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The Effect of Soil Compaction Using Rice Combine Harvesters on its Physical Properties and Bio- Activities

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ABSTRACT

Choosing the proper size of rice combine harvesters and soil moisture content are crucial factors in maintaining the soil from over-compacting and avoiding harmful effects on its physical properties and vital activities. This study aims to assess the effect of using four types of rice combine harvesters (4-rows with cereal collecting tank 4-HRC, 4-rows with cereal discharge tank 4-HRD, 5-rows with cereal discharge tank 5-HRD, and 6-rows with cereal discharge tank 6-HRD) on the soil's physical properties (bulk density, pore volume, penetration resistance, crawler print sinkage at the soil surface), soil micro-organism activities (total microbial count and dehydrogenase enzyme activity), and the next crop growth properties (plants /m^2 and forage yield), under three different soil moisture contents (30-35%, 35-40%, and 40-45%). The results revealed that the 6-HRD harvester induced the highest soil bulk density, penetration resistance, and crawler print sinkage compared with the other harvesters. However, the minimum values were associated with the 4-HRC harvester. The soil moisture content of 30-35% showed low values of bulk density, crawler print sinkage, and penetration resistance compared to the soil moisture content of 35-40% and 40-45%. The soil microbial count and soil dehydrogenase enzyme activity are inversely proportional to the soil compaction level at all combine harvesters and soil moisture contents. The values of the total count of fungi, actinomycetes and bacteria, and dehydrogenase activity were found to be decreased as the combine size (width) increased.

Keywords: Soil compaction, physical properties, microorganism activities

INTRODUCTION

Recently, to meet the requirements of global food security, agriculture has been intensified to feed the rapidly growing world population. This has quickly expanded mechanized agriculture soil preparation to crops harvesting and intensive use of farm machinery operations, consequently increasing soil compaction (Orzech *et al.*, 2021). compaction of the soil occurs when external stress applied on the soil surface exceeds the mechanical stability of the soil (Gürsoy, 2021). Soil compaction is a concealed type of soil deterioration that is challenging to identify on the soil surface. As a result of this compaction, the soil becomes stiffer, resulting in higher energy requirements for cultivation and an increase in traction forces and fuel consumption (Bengough *et al.*, 2011; Ramazan *et al.*, 2012). The compactness of the soil is determined by three primary factors: the soil's water content, texture and structure, and organic matter content (Nawaz *et al.*, 2013). However, the major factors affecting soil compaction are the heavy wheel loads of machinery and the number of machinery passes in the field, poor timing of field operations with respect to soil moisture content and intensification of crop production (Augustin, 2020; Fred and Vanes, 2021).

Soil compaction, which denotes lessening the soil pores and increasing the soil density and strength, plays an essential role in plant growth (Sudduth *et al.*, 2008). It harms crop production by decreasing porosity, aeration and infiltration capacity, increasing resistance, soil bulk density, water inter-flow, and erosion (Grigal, 2000; Holshouser, 2001). The compaction of soil caused by passaging machinery has significant economic and biological implications, including reduced crop productivity due to increased mechanical strength, resulting in a decrease in water and nutrient uptake (Sadras *et al.*, 2016; Horn *et al.*, 2019; Keller *et al.*, 2019). This circumstance can obstruct root elongation and considerably reduce crop growth and yield (Shah *et al.*, 2017; Wozniak, 2020). The majority of studies have indicated that crop yields have been adversely impacted by soil compaction. Byszewski and Haman (1974) conducted research that revealed how field operations utilizing a tractor weighing over 2 tons resulted in an increase in soil density from 1.57 to 1.68 g/cm^{-3}. Lipiec *et al.* (2003) concluded that increasing soil compaction decreases the root extent and concentration in the upper soil layer, lower rooting depth, and a widening distance between the roots. The primary contributors to soil compaction are the excessive weight loads exerted by wheels and the frequency of tractor passes in the field (Augustin, 2020). Charma and Murphy (2007) reported that simultaneous high axle load and high moisture could cause soil compaction at greater depths. Fred and Vanes (2021) illustrated that at height soil moisture content, the force causing compaction in the upper surface is easy to move to the subsoil layer, resulting in further damage from compaction.

Soil compaction is widely recognized as a significant issue that disrupts the structure and function of soil microbes. This is primarily due to the restricted permeability of air and limited availability of oxygen, which in turn affects soil nutrition (Defossez and Richard, 2002). In addition, soil compaction plays a crucial role in influencing the activity of the microbial community. The increase in soil density alters

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the size and distribution of pores, resulting in reduced rates of oxygen and carbon dioxide diffusion. This creates an environment with more anaerobic microsites, leading to a decline in aerobic microbial activity. These changes in microbial activity have significant implications for nutrient cycling patterns and their availability to plants, ultimately leading to decreased soil productivity (Tan *et al.,* 2005; Sérgio *et al.,* 2011). Also, soil compaction decreases the carbon dioxide produced by soil micro-organisms. The soil respiration of micro-organism was affected by the soil texture, and the soil respiration is considered the index of microbial activity measurement under soil compaction conditions. Therefore, the inadequate oxygen supply to plant roots has a detrimental impact on their physiological functions. Moreover, the activities of soil animals and aerobic micro-organisms are hindered, leading to a decrease in soil enzyme activity. As a result, soil fertility is diminished (Niu *et al.,* 2012a; Akhavan, 2012). Soil micro-organisms and the associated soil enzymes are integral components of agricultural ecosystems. They serve as sensitive biosensors, indicating environmental changes, and play crucial roles in soil functions. Furthermore, they have been utilized as indicators to assess the impact of soil management practices and overall soil quality. Bacteria fulfill significant functions, such as decomposing organic matter and breaking down cellulose. On the other hand, fungi contribute to the soil carbon cycle by decomposing cellulose, lignin, and pectin, releasing nutrients. Additionally, the growth of fungal mycelium enhances the physical structure of the soil. Actinomycetes are the major producers of antibiotics, which have a crucial bio-control effect critical to soil phosphatase activity (Ghorbani-Nasrabadi *et al.,* 2013; Tedersoo *et al.,* 2014). Soil compaction destroys the physical environment, including soil pore size and the stability of soil aggregates. Consequently, these alterations directly impact the soil organisms that inhabit these environments (Ouyang, 2016). Moreover, any form of soil disturbance or stress can have an impact on enzymatic activities within the soil, resulting in a decrease in dehydrogenase activities. This situation, in turn, can influence the soil's nutrient cycle and subsequently affect crop plants (Beylich *et al.,* 2010; Jezierska-Tys *et al.,* 2010; Al-Maliki, 2016).

Clay soil is the dominant soil class of agricultural soils in the northern delta region of Egypt. where, the mechanical harvesting is rapidly increasing locally for rice fields in this region and the increasing utilization of a rice combine harvester has a critically and a significant impact on soil compaction in these areas. From these points of view, the proper size of the rice combine harvester and the appropriate moisture content of the soil are crucial factors in reserving over-compacting and avoiding harmful effects on the soil's physical and its bioactivity during rice crop harvesting. Therefor, this study aims to assess the use of different size of rice combine harvesters on soil compaction and its effect on soil phsical properties and its bioactivity. In addtion to determine the optimum conditions for rice harvesting in such soil condition.

MATERIALS AND METHODS

Field trials were conducted at the Rice Mechanization Center (RMC) experimental farm in Meet El-Deeba, Kafr El-Sheikh Governorate, Egypt. The experimental farm is situated at approximately 31° 6′N latitude, 30° 50′E longitude, with an elevation of around 6 meters above sea level, in the rice harvesting season of 2020. Soil samples were randomly sampled from the experimental sites at 0-60 cm depth and analyzed to determine the soil texture of the experimental field. The samples were analyzed in the laboratory of Soil Research Institute, Sakha Research Station, Kafr El-Sheikh, and the soil mechanical analysis is shown in Table (1).

Table 1. Soil mechanical analysis and soil texture of the experimental field.

Clay, %	Silt, %	(Clay + Silt), %	Sand, %	$Caco_3$, %	Organic matter, %	Soil type
53.32	17.63	70.95	29.05	1.3	1.71	Clay

The experiments were conducted to evaluate the effect of soil compaction using rice combine harvester that different in number of harvesting rows and cereal tank capacity (four, five, six harvesting rows with discharge tank and four harvesting rows with collecting tank) at different soil moisture contents (30-35, 35-40, and 40-45%). Experimental treatments are laid out in a split plot design with three replications. The main plot was combine size, and harvesting at different soil moisture content was the subplot. The specifications of combine harvesters used in this study are presented in Table (2). The agronomic consideration and treatments for the next forage crop of alfalfa, Meskawy variety with a seed rate of 30 kg/fed (seeds mass of 4.16 g for 1000 seeds), including sowing date, fertilizers, irrigation and etc. were carried out according to the technical recommendation of Forage Crops Department, Crop Research Institute, Agricultural Research Center.

Table 2. The specification of different combine harvesters.

Type	KUBOTA PRO-588I	DAEDONG	KUBOTA PRO-888GM	KUBATA AR80
Model	PRO-5881	DSM 65G	4LBZ-1728	SDMTSQ
Number of rows	4	4	5	6
Dimensions, mm Length × width × height	4240×1900×2200	4740×1790×2320	4615×2100×2415	4750×2150×2670
Weight, kg	2300	2860	3350	3530
Grain tank type and capacity, kg	Packing tank in bags (200)	Storage tank with discharge auger (1100)	Storage tank with discharge auger (1500)	Storage tank with discharge auger (1900)
Harvesting width, mm	1450	1500	1720	1940
Rated power, kW (hp)/rpm	46 (62.6)/2700	47.8 (65)/2800	66.1 (89.9)/2400	59 (80)/2600
Crawler dimension, mm	400 × 1350	450 × 1530	500 × 1670	500 × 1780
Contact pressure (with full grain tank, (kg/cm^2)	0.231	0.288	0.290	0.305
Combine name abbreviation	4-HRC	4-HRD	5-HRD	6-HRD

Study measurements.

In this study, the soil physical properties (soil bulk density, pore volume, penetration resistance, and crawler print sinkage); soil microorganism activities (total count of fungi, actinomycetes and bacteria and dehydrogenase enzyme activity), and next crop growth properties (No. of plants/m^2

and forage yield/fed) were taken as an indicators of induced soil compaction after rice mechanical harvesting. These experimental measurements could be explain as follows:

1- Soil physical properties.

The soil samples were randomly collected from the pathways of the left and right crawlers using a core sample at three different depths (0-10 cm), (10-20 cm), and (20-30 cm). The samples were dried at 105 Cº for 24 hours in the electric oven. Soil bulk density (B_d, g cm^{-3}) before and after all treatments was determined using formula (1). However, the pore volume percentage (V_p, %) was determined using formula (2), and the soil moisture content (M_C, %) was calculated using formula (3):

$$B_d = \frac{W_d}{V} \quad \text{......} (1)$$

$$V_P = 1 - \frac{B_d}{S_d} \times 100 \quad \text{......} (2)$$

$$M_C = \frac{M_w - M_d}{M_d} \times 100 \quad \text{......} (3)$$

Where:

W_d denotes the mass of the cylinder with soil after drying, (g); V denotes the volume of the cylinder, (cm^3); S_d denotes the soil substance density (2.63 g cm^{-3}); M_w denotes the wet soil mass (g), and M_d denotes the dry soil mass, (g).

The soil penetration resistance was measured at at three different depths (0-10 cm), (10-20 cm), and (20-30 cm) using a Japanese cone penetrometer, model SR-2 Dik 5500, to determine the average soil penetration resistance under combined traffic. The penetration resistance (P.R, kPa) is determined using formula (4):

$$P.R = \frac{10 \times F}{A} \quad \text{......} (4)$$

Where:

F denotes the required force, (N), and A denotes the cone area, (cm^2).

The print sinkage of the combine crawlers in the soil (Fig. 1) was measured using a measuring tape to determine the distance of the deepest point under the crawler to the soil surface adjacent of the crawler track as an average of the left and right crawlers under combine traffic.

Fig. 1. Measuring soil penetration resistance and print sinkage of the combine crawlers.

2- Soil microorganism activity.

The Soil microorganism activity including total count of fungi, actinomycetes and bacteria and dehydrogenase enzyme activity were taken as bio-indicators of overall micro-organism activities in compacted soil using a combine harvester during rice harvesting season. The soil samples were randomly collected from compacted soil under each combine crawler and from uncompacted soil between combine crawlers (as a control treatment) at 0–10 cm depth with three replicates after harvesting rice crop immediately and after 2 months of clover (next crop) planting. The soil samples were air dried for 48 hours, sieved to <45 mm, and sent to the microbiology laboratory of Soil Science and Water Research Institute, Agricultural Research Center, for measuring the soil micro-organism activities of fungi, actinomycetes and bacteria total count and dehydrogenase activity according to their analyzing protocol for these types of measurements.

3- Next crop growth properties.

To recognize the harms of compacted soil caused by the different combine harvesters, the next crop growth properties, such as the number of plant/m^2 and total forage yield of alfalfa crop growing in compacted soil under combine traffic as an average of the left and right crawlers compared with uncompact soil between combine crawlers were determined. The number of alfalfa plants was counted in the combine crawler tracks and between them 25 days after sowing. A wooden frame with dimensions of 0.4 m in width and 1 m in length was placed on the ground, and the number of plants inside the frame was counted. The fresh forage yield/m^2 of the alfalfa crop was determined by cutting the forage from areas under combine crawler tracks and between them. The number of plant/m^2 and forage yield/m^2 samples were randomly taken with 3 replicates and forage yield/m^2 was converted to Ton/fed.

RESULTS AND DISCUSSION

1- Soil bulk density and pore volume

The results illustrated in Figs. (2 and 3) show the average soil bulk densities and soil pore volume percentages after one pass for different types of combine harvester at three different soil moisture contents (30-55, 35-40, and 40-45%) and three soil depths (0-10, 10-20, and 20-30 cm). From these results, it could be noticed that there is an increment of soil bulk density and a decrement in soil pore volume for all combine harvesters with increasing soil depth (up to 30 cm) and soil moisture content (up to 45%). However, the increment rate in soil bulk density and decrement rate in soil pore volume increased with increasing soil depth and soil moisture content. In other words the percentage of increment of the soil bulk density accordingly the decrement of pore volume was higher at soil depths of 10-20 and 20-30 cm than at 0-10 cm soil depth. This is because the trafficking in wet soil causes a hydraulic ram effect and the soil is compacted quickly to saturation and the surface stresses are directly transferred to the subsoil as water cannot be compressed.

On the other hand, using the combine harvester 4-HRC induced the lowest values of soil bulk density and highest values of pore volume, whereas, using the combine harvester 6-HRD resulted in the highest values of soil bulk density and lowest values of pore volume compared to the other harvesters. Increasing soil moisture content from 30-35% to 40-45% increased the soil bulk density from 1.315 to 1.372 kg/cm^3, from1.320 to 1.387 kg/cm^3, and from1.232 to 1.398 kg/cm^3, and decreased the soil pore volume from 50.01% to 47.84%, from 49.81% to 47.25%, and from 49.70% to 46.83% as an average values for all combine harvesters under study at a soil depth of 0-10, 10-20, and 20-30, respectively. However, using the combine harvesters of 4-HRC, 4-HRD, 5-HRD, and 6-HRD resulted in an increase in the mean values of soil bulk density by 4.32%, 6.44%, 7.99%, and 9.67%, respectively compared to the mean values that found between harvesting traffic (uncompacted soil). However, the pore volume mean values decreased by 3.98, 5.94, 7.37, and 8.93%, respectively. These data are in agreement with the results obtained by Silva *et al.* (2011); Svoboda *et al.* (2016); Huo *et al.* (2020).

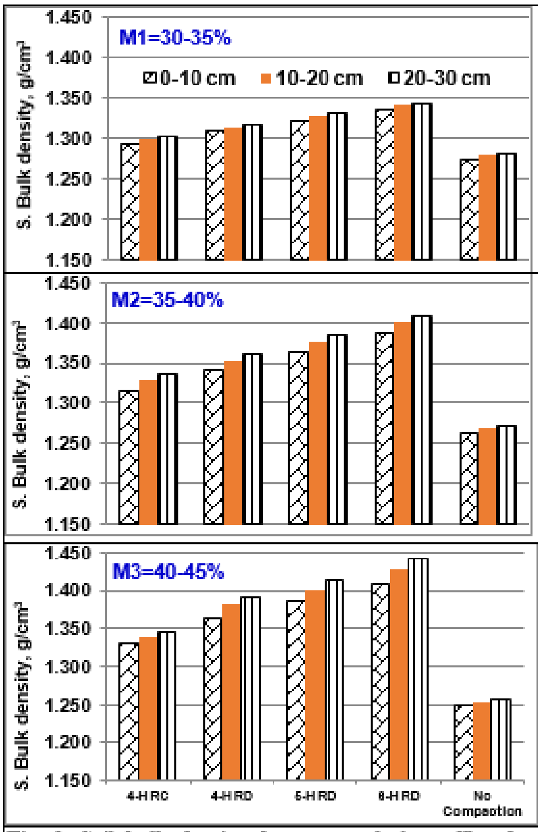

Fig. 2. Soil bulk density due to crawler's traffic of different rice combine harvesters under different soil moisture contents.

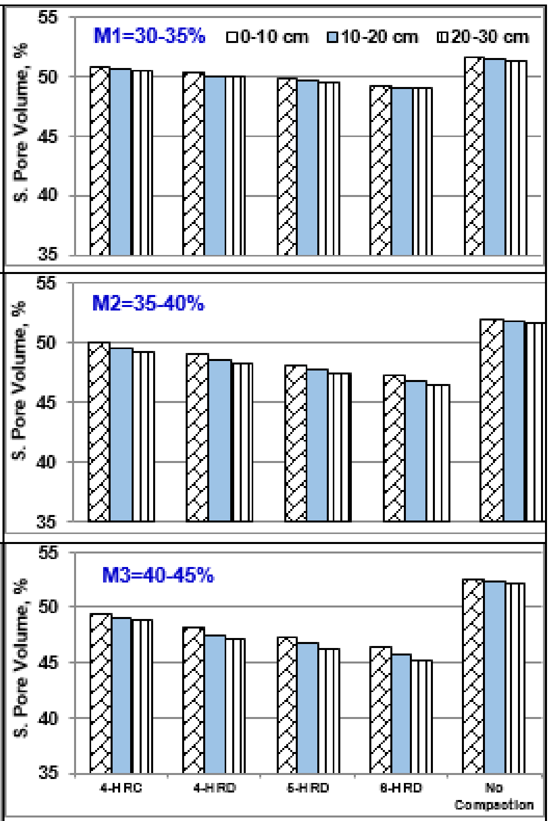

Fig. 3. Soil pore volume due to crawler's traffic of different rice combine harvesters under different soil moisture contents.

Table (3) displays the summary of statistical information (ANOVA analysis, significant level of F-test) for some soil properties (soil bulk density and soil pore volume percentage) as an indicator for soil compaction when using different types of combine harvesters under different soil moisture contents.

Table 3. F values and degree of freedom (df) for the effect of size of combine harvester, soil moisture content, and their interaction by ANOVA on some soil properties.

Effect	S	M	S × M
df	3	2	6
Soil bulk density at 0-10 cm	229.53***	23.93***	1.51 ns
Soil bulk density at 10-20 cm	890.11***	1528.45***	157.51***
Soil bulk density at 20-30 cm	1233.24***	479.84***	69.10***
Soil pore volume at 0-10 cm	1021.52***	3387.60***	0.36 ns
Soil pore volume at 10-20 cm	183.48***	376.06***	0.29 ns
Soil pore volume at 20-30 cm	1576.89***	3117.92***	0.23 ns

F values from the ANOVA analysis revealed that the effect of the type of combine harvester (M) and harvesting at different soil moisture contents (S) were highly significant effects (P>0.01) on soil bulk density and soil pore volume at all depths used in this study. Whereas, the interactions (S × M) between the soil moisture content (S) and type of combine harvester (M), showed a highly significant effect on the soil bulk density at all depths, except the depth of (0-10 cm), and it had no significant effect on soil pore volume at any given soil depth.

The results presented in Figure (4) show the average soil penetration resistance after one pass for different types of combine harvester, at three different soil moisture contents (30-35, 35-43, and 40-45% d.b.) and three soil depths (0-10, 10-20, and 20-30 cm). From these results, it could be indicated that the harvesting traffic for all combine harvesters under study resulted in an increment percentages in the soil compaction due to increase the soil penetration resistance after harvesting rice crop at any given soil moisture content and soil depth. Also, an increase in the soil compaction as an indicator for soil penetration resistance was observed with increasing combine size (weight) due to the full capacity of the grain tank; of course, this effect depends on the harvesting width of the combine harvester and the volume of its grain tank. The lowest values of soil penetration resistance (194.7, 389.2 and 417.3 kPa) were associated with the traction crawlers of 4-HRC compared with other combine harvesters under study at any given soil moisture content and soil depth. In contrast, the highest values of soil penetration resistance (360.4, 554.9 and 592.8 kPa) were recorded under the traction crawlers of 6-HRD compared with other combine harvesters under study at any given soil moisture content and soil depth.

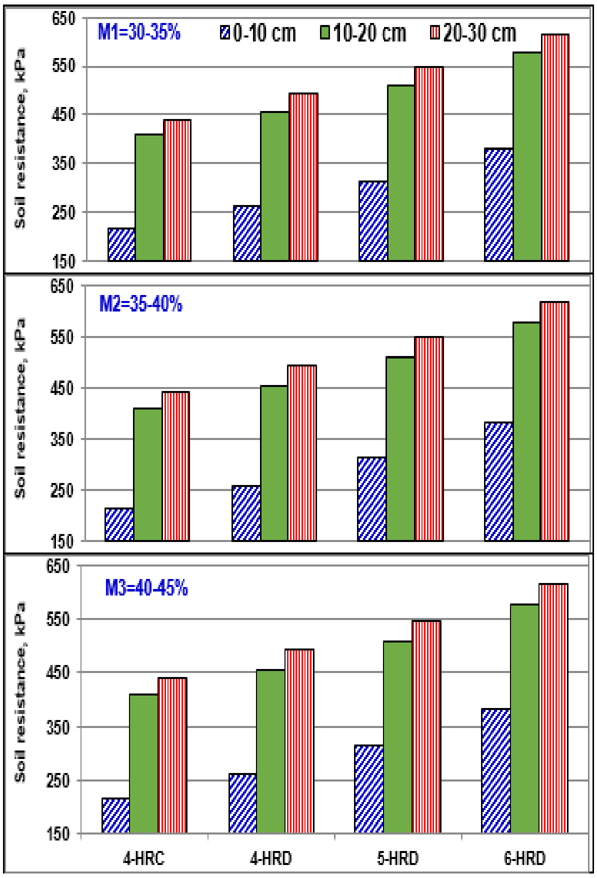

Fig. 4. Soil penetration resistance due to crawler's traffic of different rice combine harvesters under different soil moisture contents.

It can be noticed from Figure (4) that the soil compaction was inversely proportional to harvesting at different soil moisture content. Increasing soil moisture content from 30-35% to 40-45% decreased soil penetration resistance from 293.0 to 249.8 kPa, from 488.1 to 444.0 kPa, and from 524.9 to 477.8 kPa as an average values for all combine harvesters under study at a soil depth of 0-10, 10-20, and 20-30, respectively. For all harvesters used in this study, harvesting at a soil moisture content of 40-45% resulted in a minimum value of an increment percentage in soil penetration resistance. The maximum values of increment percentage in soil penetration resistance were recorded at 30-35% soil moisture content. The obtained values of soil penetration resistance ranged from 194.7 to 360.4, from 389.2 to 554.9 and from 417.3 to 592.8 kPa as an average values for all combine harvesters under study at soil depths of 0-10 cm, 10-20 cm, and 20-30 cm, respectively. These results may attribute to the fact that in wet soil, the compaction that occurs near the surface is transferred to the deeper surface. These outcomes are in line with the results reported by Mooney and Nipattasuk (2003); Lanzanova *et al.* (2007); Usowicz and Lipiec (2009); Abich *et al.* (2022).

The obtained values of sinkage depth due to crawler's traffic of different rice combine harvesters under different soil moisture contents are shown in Fig. (5). These results concluded that the sinkage depth (cm) of combine crawler print was directly proportional to the size of the harvester. Using 4-RHC, 4-RHD, 5-RHD and 6-RHD combine harvesters at the highest level of soil moisture content (40-45%) resulted in maximum values of crawler print sinkage (4.73, 5.25, 6.10 and 6.92cm, respectively). However, the minimum values of crawler print sinkage (4.11, 4.42, 5.02 and 5.72cm, respectively) were recorded at 30-35% soil moisture content. On the other side, there is a positive correlation was found between sinkage depth and soil moisture content. An increment precentages about 7.54, 24.57 and 44.04% in the crawler print sinkage of the combine were recorded by increasing size and weight of combine due to the filling grain tank of 4-RHD, 5-RHD and 6-RHD combine harvesters, respectively compared with 4-RHC combine harvester at 30-35% soil moisture content. Also, the combine weight effect was observed to be increased by incresing soil moisture content at harvesting time. Therefor, the crosponding values of increment precentages about 10.99, 28.96 and 46.30% in the crawler print sinkage of the combine were recorded at 40-45% soil moisture content by increasing size and weight of combine due to the filling grain tank of 4-RHD, 5-RHD and 6-RHD combine harvesters, respectively compared with 4-RHC combine harvester. The total harvesting traffic area of combine harvesters represents 35-40% of the total harvested field area, depending on the field dimensions. The crawler print sinkage induced on the soil surface due to the combine's traffic in addition to the bad changes in soil physical properties led to collect irrigation water in the passes sinkage, especially with the surface irrigation system, causing damage to the next crop seeds, especially in the germination stage, as confirmed by Svoboda *et al.* (2016); Augustin, (2020); Fred and Vanes (2021).

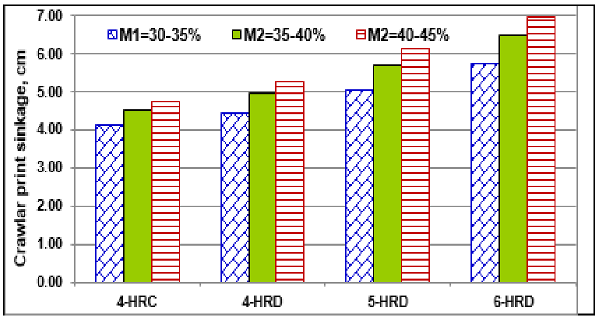

Fig. 5. Crawler print sinkage due to crawler's traffic of different rice combine harvesters under different soil moisture contents.

The analysis of variance for the change in soil penetration resistance due to harvesting traffic of different sizes of rice combine harvesters under different soil moisture contents was conducted, and the obtained results are listed in Table (4). There were highly significant differences ($p<0.01$) between the size of the combine (M) and soil moisture content (S) at any given soil depth. While, the interactions effect ($S \times M$) between the previous factors was insignificant. Similar significant trends have been obtained for crawler print sinkage, which was highly significantly affected by the harvester type and soil moisture content, while the interaction effect (S × M) was not significant at any given soil depth.

Table 4. F values and degree of freedom (df) for the effect of size of the combine harvester, soil moisture content, and their interaction by ANOVA on some soil properties.

Effect	S	M	S × M
df	3	2	6
Soil penetration resistance at 20-10 cm	684.73***	23.24***	0.32 ns
Soil penetration resistance at 10-20 cm	718.96***	24.84***	0.32 ns
Soil penetration resistance at 20-30 cm	766.16***	28.53***	0.32 ns
Crawler print sinkage	39.25***	18.60***	0.267 ns

2- Soil microorganism activity

The obtained results of soil micro-organism activities, including a total count of fungi, actinomycetes and bacteria and dehydrogenase enzyme activity in the compacted soil by harvesting traffic of different rice combine harvesters, under different soil moisture contents compared with uncompacted soil are illustrated in Figure (6). These results indicated that there is a negative correlation between total soil microbial count or soil dehydrogenase enzyme activity and soil compaction level for each size of combine harvester under any given soil moisture content. The values of the total count of fungi, actinomycetes and bacteria and dehydrogenase activity were found to be decreased as the combine size (width) increased; while the decrement rate was increased with increasing soil moisture content at harvesting time. Regarding to soil compaction due to use 6-HRD combine harvesters for rice harvesting at the highest soil moisture content of 40-45%, decreased the total count of fungi, actinomycetes, bacteria and dehydrogenase activity by about 64.88; 63.93; 58.89 and 51.78%, respectively while, it were decreased by about 26.45; 30.51; 22.80 and 33.49%, respectively in the compacted soil by harvesting traffic of 4-HRC comparing with uncompacted soil. Moreover, when using combine harvesters for rice harvesting at the lowest soil moisture content of 30-35%, the total count of fungi, actinomycetes, bacteria and dehydrogenase activity were decreased by 38.70; 41.74; 34.60 and 26.09%, respectively in the compacted soil by harvesting traffic of 6-HRD, while, it were decreased by about 6.64; 3.68; 4.45 and 7.20% respectively in the compacted soil by 4-HRC comparing with uncompacted soil.

These results means that using 6-HRD, gave the highest level of soil compaction comparing with other sizes of combine harvesters under study at any given soil moisture content under study. Also, using 4-HRC gave the lowest level of soil compaction comparing with other sizes of combine harvesters under study at any given soil moisture content under study. Meanwhile, the compaction level was rapidly increased when harvesting rice crop with any size of combine harvester under study at soil moisture content higher than 30-35%.The total count of fungi, actinomycetes and bacteria and dehydrogenase activity have been negatively affected by soil compaction due to the consequences of soil compaction, including an increase in the soil bulk density, decreased soil porosity and decreased soil aggregates stability which affected on water infiltration rate, reduction of aeration and temperature and resulted in substantial biological consequences, such as reduces hydraulic conductivity and O_2 and CO_2 diffusion rates, caused a restriction of the growth of a total number of soil bacteria and decreases the dynamic and hydrolytic enzymes activity, especially dehydrogenases. These results were agreed with the finding of Sérgio *et al.* (2011); Niu *et al.* (2012a); Ghorbani-Nasrabadi *et al.* (2013); Tedersoo *et al.* (2014); Ouyang (2016); Al-Maliki (2016).

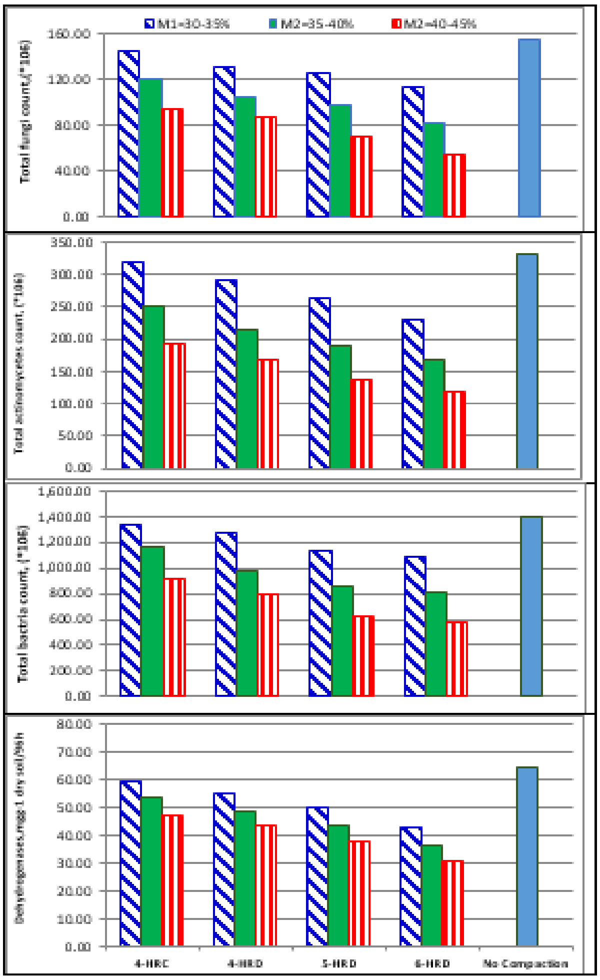

Fig. 6. Effect of crawler's traffic of different combine sizes on the soil microorganism activities during growing next forage crop under different soil moisture contents.

The statistical analysis of ANOVA cleared that the size of combine harvester (M) and harvesting at different soil moisture contents (S) had a highly significant effect (P>0.01) on the total count of fungi, actinomycetes and bacteria and dehaydrogense enzyme activity as shown in Table (5).

Table 5. F values and degree of freedom (df) for the effect of size of the combine harvester, soil moisture content, and their interaction by ANOVA on soil micro-organism activity.

Effect	S	M	S × M
df	3	2	6
Total fungi count	624.68***	5201.69***	36.00***
Total actinomycetes count	4088.59***	18563.11***	12.04***
Total bacteria count	2476.99***	18310.11***	3.69*
Dehydrogenase enzyme activity	163.41***	764.69***	1.31 ^{ns}

However, the interaction between the previous variables (S x M) had a highly significant effect (P>0.01) for the total count of fungi, actinomycetes and bacteria and significant effect (P>0.05) for the dehaydrogense enzyme activity.

3- Next crop growth properties

The next alfalfa crop (Meskawy variety) was planted directly after mechanical harvesting of rice crop with no seedbed preparation (No-till) to measure the growth properties of alfalfa crop, including the average number of plants/m^2 (NP) and average forage fresh yield/feddan (FY) in the compacted soil under harvesting traffic of combine harvesters compared with crop growth properties in uncompacted soil in the areas between combine crawlers, and the obtained results were illustrated in Figure (7). These results indicatd that a decrement percentages were observed in the values of average number of plants/m^2 NP and average forage fresh yield/feddan FY with increasing combine size (weight) for the grown crop in the compacted soil under harvesting traffic of combine harvesters compared with uncompacted soil between combine crawlers. Using a 4-HRC, 4-HRD, 5-HRD , and 6-HRD, harvester decreased NP by 25.54, 33.10, 41.49, and 48.64% and FY by 28.42, 36.35, 43.09, and 48.90%, respectively compared to the values of NP and FY, in the compacted soil between harvester crawlers (control treatment).

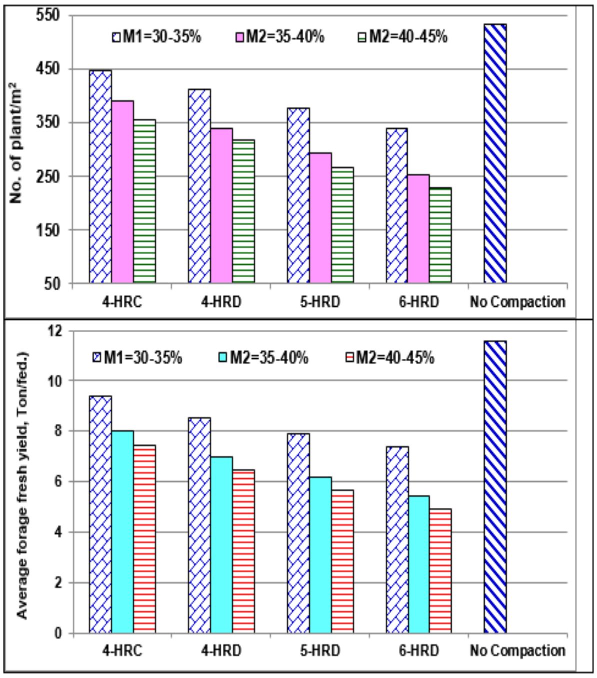

Fig. 7. Effect of crawler's traffic of different combine sizes on the No. of plants/m2 and yield of next forage crop under different soil moisture contents.

The results also indicated that the NP and FY were inversely proportional to the different soil moisture contents for all types of combine harvesters under study. Increasing the soil moisture content from 30-35% to 40-45% decreased the NP and FY by 21.10%, and 26.86%, respectively.Also, from these results it could be observed that the lowest values of NP and FY were attendant with a 6-HRD and 40-45% soil moisture content. Whereas, using 4-HRC at 30-35% soil moisture content resulted in the highest values of NP and FY. This was attributed to increasing the soil compaction and decreasing the porosity, aeration, and infiltration in which the water and nutrient uptake decrease. These results are in harmony with the findings obtained by Sadras *et al.* (2016); Horn *et al.* (2019); Keller *et al.* (2019).

The analysis of variance (ANOVA) shown in Table (6) cleared that the soil moisture content (S) and harvester size (M) had a highly significant effect (P>0.01) on the average number of plants/m^2 (NP) and average forage fresh yield per feddan (FY) for alfalfa forage crop. However, the interaction effect (S × M) between the previous variables had no significant effect on (NP), and it was significant (P>0.05) for FY.

Table 6.. F values and degree of freedom (df) for the effect of size of combine harvester, soil moisture content and their interaction by ANOVA on the next crop growth properties.

Effect	S	M	S × M
df	3	2	6
Number of plant/m^2	9.74***	86.80***	0.45 ^{ns}
Average forage yield/fed.	2280.02***	8858.32***	6.22**

CONCLUSION

- All types of combine harvester under study caused soil compaction due the negatively effect of harvesting traffic of combine harvester on soil physical properties, next crop growth and yield, soil biological activity as a functions of soil compaction.
- The negative effect due to harvesting traffic of combine harvester has incited direct and adverse changes in soil physical parameters, which increases soil bulk density, reduces soil pore volume percentage and its distribution, increases soil penetration resistance and increase crawler print sinkage, which affected on water infiltration capacity, air permeability, temperature, rooting space, nutrient flow, consequently affected on plant growth and its productivity in addition the soil microorganisms community and its biological activity.
- This effect was increased with increasing combine harvester size (weight) and increasing soil moisture content at harvesting time. Therefore, using 6-HRD combine harvesting gave the highest level of soil compaction comparing with other sizes of combine harvesters under study at any given soil moisture content under study. Also, using 4-HRC gave the lowest level of soil compaction comparing with other sizes of combine harvesters under study at any given soil moisture content under study.
- The authors recommended that, if rice crop has been harvesting at soil moisture content higher that 35-40%, it is better to use 4-HRC or 4-HRD of crawler type combine harvester. Also, it could be using 5-HRD or 6-HRD under this conditions, with consideration of keeping the grain tank always near empty.

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تأثير انضغاطية التربة باستخدام آلات حصاد الأرز الجامعة على خواصها الفيزيائية وأنشطتها الحيوية

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الملخص

يعد اختيار الحجم المناسب لآلات حصاد الأرز الجامعه ومحتوى رطوبة للتربة المناسب من العوامل الحاسمة في الحفاظ على عدم الانضغاط الزائد للتربه وتجنب التأثيرات الضارة على خواصها الفيزيائية وأنشطتها الحيوية. أثناء حصاد محصول الأرز خاصة فى التربة الطينية لشمال الدلتا فى مصر. لذلك تهدف هذه الدراسة إلى تقييم استخدام اربع أنواع مختلفة من آلات حصاد الأرز الجامعة (الكومباين) على انضغاطية التربة وتأثيرها على الخواص الفيزيائية للتربة ونشاطها الحيوي لتحديد الظروف المثلى لحصاد الأرز. حيث تم استخدام أربعة أنواع مختلفة من آلات حصاد الأرز الجامعة :4 صفوف بخزان تجميع الحبوب (4-HRC)، 4 صفوف بخزان تفريغ الحبوب (4-HRD)، 5 صفوف بخزان تفريغ الحبوب (5-HRD) و 6 صفوف مع خزان تفريغ الحبوب (6-HRD) عند ثلاثة محتويات رطوبة للتربة (30-35%، 35-40%، و 40-45 %). تم دراسة تأثير هذه الالات على الخصائص الفيزيائية للتربة (الكثافة ، حجم المسام، مقاومة الاختراق، عمق أثر كتينه الكومباين على سطح التربة)، والنشاط الحيوى للتربة (إجمالي العدد الميكروبى (الفطريات والخمائر والبكتيريا) ونشاط إنزيم الديهيدروجينيز)، وخصائص نمو المحصول التالي (عدد النباتات /م^2 وإنتاجية محصول العلف /فدان). وقد أظهرت النتائج أن استخدام آلة الحصاد 6-HRD أعطى أعلى كثافة ومقاومة اختراق للتربة وعمق أثر كتينه الكومباين بالمقارنة مع آلات الحصاد الأخرى، بينما كانت أقل قيم عند استخدام آلة الحصاد 4-HRC . اعطى الحصاد بهذه الالات قيمًا منخفضة لكثافة ومقاومة اختراق التربة وعمق أثر كتينه الكومباين عند محتوى رطوبة التربة 30-35% مقارنةً بمحتويات الرطوبة الاخرى 35-40% و 40-45%. انخفضت قيم إجمالي العدد الميكروبى (الفطريات والخمائر والبكتيريا) ونشاط إنزيم الديهيدروجينيز بزيادة حجم كومباين الحصاد (العرض والوزن).