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The agricultural traffic effects on soil and maize (*Zea mays* L.) yields under two different tillage systems

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Abstract. This study investigated the agricultural traffic effects on soil and maize (*Zea mays* L.) yields under No-tillage (NT) and conventional tillage (CT) during three cropping seasons on an *Entic Haplustoll* soil. Cone index (CI), dry bulk density (DBD), soil water content (SWC), root dry matter per plant (RDM), seed emergence (SE) and maize yields (MY) were measured. The highest average RDM values were found in CT (60.6 g plant^{-1}), while the highest value in NT was 48.0 g plant^{-1}). After traffic, for the two tillage systems, the obtained CI results followed a similar trend to those of DBD up to 150 mm. From this depth, the values of both parameters increased sharply up to the 450 mm depth level. At 150 to 450 mm average CI and DBD values were higher than 1,680 kPa and 1,472 kg m^{-3}, and 2,610 kPa and 1,677 kg m^{-3} for CT and NT, respectively. The average yields for the 3 cropping seasons were 9.93 ton ha^{-1} and 8.26 ton ha^{-1} for CT and NT, respectively. It was demonstrated that even using medium-weight equipment (479.8 kN), subsoil compaction could not be avoided.

Key words: cone index, conventional tillage, crop yields, dry bulk density, no-tillage.

INTRODUCTION

One of the major problems produced by agricultural machinery traffic is soil compaction. Soil compaction produced by machinery traffic is one of the main causes of agricultural soil deterioration worldwide (Antille et al., 2019).

The scientific literature on soil compaction is abundant, but there are few studies linking traffic intensity with different tillage systems, and available information often reports on the effect of tillage on soil compaction without specific reference to the contribution of traffic to such an effect, with some exceptions (e.g., Godwin et al., 2015; Godwin et al., 2023). The effect of tillage on soil compaction is dependent on several factors, including the crop being established or grown, climate and soil type, soil conditions at the time field operations are performed, and importantly, field traffic intensity (Boizard et al., 2002). In this sense, when a compacted soil presents CI values > 2 MPa, the roots of most field crops stop growing (Alesso et al., 2020). A study by Antille et al. (2016) showed that in medium-textured soils, the critical soil bulk density above which root elongation is impeded ranges between 1.45 and 1.50 mg m^{-3}.

Further work by Botta et al. (2013) on maize demonstrated that subsoil compaction reduced crop root biomass, leading to a decreased number of grains per square meter and therefore grain yield.

It should be noted that maize is the second most important crop in South America, with an approximate area of 20 Mha. The main producers are Brazil and Argentina, which produced 165 million metric tons in the 2021–2022 season. Argentina produced 49.50 million metric tons in the 2021–2022 season (USDA, 2023).

Argentina has over 30 million ha of arable land planted annually under the permanent no-tillage (NT) system (Nardón et al., 2021). The rest of the arable agricultural area (8 Mha) is cultivated under conventional tillage (CT), which involves both primary and secondary tillage operations for crop establishment. Controlled traffic farming is not practiced in either of the two tillage systems (Antille et al., 2015). Maize (Zea mays L.) is grown in central and western regions of the country; light-textured soils are dominant (e.g., Entic Haplustolls), which are prone to compaction (Quiroga et al., 1999; Díaz-Zorita et al., 2002). Maize (*Zea mays* L.) is a key crop grown in Argentina (~20 M ha are established annually) and is important both from agronomic (i.e., crop rotation and feedstock in mixed and dairy farming systems) and economic (i.e., farm income) perspectives (INTA, 2012).

The NT systems in Argentina are characterized by relatively high traffic intensities (e.g., ≥ 40 mg km^{-1} ha^{-1}) as shown by Botta et al. (2023). Such traffic intensities can lead to severe soil compaction to depths (e.g., ≥ 0.40 m) at which tillage repair treatments are either impractical or increase production costs (Botta et al., 2023; Tullberg 2014).

With reference to the CT systems, the machinery used by the average Argentine farmer produces traffic intensities that are between 20 and 25 mg km^{-1} ha^{-1} during the seedbed preparation. The complexity of this situation lies in the fact that this movement of machinery occurs after the primary and secondary tillage have been carried out, precisely at the moment when the soil is mechanically less stable; hence, significant compaction can occur after planter traffic (Draghi et al., 2015).

In addition to the differences in traffic intensities between the NT and CT systems mentioned in the previous paragraph, another important difference is the spatial distribution of the crop residues on the soil surface. The spatial distribution of the crop residues on the surface of the soil worked under no-tillage (NT) is not uniform (Hidalgo 2012). Consequently, areas of different temperatures can be formed, impairing crop germination and emergence, which does not occur when the soil is worked under CT since the soil was previously removed during the preparation of the seedbed (Håkansson et al., 2002). Crop residues left on the soil surface tend to slow down evaporation and lower soil temperature by limiting the energy input (Abrecht & Bristow, 1990). As a result, seedling emergence can be impaired.

For all these reasons, soil conditions must be taken into account when maize cultivating, and care must be taken to reduce the subsoil compaction caused by the heavy agricultural machinery used during crop labour.

Then, considering these situations and the steady increase in the area under maize cultivation worldwide, both in no-tillage and conventional systems, and considering that there is a scarcity of information on this particular aspect of the agricultural traffic effect on *Entic Haplustoll* soil and maize production in the semiarid regions, we believe that filling this information gap can be an important contribution. We also believe this work can have an important scope, both in terms of practical and scientific impact.

The objectives of this work reported in this article were to (a) determine the effects of agricultural machinery traffic on the maize yield cultivated in two soil conditions (NT and CT) and (b) quantify the effect of machinery traffic on soil compaction for the same soil managed under NT and CT.

MATERIALS AND METHODS

Study area

The study was conducted between 2013 and 2016 on a commercial farm located in the west of the Pampeana region of Argentina (36° 40' 33.18"S and 62° 29' 14.57" W) on an Entic Haplustoll soil USDA Soil taxonomy 2014), see Table 1. Prior to the study soil includes twenty years of continuous crop sequence, for example: three winter crops and maize (*Zea mays* L.) in spring/summer.

Table 1. Soil profile characteristics of the *Entic Haplustoll* recorded at the study area. Values are means ± SD

Soil horizons (cm)	0–15	15–30	35–65	65–112
SOC (g kg^{-1})	10.20 ± 4.1	6.10 ± 1.1	5.10 ± 1.2	Not available
Clay (g kg^{-1}), fraction <2 µm	161 ± 3.02	284 ± 2.31	184 ± 2.21	63 ± 2.10
Silt (g kg^{-1}), fraction 2–20 µm	98 ± 2.16	63 ± 2.11	76± 2.27	99± 2.01
Silt (g kg^{-1}), fraction 2–50 µm	176 ± 3.20	144 ± 2.10	131 ± 2.20	206 ± 1.50
Very fine sand, (74–100 µm) g kg^{-1}	402 ± 2.14	302 ± 2.02	398 ± 2.21	367 ± 2.12
Fine sand, (100–250 µm) g kg^{-1}	159 ± 3.10	201± 291	207± 276	261± 2.18
pH in H_20 (1:2.5)	6.4 ± 0.03	6.6 ± 0.04	6.9 ± 0.03	6.9 ± 0.02

Analytical method for soil organic carbon (SOC) determination (Walkley & Black, 1934) and for determination pH in H_2O (MAFF, 1986).

In the Trenque Lauquen County, the summers (November to February) are hot and humid and the winters are cold and dry (June to August). Throughout the year, the average temperatures generally range between 2 °C and 30 °C. Table 2 shows the total precipitation and average air temperatures between October 1 and March 31 for each cropping season.

Table 2. Meteorological data in the three cropping seasons (October 1^{st} to March 31^{st})

(October 1^{st} to March 31^{st})	Max. air temp (°C)	Min. air temp (°C)	Average air temp (°C)	Total rainfall (mm)
2013–2014	35.6	2.6	19.1	570.7
2014–2015	34.0	3.5	18.7	531.4
2015–2016	36.8	2.5	19.6	669.8

Experimental variables measured

Soil water content (SWC) (%, w/w) (θg) (MAFF, 1986), dry bulk density (DBD) (Erbach, 1987), and cone index (CI) (EP542.1 ASABE 2019) were measured at the time of seeding each year at random locations taking into account tracks in all the plots after the traffic events.

The DBD and SWC were measured up to 450 mm depth using 25 mm diameter by 150 mm long cylinders. The inside of the cylinder was sprayed with cooking spray lubricant before sampling (Logsdon & Karlen, 2004). The average of twenty measurements per plot ($n = 20$) of soil water content and dry bulk density were used. The root dry matter per plant (RDM) was measured 8 weeks after seedling emergence (in tasseling) according to the method proposed by (Botta et al., 2013).

Cone index (CI) was measured with a Scout 900 Field ScoutTM electronic penetrometer. The measurements of this parameter ($n = 20$) were taken in each plot up to 450 mm deep according to the method proposed by Botta et al. (2020).

It should be noted that CI and SWC measurements ($n = 20$) up to 450 mm were taken to use SWC as a covariate to account for the effect of SWC on soil strength (EP542.1 ASABE 2019) and Ayers & Perumpral (1982). For the two soil treatments before planting, plant residue cover was measured according method proposed by Iowa State University.

Using the Standard Proctor test (Ray & Chapman, 1954), the maximum dry bulk density and water content of the soil at that point were measured ($n = 3$ per plot). This test was performed up to 450 mm depth.

Maize emergence (SE) was measured according to the method proposed by Botta et al. (2022a) in square meter. The maize yield (MY) was measured as total grain production divided by surface area of each plot.

Experimental treatments and agricultural machinery

Two tillage treatments representing the different mechanical soils were used. The first one was: a) T1: No-tillage (NT) for 20 consecutive years and the second one was: b) T2: Conventional tillage (CT) historically worked under this modality. Table 3 shows tillage treatments and agricultural machinery traffic sequence used during three cropping seasons.

Table 3. Tillage treatments and machinery used during three cropping seasons on commercial farm

Treatments	Machinery used	Machinery passages per hectare	Overall weight (kN)	Wheel tracked area (%)[a]
No-tillage (NT)	Sprayer (pre seeding), no-tillage planter, fertiliser applicator, sprayer and harvest	5	659.03	60.20
Conventional tillage (CT)	Chisel plow - disk harrow - 9 section spike tooth harrow - basket roller, conventional planter, fertiliser applicator, sprayer and harvest	10	479.80	66.32

a – Wheel tracked areas for all field operations, expressed as a percentage of field-cropped area (%).

The plot sizes and repetitions for each tillage treatment were determined according to the design proposed by Botta et al. (2022a). Wheel tracked areas for all field operations in NT and CT, expressed as a percentage of field-cropped area were determined using the method proposed by Botta et al. (2023).

The maize seeds were planted taking into account the dates adopted by Botta et al. (2022a) for southern hemisphere. Then, the maize was planted on 10/14/2013 in the 1st period; on 10/15/2015 in the 2nd period and on 10/17/2016 in the 3rd period studied.

The seeding density was 6 plants m^{-2} at a depth of 30 mm, according to the standard agronomic practice of the region and it was fertilized with 120 kg ha^{-1} di-ammonium phosphate (at planting time) and urea at the rate of 100 kg ha^{-1} eight weeks after sowing. In the three cropping seasons studied, the maize seed used was: DK4F37 hybrid maize. The maize crop was harvested on March 28, 2014, March 27, 2015 and March 30, 2016 for all treatments.

Table 4. Agricultural machinery used in the field trial

		FWA tractor	Harvester combine	Sprayer	Fertilizer applicator	Grain chaser
Engine power	CV kW	140 (102.6)	325 (238.3)	173 (129)	240 (179)	------
Front tires	-	18.4–26	900/60R32	12.4 R 46	12.4–36	23.1–30
*Tire inflation pressure (front axle)	kPa	100	200	260	260	200
Rear tires	-	24.5–32	28 L-26	12.4 R 46	12.4–36	23.1–0
*Tire inflation pressure (rear axle)	kPa	80	120	260	260	200
Total load	kN	77.70	162.90	90.00	98.60	196
Load front axle	kN	31.00	105.30	36.72	39.44	98
Load rear axle	kN	46.70	57.60	53.28	59.16	98
Load (front tire)	kN	15.50	52.65	18.36	19.72	49
Load (rear tire)	kN	23.35	28.80	26.64	29.58	49
Front track width	mm	2,650	2,800	3,000	2,100	3,000
Rear track width	mm	2,650	2,800	3,000	2,100	3,000
Ground contact pressure (front tire)	kPa	40.30	70.34	220	239	112
Ground contact pressure (rear tire)	kPa	39.50	37.12	237	251	112

		Planters	
		Planter 1 (No-Tillage Planter)	Planter 2 (Conventional Tillage)
Overall load	kN	111.23	10.7
Overall width	m	7.00	4.00
Seed metering system	-	Standard disc	Standard disc
Tires	-	400/60 - 15.5×4 tires (300 kPa) 7.50 - 16×2 tires (137 kPa)	12.4 - 28×2 tires (80 kPa)
Ground contact pressure per wheel	kPa	122.62	72.11
Cutting and soil penetration furrower	-	Turbo blades, single-disc with one depth limiting wheel	Double-disc with two depth limiting wheel
Covering press wheels	-	Yes	Yes

* The tire inflation pressures at which the tires were operated may be different from the manufacturers' designated tire inflation pressures for cyclic loading operations, speed, and slope.

The agricultural equipment used in this experiment is that commonly used by producers in the area. It is important to note that two different planters were used: one planter for the NT treatment and another planter for CT treatment (Table 4 shows the characteristics).

The weight of each of the machines used in this trial was determined with an electronic scale. Tires ground contact pressure area was measured with Tekscan® device. Harvest traffic was the same for both treatments, and only the harvester trafficked the cultivated land, unloading at the head of the field where the tractor and grain cart were waiting.

Statistical analyses

The Statgraphics (2009) software was used to analyse, dry bulk density, cone index, root dry mater, seed emergence and maize yield using ANOVA. The DMRT[1] (Duncan's multiple range test) was used to compare means. The CI and SWC were simultaneously determined and used as covariates of the soil CI data because of their effects on soil compaction (EP542.1 ASABE 2019).

The same statistical approach (repeated measurement of ANOVA) was applied to determine traffic treatments effects on soil water content, but without adjusting for any covariate (Botta et al., 2022b).

RESULTS AND DISCUSSION

Table 2 shows the meteorological data at the trial site during the three cropping seasons of this study. Between October and March, the average maximum air temperature was high (the maize crop development period in the southern hemisphere), exceeding 34°C in the three cropping seasons studied. According to Sadras et al. (2009), air temperature has an impact on the vegetative and reproductive phases.

From what it has been determined in the previous paragraphs, we understand that the environmental conditions that influence the germination, growth and development of the maize crop were quite similar during the study period, as well as the crop management. Hence, we consider that any differences in the behavior of the crop could be due to the soil mechanical conditions and the machinery used for each treatment. During the traffic of agricultural machinery in the two soil mechanical conditions studied (NT and CT), the SWC averaged 17.6% ± 1.47% on a dry basis between 0 and 150 mm depth, 16.2% ± 1.33% between 150 and 300 mm depth, and 18.1% ± 1.50% (300 to 450 mm depth). In other words, these SWC values were close to but below field capacity. SWC (w/w) on the sowing day averaged for the three years was 18.9%, 19%, and 19.7%, respectively, for each of the depth intervals mentioned above. In general, there were no significant differences in soil water content among the treatments when seed emergence was measured. Hence, any differences in seed emergence and soil compaction could be due to the three treatments applied.

[1] DMRT is an abbreviation of Duncan's multiple range test.

Regarding the results of the Ray & Chapman (1954), it resulted in the range from 0 to 150 mm depth in a bulk density of 1,530 kg m^{-3} ± 99 kg m^{-3}. In the range of 150 to 300 mm depth, the value was 1,570 kg m^{-3} ± 110 kg m^{-3} and in the range of 300 to 450 mm depth, the value was 1,600 kg m^{-3} ± 104 kg m^{-3} with a soil water content of 21% ± 1.41%, 21.7% ± 1.35% and 22% ± 1.39%, respectively. Consequently, when machinery traffic was carried out, with SWC values close to the Proctor value, significant soil compaction occurred. In the 0 to 150 mm depth range (Topsoil), the initial DBD in the NT and CT treatments (Control) for example averaged 1,398 kg m^{-3} ± 112 kg m^{-3} and 1,050 kg m^{-3} ± 97 kg m^{-3} respectively (Fig. 1, a) and increased, after traffic, to an average (for three years) of around 1,673 kg m^{-3} ± 168 kg m^{-3} and 1,435 ± 122 kg m^{-3} for CT and NT respectively.

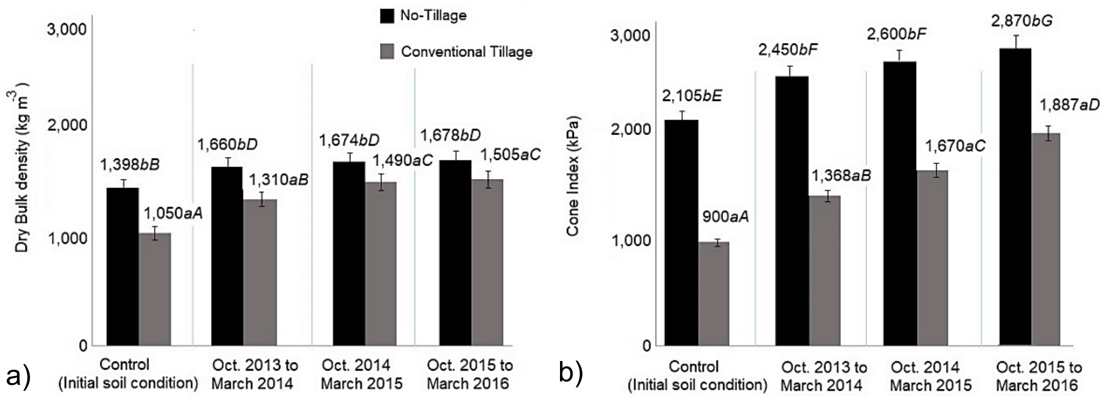

Figure 1.: a) Soil dry bulk density values (0–150 mm) and b) Soil cone index values (0–150 mm) after traffic for three cropping seasons respect to the control plot in two soil conditions (CT and NT). Means values with different lowercase letters show significant differences between CT and NT in the same crop season and capital letters show significant difference between CT and NT in the different crop seasons (1% probability level based on the Duncan's multiple range test). Error bars on mean values denote the standard deviation.

Figs 1, a and 1, b show the DBD and CI results for the two mechanical soil treatments (NT and CT). In the 0 to 150 mm depth interval, the DBD values after traffic exceeded the 1,200 kg m^{-3} indicated by Mwiti et al. (2023) as the critical level for maize growth. The same occurred with the CI parameter, where all the values after traffic at the 0 to 150 mm level exceeded 1,210 kPa, which produced, according to Wang et al. (2015), a crop yield decrease. In any case, the CI and DBD values were always higher for NT than for CT. Considering the above, this could have been a cause of the slow emergence of maize seeds in the soil worked under NT.

The germination and subsequent maize emergence were slower in the no-tillage than in the conventional tillage, showing significant differences in all the measurements made (Table 5). This situation is not consistent with the results obtained by Botta et al. (2022a) for soybean and wheat crops, which, after 22 days, showed no significant differences in the seed emergence of these crops in the CT and NT systems. Maize seeds are probably more susceptible to soil compaction by high axle load machinery traffic since the differences between the penetration resistance and soil bulk density values are significantly higher in the soil worked under no-till with respect to conventional tillage (Figs 1, a and 1, b).

Furthermore, although the residue coverage was high in the NT treatment (in average of 97.3% - SD: 5.2%), the delay in the maize emergence cannot be attributed to this, because according to Nardón et al. (2021), the crops residues are cleared from the row due to the work of the turbo blades of the NT planters.

Table 5. Maize emergence (plants per square meter)

	1st Cropping season 2013–2014			2nd Cropping season 2014–2015			3rd Cropping season 2015–2016		
	Days from sowing date			Days from sowing date			Days from sowing date		
	11	15	22	11	15	22	11	15	22
NT	0.40*a*	2.60*a*	3.60*a*	0.30*a*	2.70*a*	3.90*b*	0.40*a*	2.90*a*	3.70*a*
CT	1.00*b*	4.20*b*	4.90*b*	1.10*b*	3.90*b*	5.20*b*	1.20*b*	4.30*b*	5.10*b*

Different letters (vertically arranged) are significantly different ($P < 0.01$) Duncan's multiple range test.

This delays maize seeds germination and emergence, favoring the attack of pathogens. In any case, the situations expressed in the previous paragraphs show situations related to trampling and soil compaction due to machinery traffic with evident results as shown for the three cropping seasons studied (Figs 1–3). These figures show that the CI and DBD after traffic in the NT treatment were over 2,450 kPa and 1,660 kg m^{-3}, respectively, at the 0 to 450 mm depth.

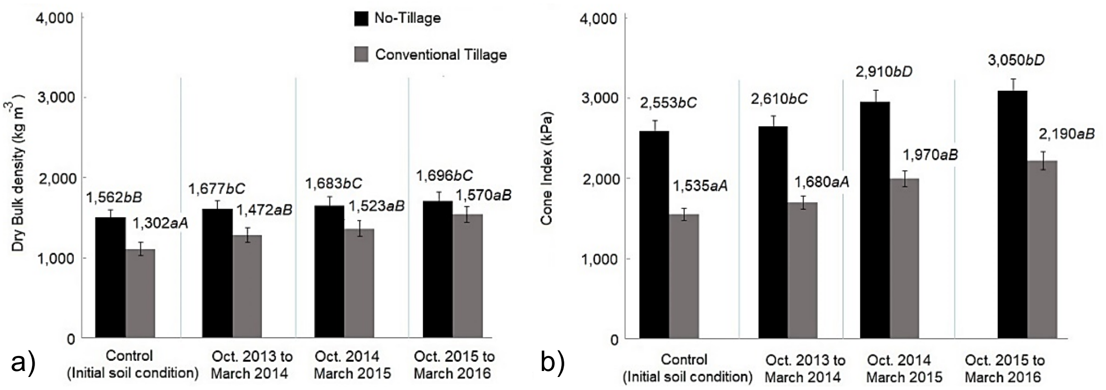

Figure 2.: a) Soil dry bulk density values (150–300 mm) and b) Soil cone index values (150–300 mm) after traffic for three cropping seasons respect to the control plot in two soil conditions (CT and NT). Means values with different lowercase letters show significant differences between CT and NT in the same crop season and capital letters show significant difference between CT and NT in the different crop seasons (1% probability level based on the Duncan's multiple range test). Error bars on mean values denote the standard deviation.

Consequently, the CI between 150 and 300 mm depth in the three growing seasons was higher than the 2,300 kPa limit informed by Arvidsson & Håkansson (2014) to avoid limited root growth (Fig. 2, b). The highest CI and DBD values for CT and NT were found in the 300 to 450 mm depth range in all years (Figs 3, a and 3, b). The peak values of soil cone index and soil bulk density were found at greater depths year after year. All the values of these two parameters exceeded those quoted by Alesso et al. (2020) and Arvidsson & Håkansson (2014) as limiting root growth.

The soil response to agricultural machinery traffic at subsoil levels showed that the CI and DBD values increased significantly in the 300 to 450 mm depth range. Despite this, no significant differences were observed between the two soil conditions or treatments studied (NT and CT). It was verified that the increases produced by the heavy equipment (NT equipment = total load 659.03 kN) on the physical properties (CI and DBD) at surface and subsoil levels were greater than those produced by the conventional equipment for conventional tillage (CT equipment = total load 479.8 kN).

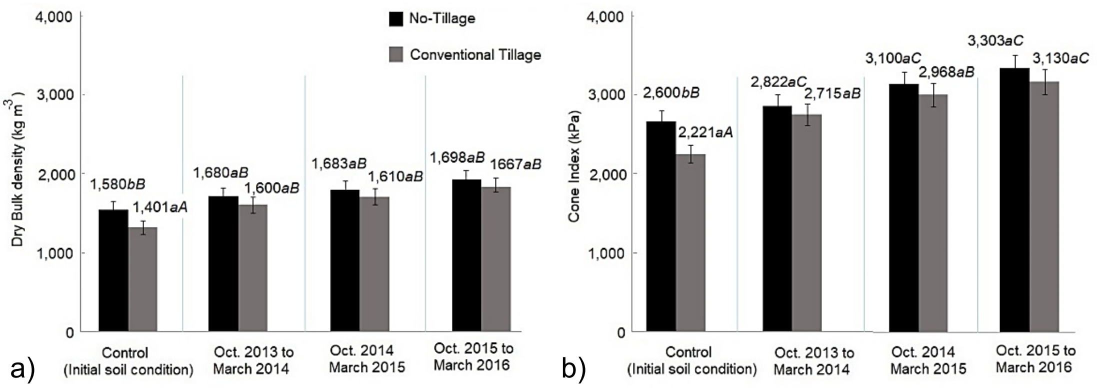

Figure 3.: a) Soil dry bulk density values (300–450 mm) and b) Soil cone index values (300–450 mm) after traffic for three cropping seasons respect to the control plot in two soil conditions (CT and NT). Means values with different lowercase letters show significant differences between CT and NT in the same crop season and capital letters show significant difference between CT and NT in the different crop seasons (1% probability level based on the Duncan's multiple range test). Error bars on mean values denote the standard deviation.

These results were related to the compaction produced by a high axle load and agree with those of Botta et al. (2022a) and Antille et al. (2019), but they are also related to the agricultural machinery passes number and the soil type on which it travels. Clarifying the above, possibly, the combination of the high axle load (see Tables 3 and 4), the total wheel tracked areas of the machinery (NT = 60.20% and CT = 66.32% (whit annual soil tillage) and the high tire ground pressures of the sprayer and fertiliser machines (between 220 to 251 kPa) were the cause of the aforementioned soil compaction situation. Finally, this study showed that maize production, expressed as crop yield, decreases with increasing soil compaction due to agricultural machinery traffic. Following this, the maize yield decreased as the agricultural machinery traffic and the soil compaction increased. Nevertheless, the difference in maize crop yield between two tillage systems was important in the three growing seasons (Table 6). The low soil densification was associated with higher maize yields.

Table 6. Agronomic parameters (root dry matter per plant and grain yield) expressed as the mean ± standard deviation measured for the three cropping seasons (between 2013–2014, 2014–2015 and 2015–2016)

Crop season	Root dry matter (g per plant)		Grain* yield (mg ha^{-1})	
	Conventional tillage	No tillage	No tillage	Conventional tillage
2013–2014	59.0 ± 0.032*a*	48.5 ± 0.061*b*	8.30*a*	9.80*b*
2014–2015	62.0 ± 0.048*a*	51.0 ± 0.037*b*	8.40*a*	10.10*b*
2015–2016	61.0 ± 0.039*a*	44.5 ± 0.041*b*	7.80*a*	9.90*b*
Average ± SD	60.6 ± 0.040*a*	48.0 ± 0.047*b*	8.26 ± 0.011*a*	9.93 ± 0.072*b*

*Grain moisture content at the time of harvest: 13.8%. Means values with different letters show significant differences between conventional tillage and no-tillage ($P < 0.01$) Duncan's multiple range test.

In the most compacted soil (NT soil), the number of plants found overturned was important as a consequence of the impossibility of the root to develop. For three cropping seasons, the root dry matter per plant found in the plants of the soil worked under CT is notable respect to NT soil (Table 6). Root dry matter per plant was influence adversely by soil densification. As the soil CI increased, root dry matter per plant decreased within the 0 to 150 mm depth profile (Fig. 4).

Consequently, the results of this study confirm that maize yield decreased due to the high weight of the agricultural machinery used and the high trampling of the soil due to the traffic applied during the development of this crop.

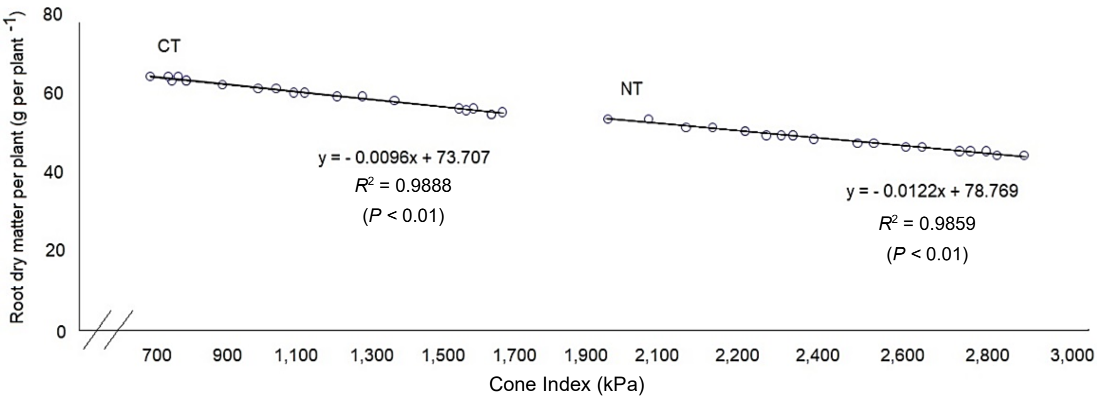

Figure 4. Relationship between root dry matter per plant and cone index (0–150 mm depth range) for two soil mechanical conditions (CT and NT).

Furthermore, according to Daddow & Warrington (1983) and based on the textural class, the growth-limiting DBD for this soil is between 1,600 and 1,650 kg m^{-3}.

In the three growing seasons, it was found that the soil densification in no-tillage resulted in lower maize crop yields (decreased by an average of 15%) compared to the soil worked under CT (Table 6).

CONCLUSIONS

The maize seeds germination and emergence was slower in the soil with higher bearing capacity or in a higher state of compaction, in this case, the soil worked for 20 years under the NT system. The soil worked under CT is a soil with low compaction levels up to 150 mm depth. This, in turn, led to greater seed emergence and more uniform seed establishment than in the soil worked under NT. With these results, it is recommended that the producer, after working continuously under the NT system, performs topsoil and subsurface soil loosening every few years depending on the soil type on his farm.

Subsoil compaction was high in the conventional tillage system even using medium-weight equipment (total load 479.80 kN). In addition, it was shown that increasing the equipment weight (total load 659.03 kN) and the tire ground pressure (up to 220 to 251 kPa), even in soils with high bearing capacity, subsoil compaction increases and maize yields decrease.

Finally, the producer should think about a planning strategy for machinery traffic or the use of low ground pressure systems. In this way, he could reduce the detrimental effects that compaction produces on the soil and, in this case, on the maize crop.

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