Power and draft required by chisel plow on soils under no- tillage in the Argentinean flat Pampas

Potencia y tiro requerido por el arado de cinceles sobre suelos trabajados en no- labranza en la región llana de la Pampa de Argentina

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Abstract

No-tillage system production in Argentina requires high traffic intensities, for example, 50 to 65 Mg km^{-1} ha^{-1}. Due to these traffic intensities, continuously and successively applied, the soils are compacted. One of the frequently utilized techniques for management of topsoil and subsoil compaction is chiseling. The objectives of this work were: a) to evaluate the effect of vertical tillage on the physical properties of a Typic Argiudol soil from north-eastern Rolling Pampa Region at Argentina and b) to quantify the power required by a chisel plow working in one and two depth levels on a soil under no-tillage. Three treatments were applied: T1) control plot (unloosened soil), T2) loosened with one chisel plow pass at a 0.25m deep range, and T3) loosened with two chisel passes, the first at 0.15m and the second at 0.25m. The following variables were measured: cone Index (CI), soil water content, (SWC), tractor slip (TS) and power and draft force (PD). The main results and conclusions showed: a) The CI values on the two deep tillage treatments were statistically different ($P < 0.01$) from that of the control plot, up to 300 mm and b) the chisel plow working in two depth ranges (T3) could significantly increase the specific resistance and drawbar power. This means that vertical tillage carried out in two chisel passes (T3) was, from an energy point of view, less efficient than one single pass (T2).

Keywords
cone index • soil carrying capacity • soil compaction • drawbar

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Resumen

La producción bajo el sistema de no-labranza en Argentina requiere altas intensidades de tráfico, por ejemplo de 50 a 65 Mg km ha. Debido a estas intensidades de tráfico aplicadas de forma continua y sucesiva, los suelos se compactan. Una de las técnicas comúnmente utilizadas para el manejo de la compactación de la capa superficial y subsuperficial es el cincelado. El objetivo de este trabajo fue: a) evaluar el efecto de la labranza vertical en las propiedades físicas de un suelo Argiudol típico en el noreste de la Región Pampena en Argentina y b) cuantificar la potencia requerida por un arado de cinceles que trabaja en una y dos profundidades en un suelo bajo no-labranza. Se aplicaron tres tratamientos: (T1) parcela de control (suelo no cincelado), (T2) suelo arado con una pasada de cincel a una profundidad de 0.25 m y T3) suelo arado con dos pasadas de cincel, el primero a 0.15 m y el segundo a 0.25 m. Se midieron las siguientes variables: índice de cono (IC), contenido de agua del suelo, (CAS), patinamiento del tractor (S) y potencia y esfuerzo de tracción (PE). Los principales resultados y conclusiones fueron: a) Los valores de IC en los dos tratamientos de labranza profunda fueron estadísticamente diferentes (P <0.01) de los del testigo hasta 300 mm y b) el trabajo del cincel en dos rangos de profundidad (T3) puede aumentar significativamente la resistencia específica y la potencia en la barra de tiro. Esto significa que la labranza vertical realizada en dos pasadas de cincel (T3) tuvo, desde un punto de vista energético, una menor eficiencia que (T2).

Palabras clave

Indice de cono • capacidad portante del suelo • compactación de suelo • barra de tiro

Introduction

Soil compaction has long been known to cause reductions in root growth and yield in many crops, but soybeans (*Glycine max* L.) and maize (*Zea mays* L.) from the Argentine pampas region, where these crops are usually managed under no-tillage, are particularly susceptible (12). Canarache *et al.* (1984) found that in Romanian soils each 1 kg/m^3 increase in bulk density, decreased maize yield in 18% with respect to a non-compacted soil. Botta *et al.* (2002) identified two aspects of compaction: (a) topsoil compaction within the cultivated (Ap) horizon, and (b) subsoil compaction. It is important to note that typical tillage depths in Argentina are approximately 180 mm, so the Ap horizon is considered to be in the 0–200 mm topsoil layer based on criteria posed by Marquéz Delgado (2001). Traffic-induced subsoil compaction (below 200 mm in our case) tends to be cumulative as standard tillage operations are rarely performed at depths greater than about 25-30 cm (14, 29).

Threadgill (1982) noted that soils with a CI >2000 kPa reduced crop yields and that CI >1500 kPa reduced root growth. As a result, when soils are compacted with CI values > 2000 kPa, roots from most annual crops practically stop growing (8).

In order to alleviate the effects of topsoil and subsoil compaction, numerous techniques for subsoil loosening have been developed. Such operations are expensive and rarely can completely ameliorate compaction in the subsoil, particularly in deeper layers (19). The power and draft required by deep tillage equipment vary according to depth, soil type and forward speed. A conventional straight shank subsoiler operating at 450 mm depth in loamy Entic Haplustoll soil required about 6.5 kN/shank, while a chisel plow operating at 280 mm required 3.6 kN / shank. Drawbar power ranged from 67.3 kW at 6.12 km/h and 65.5 kW at 5.2 km/h for the chisel plow and subsoiler respectively (9).

With respect to the required energy for deep tillage, Marquéz Delgado (2001) worked in different soils (sandy and clayey) at a depth of 300 mm. He found that the power demanded from the tractor engine increased 15% from approximately 26 kW per curve shank at around 34 kW per straight shank. The author concluded that the main factor affecting the power requirement is the horizontal friction of the shank against the soil, which increased its cutting force. Shinners (1989) found that a paraplow operating at 3.96 km/h required 28 kW at 220 mm depth and 32 kW at 300 mm depth. Increasing the operating depth to 380 and 460 mm meant that the forward speed had to be decreased to 3.38 and 3.2 km/h, respectively, to keep the required power at about 32 kW.

One of the advantages of using a chisel plow is that it allows multiple shank combinations. They can be arranged with all shanks working at the same depth, as in most cases, or with shallow shanks working ahead of deep shanks (two depth levels), as suggested by Spoor and Godwin (1978). For example, Godwin *et al.* (1984) worked in two depth levels, having found that the positioning of a single shallow shank immediately ahead of a deep shank, marginally increased the draught force, marginally reduced the area of soil disturbance and significantly increased the specific resistance.

The objectives of this work were: a) to evaluate the effect of vertical tillage on the physical properties of a Typic Argiudol soil from northeastern Rolling Pampa Region in Argentina and b) to quantify the power required by a chisel plow working in one and two depth levels on soil under no-tillage. Our hypothesis stated that a chisel plow working in two depth levels on a no-tillage soil requires less total draft force than when working at one depth level.

Materials and methods

The site

The experiment was conducted in the east of the Rolling Pampa region, Buenos Aires State, Argentina at 34° 25' S, 59° 15' W; altitude 22 m above sea level; slope type 1 with gradient 0.5%; well drained, drainage class 4; no stone class 0. The soil is a Typical Argiudol (30) worked under no-tillage system. Soil physical and mechanical properties are given in table 1.

Table 1. Profile characteristics of the Typical Argiudol soil.

Tabla 1. Características del perfil del suelo Argiudol tipico.

HORIZONTS	Ap1	Ap2	AB	Bt1	Btss	Bt2	BCk	2Ckk
Depth (mm)	0 -10	16 - 20	25 - 32	40 - 55	65 – 80	90 - 110	120 - 150	160 - 220
Soil Organic Carbon (%)	1.85	1.44	0.95	0.61	0.55	0.32	0.20	0.11
Total nitrogen (%)	0.23	0.132	0.102	0.081	0.072	0.053	0.031	-
C/N ratio	8.9	10	9	8	8	6	6	-
Clay (<2 µm)	20.1	24.8	27.9	34.2	46.4	32.0	22.0	14.9
Silt (2-20 µm)	33.1	34.6	29.5	28.1	20.7	30.0	31.8	29.9
Silt (2-50µm)	75.6	70.8	67.2	61.3	50.0	63.0	72.7	79.9
Fine Sand (50-250 µm)	0.3	0.2	0.3	0.4	0.4	0.4	0.5	0.4
Equivalent Moisture (%)	26.6	28.5	26.8	28.7	35.2	31.9	27.0	23.5
pH	5.4	5.3	5.5	5.5	5.8	6.0	6.0	7.5
pH in H_20 (1: 2.5)	5.8	5.8	6.0	6.2	6.5	6.4	6.4	7.9
Cation exchange (m.e. 100g)								
Ca++	11.4	12.7	12.0	13.8	18.3	17.2	16.5	-
Mg++	2.9	2.5	3.1	4.5	6.5	6.4	3.8	-
Na+	0.2	0.1	0.2	0.1	0.2	0.2	0.3	0.5
K+	1.4	1.0	0.9	1.3	2.3	2.4	2.3	2.4

Treatments

Treatments consisted of two deep loosening operations and a control. Deep loosening was conducted with a 75.53 kW, FWA tractor (table 2, page 105) in autumn (corresponding to the southern hemisphere) using the following different treatments: T1) control plot (unloosened soil), T2) loosened with one chisel plow pass at 0.25 m deep range, and T3) loosened with two chisel plow passes, the first at 0.15m and the second at 0.25m (figure 1, page 105).

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).

Table 2. Tractor technical description and specifications.

Tabla 2. Descripción del tractor y especificaciones técnicas.

Tractor	FWA Tractor Design
Engine power (CV/kW)	103/75.53
Front tyres	14.4 -24
Rear tyres	18.4-34
Inflation pressure, front tyre (kPa)	110
Inflation pressure, rear tyre (kPa)	100
Overall weight (kN)	47
Front weight (kN)	18.6
Rear weight (kN)	28.4
Mean ground pressure per for front tyre (kPa)	32.54
Mean ground pressure per rear tyre (kPa)	29.62

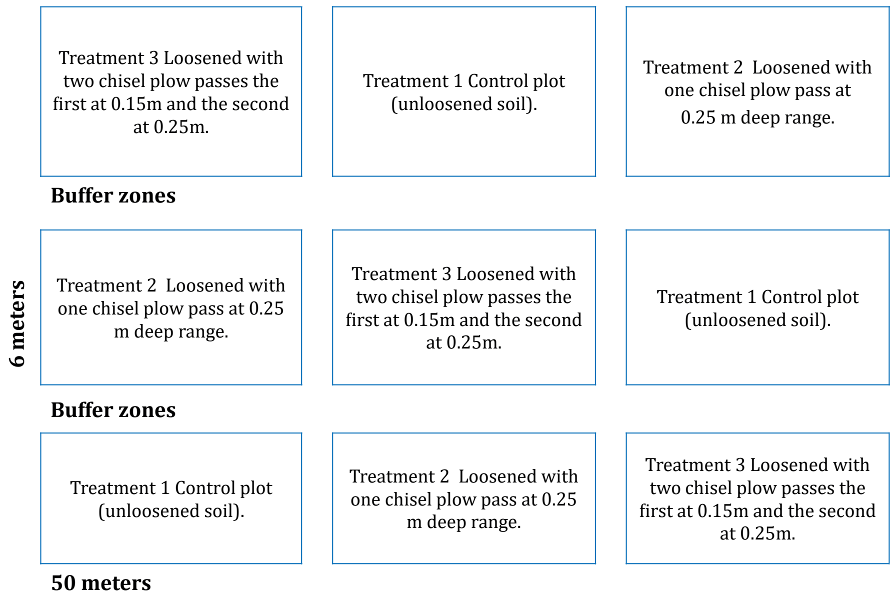

Figure 1. Diagram of the experimental design.

Figura 1. Esquema del diseño experimental.

All treatments were settled on 50 m long by 6 m wide (300 m^2) plots, with three replications in a completely randomized design, with a 10 meters buffer zone, between plots according to Botta (2000). Technical description and specifications of the tractor used in the study are given in table 2. The real work speed was calculated with the distance/time equation. For this, the time expended by the equipment to cover the central 25 m of each loosened plot, was recorded.

The mean ground contact pressure (GCP) was measured with a Tekscan device. Tyre inflation pressures were adjusted following the tyre manufacturers' recommendations for the carried load and operation speed.

A chisel plow with 5 mounted curved shanks measuring 51 mm x 25 mm, spaced 300 mm apart, operated at 250 mm depth.

During treatment 3, the second pass of the chisel plow was carried out with a displacement angle of 20° with respect to the first pass, according to Ressia's proposal (Personal communication 2019).

Parameters monitored

Cone index (CI), soil water content (SWC), power and draft force (PD) and tractor slip (TS) were measured on the same day as the traffic treatments were applied. The parameters (CI, SWC, PD and TS) were measured along the central 25 m of each plot. The CI was measured with a mechanic penetrometer (1) and in accordance with ASAE (2013). Each datum is an average of 25 samples for each plot at the depth range of 0–450 mm. The procedure used to obtain SWC values and TS, is described in Botta (2000). Power and draft force (PD) required for chisel plow was measured with a 50 kN maximum load hydraulic dynamometer located between the tractor and the chisel plow. The characteristics of the dynamometer were as follows: Cylinder diameter: 8.9 cm, stem diameter: 2.8 cm and action surface: 56 cm^2, according to the methodology proposed by Botta *et al.* (2012a). Each datum is an average of 25 samples for each plot.

Explanatory variables

Removed area (RA) was measured after the chisel plow pass. with a profile meter consisting of a set of vertical metal rods (length 500 mm and diameter 5 mm), spaced at 25 mm horizontal intervals, sliding through holes in a 1-m long iron bar. The bar was placed across the removed soil, perpendicular to the direction of travel and rods positioned to conform the shape of the depression. The removed area was calculated as the average depth of 20 reads on the 1 meter bar.

Specific resistance (SR) was calculated as the ratio between the traction effort demanded/ removed area, as proposed by Ressia *et al.* (2010). Finally, maximum bulk density (BD) and critical water content (W) were determined according to the standard Proctor method (3).

Statistical analyses

Statistical analyses were performed with the Statgraf program 7.1. An analysis of variance (ANOVA) was carried out, and means were analyzed by Duncan's multiple range test. According to the Shapiro-Wilk test, soil data followed a normal distribution. Normality was assumed after checking normality of the deviations of each data with respect to the average of the respective treatment, it Botta *et al.* (2019).

Results and discussion

Soil water content and Cone index

Differences in soil water content (SWC) on the day that the deep soil loosening treatments were imposed in each sample, were generally not significant between the different depth intervals (table 3). 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 tillage treatment.

Table 3. Soil water content (w/w). Average values ± standard deviation (n = 25).
Tabla 3. Contenido de agua del suelo (m/m). Valores medios ± desviación estándar (n = 25).

Depth range levels (mm)	Soil water content (w/w)		
	Control plot	(T2) Loosened with one chisel plow pass at 0.25 m deep range	(T3) loosened with two chisel plow passes, the first at 0.15m and the second at 0.25m
0-150	17.2 ± 1.31 a	16.6 ± 1.41 a	16.5 ± 1.43 a
150-300	18.2 ± 1.52 a	17.2 ± 1.61 a	17.6 ± 1.68 a
300-450	18.9 ± 1.42 a	18.0 ± 1.86 a	18.4 ± 1.50 a

Values with different letters are significantly different at each depth (P<0.01 Duncan's multiple range test).
Los valores con letras diferentes son significativamente diferentes para cada profundidad (P <0,01 Prueba de rango múltiple de Duncan).

Soil water content (w / w) during application of the treatments was 17.2% on the surface 0-150 mm, 18.2% at 150-300 mm and 18.9% at 300-450 mm. The SWC values at the time of the test were 4.8 % lower than the Proctor value (22.0%) in the 0 to 150 mm depth range, 5.7 % lower than the Proctor value (23.9%) in the 150 to 300 mm depth range and 5.2 % minor (23.4%) in the 300 to 450 mm depth range, respectively.

From the mentioned Proctor values, it can be inferred that soil water content, at the time of the tractor traffic, was far from the value that maximum soil compaction can produce. This situation is the most recommended when carrying out deep tillage work, since the impact of the tractor weight and the pressure in the wheel/soil contact area is minimized with the SWC values indicated in the previous paragraphs.

Cone index data provided a clear indication of the initial soil condition in each treatment. table 4 (statistical analysis between treatments) shows that CI of the unloosened control plot was greater than the 1.2 MPa cone index quoted by Soza *et al.* (2003) as critical for normal seed emergence of wheat in fine textured soils of the Rolling Pampa region.

Regarding deep tillage treatments, cone index values in the two depths were statistically different (P < 0.01) from those on the unloosened soil, up to 300 mm depth. ANOVA results, averaged over depths from 0 to 175 mm, showed a significant difference between CI from T2 and T3. For these treatments CI values were higher than 2500 KPa in the subsoil (300 to 450 mm), denoting over-compaction. Also, CI values exceeded critical values of soil strength on these treatments, where root growth and expansion are significantly affected (13, 18, 20, 21, 22).

According with Botta *et al.* (2018) subsoil compaction is caused by high wheel load, tyre ground pressure, and traffic intensity of machinery used for crop protection and harvest operations, rather than for seeding, particularly when these operations are carried out on wet clay soil, or with high tyre inflation pressure (between 140 and 218 kPa). Induced soil compaction within this layer is cumulative, as no conventional tillage is done at that depth.

Table 4. Average (n = 25) cone index values (kPa) for the tillage treatments.

Tabla 4. Valores medios (n = 25) de índice de cono (kPa) para los tratamientos de labranza.

Depth (mm)	Control plot (unloosened soil) (T1)	Loosened with one chisel plow pass at 0.25 m deep range (T2)	Loosened with two chisel plow passes, the first at 0.15m and the second at 0.25m (T3)
Topsoil (0 to 200 mm)			
0	1351 a	193 b	422 c
25	1569 a	298 b	499 c
50	1666 a	323 b	537 c
75	1809 a	400 b	635 c
100	2212 a	488 b	699 c
125	2390 a	707 b	956 c
150	2550 a	823 b	980 c
175	2670 a	934 b	1170 c
200	2700 a	1135 b	1256 b
Subsoil (> 200 mm)			
225	2792 a	1233 b	1351 b
250	2821 a	1316 b	1400 b
275	2888 a	2100 b	2133 b
300	2912 a	2650 b	2665 b
325	2978 a	2890 a	2877 a
350	2999 a	2990 a	3000 a
375	3078 a	3010 a	3089 a
400	3167 a	3187 a	3198 a
425	3199 a	3189 a	3208 a
450	3236 a	3240 a	3276 a

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).

Energy required by chisel plow

In this experiment, shape, width, rake angle and spacing of an individual soil cutting tool strongly influenced the transport and mixing of soil particles and implement draft. Table 5 shows that, although no significant differences between the draft forces were found, the sum of the draft force of the chisel plow working in two passes (or two depth levels) was 12.6 % greater than when it works in a single pass. The results are in accordance with those of Balbuena *et al.* (1996) and Contessotto (2018), who advised that the degree of interaction can be assessed through the specific resistance, both parameters inversely related, indicating that the lowest specific resistance values would provide the best possible interaction in a given situation.

Table 5. Average values (n = 20) for draft force, removed area, and specific resistance in the two tillage treatments.

Tabla 5. Valores medios (n = 20) de esfuerzo de tiro, área removida y resistencia específica en los dos tratamientos de labranza.

Tillage Treatments	Real travel speed (Km/h)	Draft force (kg)	Removed area (cm^2)	Specific resistance (kg/cm^2)
Loosened with one chisel plow pass at 0.25 m deep range (T2)	7.5	1520 a	3445 a	0.418 a
Loosened with two chisel plow passes, the first at 0.15m and the second at 0.25m (T3)*	7.5	1712 a	3600 a	0.466 a

* The values represent the sum of the work in two depth levels: first level 0.15 m and the second at 0.25m depth, and the average speed. Values with different letters (vertically) are significantly different at each depth (P<0.01 Duncan's multiple range test).

*Los valores representan la sumatoria del trabajo en dos estratos: primera pasada 0,15m y la segunda a 0,25m de profundidad, y la media de la velocidad. Los valores con letras diferentes (verticalmente) son significativamente diferentes para cada profundidad (P<0,01 Prueba de rango múltiple de Duncan).

It should be noted that the soil type in this study is one of the so-called "silts". These types of soil fail (*ie*, "cut") more easily as water content increases. Also, there is a range of soil water content within which optimal soil loosening occurs with minimal tillage requirements (4, 24).

Regarding specific resistance, it did not differ between treatments (table 5). However, the fact that these soils exhibit variable physical properties, such as structure, bulk density, cohesion and internal friction angle as well as interactions between their particles and with tillage tools, should be highlighted and taken into consideration. These properties are greatly affected by soil water content, which in this case (table 3, page 106) was homogeneous for all treatments.

Tables 5 and 6 (page 109) show the results of the two-deep tillage treatments. Chisel plow working in two depth levels, increased the specific resistance and drawbar power values. This means that vertical tillage carried out in two chisel passes produced, from an energy point of view, less efficiently than one single pass.

Also, about the drawbar power demanded, it appears that the second passage in the sequence of tillage was very inefficient, even though in this experiment, it was carried out at the lowest speed. This is probably due to the tractor, which had low tire ground pressures (table 2, page 105) making the traffic (during the second chisel plow pass) on soil with low bearing capacity. Consequently, a significant increase in power losses in the drawbar was observed. These losses were due to slip and rolling resistance, and represented coincident results, in the latter parameter, with those found by Botta *et al.* (2012b).

Hence, these results do not support the hypothesis stating that a chisel plow working in two depth levels on a no-tillage soil requires less total draft force than when working in a one depth level.

Table 6. Average values (n = 20) of draft force and drawbar power in the two tillage treatments.

Tabla 6. Valores medios (n = 20) de esfuerzo de tiro y potencia en la barra de tiro requerida en los dos tratamientos de labranza.

Tillage treatments	Real travel speed (Km/h)	Slip (%)	Draft force (kg)	Drawbar power (CV)
Loosened with one chisel plow pass at 0.25 m deep range (T2)	7.5	9.0	1520 a	42.20 a
Loosened with two chisel plow passes, the first at 0.15m and the second at 0.25m (T3)	8.1	7.9	810 b	24.30 b
	7.0	12	902 b	23.38 b
Sum of the traction effort and the drawbar power for de chisel plow working in two depth levels			1712 a	47.68 b

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

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

Conclusions

Within the limits of our experimental conditions, we can arrive at the following conclusions.

1) Even though chiseling loosened the soil and reduced cone index, measurements taken on this soil (loamy soils with clay B horizons) revealed that chisel plow requires less draft force when carrying out the work of loosened soil in one pass than when it is carried out in two passes.

2) After vertical tillage treatments were applied, soil physical parameters measured on topsoil and subsoil (below 200 mm and up to 300 mm depth) resulted in soil physical conditions that would be suitable for crop settlement and development.

3) Also, regarding the drawbar power demanded, the second passage in the sequence of tillage resulted very inefficient, even though it was carried out at the lowest speed, used in this experiment.

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