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Effect of traffic with a light-weight tractor on physical properties of an Aridisol soil in Almeria, Spain

Efecto del tráfico con un tractor liviano sobre las propiedades físicas de un suelo Aridisol en Almería, España

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Abstract

The objective of this work was to evaluate the effect of repeated traffic with a light-weight tractor on the physical/mechanical properties of an Aridisol soil from eastern Almería (Spain). The soil has been used for almond (*Prunus amigdalus* L.) production for the past 29 years. A light modal tractor (≈15 kN overall load) and different traffic frequencies or treatments; namely, 0 (control, no traffic), and 1, 5, 7, and 10 passes, respectively, were used. The following variables were measured: cone Index (CI); bulk density (BD); total soil porosity (TSP); water infiltration into soil (I), and ruth depth (RD). The results showed that, only treatments 7 and 10 led to significant increases in CI and BD throughout the soil profile (0-450 mm). Changes in TSP in those treatments were consistent with changes in soil bulk density. No significant differences in RD were found when the tractor passed 1 or 5 times. All traffic treatments resulted in significant compaction in the topsoil layer (0-150 mm) and soil physical conditions that would be regarded as unsuitable for establishment of most arable crops.

Keywords
soil carrying capacity • cone index • axle load

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RESUMEN

Nuestro principal objetivo fue evaluar los efectos sobre las propiedades físicas del suelo causados por el tráfico de un tractor que es de uso común en el este de la provincia de Almería, España. El trabajo se realizó sobre suelo Aridisol, en el distrito de Vélez Blanco, en el sureste de España. El suelo se ha utilizado para la producción de almendras (*Prunus amigdalus* L.) durante los últimos 29 años. Se utilizó un tractor modal con diferentes frecuencias o tratamientos de tráfico: 0 (sin tráfico), 1, 5, 7 y 10 pasadas, respectivamente. Las variables medidas fueron las siguientes: (1) índice de cono (CI); (2) densidad aparente (BD); (3) porosidad total del suelo (TSP); (4) infiltración del suelo (I) y profundidad de huella (RD). Los resultados mostraron que, solo 7 y 10 pasadas del tractor produjeron aumentos significativos en los valores de CI y BD en el perfil medido del suelo (0 - 450 mm). Además, este trabajo ha demostrado que la compactación del suelo por el tráfico de un tractor liviano (≈15 kN) disminuye la TSP en todo el perfil del suelo estudiado. No se encontraron diferencias significativas en RD cuando el tractor pasó 1 o 5 veces. Todos los tratamientos de tráfico compactaron el horizonte superficial del suelo (0-150 mm) generando condiciones físicas o mecánicas que no serían adecuadas para el establecimiento del cultivo.

Palabras clave
capacidad portante del suelo • índice de cono • peso en el eje

INTRODUCTION

Traffic with heavy equipment can cause severe soil compaction, particularly, when field operations are repeatedly conducted on the same track (8, 9). Botta *et al.* (2002) identified two aspects of compaction that require investigation: (i) topsoil compaction within the cultivated (Ap) horizon, and (ii) subsoil compaction. Subsoil compaction includes any plough pan that develops in the upper part of the subsoil as a result of tillage, that is, at the interface of the Ap horizon. Such compaction, may be only alleviated by subsoiling, and in some climates or soil types may be also assisted by natural processes such as drying-wetting, shrinking-swelling, and freezing-thawing cycles, and also by macrofauna activity, and root growth. However, these processes may not be effective in some cropping systems subject to relatively high field traffic intensities.

Traffic-induced compaction in the subsoil tends to be cumulative as standard tillage operations are rarely performed at depths greater than about 25-30 cm. Only subsoiling operations are capable of solving this problem, but in some soils the effects of deep tillage are transient. Maximum subsoiling depth attainable by conventional equipment is approximately 600 mm; however, mechanical loosening of soil to alleviate deep compaction can prove difficult, expensive and therefore not practical at depths greater than about 40 cm (12).

For most crops, root growth and development are severily affected by compaction; thereby, affecting water and nutrient uptake. A study in the eastern Pampas region of Argentina (4) showed that high clay content soils compacted to CI higher than about 2200 kPa and bulk densities of 1.7 Mg/m^3 or higher at a depth of 400-600 mm reduced peach (*Prunus persica* L.) yields by about 30%. Threadgill (1982) notes that soils with a CI >2000 kPa reduced crop yields, and at >1500 kPa, there was reduced root growth in groves. Iancu *et al.* (1996) demonstrated that bulk density increased by 1.7%, soil penetration resistance increased by 15% and saturated hydraulic conductivity (HC) decreased by 31% with four different treatments with the crop grown along a contour and on lower, middle and upper terraces for two types of soil (brown colluvial and slightly eroded) in apple groves at a soil depth of 0-1.0 m. Nuñez-Moreno and Valdez-Gascon (1994) showed that soil conditions affect yields and growing conditions in citric groves in a semiarid climate in north-western Mexico. The mean orange yield was ca.162 kg/tree in the best area and 48 kg/tree in the worst. Comparison of soil data in the best and worst areas showed that in the worst soil, compaction was greater by 1500 kPa, the infiltration rate was lower, and there was an increase in silt content which reduced plant growth.

Tree cover crops in the Mediterranean basin (*e.g.*, olives, almonds, nuts, and grapevine) are grown in over 9 million hectares. These crops are important part of the Mediterranean diet and require relatively simple agricultural practices for their production (10). However, between 3 and 7 tractor passes per year are required for tillage and weed control, and such repeated traffic on same track can lead to severe subsoil compaction.

Objectives and hypothesis

Quantify the change in soil parameters of Aridisol soil due to light tractor traffic.

Enhance knowledge about the effects of agricultural tractor traffic on soil during common labours on same tracks in eastern Almería, Spain.

Our hypothesis was that: Topsoil and subsoil compaction produced by traffic with a light-weight tractor (≈15 kN) with low ground pressure tyres depends of the number of tractor passes.

MATERIALS AND METHODS

The site and crop operations

The experiment was conducted in the Vélez Blanco District of the Province of Almería in southeast Spain (37°41' N, 2° 5' W) at an altitude 828 m a. s. l. (semiarid climate). The soil is an Aridisol (18). The soil physical and mechanical properties are given in table 1 (page 273).

Treatments

Experiments were performed in a 29-year-old Marcona almond (*Prunus amigdalus* L.) orchard and on soil with cereal crops production. Almond plantation density: 6 x 6 m, 4 and 5 m tall with a trunk that is about 20 cm in diameter.

Five tractor traffics frequencies or treatments were imposed on 200 m long by 4 m wide (800 m^2) plots, where the experimental variable was 0 (control plot), 1, 5, 7 and 10 tractor passes, respectively, over the same track in three replications in completely randomized plots (7). The inter-row passes were made by one 2WD tractor equipped with single rear tyres. Description of the tractor used in the study and technical specifications are given in table 2 (page 273). Tractor speed during the experiment was 4.6 km/h with no hitch load. Before the traffic treatments were applied, plots were plowed once with a rotary tiller (3). This treatment represents a tillage system commonly used in the region.

Table 1. Soil profile characteristics of the Aridisol soil.

Tabla 1. Perfil típico del suelo Aridisol.

Depth (mm)	**0 - 180**	**180 - 280**	**280 - 450**	**450 - 650**	**+ 650**
	A1	**B21t**	**B22t**	**B3**	**C**
Soil Organic carbon (g kg^{-1})	8.1 ± 0.20	3.2 ± 0.2	4.0 ± 0.51	1.7 ± 0.50	1.8± 0.42
Total nitrogen (g kg^{-1})	1.28 ± 0.04	0.8 ± 0.02	0.9 ± 0.10	0.4 ± 0.02	0.5 ± 0.01
C/N ratio	6.32	4.00	4.44	4.25	3.60
Clay (<2 m) g kg^{-1}	143 ± 2.34	251 ± 2.36	237 ± 2.68	173 ± 1.87	135± 2.64
Silt (20-50m) g kg^{-1}	521 ± 3.30	525 ± 2.98	582 ± 3.12	691 ± 2.87	566± 1.91
Sand g kg^{-1}	336 ± 1.39	224 ± 1.87	181 ± 1.88	136 ± 0.96	299 ± 1.92
pH in $H_2$0 (1: 2.5)	7.9 ± 0.03	8.1 ± 0.03	8.0± 0.02	8.3 ± 0.01	8.3 ± 0.05

Table 2. Description of the tractor and technical specifications.

Tabla 2. Descripción del tractor y especificaciones técnicas.

Tractor	**2WD Tractor Design**
Engine power (CV/kW)	47/34.4
Front tyres	650 - 16
Rear tyres	12.4 - 28
Inflation pressure, front tyre (kPa)	160
Inflation pressure, rear tyre (kPa)	95
Overall weight (kN)	15
Front weight (kN)	4.5
Rear weight (kN)	10.5
Mean ground pressure per for front tyre (kPa)	20.1
Mean ground pressure per rear tyre (kPa)	32.3

The tyre inflation pressure was within the range advised by the manufacturer for load and speed (Goodyear Agricultural Tyre Division, 2018, https://www.goodyear.com.au/tyres/tractor-and-agricultural).

La presión de inflado de los neumáticos estaba dentro del rango recomendado por el fabricante para la carga y la velocidad (Goodyear Agricultural Tire Division, 2018, https://www.goodyear.com.au/tyres/tractor-and-agricultural).

Statistical analyses were performed by the Statgraf program 7.1. An analysis of variance (ANOVA) was carried out (17), and means were analyzed by Duncan's multiple range test.

Parameters monitored

Cone index (CI), Bulk Density (BD), soil water content (SWC), Total porosity of soil (TSP), soil Infiltration (I), and rut depth (RD) were measured on the same day as the traffic treatments were applied. The parameters (CI, DB, SWC, TSP and I) were measured along the wheel tracks on the bottom of the RD in the trafficked plots (which was taken into account at data analysis) and were taken across the entire plot for the untrafficked control. The CI was measured with a mechanic penetrometer (2). Each datum is the average of 20 samples for each plot at the depth range of 0-450 mm. The procedure used to obtain the BD and SWC values, is described in Botta (2000). Total topsoil porosity was calculated from BD using soil particle density. Infiltration (I) was determined using the ring infiltrometer method. Rings were 0.25 m in diameter and 0.4 m height and were inserted 0.20 m deep in the soil to prevent lateral seepage loss. The average infiltration was determined from 20 locations per plot. This value was computed only for the topsoil (0-200 mm) because crop root development and nutrient uptake are concentrated there. Rut depth (RD): A description of the procedure used to determine RD is included in Botta *et al.* (2018).

RESULTS AND DISCUSSION

Soil water content, Cone index and Bulk density

The SWC as determined on the day the traffic treatment were imposed was 14.7% (w/w) in the topsoil (0-150 mm), 15.5% (w/w) at 150-300 mm, and 30.1% (w/w) at 300-450 mm, and there was no significant difference in the SWC between the different depth intervals.

Therefore, variations in CI at depth were not due to SWC, which suggested that cone index was a reliable indicator of the degree of soil compaction as a function of the traffic treatment.

The value of CI for the control increased with an increase in soil depth, because of the natural increase in soil resistance originated from the weight of soil above the measured depth (table 3). Lateral forces on the penetrometer cone increase with increasing depth, therefore a higher force is needed for the cone to displace through the soil. Resistance can also increase with depth because of changes in soil texture, gravel content, structure and historic traffic compaction.

Table 3. Cone Index (kPa) measured at the tyre centerline, after 0, 1, 5, 7 and 10 passes of a tractor, respectively.

Tabla 3. Índice de Cono (kPa) medido en el centro de la huella después de 1, 5, 7 y 10 pasadas de tractor, respectivamente.

Depth (mm)	Control plot	1 pass	5 passes	7 passes	10 passes
Topsoil (0-150 mm)					
0	360 a	1355 b	1400 b	2012 c	2100 c
50	465 a	1378 b	1423 b	2020 c	2122 c
100	577 a	1412 b	1490 b	2091 c	2133 c
150	770 a	1500 b	1523 b	2100 c	2290 b
Subsoil (>150 mm)					
200	1522 a	1566 a	1600 a	2287 b	2333 b
250	1694 a	1700 a	1721 a	2442 b	2500 b
300	1710 a	1767 a	1777 a	2600 b	2689 b
350	1756 a	1789 a	1800 a	2850 b	2945 b
400	1787 a	1800 a	1816 a	3010 b	3100 b
450	1774 a	1810 a	1831 a	3201 b	3290 b

Values with different letters (horizontally) are significantly different at each depth ($P < 0.01$) Duncan's multiple range test.

Los valores con letras diferentes (horizontalmente) son significativamente diferentes para cada profundidad ($P < 0,01$ Prueba de rango múltiple de Duncan).

Without traffic, increases in CI (>1700 kPa) between 300 and 450 mm deep, are likely due to high clay content at that depth interval and historic machinery traffic. An effect of traffic at this depth was also observed in the 7 and 10 passes treatments where CI values were significantly greater than that of the control.

Traffic frequencies or treatments of 1 and 5 passes had greater CI than the control only in the topsoil (0-150 mm), as shown in table 3 (page 274). By contrast, for 7 and 10 passes treatments, this study shows that compaction caused significantly greater changes in all the soil properties measured compared with the control. Such changes in soil physical properties were observed in the entire soil profile (0-450 mm depth interval).

For these treatments (7 and 10 passes), CI values were higher than 2000 KPa and 3000 KPa in the topsoil and subsoil, respectively, which denote overcompaction. Also for these treatments, such CI values exceeded critical values of soil strength above which root growth and expansion are significantly affected (*e.g.*, 6, 8, 13, 15). For the 7 and 10 passes treatments, peak CI values were found in the subsoil (400 to 450 mm).

Soil bulk density data was consistent with observations of CI only for the 7 and 10 passes treatments (table 4), showing that BD increased significantly after traffic and also with an increase in soil depth. The before traffic condition (control) also showed relatively high bulk density values. Without traffic, bulk density at the surface exceeded the 1.2 Mg/m^3 threshold recommended by Ressia *et al.* (1998) at 200 mm depth. Bulk density was higher than 1.5 Mg/m^3 either with or without traffic between 300 and 450 mm.

Bulk density and CI always increased with the number of passes, but BD tended to be less responsive than CI, probably because of the relatively high pre-traffic density. Despite this, there was an overall increase in BD of about 33% on average relative to the control, and differences between the control and the 1 or 5 passes treatments were not significant ($P < 0.01$). The corresponding increase in CI was 197% on average. Differences between the control and the 7 and 10 passes treatments were significant at the 0-200 mm depth interval.

Table 4. Bulk density (Mg/m^3) values at three depth intervals under different degrees of tractor traffic (0, 1, 5, 7 and 10 passes of a light-weight 2WD tractor).

Tabla 4. Valores de densidad aparente (Mg/m^3) en tres rangos de profundidad bajo diferentes grados de tráfico del tractor (0, 1, 5, 7 y 10 pasadas de un tractor 2WD liviano).

Depth (mm)	Control plot	1 pass	5 passes	7 passes	10 passes
0 - 150	1.24 a	1.26 a	1.29 a	1.44 b	1.65 b
150 - 300	1.30 a	1.33 a	1.43 a	1.63 b	1.67 b
300 - 450	1.52 a	1.53 a	1.54 a	1.64 b	1.66 b

Values with different letters (horizontally) are significantly different at each depth ($P < 0.01$ Duncan's multiple range test).

Los valores con letras diferentes (horizontalmente) son significativamente diferentes para cada profundidad ($P < 0,01$ Prueba de rango múltiple de Duncan).

Rut depth (RD)

Examination of the soil response to traffic at relatively shallow depths revealed that rut depth increased as the tractor traffic increased (table 5). The topsoil is the layer most vulnerable to both soil compression and soil displacement from the passage of tractors. The greatest values of rut depth were measured when the tractor passed 7 and 10 times. The results of Duncan's multiple range test (P<0.01) showed significant differences between the rut depth for the four traffic treatments (table 5).

Soil disturbance near the surface increased with the number of tractor passes, but RD was never deeper than 100 mm in none of the treatments, however this was consistenly deeper for the 10 passes treatment. In addition, for the 10 and 7 passes treatments, there was a significant correlation between RD and soil compaction (R^2 values were between 0.89 and 0.93 for CI, and between 0.85 and 0.94 for BD, respectively, P<0.01) deeper in the profile (200-600 mm depth interval). For the 1 and 5 passes treatments, this correlation was not significant (R^2 values were between 0.003 and 0.05 for CI, and between 0.008 and 0.215 for BD, respectively, P > 0.01).

Water infiltration into soil

As shown in figure 1 (page 277), only the 7 and 10 passes treatments caused a statistically significant reduction in water infiltration into soil over the 0 to 200 mm depth profile compared with the control plot. This result agrees with those reported in earlier sobtained by numerous researchers (*e.g.*, 5, 7).

Total soil porosity of soil

Total porosity of soil (TSP) is an important indicator of compaction (table 6, page 277) as it relates to density properties. Differences in TSP between the 7 and 10 traffic treatments for the 0-450 mm depth interval were statistically significant ($P < 0.01$) compared with the control. The 10 passes treatment caused the greatest reduction in TSP, consistent with the high traffic intensity applied through that treatment. This response was more significant in the subsoil (from 300 to 450 mm deep). Total porosity values for this treatment were lower than about 40%, which is considered to be the limit TSP above which crop yield can be significantly affected. These results are in accord with those of Håkansson and Reader (1994) who showed that by light vehicles can cause significant subsoil compaction after repeated passes.

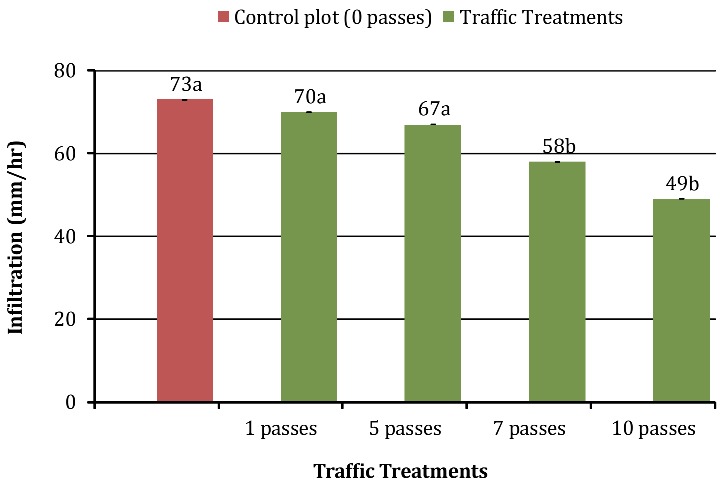
Table 5. Effect of traffic treatments on rut depth (mm).

Tabla 5. Efecto de los tratamientos de tráfico sobre la profundidad de huella (mm).

Traffic Treatments	Mean of rut depth (mm)
1 pass	37 a
5 passes	60 b
7 passes	87 c
10 passes	99 d

Different letters within each traffic treatments shows significant differences (P < 0.01 Duncan's multiple range test).

Diferentes letras dentro de cada tratamiento de tráfico muestran diferencias significativas (P < 0,01 prueba de rango múltiple de Duncan).



Bars with the same letter are not significantly different (P < 0.01) Duncan's multiple test.

Barras con las mismas letras indican que no hay diferencias significativas entre los tratamientos (P < 0,01) prueba de rango multiple de Duncan.

Figure 1. Average infiltration values (mm/h) in the 0 to 200 mm depth range for the five traffic treatments.

Figura 1. Valores medios de infiltración (mm/h) en el intervalo de 0 a 200 mm de profundidad para los 5 tratamientos de tráfico.

Table 6. Total porosity of soil (%) estimated for three depth intervals under different degrees of tractor traffic (0, 1, 5, 7 and 10 passes of a light-weight 2WD tractor).

Tabla 6. Valores porosidad total del suelo (%) calculados para tres rangos de profundidad bajo diferentes grados de tráfico del tractor (0, 1, 5, 7 y 10 pasadas de un tractor 2WD liviano).

Depth (mm)	Control plot	1 pass	5 passes	7 passes	10 passes
0 - 150	53.2 a	52.4 a	51.3 a	45.6 b	37.7 c
150 - 300	50.9 a	49.8 a	46.0 a	38.4 b	36.9 b
300 - 450	42.6 a	42.2 a	41.8 a	38.1 b	37.3 b

Values with different letters (horizontally) are significantly different at each depth (P < 0.01 Duncan's multiple range test).

Los valores con letras diferentes (horizontalmente) son significativamente diferentes para cada profundidad (P < 0,01 Prueba de rango múltiple de Duncan).

Such level of compaction can be similar to that commonly found, for example, after a single pass with much heavier (*e.g.*, 10-12 t axle load) equipment (*e.g.*, 1). Finnally, data from parameters analyzed within this study showed that traffic compaction by light-weight tractors (*e.g.*, ≈15 kN overall load) induced significant changes to the topsoil (0-150 mm) and subsoil properties

(150-450 mm). These results confirm those previously reported by Håkansson (1987), who indicated that the lasting effects of compaction are related to soil type, the number of passes, and the number of years after compaction was impossed. Hence, the data showed in this work support the hypothesis formulated prior to this study. Technological developments such as in (ultra)-low ground pressure systems (*e.g.*, IF and VF marked tyres) offer promise to mitigate the effects of traffic on soil compaction, and this is an area that merits a research priority within intensively-managed horticultural systems such as the one described in our study. Reduction in contact pressures by using tyres at the lowest (safest) operating pressure aided by the use of central tyre-inflation-pressure control systems may also be recommended if this was a more cost-effective option than IF/VF marked tyres.

CONCLUSIONS

Given the experimental conditions of this study, the following conclusions can be drawn:

One and five passes of a light-weight tractor (15 kN overall load) did not increase soil bulk density or cone index significantly at shallow depths (0-150 mm).

Only 7 and 10 repeated passes of a light-weight tractor induced significant increases in both soil cone index and soil bulk density to a depth of 450 mm.

The work reported in this article showed that soil compaction caused by a light-weight tractor can significantly decrease total soil porosity and water infiltration into soil.

The traffic treatments applied within this study affected all soil measured parameters in the topsoil and resulted in soil physical conditions that would be unsuitable for crop establishment and development.

There is a need to investigate the feasibility of using low (ground) pressure tyre technology in light-weight vehicles commonly used in almond production (and similar tree plantations) in Mediterranean soils. The utilisation of low (ground) pressure tyre technology may be a cost-effective alternative to mitigate the effect of traffic compaction in these systems compared with deep tillage.

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