to Australia (Queensland) and a few developed countries primarily due to infrastructure costs (Rochecouste *et al.,* 2015), limited global market availability

(Tullberg *et al.*, 2007), and insufficient studies (Mouazen and Palmqvist, 2015). Hence, the main goal of this investigation is to study the effect of the CTF and RTF systems on the behavior of clay loam soil via monitoring the BD, MC, and CI, and then provide recommendations for promoting using of this system in addressing the challenges that face the agricultural sector locally and globally.

Materials and Methods

Experiment's Location

The experiment was carried out at a field in the College of Agricultural Engineering Sciences at the University of Baghdad (Jadriyah) (33°16'01"N 44°22'34"E) from 1/02 - 30/04/2023. The cone of the penetrometer device (CP300) (Figure 1- C, D, and E) was inserted and soil samples were pulled using a soil sampler kit (Figure 1- A and B) to a depth of 60 cm to analyze and monitor soil physical behavior in two different farming systems (CTF and RTF), by recording CI readings and calculating the soil's BD and MC. The site's soil texture classification was clay loam, with sand, silt, and clay fractions of 243, 408 and 349 g Kg^{-1}, respectively (Al-Hassoon *et al.*, 2019). Table 1 displays some physical and chemical properties of the experiment's soil along with its particle fraction.

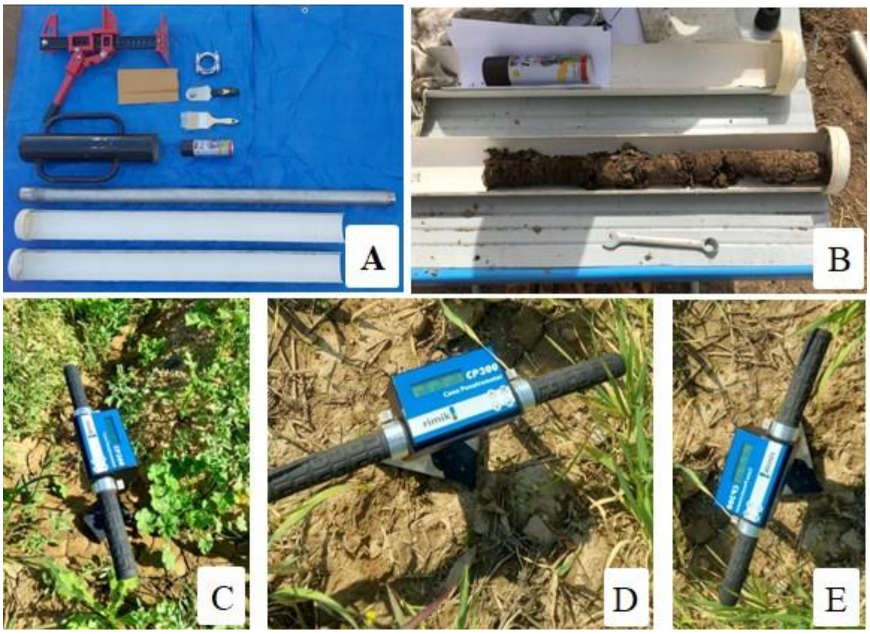

Figure 1. A; B: Soil sampling kit, C; D; and E: the Rimik - cone penetrometer 300 (CP300)

Table 1. Some physical and chemical properties of the experiment's soil

Particle density	2.63	g cm^{-3}	Na	109	mg L^{-1}
EC	1.3	dS m^{-1}	K	98	mg L^{-1}
PH	7.7	-	Ca	53	mg L^{-1}
OM	11.35	g kg^{-1}	Mg	54	mg L^{-1}
gypsum	1.20	g kg^{-1}	SO_4	210	mg L^{-1}
Sand	243	g kg^{-1}	Cl^-	390	mg L^{-1}
Silt	408	g kg^{-1}	$CaCO_3$	154	g kg^{-1}
Clay	349	g kg^{-1}	Texture	Clay Loam	

Experiment Description

The selected experimental area dimensions were 8 * 25 m. Following that, the area was split into three sections 2 * 25 m, with a buffer of 1 * 25 m between sections. After, the moldboard plow was used to till each section, and then followed by a rotary tiller for harrowing and leveling the soil. Following that,at the center of each section, the same tractor with a mounted seed-drill where its openers (double disks) in the operating position passed by. After irrigation and soil stabilization, the same tractor with an integral hydraulic sprayer drove over the soil of each section once, followed by the same tractor equipped with an integral spring-tooth field cultivator with chisel (narrow) points making three passes on the same previous tracks to mimic tractor activity during the agricultural season. In this experiment setup, the soil within the wheel tracks represented the RTF system, while the soil around wheel tracks represented the CTF system (Millington *et al.,* 2017), (Figure 2).

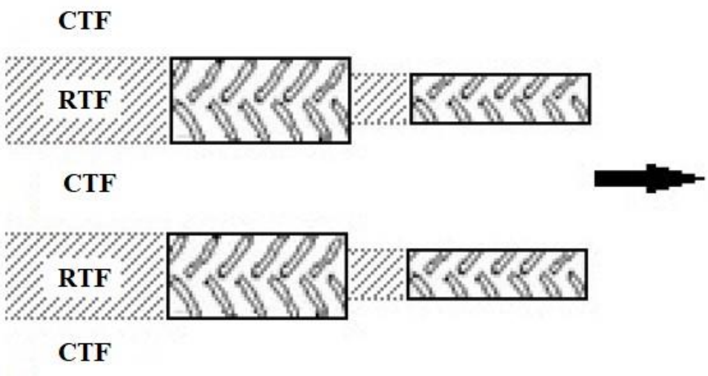

Figure 2. The positioning of the RTF and CTF system soil in the experiment's design

Experiment Measurement

Following agricultural activities in the experiment description, three sunny days after the rain stopped on 12/03/2023, with soil moisture nearing the field capacity as per Chen *et al.* (2005) suggestions, CI readings were taken and soil samples were collected from eight locations to a depth of 60 cm in each soil system across all sections. Therefore, the field soil was stitched 48 times (8 * 3 * 2) for both the penetrometer bar and soil sampling tube at a rate of 28 stitches for each traffic system (8 * 3) down to 60 cm depth. This aligns with the guidelines of Kirkham (2014), which recommend a minimum of 20 stitches for accurate results at the studied depth. The CP300 was set up to measure the CI every 2.5 cm and the findings were presented graphically and, in a table, every 10 cm, along with calculations of BD and MC every 10 cm. On 17/04/2023, three days post-rains, the same scenario of the initial date (12/03/2023) was repeated at the same locations and depth. Because the soil was a clay loam, a cone with the circular area of 130 mm^2, diameter of 12.83 mm, and angle of 30° was utilized (ASABE, 2014).

The BD and MC were calculated using the following equations (Equip. 1 and 2, respectively) used by AL-Halfi (2021).

$$BD = \frac{Wd}{Vs} \dots . (1)$$

$$MC = \frac{Wi - Wd}{Wd} * 100 \quad . \dots (2)$$

Where:

BD is the dry soil bulk density (g cm^{-3}), MC is the soil moisture content (dry base) (%), Wd is the dried soil weight (g), Wi is the initial soil weight (g), and. Vs is the soil volume (cm^3).

Statistical Analysis

The data analysis was conducted using the Statistical Package for Social Scientists (SPSS) software (Swan and Sandilands, 1995). An Anova-One Way analysis was conducted and the means were compared using the least significant difference (LSD) at 5% probability level. The statistical analysis findings of the variables average values were showcased through tables and graphs to facilitate evaluation and discussion.

Weather Data

Since the farm's soil behavior is influenced by its activity and surrounding environment, weather data from the University of Baghdad's weather station were collected for the experiment period (1/2 - 30/4/2023) to help explain the soil's behavior. Figure 3 displays the maximum and minimum temperatures as well as the precipitation levels from February to April 2023.

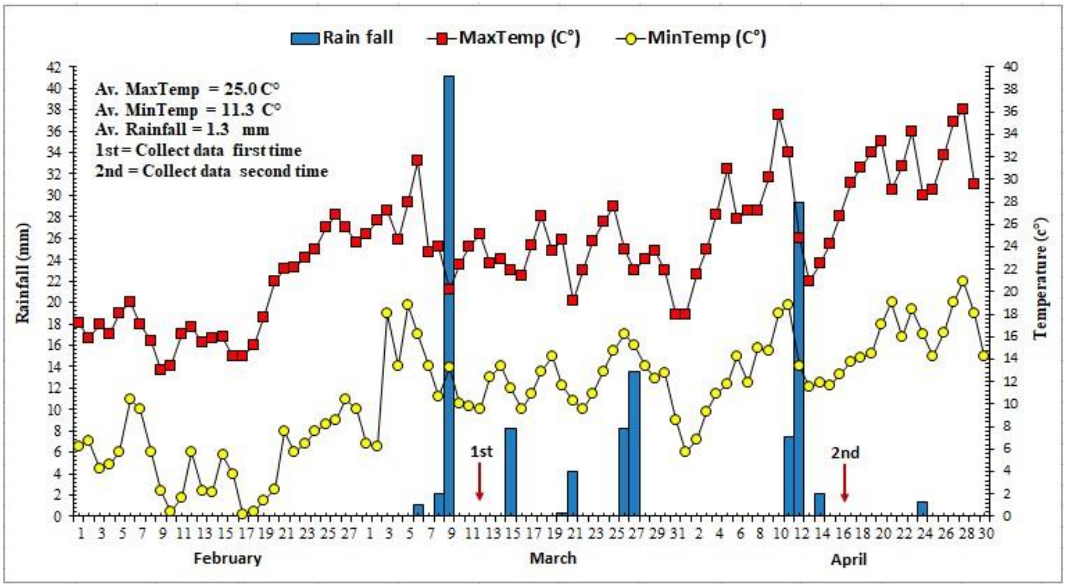

Figure 3. Climate data during the experiment period (weather station - Department of Geology, College of Science, University of Baghdad)

Results and Discussion

Soil Bulk Density (g cm^{-3})

Table 2 displays the soil's BD values for the 0-60 cm depth range, while Figure 4 illustrates the BD behavior for each soil of the CTF and RTF systems. It is evident from them that the soil's DB tends to increase as depth increases, possibly because greater depth leads to increased vertical weight and pressure on lower layers, resulting in particle convergence and increased mass within the soil layer boundaries, which in turn leads to higher soil DB as depth increases.

Both Table 2 and Figure 4 demonstrate the rise in average BD of RTF system soil from 1.45 g cm^{-3} on 12/03/2023 to 1.48 g cm^{-3} on 17/04/2023, indicating a significant increase of 2.07 %. This could be attributed to repeated vertical loads and random passes on the soil system. The Table 2 also indicates that the average BD of soil at 0-60 cm depth of the CTF system significantly rose from 1.36 g cm^{-3} on 12/03/2023 to 1.37

g cm^{-3} on 17/04/2023, showing a relative increase of 0.7 %. This increase is smaller compared to the rise in average RTF system soil density 2.07 %, likely due to lack of direct tractor tire passage.

Additionally, the Table 2 and Figure 4 show a difference in the average BD of CTF and RTF soils after both systems were established and exposed to the same weather conditions. During the initial sampling on 12/03/2023, the BD values were 1.36 g cm^{-3} and 1.45 g cm^{-3} for CTF and RTF soils, respectively, possibly due to the machinery units' traffic through both systems. The farming machinery traffic in both systems resulted in a noticeable distinction in the average BD values of their soils under similar weather conditions on April 17, 2023, with 1.37 g cm^{-3} for the CTF system and 1.48 g cm^{-3} for the RTF system.

The Table 2 and Figure 4 both show that switching from the RTF system to the CTF system resulted in a notable drop in the mean soil BD from 1.46 to 1.36 g cm^{-3}, marking a reduction of 6.85 %.

Based on the graph curves, it can be inferred that the CTF system's soil behavior was consistent, with BD increasing consistently with depth and remaining stable, and most layers had relatively high BD values at the end of the study. Regarding the soil behavior of the RTF system, it can be described as unstable turbulent behavior, as a majority of its layers showed a considerable rise in BD values one month after the initial date. Hence, the CTF system is greatly superior in regards to soil's BD.

Table 2. Dry bulk density values of both CTF and RTF system soil (0-60 cm)

Depth (cm)	Traffic farming system							
	RTF				CTF			
	12/3/2023	17/4/2023	Average	%	12/3/2023	17/4/2023	Average	%
0 -10	1.33	1.37	1.35	+3	1.19	1.21	1.20	+1.68
10 -20	1.43	1.44	1.44	+0.69	1.26	1.26	1.26	0.00
20 -30	1.41	1.44	1.43	+2.12	1.31	1.33	1.32	+1.53
30 - 40	1.47	1.47	1.47	0.00	1.41	1.41	1.41	0.00
40 - 50	1.50	1.54	1.52	+2.66	1.45	1.46	1.46	+0.68
50 -60	1.58	1.59	1.59	+0.63	1.54	1.53	1.54	-0.64
Average	**1.45 a**	**1.48 b**	**1.46 a°**	**+2.07**	**1.36 a′**	**1.37 b′**	**1.36 b°**	**+0.7**

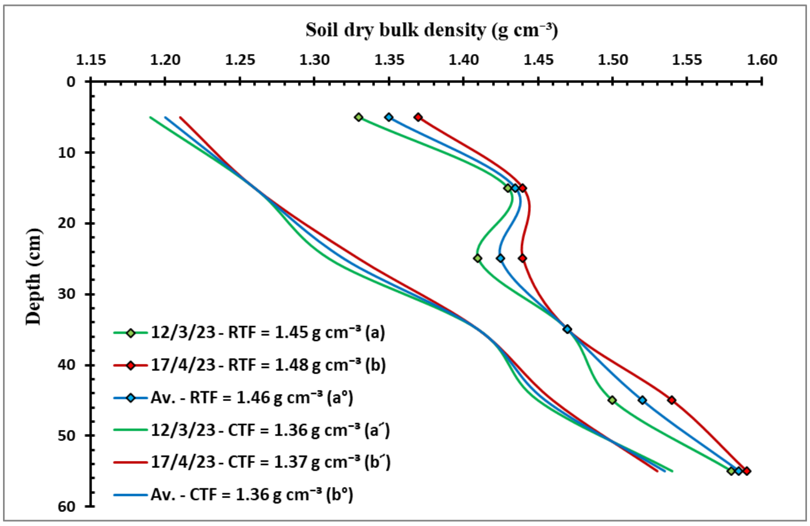

Figure 4. Bulk density behavior of both CTF and RTF system soils (0-60 cm)

Soil Moisture Content (%)

Table 3 and Figure 5 display the MC rate and its behavior at depths ranging from 0 to 60 cm for CTF and RTF system soils throughout the experiment. It can be observed from them that as the depth increases, the MC value also increases. This could be because at greater depths, water is less likely to evaporate due to intense heat from direct sunlight on the soil surface and layers underneath. Furthermore, the higher porosity of surface soil makes air movement easier, resulting in lower moisture content compared to denser lower soil layers that hinder airflow.

In Figure 3, the weather data shows that during the experiment period from 01/02 to 30/04/2023, the average maximum and minimum temperatures, along with total rainfall, were 25.0 ºC, 11.3 ºC, and 113.5 mm (4.47in) respectively. Before the soil samples were collected on March 12, 2023, there was a precipitation of 42.17 mm (1.66 in), with average maximum and minimum temperatures of 21.6 ºC and 7.6 ºC, respectively. The precipitation amount and the average maximum and minimum temperatures before the second soil samples were collected on 17/04/2023 were 70.1 mm (2.76 in), 25.8 ºC, and 13.0 ºC. Accordingly, the first time had less rainfall and lower average maximum and minimum temperatures compared to the second time.

Table 3 and Figure 5 illustrate a notable rise in the average CTF soil MC from 36.16 to 37.64 % at 0-60 cm depth. This represents a 4% increase, which is considered significant. The explanation could be that the system's soil had a low BD and high porosity, leading to increased storage and improved rainwater penetration, resulting in higher MC. Regarding the RTF system's soil, the data shows that the average soil MC at 0-60 cm depth has risen from 27.7 to 28.08 % between the two dates, marking 1.4 % increase which is considered insignificant compared to the CTF system's soil MC increase (4 %). This could be because the high BD and low porosity of the RTF soil are preventing rainwater from penetrating deeply into the soil, causing it to either stay on the surface or in the top layers and to evaporate due to high temperatures.

The Table 3 and Figure 5 both indicate that the MC rates of CTF soil and RTF system soil varied when first sampled on 12/03/2023 after being exposed to the same weather conditions, with rates of 36.16 % and 27.7 % for CTF and RTF soil, respectively. The high soil BD of the RTF system and the low BD of the CTF system soil could be the highly likely reason. Nevertheless, the top layer (0-10 cm) the CTF system soil exhibited a lower MC 17.95 % than the RTF system soil surface layer (0-10 cm = 22.40 %), potentially as a result of the differing soil BD between the two systems. The higher BD of the RTF system may have led to less evaporation of water from the soil compared to the CTF system soil, where the lower BD allowed for more water loss due to temperature and air movement. The difference in the two-systems nature resulted in distinct average soil MC levels of 37.64 % for the CTF system and 28.08 % for the RTF system during the second sampling on 17/04/2023 under similar weather conditions. Despite the CTF system having higher MC compared to the RTF system, the surface layer of CTF had lower MC 16.98 % than the RTF system soil surface layer 23.48 %. This difference may be attributed to the varying soil BD of the surface layer of each system.

Both the Table 3 and the Figure 5 show that replacing the RTF system with the CTF system has notably raised the soil MC value from 27.89 to 36.90 %, marking a 32.31 % increase that is considered beneficial for agricultural yield.

Because both systems had similar climatic conditions and soil MC is correlated to its BD, it can be concluded from Figure 5 that the CTF system had more consistent and significant moisture behavior, with MC increasing steadily with depth compared to the RTF system, which showed some fluctuations. Furthermore, the MC of both systems soil was greater on the second date (17/04/2023) compared to the first date (12/03/2023), possibly because of the higher rainfall amount during the second period (2.76 in) versus the lower amount of rainfall (1.66 in) during the first period. Hence, the CTF system outperformed the RTF system in terms of soil MC.

Table 3. Moisture content values of both CTF and RTF system soil (0-60 cm)

Depth (cm)	Traffic farming system							
	RTF				CTF			
	12/3/2023	17/4/2023	Average	%	12/3/2023	17/4/2023	Average	%
0 -10	22.40	23.48	22.94	+4.82	17.95	16.98	17.47	-5.40
10 -20	26.93	27.72	27.33	+2.93	29.13	30.58	29.86	+4.98
20 -30	27.10	26.65	26.88	-1.66	35.34	36.85	36.10	+4.27
30 - 40	29.49	29.95	29.72	+1.56	39.78	41.95	40.87	+5.46
40 - 50	29.71	29.97	29.84	+0.88	43.91	46.17	45.04	+5.15
50 -60	30.56	30.71	30.64	+0.49	50.86	53.31	52.09	+4.82
Average	**27.70 a**	**28.08 a**	**27.89 a°**	**+1.37**	**36.16 a´**	**37.64 b´**	**36.90 b°**	**+4.09**

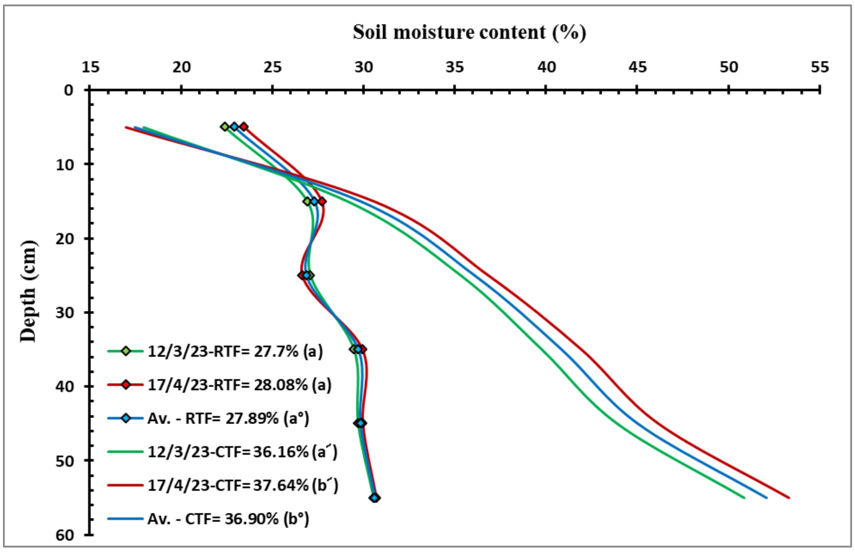

Figure 5. Moisture content behavior of both CTF and RTF system soils (0-60 cm)

Cone Index (kPa)

Table 4 and Figure 6 display the behavior and strength or CI readings of CTF and RTF system soils up to 0 – 60 cm depths throughout the experimental duration. It can be observed that the resistance of CTF and RTF system soils to penetration of the penetrometer cone increases as depth increases. This is due to the soil's vertical weight increasing with depth, leading to higher loads on lower layers causing particles to come closer together, increasing soil bulk density, and reducing soil porosity. As a result, resistance to penetration or soil shearing increases, leading to higher CI readings with depth.

Even though the BD of CTF system soil at a depth of 0-60 cm was higher on the second date compared to the first date, the data clearly indicates a significant decrease in the CI from 2096 kPa to 2018 kPa, with 3.72 % reduction. This decrease in CI could be attributed to higher rainfall before the second date (2.76 in) compared to the first date (1.66 in), resulting in a higher MC of 37.64 % on the second date versus 36.16 % on the first date. Since CI is inversely related to MC, the CI value was lower on the second date than on the first date. In the RTF system soil, there was an opposite trend where the CI value for 0-60 cm depth rose noticeably from 2438 kPa on the initial date to 2493 kPa on the subsequent date, showing 2.26 % increase. The increased soil BD during the second date hindered rainwater penetration, causing water to remain on the surface, evaporate, and then decrease soil MC, leading to an increase in CI value during the second time.

Despite experiencing similar climate conditions, both the table and graph show a notable drop in CI value from 2465 kPa to 2057 kPa, marking decrease of 16.55 %, when shifting from the RTF to the CTF system. This change is seen as a remarkable way to maintain soil structure and sustain agricultural production.

Referring back to the introduction, according to Bingham *et al.* (2010), the layers of the RTF system soil (10-20 cm, 1963 kPa) and the CTF system (20-30 cm, 1997 kpa) restrict root growth and elongation. Also, to Martino and Shaykewich (1994), the 20-30 cm (2651 kpa) RTF soil layer and the 30-40 cm (2466 kpa) CTF soil layer could impede root growth and elongation. As well, to Busscher et al. (1986), the compacted RTF soil at 20-30 cm (2651 kPa) and CTF soil at 40-50 cm (2742 kpa) will hinder root growth. Considering Atwell's (1993) results, the RTF system soil is the sole soil that inhibits root growth at the final studied depth level (50-60 cm = 3329 kPa).

Based on the above-mentioned results, the CTF system showed superior performance with lower CI readings and compacted layers further away from the root zone, unlike the RTF soil which had higher CI values and compaction levels closer to the root zone. Furthermore, the CTF system soil exhibited consistent behavior, with cone penetration resistance rising steadily with depth. In contrast, the RTF system soil showed turbulent and unstable behavior, with most layers experiencing a notable increase in CI values. In consequence, it can be observed that the CTF system has also excelled in terms of CI within the parameters of this investigation.

Table 4. cone index values of both CTF and RTF system' soil (0-60 cm)

Depth (cm)	Traffic farming system							
	RTF				CTF			
	12/3/2023	17/4/2023	Average	%	12/3/2023	17/4/2023	Average	%
0 -10	1217	1251	1234	+2.79	902	877	890	-2.77
10 -20	1957	1968	1963	+0.56	1296	1279	1288	-1.31
20 -30	2569	2733	2651	+6.38	2045	1949	1997	-4.69
30 - 40	2665	2709	2687	+1.65	2510	2422	2466	-3.51
40 - 50	2868	2989	2929	+4.22	2794	2689	2742	-3.76
50 -60	3349	3309	3329	-1.19	3029	2894	2962	-4.46
Average	**2438 a**	**2493 b**	**2465 a°**	**+2.26**	**2096 a´**	**2018 b´**	**2057 b°**	**-3.72**

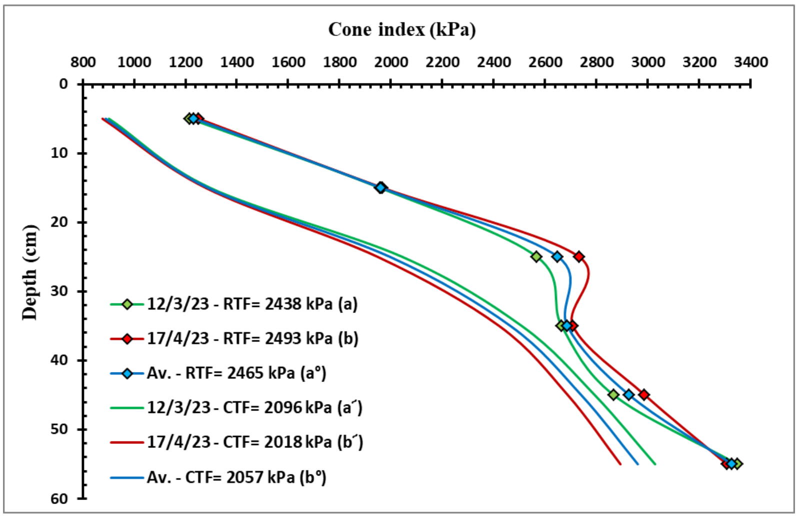

Figure 6. Cone index or strength behavior of both CTF and RTF soils (0-60 cm)

Conclusions

During the brief experiment, the soil of the CTF system showed steady physical behavior from 0 to 60 cm depths, contrasting with the unstable soil behavior of the RTF system at the same depth and under similar weather conditions. The CTF system's soil had optimal BD, MC, and CI values, making it a perfect setting for the crop's growth and development. The CTF system is a farming technique used to prevent soil structure degradation and improve crop yields. Despite the impressive and well-documented benefits for soil preservation, agricultural production sustainability, and the environment, its use remains limited to developed countries only. It is recommended that the Iraqi researchers study this system in Iraq's environment and share their findings with farmers to encourage them to adopt it as a new agricultural method to address challenges that face the Iraqi and global agricultural sectors.

Conflict of Interest

The authors declare no conflicts of interest associated with this manuscript.

Acknowledgements

I am grateful to all individuals who played a part in completing this manuscript.

References

Abdulkareem, J. H., Abdulkadir, A., and James, T. T. (2023). Effect of Compaction Energy on Selected Physical and Hydraulic Properties of Soils Amended With Different Sources of Organic Matter. *Diyala Agricultural Sciences Journal*, *15*(2), 81–89. https://doi.org/10.52951/dasj.23150209

AL-Halfi, K. M. M. (2021). Evaluation of deep tillage in cohesive soils of Queensland, Australia *(Doctoral dissertation, University of Southern Queensland)*. https://doi.org/10.26192/f9jr-bc92

Al-Hassoon, S. N. H., Al-Hayani, A. S. J. Z., and Al-Obaidi, M. A. J. (2019). Copper adsorption in two different soil texture. *Iraqi Journal of Agricultural Sciences*, *50*(2), 638-645.

Ali, A., Bennett, J. M., Roberton, S., Krwanji, D., Zhu, Y., and West, D. (2024). Selection of a stress-based soil compaction test to determine potential impact of machine wheel loads. *European Journal of Soil Science*, *75*(3), 1-14. https://doi.org/10.1111/ejss.13501

Antille, D. L., Chamen, W. C., Tullberg, J. N., and Lal, R. (2015). The potential of controlled traffic farming to mitigate greenhouse gas emissions and enhance carbon sequestration in arable land: a critical review. *Transactions of the ASABE, 58*(3), 707-731.

Antille, D. L., Peets, S., Galambošová, J., Botta, G. F., Rataj, V., Macak, M., and Godwin, R. J. (2019). Soil compaction and controlled traffic farming in arable and grass cropping systems. *Agronomy Research 17*(3), 653–682. https://doi.org/10.15159/AR.19.133

ASABE (2014). Soil Cone Penetrometer (ASAE S313.3). Retrieved from https://elibrary.asabe.org/abstract.asp?aid=44232&t=2&redir=&redirType=

Atwell, B. J. (1993). Response of roots to mechanical impedance. *Environmental and Experimental Botany*, *33*(1), 27-40. https://doi.org/10.1016/0098-8472(93)90053-I

Bangale, R. (2023). Controlled Traffic Farming: A Sustainable Solution to Soil Compaction. Acta Scientific Agriculture, 7(2), 18-24.

Bennett, J. M., Roberton, S. D., Jensen, T. A., Antille, D. L., and Hall, J. (2017). A comparative study of conventional and controlled traffic in irrigated cotton: I. Heavy machinery impact on the soil resource. *Soil and Tillage Research, 168*, 143-154. https://doi.org/10.1016/j.still.2016.12.012

Bennett, J. M., Roberton, S. D., Marchuk, S., Woodhouse, N. P., Antille, D. L., Jensen, T. A., and Keller, T. (2019). The soil structural cost of traffic from heavy machinery in Vertisols. *Soil and Tillage Research*, *185*, 85-93. https://doi.org/10.1016/j.still.2018.09.007

Bingham, I. J., Bengough, A. G., and Rees, R. M. (2010). Soil compaction–N interactions in barley: Root growth and tissue composition. *Soil and Tillage Research*, *106*(2), 241-246. https://doi.org/10.1016/j.still.2009.10.008

Busscher, W. J., Sojka, R. E., and Doty, C. W. (1986). Residual effects of tillage on coastal plain soil strength1. *Soil Science*, *141*(2), 144-148. https://doi.org/10.1097/00010694-198602000-00007

Cesco, S., Sambo, P., Borin, M., Basso, B., Orzes, G., and Mazzetto, F. (2023). Smart agriculture and digital twins: Applications and challenges in a vision of sustainability. *European Journal of Agronomy*, *146*, 126809.

https://doi.org/10.1016/j.eja.2023.126809

Chamen, T. (2015). Controlled traffic farming–from worldwide research to adoption in Europe and its future prospects. *Acta Technologica Agriculturae*, *18*(3), 64-73. https://doi.org/10.1515/ata-2015-0014

Chen, Y., Cavers, C., Tessier, S., Monero, F., and Lobb, D. (2005). Short-term tillage effects on soil cone index and plant development in a poorly drained, heavy clay soil. *Soil and Tillage Research*, *82*(2), 161-171.

https://doi.org/10.1016/j.still.2004.06.006

Godwin, R. J., White, D. R., Dickin, E. T., Kaczorowska-Dolowy, M., Millington, W. A., Pope, E. K., and Misiewicz, P. A. (2022). The effects of traffic management systems on the yield and economics of crops grown in deep, shallow and zero tilled sandy loam soil over eight years. *Soil and Tillage Research*, *223*, 105465. https://doi.org/10.1016/j.still.2022.105465

Godwin, R., Misiewicz, P., White, D., Dickin, E., Grift, T., Pope, E., and Dolowy, M. (2019). The effect of alternative traffic systems and tillage on soil condition, crop growth and production economics. *In 7th International Conference on Trends in Agricultural Engineering*, TAE 2019, Czech University of Life Sciences Prague, 133-134.

Hachim, I. T., and Jebur, H. A. (2022). A study Some Technical Indicators of the Local Designed Machine. *IOP Conference Series: Earth and Environmental Science*, *1060*(1), 1-6. https://doi.org/10.1088/1755-1315/1060/1/012136

Henry, C. G., Sarzi Sartori, G. M., Gaspar, J. P., Marchesan, E., Hirsh, S. M., Horton, A. P., and James, H. (2018). Deep tillage and gypsum amendments on fully, deficit irrigated, and dryland soybean. *Agronomy Journal*, *110*(2), 737-748. https://doi.org/10.2134/agronj2015.11.0567

Hussein, M. A., Antille, D. L., Kodur, S., Chen, G., and Tullberg, J. N. (2021). Controlled traffic farming effects on productivity of grain sorghum, rainfall and fertiliser nitrogen use efficiency. *Journal of Agriculture and Food Research*, *3*, 100111. https://doi.org/10.1016/j.jafr.2021.100111

Hussein, S. A., Hussein, M. A., and Al-Rijabo, S. A. (2023). Mechanization Assessment of Soil Compaction Induced by Traffic of Farm Machinery. *IOP Conference Series: Earth and Environmental Science*, *1214*(1), 2-8. https://doi.org/10.1088/1755-1315/1214/1/012051

Issaka, F., Zhang, Z., Li, Y., Zhao, Z., Asenso, E., Sheka Kanu, A., and Wang, J. (2019). Zero tillage improves soil properties, reduces nitrogen loss and increases productivity in a rice farmland in Ghana. *Agronomy*, *9*(10), 641. https://doi.org/10.3390/agronomy9100641

Jasim, A. A., and Madlol, K. M. (2011). Field performance of a tillage implement equipped with liquid fertilizer applicator. *1 st Nat. In Agric. Cong. and Exposition on behalf of Ali NumanKirac with Inte. Participation*, 27-30.

Jasim, A. A., Alathami, Z. A., and Yousif, A. J. (2023). Effect of Leveling and Tillage Equipment on Soil Bulk Density and Yield of Maize. *Diyala Agricultural Sciences Journal*, *15*(2), 110-119. https://dx.doi.org/10.52951/dasj.23150212

Jebur, H. A., and Al-Halfi, K. M. (2022). Studying Some Technical Indicators of the Local Manufactured Machine and Its Effect on the Wheat Crop "Tamuz cultivar". *IOP Conference Series: Earth and Environmental Science*, *1060*(1), 1-8. https://dx.doi.org/10.1088/1755-1315/1060/1/012135

Jebur, H., AL-Halfi, K., Himoud, M., and Jassim, S. (2024). Sunflower Productivity Response to tillage Depth and Harrowing Speed. *Tikrit Journal for Agricultural Sciences*, *24*(3), 50-60. https://doi.org/10.25130/tjas.24.3.5

Kirkham, M. B. (2014). Field capacity, wilting point, available water, and the nonlimiting water range. *Principles of soil and plant water relations*, 153-170. https://doi.org/10.1016/B978-0-12-420022-7.00010-0

Macák, M., Galambošová, J., Kumhála, F., Barát, M., Kroulík, M., Šinka, K., and Misiewicz, P. A. (2023). Reduction in water erosion and soil loss on steep land managed by controlled traffic farming. *Land*, *12*(1), 1-16. https://doi.org/10.3390/land12010239

Martino, D. L., and Shaykewich, C. F. (1994). Root penetration profiles of wheat and barley as affected by soil penetration resistance in field conditions. *Canadian Journal of Soil Science*, *74*(2), 193-200. https://doi.org/10.4141/cjss94-027

Millington, W. A., Misiewicz, P. A., White, D. R., Dickin, E. T., Mooney, S. J., and Godwin, R. J. (2017). An investigation into the effect of traffic and tillage on soil properties using X-ray computed tomography. In 2017 ASABE Annual International Meeting. American Society of Agricultural and Biological Engineers, p. 1. https://doi.org/10.13031/aim.201700380

Moinfar, A., Shahgholi, G., Abbaspour-Gilandeh, Y., Herrera-Miranda, I., Hernández-Hernández, J. L., and Herrera-Miranda, M. A. (2021). Investigating the effect of the tractor drive system type on soil behavior under tractor tires. *Agronomy*, *11*(4), 696. https://doi.org/10.3390/agronomy11040696

Mouazen, A. M., and Palmqvist, M. (2015). Development of a framework for the evaluation of the environmental benefits of controlled traffic farming. *Sustainability*, *7*(7), 8684-8708. https://doi.org/10.3390/su7078684

Rataj, V., Kumhálová, J., Macák, M., Barát, M., Galambošová, J., Chyba, J., and Kumhála, F. (2022). Long-term monitoring of different field traffic management practices in cereals production with support of satellite images and yield data in context of climate change. *Agronomy*, *12*(1), 128. https://doi.org/10.3390/agronomy12010128

Rochecouste, J. F., Dargusch, P., Cameron, D., and Smith, C. (2015). An analysis of the socio-economic factors influencing the adoption of conservation agriculture as a climate change mitigation activity in Australian dryland grain production. *Agricultural Systems*, *135*, 20-30. https://doi.org/10.1016/j.agsy.2014.12.002

Swan, A. R. H., and Sandilands, M. (1995). Introduction to Geological Data Analysis. Blackwell Science, Oxford, UK. 446 pp.

Tamirat, T. W., Pedersen, S. M., Farquharson, R. J., de Bruin, S., Forristal, P. D., Sørensen, C. G., and Thomsen, M. N. (2022). Controlled traffic farming and field traffic management: Perceptions of farmers groups from Northern and Western European countries. *Soil and tillage research*, *217*, 105288. https://doi.org/10.1016/j.still.2021.105288

Tullberg, J. (2010). Tillage, traffic and sustainability-A challenge for ISTRO. *Soil and Tillage Research*, *111*(1), 26-32. https://doi.org/10.1016/j.still.2010.08.008

Tullberg, J. N., Yule, D. F., and McGarry, D. (2007). Controlled traffic farming-from research to adoption in Australia. *Soil and Tillage Research*, *97*(2), 272-281. https://doi.org/10.1016/j.still.2007.09.007

Wang, X., Gao, H., Tullberg, J. N., Li, H., Kuhn, N., McHugh, A. D., and Li, Y. (2008). Traffic and tillage effects on runoff and soil loss on the Loess Plateau of northern China. *Soil Research*, *46*(8), 667-675. https://doi.org/10.1071/sr08063