International Journal of Basic Sciences & Applied Research. Vol., 3 (9), 611-615, 2014
Available online at http://www.isicenter.org
ISSN 2147-3749 ©2014

Effects of Harvesting Equipment on Soil Compaction in Sugarcane Farms

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Abstract

This study was performed in a cane field in Iran to investigate the effects of harvesting equipment on soil compaction. The study was conducted in a factorial experiment based on the completely randomized blocks design having three replications. Two models of bins, three travel speeds and two tyre inflation pressures were imposed as main plots, subplots and sub-subplots respectively. Results showed that harvester traffic significantly increased soil compaction in the 0-20 cm depth profile; however the difference of soil cone indexes before and after bin traffic was not statistically significant. Other than 0-10 cm and 30-40 cm depth profiles, other layers of soil were significantly affected by exerted treatments. Compaction effect of Shaker bin was lower compared to HEPCO bin because of wider tyres and lesser tread height. By decreasing tyre inflation pressure from 240 to 290 kPa, soil compaction effects of bin traffic decreased. Results also showed that the effect of travel speed treatment mostly appeared in toper layers of soil whereas the effects of bin type and inflation pressure treatments mostly appeared in deeper layers of soil.

Keywords: Compaction, Harvesting equipment, Travel speed, Inflation pressure.

Introduction

About 60 percent of the world's sugar is supplied from sugarcane plant and the rest is produced from sugarbeet. Basically, food, forage, fiber and other products are produced from sugarcane (ZareiShahamat et al., 2013). In recent years, cane has also assumed importance as a source of alcohol production, which can be used as a commercial replacement for petroleum products (Karimi et al., 2008). In the last decades, a great attention has been given to the sugarcane farming in Iran as a strategic crop. One of the most important stages in the cane farming is the harvesting stage. This process invokes a precise management due to the precipitation occurred during harvesting seasons and also the importance of harvesting time on the quality of cane sucrose. Harvesting process of cane in Iran is mostly done using motorized equipment named harvester. Along with travel of harvesters in the field, bins are tracked using tractors near harvesters and harvested yield is continually loaded into the bins. Therefore, each spot in the furrows bed is trafficked with four pass of tyres. The weights of harvesters and bins reach up to 25 ton. Because of the importance of time management in the process of harvesting, this process mostly is completed when the field moisture is high. Therefore, soil undergoes a high rate of compaction.

When farm soils are compacted, pores volumes are reduced and consequently aggregates crumble and smaller inter-aggregate pores with non-accommodating faces are formed (Pagliai & Vignozzi, 2002). The major loss of the largest pores caused by soil compaction changes the pore size distribution and reduces water retention (Dexter, 2004). Compacted soil impedes root growth and thereby limits water of plants. Dense soil depresses crop yields (Tolon-Becerra et al., 2011). Compaction that a machine tyre imposes on the soil is a function of four factors of axle weight, forward speed, tyre inflation pressure and number of passes. Sheikhdavoodi et al (2011) showed that soil compaction increased as forward speed and tyre inflation pressure increased. Abu-Hamdeh and Al-Widyan (2000) evaluated the effects of different tyre inflation pressures and different axle loads on soil compaction and concluded that these factors affected the density of soil layers beyond 20 cm depth. In another study, the effects of two level of axle loads (6.3 and 23.9 kN) and three levels of tyre inflation pressures (324, 524 and 724 kPa) on the compaction of a silty-loam type soil were assessed (Sharifi-Malvajerdi et al., 2013).

The results showed that the increase in the axle load mostly affected the subsoil whereas the effects of increase in the inflation pressure mostly appeared in the upper layers of soil. In a similar study, Arvidsson and Keller (2007) evaluated the effects of two wheel loads (11, 15 and 33 kN) at three inflation pressures of 50, 70 and 150 kPa on soil compaction. The researchers stated that the tyre inflation pressure have a large influence on soil stresses measured at 10 cm depth, but have very little influence in the subsoil (30 cm and deeper). In contrast, wheel load have a very large influence on subsoil stresses. Lejman and Owsiak (2005) evaluated the effects of forward speed of tractor on the cone index and concluded that the coin index value initially decreased with increasing forward speed from 0.5 to 4 m/s but eventually increased with more increase in the speed. Considering the importance of reduction of soil compaction in the harvesting process of cane farming, this study was carried out to evaluate the factors affecting soil compaction in this process.

Methodology

This study was carried out during May 2013 in Karoon agro-industry of Khuzestan, Iran, in a sugarcane field having an extension of 20 hectare. Khuzestan plain is located in southwestern Iran within a latitude gradient of 29˚58́ to 32˚58́ northern and a longitude gradient of 47˚42́ to 50˚39́ eastern. Farms soils were mostly silty-clay loam structured from alluvial materials (Sami et al., 2014). Khuzestan is the leading producer of sugarcane in Iran with several large agro-industries producing sugarcane. The study was conducted in a factorial experiment based on the completely randomized blocks design having three replications. The experiment had three factors of bin type, tyre inflation pressure and forward speed. Two types of bins (Shaker and HEPCO) were assigned as the main plots, subplots were arranged with forward speed at three levels (5, 7 and 9 km/ha) and sub subplot was tyre inflation pressure at two levels of 240 and 290 kPa. Shaker bin has higher capacity than HEPCO bin, nevertheless Shaker bin tyres were wider (more soil-tyre contact area) with lower tyres tread height. Special design of Shaker bin (one side loading) accelerates the loading and unloading processes. However this design imposes limitations when the bin is turning at row-ends of field (Figure 1). Specifications of used bins are presented in table 1.

The cone indexes were measured in different depths of soil from 0 to 80 cm. As the compaction effects of bins depended on the amount of cane stalk in the bin, the measurements were performed in different stages of loading (10 spots in equal distances) from beginning of loading process (empty bin) to unloading time (completely filled bin). Eventually the mean of 10 measured values was used as representative of that plot (Figure 2). Cone index was determined in the field before and immediately after machine traffic in the tyre tracks lanes using a hand held penetrometer (Eijkelkamp, 06.01.SA) according to the standards of ASAE (2006). The penetrometer had a 12.83 mm diameter steel rod an included angle of 30°. Data were measured in an accuracy of 1 cm in the 17.5% of soil moisture. Soil moisture was measured in three depth profiles of 0-20, 20-40 and 40-60 cm and the mean value were considered. The variance analysis and means comparison of data were conducted by Duncan multiplerange test at 5% probability levels using software MSTATC.

Table 1. Characteristics of machines used in the study.

Machine type	Characteristics
HEPCO harvester	Driving system: joy stick- control system: monitoring- maximum engine power: 265 kW- Pneumatic Rubber type wheel
Shaker bin	One side loading - maximum capacity: 8 tone- Pneumatic Rubber type wheel- two axles- connection: goose neck Tire dimensions: 21.7-22.5 cm- Tread height: 3 cm- Empty bin weight: 5.5 tone
HEPCO bin	Two side loading- Maximum capacity: 6 tone- Pneumatic Rubber type wheel- Two axles- Connection: drawbar- Tire dimensions: 17.5-25 cm - Tread height: 5 cm- Empty bin weight: 5.75 tone


Figure 1. Shaker (left) and HEPCO (right) bins.

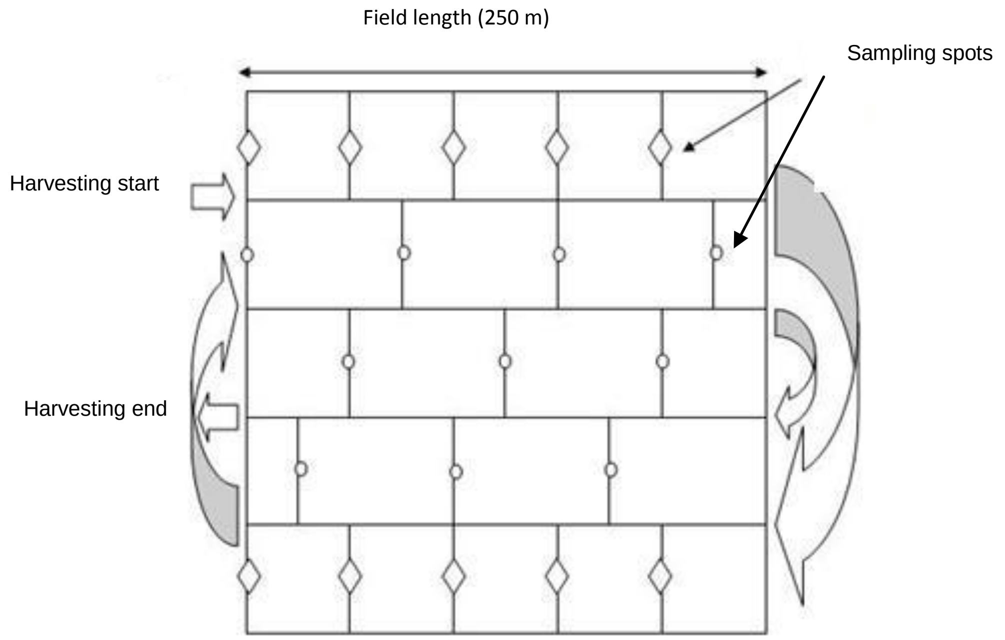

Figure 2. Pattern of equipment travel and sampling in the field.
(Shows sampling points prior and after harvester pass and <> shows sampling points after bin pass)

Results

Results of variance analysis of data are shown in table 2. These results show that in the top layers of soil (0-20 cm), there is a significant difference between soil cone index values in different stages of machines traffic. In these layers, soil cone index values before and after harvester pass were significantly different, nevertheless the difference between cone indexes of soil before and after bins pass was not significant (Table 3). It is likely that during the first passage of equipment (harvester travel) the pore volumes were significantly reduced and passage of bin could not more affect the pores volumes reduction.

Table 2. The variance analysis of soil compaction effects of harvester and bin traffic in different soil depths (Mean of squares was given in this table).

S. O. V.	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	50-60 cm	60-70 cm	70-80 cm
Replication	0.001 ns	0.188 ns	0.550 ns	0.267 ns	0.425 ns	0.474 ns	0.416 ns	1.276 ns
Passing stage	0.539 *	1.861 **	0.275 ns	0.206 ns	1.284 ns	3.251 ns	0.195 ns	1.125 ns
Error	0.044	0.082	0.378	0.354	0.351	0.393	0.548	0.854
C.V. (%)	15.46	13.14	13.68	10.06	11.13	10.02	11.19	15.57

* and **: Significant at the 5% and 1% levels of probability, respectively. NS: Non- Significant.

Table 3. Mean comparison of effects of harvester and bin traffic on cone index in different soil depths.

Item	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	50-60 cm	60-70 cm	70-80 cm
Primary compaction	0.88 b	1.27b	2.31 a	2.78 a	2.61 a	2.89 a	3.23 a	3.14 a
After harvester passing	1.61 a	2.68 a	2.56 a	2.85 a	2.64 a	3.05 a	3.51 a	3.41 a
After bin passing	1.61 a	2.59 a	2.91 a	3.27 a	3.16 a	3.45 a	3.74 a	4.31 a
LSD	0.476	0.649	1.394	1.349	1.343	1.42	1.678	2.10

Means in each column and for each factor, followed by similar letter (s) are not significantly different at the 5% probability level using Duncan's test

According to the results of variance analysis presented in Table 4, in the 0-10 and 30-40 cm depth profiles, there wasn't any significant difference between measured cone index values of different investigated treatments (bin type, forward speed and inflation pressure). This result is according to that of Elliasson (2005) who stated that the effects of farm machineries traffic on soil compaction was not significant in 0-10 cm depth profile. As, the presence of organic matter and crops biomass residue in the soil may absorb the pressure and prevent from soil compaction, it can be concluded that more presence of biomass matters in the higher layers of soil (0-10 cm) reduced the impact of equipment traffic in the studied farms. However, this layer may also be affected by high moisture content of soil, which was considered as a fixe factor in this study. It is also considerable that cone index values for all treatments, after traffic of harvester, were greater than the quoted value of 1.2 MPa cone index recommended by Terminiello et al. (2000) to avoid yield decreases.

In the depths of 10-20 and 20-30 cm the effect of the forward speed treatment on soil compaction was significant in the 5% probability level (Table 4). Soil compaction at 5% probability level significantly increased as the forward speed increased from 5 to 7 km/ha (Table 5). The highest soil cone indexes were observed in speed treatments of 7 and 9 km/ha in the soil depths of 10-20 cm (2.69 and 2.63 MPa respectively) and 20-30 cm (2.94 and 2.70 MPa respectively). The increase of soil compaction in the higher travel speeds can be attributed to the higher vertical load of tyre on the soil in the higher speeds. In other words, the increase in forward speed increased the draft load and consequently increased the vertical load of tyre on the soil. These results are consistent with those of other researchers (Sheikhdavoodi et al., 2011). However some researchers reported a reduction in the soil compaction as forward speed increased (Stafford & De Carvalho Mattos, 1981). This conflict can be answered by the results of Lejman and Owsiak (2005) who expressed the relationship between the forward speed and draft load in the form of a second degree polynomial regression ($D=aS^2+bS+c$) in which the coin index value initially decreased with increasing forward speed but eventually increased with more increase in the speed.

The bin type treatment hadn't any significant effect on soil compaction in the upper layers, nevertheless there was a significant difference between compaction effects of different types of bins in the deeper layers of soil (more than 40 cm) (Table 4). However in the Shaker bin type, the capacity was higher and therefore the axle load of filled bin was higher than that of HEPCO bin, wider tyres and lower tyres tread height of Shaker bin reduced the ground pressure (axle weight/tyre-soil contact area) and therefore reduced the compaction effects of tyre traffic. Narrower tyres are expected to cause higher soil compaction than wider tyres (Froehlich et al., 1980). Shaker bin type, in spite of having limitation when turning in the row-ends, has the higher capacity, easier unloading/loading and less compaction effects on the soil. Applying a proper management on the field/traffic patterns of Shaker type bin (especially turn patterns at row-ends) converts it to suitable equipment for the harvesting processes.

Table 4. The variance analysis of effects of bin type, travel speed and inflation pressure on the cane index in different soil depths (Mean of squares has been given in this table).

S. O. V.	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	50-60 cm	60-70 cm	70-80 cm
Replication	0.271 ns	0.335 ns	1.015 *	0.219 ns	0.007 ns	0.102 ns	0.684 ns	1.368 ns
Bin type (A)	0.370 ns	0.330 ns	0.061 ns	0.060 ns	1.200 *	3.822 **	6.980 **	5.781 *
Forward Speed (B)	0.183 ns	0.963 *	1.265 *	0.472 ns	0.517 ns	0.032 ns	0.469 ns	0.015 ns
AB	0.180 ns	0.150 ns	0.022 ns	0.700 ns	0.266 ns	0.254 ns	0.522 ns	0.411 ns
Tire inflation pressure (C)	0.107 ns	0.000 ns	0.000 ns	0.002 ns	0.353 ns	2.794 **	6.980 **	0.222 ns
AC	0.370 ns	0.067 ns	1.075 ns	0.437 ns	0.109 ns	0.035 ns	0.043 ns	0.188 ns
BC	0.098 ns	0.321 ns	0.562 ns	0.106 ns	0.418 ns	0.032 ns	0.919 ns	1.324 ns
ABC	0.180 ns	0.572 ns	0.860 ns	0.125 ns	0.158 ns	0.060 ns	0.389 ns	0.818 ns
Error	0.131	0.264	0.289	0.218	0.304	0.323	0.605	0.729
C.V. (%)	14.15	13.55	12.31	15.00	10.37	14.52	12.26	11.85

* and **: Significant at 5% and 1% levels of probability, respectively. NS: Non- Significant.

Table 5. Mean comparison of the effects of bin type, travel speed and tyre inflation on the cone index in different soil depths.

Soil depth (cm)	Bin type			Forward speed (km/h)				Tire inflation pressure (kPa)		
	HEPCO (B_1)	Shaker (B_2)	LSD	5 (S_1)	7 (S_2)	9 (S_3)	LSD	240 (P_1)	290 (P_2)	LSD
0-10	2.10 a*	1.89 a	0.249	1.89 a	1.97 a	2.13 a	0.305	1.94 a	2.05 a	0.249
10-20	2.60 a	2.40 a	0.355	2.17 b	2.69 a	2.63 a	0.435	2.50 a	2.50 a	0.355
20-30	2.61 a	2.69 a	0.373	2.30 b	2.94 a	2.70 ab	0.455	2.64a	2.65 a	0.373
30-40	2.79 a	2.71 a	0.323	2.54 a	2.93 a	2.78 a	0.396	2.74 a	2.75 a	0.323
40-50	2.89 a	2.52 b	0.381	2.48 a	2.89 a	2.75 a	0.466	2.61 a	2.80 a	0.381
50-60	3.24 a	2.59 b	0.393	2.61 a	3.23 a	2.91 a	0.481	2.64 a	3.19 b	0.393
60-70	3.93 a	3.05 b	0.537	3.34 a	3.72 a	3.43 a	0.657	3.24 a	3.75 b	0.537
70-80	4.31 a	3.51 b	0.59	3.87 a	3.91 a	3.94 a	0.722	3.83 a	3.99 a	0.59

Means, in each column and for each factor, followed by similar letter (s) are not significantly different at the 5% probability level using Duncan's test

The effect of inflation pressure treatments on soil compaction was only significant in a 50 to 70 cm depth profile (Table 4). Soil compaction increased as tyre inflation pressure increased from 240 to 290 kPa (Table 5). The increase in the inflation pressure decreased the tyre-soil contact area and therefore increased the ground pressure. The results of Van den Akker (1998) showed diminutions of maximum pressure as a reduction in the inflation pressure. Several past researchers also reported that the effects of increase in the inflation pressure mostly appeared in the deep layers of soil (Abu-Hamdeh & Al-Widyan, 2000). It is likely that flexibility of soil texture in the toper layers is the reason why the pressure mostly affected the deeper layers. Totally it can be concluded that the decrease in the tyre inflation pressure will decrease soil compaction effects of traffic, however the more decrease in the inflation pressure may increase tyre wear. Within the limits of our experimental conditions, we arrived to the following conclusions:

- The traffic of both harvester and bin significantly increased soil compaction in 0-20 cm depth profile, however the effects of bin which passed after harvester in the field was lesser. Shaker bin was more suitable than HEPCO bin in terms of soil compaction and field capacity, nevertheless invokes a more precise management in turn patterns at farm row-ends.
- Cone index value in the 0-10 and 30-40 depth profiles was not affected by any of applied treatments.
- Use of lower speeds for harvesting equipment decreased the soil compaction compared to higher speeds.
- By decreasing tyre inflation pressure from 240 to 290 kPa, soil compaction effects of bin traffic decreased.

From applied treatments, the effects of travel speed on soil compaction were significant in the upper layers whereas the effects of bin type and tyre inflation pressure on soil compaction were significant at deeper layers. Therefore, plowing in the topsoil cannot solely diminish the compaction effects of harvesting equipment.

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