DEEP LOOSENING FOR DIRECT DRILLED SOIL RECOVERY

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Abstract

Maintaining a sustainable soil management system with annual double cropping is a considerable challenge, even when a conservation technique such as direct drilling is used. No tillage means less vehicular traffic, but not necessarily a reduction in traffic intensity because of the excessively high axles loads associated with some agricultural machines. Direct drilled soils appear to have a better recovery following agricultural traffic, but evidence has suggested that problems related to compacted layers occur in these profiles with time. Subsoiling, as a well known technique to alleviate soil compaction, has been widely quoted for tilled soils, but rather little is known about how no tilled soils respond to this technique. The task is to loosen compacted subsoil layers, with minimal disturbance of the topsoil to avoid subsequent problems during drilling. Research was performed on a fine Typic Argiudol soil managed with no tillage, annual double cropping and with and without deep loosening. Both soil treatments received the standard traffic demanded by the cropping system. Soil penetration resistance and dry bulk density were the dependant variables assessed. Results showed that although there was a major compaction tendency after traffic on loosened soil, there was also evidence that the effects of loosening persisted for almost nine months. Interestingly, it was also evident that layers below the mechanically loosened horizon exhibited a reduction in penetration resistance and bulk density. It was concluded that periodic subsoiling can alleviate the soil compaction caused by agricultural traffic in deep soil layers and will allow direct drilling to continue sustainably. Subsoiling not only alleviates compaction in the mechanically disturbed layers, but also in the horizon immediately below.

Keywords: No-tillage agriculture, soil loosening persistence, soil compaction, soil compaction alleviation, soil resilience, agricultural traffic.

LABRANZA VERTICAL PARA RECUPERACIÓN DE SUELOS BAJO SIEMBRA DIRECTA

Resumen

la siembra directa puede asociarse a menos tráfico vehicular pero no necesariamente a una menor intensidad de tráfico, debido a las excesivas cargas por ejes que presentan ciertas máquinas de uso actual. Asociado a esta característica se han reportado algunos problemas de compactación ligados a esta práctica de cultivo. Aún es poco conocido la respuesta que presentan estos tipos de suelos, no labrados, al pasaje de un subsolador. El presente trabajo se llevó adelante entre los años 2004 y 2009 en un suelo Argiudol típico trabajado bajo siembra directa, al cual se le hizo un doble cultivo anual con dos tratamientos: con y sin subsolar. Ambos tratamientos fueron sometidos a las demandas de tránsito usuales incluyendo pulverización, siembra directa, cosecha y transporte de granos. Las variables dependientes del ensayo fueron la densidad aparente y la resistencia a la penetración. Los resultados mostraron que aunque hubo una mayor tendencia a la compactación en los suelos subsolados, los efectos de esta operación persistieron al menos nueve meses. Se registraron reducciones de la resistencia a la penetración y la densidad aparente en las capas inmediatamente inferiores a las alcanzadas por el subsolador. El subsolado permite mejorar las condiciones de compactación inducida y contribuir a un manejo sustentable de los suelos bajo siembra directa.

Palabras clave: Agricultura sin labranza, persistencia del laboreo vertical, compactación de suelos, resiliencia del suelo, tráfico agrícola.

Introduction

Soil compaction due to vehicular traffic during the harvesting of summer crops is of particular concern in the Rolling Pampa of Argentina because at this time soils have a significant decrease in their bearing capacity due to the increase of rainfall (1). When trafficked with high axle loads in this wet condition, soils develop deep tracks that remain as tramlines and cause problems in later sowings. The impact of these deep tracks is of particular significance if the field is direct sowed.

Soil compaction affects soil physical properties by increasing soil bulk density and by changing the size distribution as well as the tortuosity and connectivity of soil pores (2, 3).

More than 27 million ha of arable soils are managed under no tillage systems in Argentina and account for almost 70% of national crop production (4). In spite of the fact that agricultural soils managed under this system receive less tractor passes than their conventionally tilled counterparts, the traffic intensity, measured in Mg km ha^{-1}, is not significantly reduced. This is due not only to the increasing mass of drillers and planters, which easily attain 10 Mg on a single axle, but also the chasers used for grain transportation from combine harvester to truck. In addition, the main crop production systems employs tractor towed containers or hoppers with 30 Mg on one axle to transport grain out of the field. This mass per axle is five to six times above that recommended to reduce or control soil over-compaction (5). Direct sowing requires heavy seeding machines (5–11 Mg) and tractors (5–10 Mg) and these high loads produce subsoil compaction (6). In Sweden, a limit of 6 Mg per axle has been recommended to farmers since 1974 (7). Van den Akker (8) suggests limits for permissible wheel loads and tyre inflation pressures that depend on the mechanical properties of the subsoil at the time of trafficking.

The limits of bulk density and penetration resistance for various crops on different soils and under different conditions have been well established, so the principal task for soil mechanics research is to find relationships between the loads imposed by vehicle running gear and the increase in bulk density and penetration resistance at different depths in the soil profile.

Penetration resistance and bulk density are the most frequently used parameters for assessing soil compaction, as it was stablished by Alakukku *et al.* (9). It has often been stated that penetration resistance is a more sensitive and rational way of assessing increments in soil compaction following traffic than bulk density, even if the latter is assessed with a high resolution gamma probe as Jorajuria quoted (10). It is also the case that the relative ease of measuring penetration resistance allows a good degree of data replication that compensates for high levels of field variability.

Schäfer-Landefeld *et. al*. (11), studying soil behavior after sugar beet (*Beta vulgaris var. sacharata L.*) harvester traffic, reported that previously subsoiled soils showed higher increments in topsoil and subsoil compaction than those without mechanical loosening. It could be inferred therefore that soil loosening treatments such as subsoiling should be carried out immediately before sowing to avoid undesirable increments in soil compaction.

Arvidsson (12) established that harvesting vehicles with an axle load of 35 Mg used on wet soils (18 to 20% volumetric water content), induced compaction below 50 cm depth. They concluded that soil moisture was the principal factor affecting the change in soil compactness due to traffic.

In Argentina's commercial production systems there are still doubts related to the advantages, opportunity and frequency of mechanical soil treatments to alleviate soil over-compaction on no-tillage soils. To improve knowledge about this problem, data related to the behavior of loosened soil with time is still lacking. It will be important to decide the frequency and to predict the benefits from subsoiling treatments and to gather data referring to soil recovery after traffic on loosened soil.
This work was performed on the hypothesis that periodic subsoiling can alleviate soil hard layers due to agricultural traffic and allow direct drilling to be sustained.

The main objective of the work was to evaluate soil recovery following traffic in a direct drilling regime after different periods and in the presence and absence of mechanical loosening with a curved shank subsoiler.

Materials and Methods

Experimental site:

The experimental field plots were located at *San Antonio de Areco* county, *Buenos Aires* Province, (34º18' S, 59º56' W). Site history was: twelve years of double cropping with direct drilling of winter wheat (*Triticum aestivum L.*) sowed in July, harvested by 20 to 25 th of December, followed immediately by soybean (*Glicyne max L. Merr.*) sowed directly, without any tillage, harvested at the end of May. June and sometimes the beginning of July is the only period without crop growing.

The soil:

Silty loam classified as Typic Argiudol (13) included in Rio Tala series, with the following analytic description of horizons: A: 0-16 cm, silty loam textured. Friable, adhesive. Organic matter (OM): 3.2%. A2: 16-30 cm. Clayey silt loam. Friable, adhesive. OM: 1.2%. BT1: 30-50 cm. Clayey. Extremely hard when dry. Firm when wet. Very plastic and adhesive. B2T: 50-84 cm. Clayey silt. Very hard when dry. Very firm when wet. Plastic, adhesive.

Treatments and experimental design:

The experimental design was a completely randomized one. The experimental site was divided into three replications plots, each measuring 30 m by 90 m. Each replication plot was partitioned into two sectors, one of which was subsoiled at 6 km h^{-1} with curved shank tines ("*cultivie*" type) at 70 cm lateral spacing and average depth of 30 cm; this treatment was referred to as Previously Subsoiled Soil (PSS). The other sector, which had no mechanical treatment, was referred to as Not Subsoiled Soil (NSS).

The data were assessed during three different periods:

1.A month after subsoiling, which was immediately after the self propelled sprayer and direct drill (tractor + drill) had run over the parcel in July 2008 (**P1**);

2. After wheat harvesting and grain transport with the tractor towed hopper but before soybean planting in December 2008 (**P2**);

3. In March 2009, prior to soybean harvesting when the only traffic since drilling had been the limited amount due to the sprayer with its 24 m wide boom (**P3**).

Between the last two assessments, both soil treatments (PSS and NSS) receive the same traffic. Knowing the exact traffic intensity of the self-propelled sprayer with its varying load is difficult, but as it is 24 m wide and carries 4 Mg on two axles it only adds about 1.6 Mg km ha^{-1} to total traffic intensity.

The trafficking vehicles:

Table 1. Main characteristics of the trafficking vehicles.

	Combine Harvester	**Tractor**	**Hopper 1 axle**	**Planter**	**Sprayer**
Front axle load (Mg)	11.40	2.78	14.1	10.2	2.2
Rear axle load (Mg)	2.80	5.1	-----	-----	1.8
Front wheels size	30.5x32	14.9x24	23.1x30	12.4x28	12.4x46
Rear wheels size	16.9x26	23.1x30	-----	----	12.4x46
Wheel pressure, front (kPa)	151.7	120.7	160.8	130	120
Wheel pressure, rear (kPa)	114.5	75.8	-----		120
Ground pressure, front (kPa)	114	67.6	116.08	98	101
Ground pressure, rear (kPa)	60.0	62.1	-----	-----	96

Experimental variables assessed:

Penetration resistance (PR) was measured using an ASAE S 313 soil penetrometer (Rimick CP20 model) from the surface to a depth of 60 cm, each 10 cm. Measurements of bulk density (BD) were made using a Troxler gamma probe from the surface to a depth of 30 cm. Complementary measurements of soil moisture for each of the depth profiles were taken as well as ground pressure under the wheels of every vehicle involved in the traffic experiment.

Twelve replications of each penetration profile were made on each of the three plot replications during each of the three periods of measurement. Bulk density was measured similarly with three measurement replications in each occasion. Gravimetric soil moisture content (w/w) was assessed using six replications on each measurement occasion. Data were processed with an ANOVA (analysis of variance) to test the null hypothesis and then submitted to a LSD (least significant difference) media test.

Ground pressure was measured using the method quoted by Jorajuria *et al.* (14). This involves painting the soil around each of the vehicle tyres while in the field, lifting the vehicle vertically and then transferring the defined footprint to a medium that allows measurement of the footprint periphery with a planimeter. Ground pressure is then calculated by dividing wheel weight by the measured footprint area.

Results

Table 2: Penetration resistance (kPa) measured on the Not Subsoiled Soil treatment (NSS)

Evaluation Dates	**DEPTH RANGE (cm)**					
	0-10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**
P1: July/08	1888 a	1637 b	1703 c	2239 b	2973 b	3633 b
P2: December/08	2210 b	1406 a	1260 a	1949 a	2732 a	3640 b
P3: March/09	2213 b	1657 b	1488 b	2003 a	2708 a	3669 b

Different letters in each column show statistically significant differences between values (P<0.05) LSD (least significant difference).

Table 3: Penetration resistance (kPa) measured on the Previously Subsoiled Soil treatment (PSS).

Evaluation Dates	**DEPTH RANGE (cm)**					
	0-10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**
P1: July/08	944 a	1231 a	1260 b	1707 b	2514c	3384 c
P2: December/08	1157b	1183 a	983 a	1509 a	2262 b	3082 b
P3: March/09	1204 b	1405 b	1174 b	1330 c	2095 a	2727 a

Different letters in each column show statistically significant differences between values (P<0.05) LSD test.

Table 4: Soil moisture measured in each period of assessment (% w/w).

Evaluation Dates	**DEPTH RANGE (cm)**					
	0-10	10-20	20-30	30-40	40-50	50-60
P1: July/08	25 b	25 b	28 b	27 a	32 a	33 a
P2: December/08	25 b	27 c	29 b	32 b	32 a	33 a
P3: March/09	23 a	22 a	24 a	25 a	27 b	30 a

Different letters in each column show statistically significant differences between values (P<0.05) LSD test.

Table 5: Dry bulk density (Mg m^{-3}) measured with a gamma probe in three depth ranges on the Not Subsoiled Soil treatment (NSS) and Previously Subsoiled Soil treatment (PSS) for the three periods of assessment.

DEPTH RANGE (cm)	NSS TREATMENT			PSS TREATMENT		
	P1	P2	P3	P1	P2	P3
0.0-10	1.306 a	1.534 b	1.445 b	1.257 c	1.330 a	1.340 a
10-20	1.338 a	1.421 a	1.404 a	1.088 b	1.255 c	1.270 c
20-30	1.434 a	1.445 a	1.480 a	1.308 a	1.250 b	1.246 b
30-40	1.384 a	1.406 a	1.410 a	1.345 a	1.206 b	1.106 c

Different letters in each row show statistically significant differences between values (P<0.05) LSD test.

Table 6: Statistical difference among penetration resistance media values (kPa), measured in six depth ranges, comparing the Not Subsoiled Soil treatment (NSS) to Previously Subsoiled Soil treatment (PSS) for the three periods of assessment.

Depth range (cm)	NSS Treatment			PSS treatment		
	P1	P2	P3	P1	P2	P3
0.0-10	**1888 a**	**2210 b**	**2213 b**	**944 c**	**1157 d**	**1204 d**
10-20	**1637 a**	**1406 b**	**1657 c**	**1231 d**	**1183 d**	**1405 e**
20-30	**1703 a**	**1260 b**	**1488 c**	**1260 b**	**983 d**	**1174 e**
30-40	**2239 a**	**1949 b**	**2003 b**	**1707 c**	**1509 d**	**1330 e**
40-50	**2973 a**	**2732 b**	**2708 b**	**2514 c**	**2262 d**	**2095 e**
50-60	**3633 a**	**3640 a**	**3669 a**	**3384 b**	**3082 c**	**2727 d**

Different letters in each row show statistically significant differences between values (P<0.05) LSD test.

Discussion

First data group (P1):

Data assessed during period P1 show that the traffic due to the direct drill and tractor, with the addition of a month's natural consolidation from the date of loosening, induced the following:

PR on treatment PSS (Tables 3 and 6) was lower in all depth ranges compared with NSS) (Tables 2 and 6) with an average 24% reduction.

In agreement with these data were those for BD which showed an average reduction of 3.5% on the PSS treatment. (Table 5)

From these data it is considered that there is enough evidence to confirm the previously established hypothesis that soil loosening has a lasting effect, even in the presence of subsequent traffic, in agreement with Alakukku *et al.* (9). Furthermore, there were no problems during subsequent drilling operations on PSS, due either to soil surface disturbance or with correct seed location, as evidenced by good crop establishment.

Second data group (P2):

Almost five months later (P2), with practically the same soil moisture as that measured in P1, the soil under the NSS treatment showed a significant decrease in PR for intermediate depth ranges (10-20, 20-30, 30-40 and 40-50 cm). The average decrease was 15%.

Soil under the PSS treatment showed the same tendency with an 11% average reduction except at the shallowest depth range (0-10 cm) where no change was discernable.

Final data group (P3):

Three months after the first assessments, soil under the NSS treatment deviated from the previous trend and showed increments in PR in three intermediate depth ranges (10-20, 20-30 and 30-40 cm) as shown in Table 2. This change in soil behavior with respect to PR was not mirrored by the BD data (Table 5) where no statistical differences were isolated for the three different opportunities for measurements.

On the other hand, PR data corresponding to soil with the PSS treatment (Table 3), showed no evidence of changes in the shallowest layer (0-10 cm), but an increment of 16% in deeper layers (10-20 and 20-30 cm). These unexpected figures could be attributed to the fact that these layers had the lowest soil moisture content (22 and 24%) (Table 4). In agreement with this *ad-hoc* hypothesis, data in Table 5 showed no significant differences in BD measured in those layers between the two periods considered.

Finally, another interesting fact emerges if the layers below subsoiling depth are considered (Table 3). In spite of the decrement in soil moisture (Table 4), the layers corresponding to ranges of 30-40, 40-50 and 50-60 cm showed a statistically significant difference in the decrement of PR with measurement period. From P2 to P3 this reduction averaged 10% and similar evolutionary behavior and reduction of PR occurred in the three layers from P1 to P2. The behavior of soil under the NSS treatment for the same layers was quite different because no significant changes in PR were apparent. These data have no concordance to those quoted by Alakukku *et al.* (9), nevertheless, this PR alleviation measured, below subsoiling depth, is an interesting result that should be considered in a future research. At this time we can only establish an *ad-hoc* hypothesis like that the loosened soil increased oxygen diffusion and ameliorated the nitrification process. It appears that it improves actual fertility in layers deeper than those reached by the subsoiler tine. This increment in the fertility of that layer leaded to an increment of root exploration and consequently the increment in soil macropores.

In view of these results it is strongly recommended that further research is undertaken to provide a satisfactory explanation.

Analyzing other results:

If only the topsoil is considered (0-10 and 10-20 cm layers) it is evident that soil loosened by subsoiling (PSS) showed a significantly higher increment in compaction after traffic (Table 6). This soil behavior could be measured not only as PR increments, but also by an increase in BD (Table 5). In soil of the NSS treatment the mean increment of PR in the 0 - 20 cm depth profile between P1 and P3 was 7.5%, while the same comparison for the PSS treatment showed an increment of 17%. Figures taken from the BD data show a similar trend. Table 5 shows that BD of the soil corresponding to the NSS treatment increased by an average of 7.5% and under the PSS treatment it rose by 10% for both the shallowest layers.

Although the lower soil moisture (about 2 to 3%) in P3 compared with P1 might have reduced the magnitude of PR differences between the treatments, it was not sufficient to preclude our agreement with the findings of Schäfer-Landefeld *et al.* (11). They concluded that increments in topsoil compaction after traffic were greater on previously subsoiled soils compared with those that had not been deep loosened.

If deeper soil layers are considered in soil under the PSS treatment, our figures differed from those of Schäfer-Landefeld *et al.* (11). The most important difference was compaction alleviation of soil layers below the loosened horizon (30 cm), as indicated by both PR and BD (Tables 3, 5 and 6).

Considering our soil in the management framework of direct drilling and subsoiling of one half of the complete parcel, this could explain some differences with data quoted by Arvidsson (12). Our experimental design did not include a machine with a 35 Mg load on one axle, but the number of passes during the studied period compensated and led to similar traffic intensities. However, no increments in soil compaction were assessed in the deepest layers (40-50 and 50-60cm). Furthermore, in soil under the NSS treatment, PR diminished by about 4.5% in the depth range considered. Meanwhile, in soil under the PSS treatment, PR diminished by an average of 18% in the same layers.

Conclusions

Periodic subsoiling can alleviate compacted soil layers due to agricultural traffic and this allows direct drilling to continue sustainably.

Soil previously loosened by subsoiling can modify the way that soil recovers during subsequent traffic.

In spite of being more sensitive to compaction due to traffic, loosened soil maintains advantages from subsoil treatment that last the whole cycle of both crops within annual double cropping. Subsoiling not only alleviates compaction in the loosened layers but also in a horizon immediately below.

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