

Evaluation of the intensity of the traffic of tractors and implements on agricultural soil

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Abstract

Various authors, establish that soil compaction is considered the greatest environmental problem caused by conventional agriculture, it is the type of degradation that is most difficult to locate and understand, because it shows no obvious marks on the ground surface. To know the intensity of the passes and their effect on the compaction or cone index of the tractor machine assembly during the agricultural cycle of corn, with the conventional and minimum tillage technologies, each tractor was equipped with a DGPS signal receiver when entering to the cultivation field, to monitor traffic in all tasks, and the data were recorded with a frequency of 2 s. The width of the tires was measured by observing the footprint reflected on the ground with an air pressure of 140 kPa. In traditional tillage with disc plows 91.15% was covered and in total it was 384.83% of the surface. In the minimum tillage technology with the multi-plow 36.95% was covered and in total it was 170.08%. Being ostensibly less in this technology than in traditional tillage. Regarding the cone index (Ic) in tillage with disc plows after sowing, the Ic exceeded 3 MPa after the depth of 12.5 cm, while with multi-plow, 80% of the data is below them. 3 MPa, coinciding with the Ic after harvest in both cases.

Keywords: break-in system, DGPS, disc plow, drag, multi-plow, seed drill, soil compaction.

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Introduction

Soil engineering defines compaction as the process by which soil particles are rearranged to decrease the pore space and place them closer to each other, causing an increase in bulk density. In an agronomic sense, compaction is the result of the application to the soil of any force, for example, that exerted by tillage and the rolling traffic of agricultural machinery, which increases the apparent density of the soil and, concurrently, decreases the porosity of this (Soil Science Society of America, 2013).

In dense or compacted soils, the growth of the roots is prevented and in this way the consumption of water is limited to the plant, which affects its performance to the repeated passage of agricultural machines. According to Martiren *et al.* (2016), in Europe alone 33 000 000 ha of arable land is highly degraded by the repeated passage of the taxi system of agricultural tractors. FAO (2015) establishes the top 10 threats to soil functions: erosion, loss of organic carbon, nutrient imbalance, soil acidification, contamination, waterlogging, soil compaction, sealing, salinization, and loss of soil biodiversity.

On the other hand, Cerisola *et al.* (2015) establishes that the great challenge is the diagnosis of the quality of life of the soils to develop a productive system, based on sustainable agriculture, and states that the best conditions for traffic are undeniable, provided they are controlled, since the traffic results in physical modifications that lead to compaction. Draghi *et al.* (2015) states that it is notorious that traffic on tilled soil causes 83% of the final sinking in the first pass. Subsequent traffic and up to ten passes cause only 17% of the remaining subsidence.

In short, the non-tillage shows a soil with a greater bearing capacity, but sensitive to the intensity of traffic, even more than the tilled soil. Soil compaction also affects the carbon (C) and nitrogen (N) mineralization of soil organic matter and stubble (Neve and Hofman, 2000), as well as the concentration of carbon dioxide (CO₂) in the soil (Conlin and Driessche, 2000).

Currently compaction is considered a very serious environmental problem caused by technological practices in conventional agriculture, it is very difficult to locate and rationalize it, because the marks of the running-in system of tractors and agricultural machines on the ground surface are not evident. (McGarry, 2001). Unlike salinization and erosion that provide strong surface evidence of the presence of land degradation, land structure degradation requires physical monitoring and examination before discovery, and its extent, nature, and cause resolved (Hamza and Anderson, 2005).

Soil compaction is caused by high traffic intensity and tire pressure on the tractor soil and is combined at harvest, especially when these operations are carried out on wet soil or with high pressure tires on the ground. According to Kirkegaard (1990) the effect of soil hardness on the root damages its growth in most species and reduces growth by 50%, when the I_c is from 0.7 to 1.5 MPa and is completely limited to values greater than 4 MPa.

In tests carried out, a GPS receiver (global positioning system) has been used as simple equipment which is placed on a tractor and can detect the areas in the field where the traces of the passing of the taxi system of agricultural machines appear during the work of this. Richards (2000) used the tractor-based global positioning system to map all vehicle movements within a field during an agricultural cycle.

It is necessary to highlight the hidden nature of structural soil degradation (DES), which entails specific problems such as poor crop growth or water infiltration, which could be attributed to other causes. Additionally, DES can be found guilty of poor crop performance when it is not actually present (Hamza and Anderson, 2005).

In this sense, because the compaction of the subsoil is very persistent and the natural or artificial possibilities of its loosening have been disappointing, the European Union (EU) has recognized it as a severe form of soil degradation (Akker and Canarache, 2001). Wild (1992), argues that the compaction and consolidation of the soil, accompanied by the loss of the largest pores, is the result of deformation and breakage under load of the aggregates and pores of the soil, which leads to a loss of permeability for water and roots.

With high water contents, the soil is usually easily deformed, little compaction can occur unless there is time and opportunity for water to escape. With wet soils, under the transient loads produced by traffic and some tillage implements, there may be waterlogging, deformation, loss of aggregates and perhaps some dispersion, but little loss of soil volume. However, as it dries, the soil becomes intrinsically stronger and the susceptibility to compaction may increase as the larger pores, which are emptied first, are relatively weak.

Thus, with the increase in drying, the increase in soil resistance becomes predominant. Therefore, in shrinkable/expandable soils, the bulk density should be determined at standardized moisture contents, to prevent problems caused by variations in water content (Håkansson and Lipiec, 2000). On the other hand, soil hardness is used as a measure of compaction because it reflects the resistance of the soil to root penetration (Hamza and Anderson, 2005).

As for the rate of infiltration of water into the soil, it can also be used to monitor the status of compaction, especially of the surface layer, since water infiltrates non-compacted soils that have well-added soil particles much faster than heavy soils, with less structure (Hamza and Anderson, 2005). Bouwman and Arts (2000) maintain that a slight degree of surface compaction can be beneficial for some types of soil, interestingly indicating that there is an optimal level of compaction for crop growth.

The concept of optimal compaction level is important, especially in controlled traffic systems, where any external source of compaction is avoided because it could cause less than optimal compaction level and decreases in performance. In order to evaluate the traffic of the tractors through the cultivation field, two tillage methods were chosen, with the aim of knowing the number of times that the tractors make their respective passes in the preparation of the soil and to what extent they cover the surface of the plot under investigation.

Materials and methods

This study was carried out from April 2018 to March 2019 at the Faculty of Agricultural Sciences of the Autonomous University of the State of Mexico, located at 19° 23' 30'' north latitude and 99° 41' 30'' at an altitude of 2 640.5 m. In the University *Campus* the total available surface is 110 ha. The soil classification, according to USDA (2013), is in the vertisol order and within the Entic pelluderts subgroup, with a clay content greater than 30% up to 50 cm depth.

The terrain used for the test had five years without agricultural use and the chosen parameters were the mapping of the passes of the taxi system of the tractors registered by means of the DGPS signal receiver. The soil preparation technologies used were conventional plow-based tillage, which traditionally consists of a drag pass, a plow pass, one or two drag passes, sowing and one or two passes. of eschar or cultivation, on a surface of 16.41 ha as well as minimum or reduced tillage, consisting of a drag pass, a multi-plow pass, a drag pass, sowing and a weeding, using the multi-plow with an area of 17.51 he has. The average depth of the drag is 15 cm deep, the disc plow averages 20 cm deep, sowing 12 cm deep, the cultivator 20 cm deep and the 35 cm deep multi-plow in average.

These tasks were simultaneous in both plots, in the furrow-breaking drag, clod-breaking drag, after disc plowing or multi-plowing, planting and weeding. Disc plow was used on one plot and multi-plow was used simultaneously on the other. The characteristics of the tractors and implements used for the primary and complementary tasks (sowing and cultivation) in both technologies are shown in Table 1, where the determination of the mass was carried out on a public scale where 50% of the front part the center of gravity of the tractor is located and in the same way the rear, where it was obtained that approximately 40% of its mass, is in the front and 60% in the rear, free of counterweights, such as stipulates the manufacturer, to later add the liquid and solid to the tires, also as stipulated by the manufacturer for a good operation in the field.

Table 1. Technical characteristics of the tractors used in the test. Toluca, Mexico, 2018-2019.

Tractor model	Tractor mass (kg)	Rear and front wheel measurement (inches)	Rear wheel specific ground pressure (pneumatic pressure 140 kPa)	Specific mean pressure on the ground front wheel (pneumatic pressure 140 kPa)
6603 John Deere (4X4) tires radial	5 872	18.4-34 14.9-24	249 kPa (both wheels 498 kPa)	177 kPa (both wheels 354 kPa)
5715 John Deere (4X4) tires radial	2 790.0	15.5-38 7.50-16	162 kPa (both wheels 324 kPa)	90.5 kPa (both wheels 181 kPa)

The tractors used were instrumented with a Garmin model Oregon 650 650 DGPS signal receiver, which sent a signal every 2 s, stored in the measurement memory device and with these data the traffic mapping was performed. Soil mapping was performed and data accounted for using the MapSource program. The intensity of the traffic of the tractor-implement set was monitored in the two mentioned soil tillage technologies. Sampling of the soil was carried out in pre-sowing, in sowing and in harvesting, to determine the apparent density, humidity and texture.

All the used tractors were equipped with single wheels on both axles. In soil preparation work, in each application of each technology, the tractors used were equipped with solid and liquid ballast on the driving wheels and the latter up to 75% of their capacity with water, and although this increases from 5 to 10% Fuel consumption per unit of soil produced also decreases the slippage of the driving wheels and increases the compaction of the soil.

However, it must be stated that under these design conditions tractors are traditionally worked in each agricultural cycle and under these conditions the experiments were carried out. During the test the I_c was determined with the use of a Scout 900 S313 penetrometer (ASAE Standards S313.2, 1993). To determine the surface covered by the machinery and implements, a simple arithmetic operation is made: width of tires (the 2) by length of the plot by number of passes of the machine-tractor unit.

Pre-sowing samples are taken at each of the 25 predetermined points, where the apparent density (D_a), cone index (I_c) is determined. Subsequently, soil samples were taken at every 10 cm depth, that is, 0-10, 10-20 and 20-30 cm depth at 25 pre-established points in each plot, at planting and at harvest.

Results and discussion

Soil samplings were carried out before the primary soil preparation work, where the apparent density (D_a) yielded an average of 1.43 Mg m^{-3} , the cone Index (I_c) could not be measured because in the 0 layer at 10 cm depth it was more than 7 MPa, exceeding what the compactometer could measure and at depths greater than 10 cm it was 6 MPa on average. Table 2 shows the different works carried out with the tractor-machine set in traditional tillage technology, which were eight passes with the different implements and with different tractors in mechanized work.

Table 2. Frequency of transit given in percentage, in the plot with conventional tillage technology. Toluca, Mexico, 2018-2019.

Implement types	Implement width (m)	Tractor rear wheel width (m)	Surface covered in (ha)	Traffic frequency (%)
First drag (tractor 6603)	3	0.41 (both 0.82)	6.02	36.7
Second drag (tractor 6603)	3	0.41 (0.82) *	6.17	37.6
Third drag (tractor 6603)	3	0.41 (0.82) *	9.85	60

Implement types	Implement width (m)	Tractor rear wheel width (m)	Surface covered in (ha)	Traffic frequency (%)
Disc plow (tractor 5715)	1.02	0.47 (0.94) *	14.96	91.1
Fourth drag (tractor 6603)	3	0.41 (0.82) *	11.73	71.5
Sowing (tractor 6603)	3.2	0.41 (0.82) *	4.41	26.9
First weeding (tractor 5715)	2.4	0.47 (0.94) *	5.33	32.5
Second weeding (tractor 5715)	2.4	0.47 (0.94) *	4.66	28.4
Total			63.13	384.7

* = width of both rear wheels of the tractor used.

The actual width of the driving wheels that were taken into account was 0.86 m (both 1.72 m), and after counting the number of passes through the tractor plot with the implement, the covered area was 6.03 ha, equivalent to 36.7 % coverage of the cultivation surface by the tractor's rolling system and in this way the drag was passed three times at an average depth of 15 cm, which led to a total surface of 22.04 ha, equivalent to 134.4% of the total of the removed surface.

In the Table 2 shows the different tasks that were carried out in chronological order during the work that was carried out in the field during the primary and complementary preparation of the soil. The drag was passed through the field three times, which was performed according to destroy the pillars produced by the cultivation of corn plants in previous years and leave them as flat as possible so that the disc plow could work at a depth of 20 cm, in the most optimal conditions possible.

In the second drag pass, 37.6% of the surface was covered, and in the third drag pass, 60% was covered, and in this last pass, almost the same footprint left by the tractor's running-in system was passed again, and no there was overlap, so the surface left by the tractor break-in system and registered by the DGPS could be counted and calculated, and the latter came to 60%. Likewise, all the lines registered by the DGPS in all cases were evaluated in the same way for the two soil preparation technologies, without excluding any operation, however basic.

It is important to point out that the first three drag operations, which appear with an asterisk, are not a traditional part of this soil preparation technology, but it is widely used when vertisol soils in the Toluca Valley area are no longer cultivated for space of one or more agricultural cycles, since they can achieve penetration resistance in the arable layer that can exceed 5 MPa, these operations are not normal or recurrent in this technology, and that their application depends on the previous use of the soil.

In the plowing work, it can be seen that the disc plow has a fairly small cutting width (1.02 m), which significantly increased the number of passes of the machine-tractor unit on the tillage surface and when counting them on the map, the transit of the system of taxiing of the tractor on the ground was 91.1%, which contributed to increase the compaction, which is coincident with some researchers (Tullberg *et al.*, 2007; Tullberg, 2010).

Figure 1 (left) shows the number of passes that were made with the disc plow and in which the tractor-implement assembly moves parallel in each of the passes and there are no points of agreement, but there is a high density of these, because every 1.02 m the implement has to be passed in order to remove the entire ground surface in this technology. In Table 2, it can be seen that the drag after plowing was used, in order to find a good fluff or destruction of all the clods of soil.

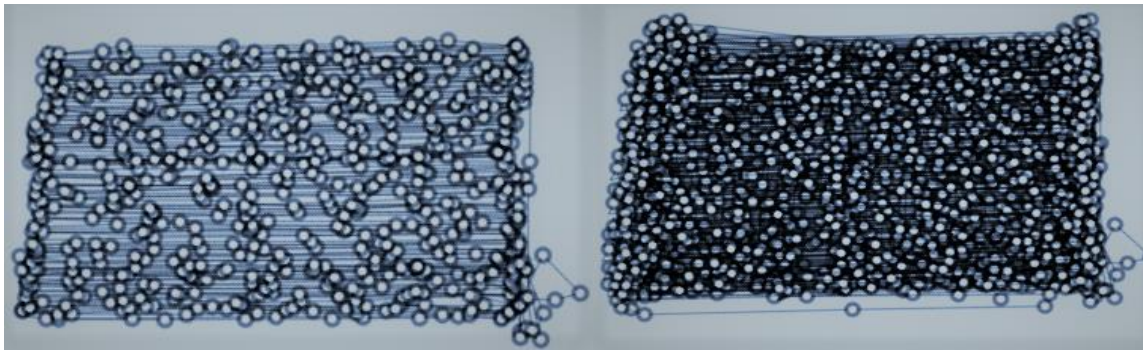


Figure 1. Transit of tractors and agricultural machinery for conventional soil tillage technology in 1.64 ha. Left= tractor path with disc plow; right= movement paths in the field during the complete cycle of maize cultivation. Toluca, Mexico, 2018-2019.

This caused the running-in system of the tractor to transit the surface in process again by 71.5%, which is highly destructive to the physical-mechanical structure of the soil, as well as an increase in bulk density and a decrease in soil productivity, which is coincident with that stated by Laureda *et al.* (2016). In Figure 1 (right) you can see the density of the passes on the entire surface made in this technology, where there is no point, where the tractor wheels have not passed and where there are around 500 points of agreement and in number of two repetitions at least and up to five in the same point at most.

In this figure, the eight maps obtained from the different technological operations of soil preparation were superimposed. In the last five mechanized operations (Table 2) a total of 250.3% was passed above the surface in the preparation of the soil, which is an appreciable value, especially if you take into account that it is a Vertisol soil, which is one of the most compact and highly susceptible to increasing the apparent density when the tractor running-in system passes in the different mechanized tasks.

It is important to observe the results of the calculation of the surface covered by the taxi system shown in Table 2 and according to what was stated by Hamza and Anderson (2005), conventional tillage was evaluated by these researchers as the most damaging of the technologies of soil preparations, and in the case of this research, the concentration observed in Figure 1 (right) the repeated passes of the taxiing system of the tractors is one of the most important disadvantages, mainly on Vertisol soils.

Figure 2a shows the behavior of the I_c after planting corn with the preparation of the soil with disc plow. It is necessary to state that before applying the disc plow, the disc drag was applied three times to destroy the ridges that were five years ago and up to 10 cm depth the I_c was 1.22 MPa and the apparent density (DA) of 1.21 Mg m^{-3} ; from 12.5 cm it was 2.16 MPa, where the root system of plants does not achieve good growth and reaches an I_c of 5.84 MPa and DA of 1.21 Mg m^{-3} at 30 cm, which is coincident with what is stated by where it also indicates that in extremely dense soils the growth of the roots is limited, as well as the consumption of water to the plant and therefore affects the yield.

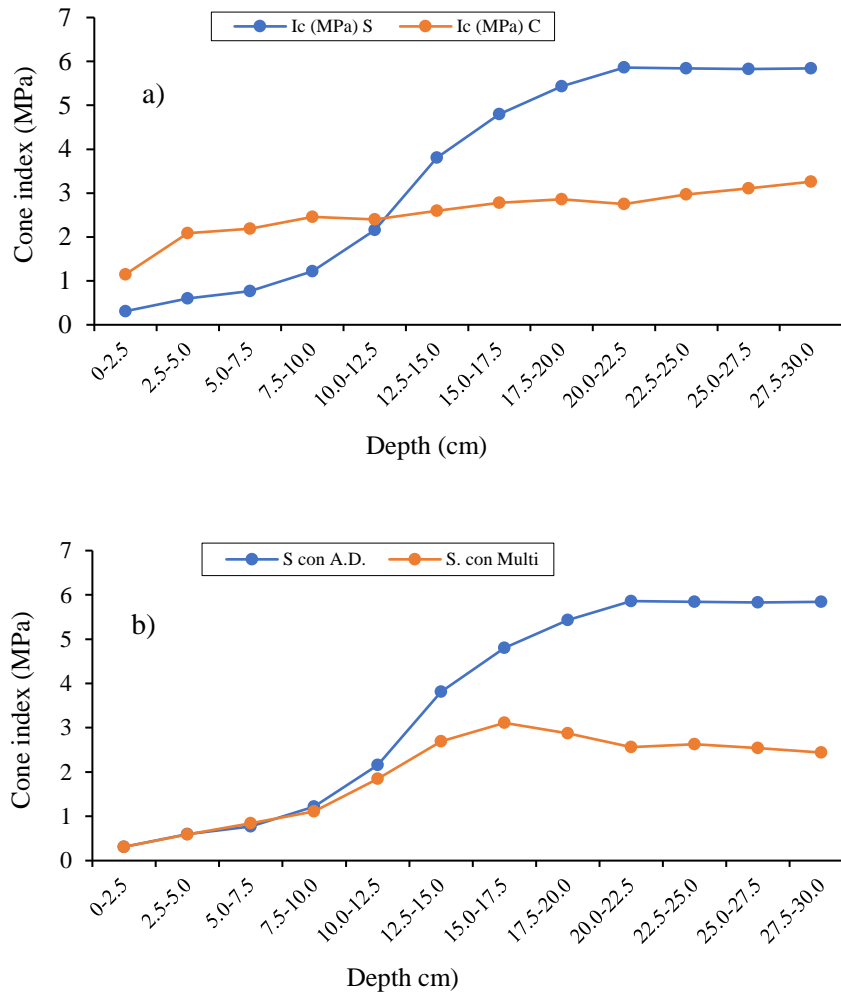


Figure 2. Cone index in the different fields; a) behavior of soil compaction after planting and harvesting in traditional tillage with disc plows; b) cone index comparison after sowing for tillage with disc plows and multi-plov.

In the determination of the DA in the laboratory at seeding, the means in the sampling every 10 cm, that is, 0-10, 10-20 and 20-30 cm, those of 1.21, 1.18 and 1.21 Mg m^{-3} were obtained, respectively, which is below before the primary soil preparation, with disc plow. In the post harvest I_c measurements it was always above 1.25 MPa; from 5 cm depth, it was always above

2.09 MPa, reaching 3.26 MPa at 30 cm depth, but always below the post seeding Ic, it is important to consider that the apparent density (DA) in the different profiles were from 1.17 to 1.2 Mg m⁻³.

In the Figure 2b presents a comparative state of the post-seeding Ic (S) in both soil preparations and it is observed that the preparation of soil with multi-plow was always below 2 MPa up to 22.5 (12.5) cm, with DA of 1.17 at 1.22 Mg m⁻³, it follows that repeated passes in the cultivation soil is sufficient to increase the Ic in the superficial and subsurface layers.

Regarding tillage technology using the AS-250 multi-plow, at a working depth of 35 cm, the behavior was somewhat different, since the situation behaved better in terms of the number of passes of the tractors in the different soil preparation operations, since only five mechanized operations were carried out in the agricultural cycle (Table 3) and that when passing the multi-plow with the John Deere 6603 tractor, only 36.9% of the surface to be processed was covered (Figure 3). From the surface that had to be elaborated, it can be seen in Figure 2 (left) the way in which the transit of the tractor-multi-plow assembly was registered with the DGPS, which having a real width between both driving wheels of 1.72 m and with which covered an area of 6.47 ha.

Table 3. Traffic frequency, on the plot with multi-plow tillage technology. Toluca, Mexico, 2018-2019.

Implement type	Implement width (m)	Tractor rear wheel width (m)	Area covered by taxiing system traffic (ha)	Traffic frequency (%)
Multi plow	2.4	0.41(0.82) *	6.47	36.9
Drag (two passes)	3	0.41(0.82) *	11.76	67.2
Sowing	3.2	0.41(0.82) *	4.7	26.9
1 st . weeding	2.4	0.47(0.94) *	6.84	39.1
Total			29.78	170.1

*= width of both rear wheels of the tractor used.

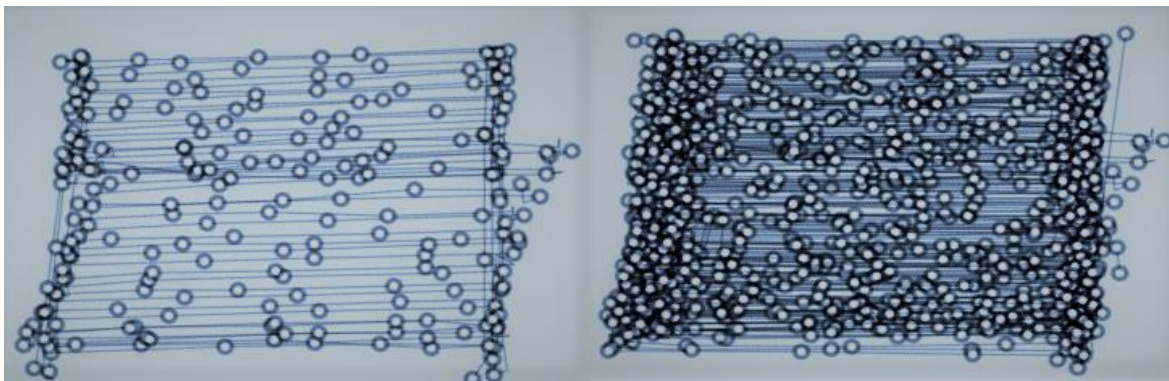


Figure. 3. Representation for minimum tillage technology. Left: multi-plow tractor travel; right= trajectories during the full cycle of maize cultivation.

After working the soil with a multi-plow, it was necessary to apply two drag passes with the same tractor, to destroy the large clods produced by this implement and this led to covering the surface of the cultivation soil 67.2%, which is much less than the carried out in traditional tillage and from 12.5 cm it was 2.16 MPa. As for the apparent density (DA) recorded in the laboratory, it was 1.2, 1.23 and 1.26 Mg m⁻³, at the depth levels of -10, 10-20 and 20-30 cm.

In this pre-sowing technology, a surface was covered with the shoot system of 104.1% and when carrying out a comparative study with that investigated by Kroulik *et al.* (2009), it can be stated that it is quite close to what has been done, although all the agricultural machines used by this researcher have working widths from 6 to 36 m. The results analyzed with the multi-plow are ostensibly better than those obtained in conventional tillage.

When using a planter with four bodies or working organs (2.4 m), it was coupled to a John Deere 6603 tractor with a 4 x 4 formula and the area covered by the traces of the tractor wheels had a significance of 26.9%, practically the same amount as in traditional tillage; however, when compared with the tests carried out with what Kroulik *et al.* 2009, the area covered in the experiment carried out was 5.1% greater, since the planter used in the Czech Republic is 8 m wide, which gives the possibility of less structure damage to the soil and especially compaction.

The surface covered by the traces of the taxiing system of the tractors used in this technology added up to 170.1%. In this technology, practically all the work carried out has a high coverage due to the traces of the tractor wheels and in this case Li Hong Wen *et al.* (2000), suggests that, although the footprints of the road can occupy 20% of the land, the losses in this area can be compensated by a higher crop yield.

When comparing Figure 1 with Figure 3, a disk plow-only traffic frequency is on the order of 91.1% with a total of 384.7%, compared to multi-plow work which is 36.9% and a total of 170.1%, where it can be seen that in traditional tillage the area affected by the passage of tractors is greatly exceeded compared to the minimum tillage technology. Based on the data and the study carried out, the rolling traffic of machinery can be considered common in most agricultural operations, even in zero-tillage systems (Tullberg, 1990).

Soil compaction by road traffic is characterized by a decrease in soil porosity under the bearing footprint (Hamza and Anderson, 2005). However, Tullberg *et al.* (2007) stated that considering some combinations of tires with the used tractors, as well as taking into account the tractive characteristics of these tractors, the area of the crop field affected by the traffic of the taxi system is usually in the range of 20 to 35 %.

For controlled traffic, but the particular case of Mexican agriculture is that the vast majority of the agricultural implements used are of a small working width, which is one of the great problems that may arise from constantly damaging the soil where it is transited, which causes the amount of pores in the soil to be restricted and an increase in soil compaction is registered that could affect crop yields.

As can be seen in the field tests carried out, the surface covered by the traces of the taxiing systems of the tractors far exceeds that raised by other researchers and despite the many advantages reported for controlled traffic, some researchers are still critical of the concept, arguing that this system has not resulted in a marked benefit in soil properties or crop yield (Braunack *et al.*, 1995).

In Figure 4a, the behavior of the Ic during sowing (S with multi-plow) and after harvest (C with multi-plow) and in the profile of 12.5 cm depth the Ic at sowing was above 2 MPa and contrary to this at harvest the Ic with the exception of 30 cm exceeded 2 MPa which may have been due to the complementary preparation of the soil, such as weeding. On the other hand, González-Cueto (2009), states that the tire pressure shows an increase in compaction as the inflation pressure increases.

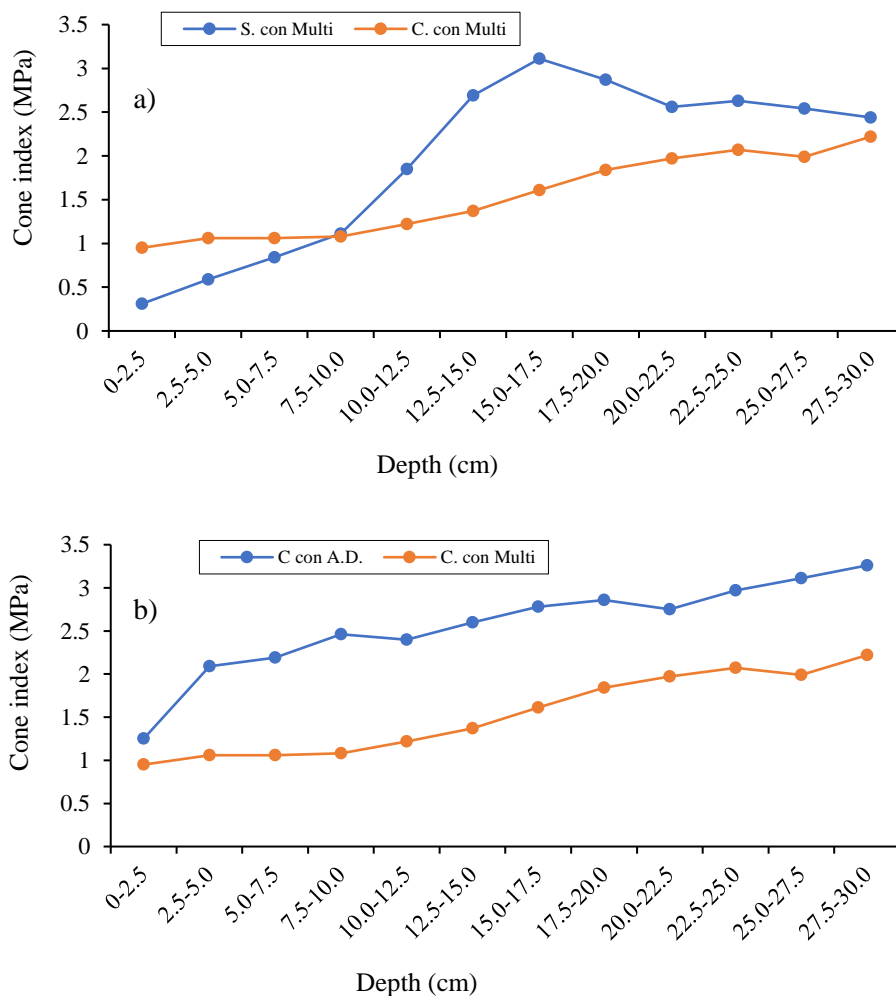


Figure 4. Cone index in the different fields; a) behavior of the cone index after planting and harvesting in preparation of the soil with multiarado; b) comparison of the cone index after harvest between both soil preparations.

However, the pressure in the tires was maintained in the trial and the behavior coincides with that proposed by this researcher and is also the criterion of Botta *et al.* (2012), both in the surface layer and in depths of approximately 30 cm. In Figure 4b, the behaviors of the I_c after harvest in both soil preparations are presented, where it can be seen that the values of the I_c after harvest in the soil preparation with multi-plow is lower than what is shown, where the disc plow was used, where the latter reaches more than 2 MPa in practically the entire profile of the soil, although this is not the behavior where the multi-plow was used, it is important to note that repeated passing is one of the preponderant conditions for there is great compaction, regardless of whether radial tires have been used in both cases, in depth ranges greater than 20 cm the I_c values tend to grow in agreement with what was found by Martiren *et al.* (2016).

Conclusions

In traditional tillage technology, the drag was passed four times, which added 205.8% of the traffic of the tractor's rolling system, practically twice the surface that was being developed, which had a negative influence on the compaction of the soil; however, in multi-plow tillage, only 67.2% were transited. When carrying out the plowing of the soil with a disc plow, 91.1% was used against 36.9% of the multi-plow.

The transit of the total tractor machine set in tillage with disc plows throughout the agricultural cycle was 384.9%, practically four times of the cultivated area and in tillage with multi-plow, it was 170.1%. In these last values shown, it can be deduced that the tillage where the multi-plow is used has advantages, in speed of soil preparation, lower fuel costs, maintenance of the tractor machine assembly and soil damage, as this minimally alters the apparent density.

Soil micropores and compaction. As shown in the I_c measurements, the primary preparation with multi-plow in the first 25 cm depth never exceeded 3 MPa, contrary to the preparation of the soil with disc plow, which exceeded 5.5 MPa and the advantage of multi-plow after harvest was also observed where I_c records were lower with the use of multi-plow. The apparent density had a different behavior from that shown before starting the soil preparation, which was 1.43 Mg m^{-3} of soil or showing 1.2 Mg m^{-3} after mechanized sowing in traditional tillage and 1.18 Mg m^{-3} after harvest and in minimum tillage technology, it yielded the following results: 1.23 Mg m^{-3} after sowing and 1.19 Mg m^{-3} after harvest.

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