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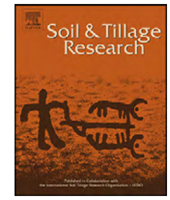

Tillage and traffic effects (planters and tractors) on soil compaction and soybean (*Glycine max* L.) yields in Argentinean pampas

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ABSTRACT

Direct drilling systems usually have lower traffic intensities than those using conventional tillage, but despite this, after several years of continuous direct drilling yields tend to decrease. This could be the result of increased weed control problems and root diseases as well as a gradual increase in soil compaction due to agricultural traffic. The draft required, soil cone index, root growth, soybean (*Glycine max* L.) yield and traffic (planters and tractors) compaction over the subsequent three growing seasons were measured. This initially high level of soil compaction in some direct sowing systems might suggest that the impact of subsequent traffic would be minimal, but data have not been consistent. Soil compaction is caused by the high traffic intensity and weight of tractor and seeding machines and combines in harvest operations, especially when these operations are carried out on wet soil or with high ground pressure. The techniques commonly used for control and management of topsoil and subsoil compaction are: subsoiling and chiseling and axle load reduction. Outlined hypothesis was: Traffic with high axle load equipment increases soil compaction and decreases soybean yield. This article quantifies: (a) the effects of subsoiling and chisel plowing were carried out at 350 and 280 mm depth, respectively, on soil compacted under 12 years of direct drill systems and (b) traffic effect on this soil conditions of two equipment for direct sowing (planters and tractors) on soybean yields (*G. max* L.) with two different loads: light equip (LE) and heavy equip (HE). The study showed that: In topsoil for three growing season, traffic with HE (185 kN) caused mean values of CI of 2178, 1506 and 1406 kPa for direct sowing, chiseled and subsoiled soil, respectively, while for the LE (127 kN) the values were of 1855, 1210 and 1206 kPa, respectively. Also in the subsoil traffic with HE caused higher CI values than the LE in all treatments. The CI mean values of the HE traffic were: 2465, 1920 and 1854 kPa for direct sowing, chiseled and subsoiled soil, respectively, while the LE traffic produced 2298, 1639 and 1637 kPa, respectively. For three growing seasons the HE traffic in soil under direct sowing reduces soybean grain yields close to 460 kg ha^{-1}, while for the LE was 250 kg ha^{-1}. When the traffic was made with LE on subsoiled soil there is an effective increase in soybean grain yields of about 330 kg ha^{-1}.

1. Introduction and literature review

Conservation tillage includes any tillage or sowing system that maintains at least 30% soil cover with crop residue after planting (EP291.2, ASAE Standard, 1993). This includes non-inversion tillage systems, such as chisel plowing, and sowing without previously plowing, also called direct sowing or no-till. Direct sowing has been in use in Argentina since the 1980s due to the increased availability and lower price of agrochemicals, and also due to the reduction in number of operations and the machinery required (Botta et al., 2006).

In Argentina, of the total area cropped, 16 million hectares are planted by continuous direct sowing (DS), and the rest, approximately 22 million hectares, are cultivated using conventional tillage (CT). Direct drilling systems usually have lower traffic intensities than those using conventional tillage, however, after several years of continuous direct drilling, yields tend to decrease (Botta et al., 2008). This could be from a combination of increased weed control problems, root diseases, soil compaction, high axle load of the direct sowing machines and agricultural traffic. In this regard Botta et al. (2009) found that: the tracked area when sowing 1 ha with the conventional equipment is 4073 m^2 compared with 2461 m^2 for the direct sowing equipment; this is because the tyres of the tractor and planter, in direct sowing, track in the same place.

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Soil compaction has long been known to cause root growth and yield reductions in many crops, but both soybeans (*Glycine max* L. Merr.) and perennial crops are particularly susceptible in the west Argentine pampas region (Botta et al., 2004; Jorajuria et al., 1997). In this context Canarache et al. (1984), in Romanian soils, found that for each 1 kg/m^3 increase in bulk density, a decrease in maize grain yields was 18% relative to the yield on a non-compacted plot.

When agricultural soils are compacted the volume of pore is reduced, the aggregates crumble and smaller inter-aggregates pores are formed with non-accommodating faces (Pagliai and Vignozzi, 2002). The major loss of the largest pores, caused by soil compaction, has the effect of changing the pore size distribution and hence the water retention characteristic (Dexter, 2004).

These results illustrate the potential for compaction to depress crop yields. Extremely dense soil impedes root growth and thereby limits plants water consumption.

Root responses to compaction may be complex due to the numerous ways in which compaction can modify the physical properties of soil. There have been many attempts to find critical values of cone index, soil strength or permeability that are related to root growth limiting factors.

Taylor et al. (1966) measured the number of taproots of the cotton plant which penetrated compacted layers of different soils (soil types: Quinlan, Columbia, Naron and Miles), and characterized the degrees of compaction by means of measurements with a cone penetrometer. They found that: number of roots penetrating soil was reduced drastically as the penetration resistance approached 2 MPa pressure. In fact, at soils compacted to more than 2 MPa resistance, virtually no roots at all were able to grow.

The techniques commonly utilized for control and management of topsoil and subsoil compaction are: subsoiling and chiseling, controlled traffic farming and axle load reduction. Subsoiling and chiseling (depth of 280–450 mm) are utilized for controlling subsoil compaction and to increase crop yields (Balbuena et al., 1998; Cisneros et al., 1998).

Subsoiling and chiseling are carried out on an annual basis in some sandy and lime-rich soils in the west Pampas region because of these soils's susceptibility to aeolian erosion and soil compaction. The extent to which this compaction occurs naturally and the amount that is caused by wheel traffic has not been well quantified.

Reeder et al. (1993) studied the effects of deep tillage on physical properties in silty clay loam and on crop yields. They found that two passes of a tractor re-compacted the soil by the time the first crop was planted. They advised that controlled traffic is essential to obtain long term benefits from subsoiling. Deep tillage increased soybean and corn yields (3.0–6.9% in 1991 and 1.5–3.0% in 1992) in areas not trafficked.

Raper et al. (1994) compared various cotton tillage systems on a sandy loam complex soil (Typic Hapludults), including annual subsoiling at 0.4 and 0.5 m depth. They found that the positive effects of controlling traffic were significant only when in-row subsoiling was not used as an annual tillage treatment. In addition to the environmental benefit of maintaining surface residues, they found that strip tillage involving only in-row subsoiling to 0.4 m depth decreased cone index directly beneath the row, decreased topsoil bulk density, increased soil water content, decreased energy usage and increased yields.

The power and draft required by deep tillage implements vary according to depth, soil type and forward speed. A conventional straight shank subsoiler operating at 520 mm depth in clay soil required about 29 kN of draft. Drawbar power ranged from 24 kW at 1 ms^{-1} to 36 kW at 1.4 ms^{-1}. In same soil conditions Shinners (1989) found that a paraplow operating at 1.1 ms^{-1} 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 0.94 and 0.89 ms^{-1}, respectively, to keep required power at about 32 kW.

Botta et al. (2004) working in different soils (sand and clay) at 350 mm depth, found that engine power increased by an average of 18% from about 28 kW per shank for a curved leg to about 36 kW per shank for a straight leg. The author concluded that a major factor in power requirement is the horizontal pressure of the leg against the soil, which significantly increased the shear force.

The main objectives of this work were: (a) to determine the main and interactive effects of various high load traffic (tractor and planter) and tillage systems on soil cone index and soybean productivity; (b) to quantify the change in cone index of a Typical Argiudol soil due to deep tillage operations (subsoiler and chisel plow) in three growing seasons; (c) to quantify power and draft required by deep tillage.

2. Hypothesis

Outlined hypothesis was: Traffic with high axle load equipment increases soil compaction and decrease soybean yield.

3. Materials and methods

3.1. The site

The experiment was conducted in the east of the Rolling Pampa region, Buenos Aires State, Argentina at 34°27′S, 58°40′ 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 was a fine clayey, illitic, thermic Typical Argiudol (Soil Conservation Service, 1994), with an organic matter content ranging from 3.6% (w/w) in the surface to 1.4% at 0.6 m depth. Soil physical and mechanical properties are given in Table 1.

3.2. Experimental treatments and layout

The soil management history includes 12 years of crop rotation following a very common regional pattern, winter wheat (*Triticum aestivum*) followed by soybean (*G. max* L.) in summer. For the duration of this trial only soybean was as summer crop, because in the Argentina the farmers (generally) does not own of the big sowing machine (the contractors are the owners of the machinery and work all over the productive zone). The contractors work against the time. It is very difficult to request them to delay their labors.

The experimental design consisted of a completely randomized blocks with six replications. The main plots were:

(T1) Soil under direct sowing for 12 successive years (unloosened).
(T2) Chisel plow (deep loosening to 280 mm depth) in the spring followed by secondary tillage in the sowing date.
(T3) A V-frame 7 shank subsoiler (deep loosening to 350 mm depth) in the spring followed by secondary tillage in the sowing date. The control plot was soil under direct sowing system per 12 years.

Power and draft (PD) required for subsoiler and chisel plow: drawbar load cells were provided by the Agricultural Machinery class (Agronomy Faculty Buenos Aires University Argentina). A cab-mounted unit collected draft force data with a sampling frequency of 200 Hz. Data were stored in a data logger and downloaded to Excel files for analysis.

Secondary tillage was similar for two deep tillage treatments and consisted of: two passes of a tandem disk harrow (490 N/disk,