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Soil compaction management and soybean yields with cover crops under no-till and occasional chiseling

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ABSTRACT

The introduction of cover crops in agricultural systems under no-till is important in soil structuring and remediation. However, there is a lack of studies exploring the effects of cover crops compared with other soil compaction control tools, such as chiseling, in the long term, mainly under tropical climates. This study aimed to evaluate soil physical properties by cover crops and chiseling in a compacted soil, as well as its effects on soybean yields. The experiment was conducted in Botucatu, Brazil, under no-till. Three crops were grown per year. Soybean [*Glycine max* (L.) Merrill] was cropped as summer crop in rotation with triticale (X *Triticosecale* Wittmack) or sunflower [*Helianthus annuus* (L.)] as fall/winter crop. In spring, three different cover crops were grown, pearl millet [*Pennisetum glaucum* (L.) R. Brown], forage sorghum [*Sorghum bicolor* (L.) Moench] and sunn hemp [*Crotalaria juncea* (L.)], compared to a fallow treatment, which was chiseled in 2003, 2009 and 2013 only, always in October and down to 0.60 m depth. The first chiseling increased soil macroporosity and soybean yields in the immediate cropping season (2003/2004). However, these benefits were short-lived and in two years the use of cover crops resulted in higher yields. In the long-term, cover crops improve soil structure, with equal or better results than those obtained by occasional chiseling, as an increase in soil macroporosity by sunn hemp up to 0.20 m depth and a decrease in soil bulk density by sunn hemp and pearl millet in the 0.40–0.60 m layer. Among the cover crops, sunn hemp is particularly interesting, because it increases macroporosity in clay soils otherwise with limited aeration and increases the soybean yield.

1. Introduction

Compacted layers develop in agricultural soils as a result of external pressures from machines or animals, or it may be a natural process of accommodation of soil particles (Hamza and Anderson, 2005). As soil bulk density increases and total porosity decreases, soil resistance to root penetration increases, posing an impediment to root growth and restricting water and air movement throughout the profile (Chen et al., 2014), resulting in poor aeration of the root system (Marschner, 1995). Water infiltration is hindered and runoff increases resulting in water and soil loss, leading to the impoverishment of the topsoil. When growing roots encounter a high resistance layer in the soil profile, they proliferate in the uppermost soil layer, which is quickly depleted in water and nutrients (Soane and van Ouwerkerk, 1995), thus resulting in yield loss. Therefore, soil compaction effects on crop yield are magnified in low rainfall years (Calonego and Rosolem, 2010).

Although mechanical methods used to remediate soil compaction, such as chiseling, improve soil physical conditions, they have ephemeral effects (Busscher et al., 2002). In the medium- and long-term, significant benefits can be seen in soil structure with no-till (NT) and the use of cover crops with aggressive root systems (Calonego and Rosolem, 2008). Some forage grasses, such as brachiaria, pearl millet, sorghum, sorghum-sudangrass, and finger millet have large root systems with high ability to explore the soil profile. In contrast, species with taproot systems, such as pigeon pea, sunn hemp, and radish have fewer roots, but they have greater ability to break through compacted soil layers (Rosolem et al., 2002). Garcia et al. (2012) noted growing sorghum–sudangrass and pearl millet, compared with fallow, resulted in higher porosity (total, macro and micro), lower bulk density and higher number

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Table 1
Rainfall and average temperature during ten soybean seasons (from December to March). Botucatu, Brazil.

2003/04	2004/05	2005/06	2006/07	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15
Rainfall (mm)									
770	767	829	751	997	1094	726	1239	359	1037
Average temperature (°C)									
21.1	21.6	21.4	20.2	23.0	23.9	24.6	24.3	24.8	23.2

of aggregates larger than 2 mm in the layer 0–0.10 m; on the other hand, sunn hemp presented intermediate values, resulting in lower bulk density and higher macroporosity compared with fallow.

Cover crops with extensive, aggressive root systems help in the formation of soil aggregates, thereby facilitating root growth of succeeding crops and higher water infiltration. Soil aggregation is usually improved by management systems including crops with high ability to form roots and increase soil organic matter (SOM) (Castro et al., 2011). The contribution of SOM in the formation of stable aggregates is attributed to processes such as the formation of cationic bridges, cementation between particles, and stability promoted by root and microbial exudates around and within aggregates (Castro et al., 2015; Tisdall and Oades, 1982). Therefore this could be a mechanism whereby the use of cover crops in rotation with the main crop would have a long-lasting effect on alleviating soil physical limitations.

The objective of this study was to evaluate, in a compacted clay soil, the changes in physical properties and its influence on soybean grain yield as affected by cover crops and chiseling in a long-term experiment.

2. Materials and methods

2.1. Experimental site and treatments

The experiment was carried out in Botucatu, São Paulo, Brazil (22°49 S, 48°25′ W altitude: 786 m). The climate is mesothermal with dry winters, and the dry season is well defined from May to September, with yearly average rainfall of 1450 mm, distributed mostly between October and April. Average temperatures and total rainfall during 10 soybean seasons (from December to March) are shown in Table 1. The soil is a clay Typic Rhodudalf (Soil Survey Staff, 2014). Before starting the experiment (April 2003), the soil was sampled for chemical (Raij et al., 2001), physical and granulometric (Embrapa, 1997), and aggregate stability (Kemper and Chepil, 1965) analysis (Table 2). The soil physical characterization showed the presence of compacted soil, mainly in the 0.10–0.20 m layer, which limits the root growth of soybean (Rosolem and Calonego, 2010).

The experiment has been conducted since 2003 with triticale (X *Triticosecale* Wittmack) and sunflower [*Helianthus annuus* (L.)] grown in the fall/winter, followed by pearl millet [*Pennisetum glaucum* (L.)], forage sorghum [*Sorghum bicolor* (L.) Moench], sunn hemp [*Crotalaria juncea* (L.)], and fallow/chiseling in the spring (Table 3). The assigned plots were chiseled in 2003, 2009 and 2013 just before soybean [*Glycine max* (L.) Merrill] planting. Soybean was grown in the summer. The experimental design was a randomized block with split plots, with four replications and eight treatments. Treatments consisted of grain crops (triticale or sunflower) grown in the fall/winter as main plots (plots with 256 m^2) and cover crops (pearl millet, forage sorghum or sunn hemp) or fallow/chiseling as subplots in spring (subplots with 40 m^2). Crop rotations were repeated annually (Table 3). Triticale and sunflower were planted without fertilizer, at row spacings of 0.17 and 0.51 m, respectively, using 165 kg ha^{-1} of triticale seeds and 22 kg ha^{-1} of sunflower seeds. The fall/winter crops were sown each year in the second half of April and harvested from the second week of August to the first week of September, using a plot harvester. The spring cover crops were sown in the first half of October, in rows spaced of 0.17 m from each other. We used 25, 30, and 15 kg ha^{-1} of seeds of pearl millet, sorghum, and sunn hemp, respectively. In the first half of December, around 60 days after planting, the spring cover crops were chemically desiccated with glyphosate at 2.5 kg ha^{-1} (a.i.), and then soybean was planted in rows 0.45 m apart, targeting a population of 300,000 plants ha^{-1}. Each year soybean seeds were inoculated with *Bradyrhizobium* sp. and fertilized with 50 kg ha^{-1} K and 26 kg ha^{-1} P, as potassium chloride and triple superphosphate, respectively, at the sowing time, 0.05 m below and beside the seeds and with fertilizer seeder equipment. The spring cover crop species

Table 2
Selected chemical, physical, granulometric and aggregate stability properties of the soil before the experiment was started (April 2003). Botucatu, Brazil.

Chemical properties[a]

Soil depth (m)	pH ($CaCl_2$)	OM[b] (g dm^{-3})	P_{resin} (mg dm^{-3})	H + Al (cmol$_c$ dm^{-3})	K	Ca	Mg	CEC[c]	BS[d] (%)
0–0.10	5.0	29.5	31.5	7.40	0.39	3.30	1.36	12.45	40.6
0.10–0.20	4.6	25.9	15.2	9.72	0.25	3.52	1.57	15.06	35.4
0.20–0.40	4.8	22.4	0.33	6.87	0.11	4.63	1.50	13.11	47.6
0.40–0.60	5.1	22.0	0.23	6.35	0.02	5.67	1.15	13.19	51.8

Physical properties[e]

	PR[f]	Moisture[g]	Bulk density	Porosity		
				Total	Macro	Micro
(m)	(MPa)	(g g^{-1})	(g cm^{-3})	(m^3 m^{-3})		
0–0.10	2.1	0.29	1.31	0.55	0.10	0.42
0.10–0.20	2.5	0.34	1.38	0.52	0.07	0.45
0.20–0.40	2.3	0.38	1.29	0.50	0.05	0.45
0.40–0.60	1.8	0.42	1.31	0.58	0.05	0.48

Granulometry[e]

	Sand	Clay	Silt
(m)	(g kg^{-1})		
0–0.10	134	584	282
0.10–0.20	128	599	273
0.20–0.40	110	645	246
0.40–0.60	88	715	197

Soil aggregate stability[h]

	Aggregates[i]	MWD[j]	GMD[k]	ASI[l]
(m)	(g g^{-1})	(mm)	(mm)	%
0–0.10	0.39	1.86	2.53	93.64

[a] Raij et al. (2001).
[b] Organic matter.
[c] Cation exchange capacity.
[d] Soil base saturation.
[e] Embrapa (1997).
[f] Penetrometer resistance.
[g] Soil moisture at the time of PR determination.
[h] Kemper and Chepil (1965).
[i] Aggregates > 2 mm.
[j] Mean weight diameter.
[k] Geometric mean diameter.
[l] Aggregate stability index.