SOIL COMPACTION AND FERTILIZATION IN SOYBEAN PRODUCTIVITY

Amauri Nelson Beutler[1]; José Frederico Centurion[1]*

UNESP/FCAV - Depto. de Solos e Adubos, Via de Acesso Prof. Paulo Donato Castellane, s/n - 14884-900 - Jaboticabal, SP - Brasil.
**Corresponding author <jfcentur@fcav.unesp.br>*

ABSTRACT: Soil compaction and fertilization affect soybean development. This study evaluated the effects of soil compaction and fertilization on soybean (*Glycine max* cv. Embrapa 48) productivity in a Typic Haplustox under field conditions in Jaboticabal, SP, Brazil. A completely randomized design with a 5 × 2 factorial layout (compaction vs. fertilization), with four replications in each treatment, was employed. Each experimental unit (replicate) consisted of a 3.6 m^2 useful area. After the soil was prepared by cultivation, an 11 Mg tractor passed over it a variable number of times to create five levels of compaction. Treatments were: T_0= no compaction, T_1= one tractor pass, T_2= two, T_4= four, and T_6= six passes, and no fertilizer and fertilizer to give soybean yields of 2.5 to 2.9 Mg ha^{-1}. Soil was sampled at depths of 0.02-0.05, 0.07-0.10, and 0.15-0.18 m to determine macro and microporosity, penetration resistance (PR), and bulk density (D_b). After 120 days growing under these conditions, the plants were analyzed in terms of development (plant height, number of pods, shoot dry matter per plant and weight of 100 seeds) and seed productivity per hectare. Soil compaction decreased soybean development and productivity, but this effect was decreased by soil fertilization, showing that such fertilization increased soybean tolerance to soil compaction.
Key words: bulk density, penetration resistance, fertilizer, yield

COMPACTAÇÃO DO SOLO E ADUBAÇÃO NA PRODUTIVIDADE DE SOJA

RESUMO: A compactação e adubação do solo afetam a produtividade de soja. O objetivo do trabalho foi avaliar o efeito da compactação e adubação do solo na produtividade de soja (*Glycine max* cv. Embrapa 48) em um Latossolo Vermelho de textura média em condições de campo, em Jaboticabal, SP. O delineamento experimental foi inteiramente casualizado em esquema fatorial 5 × 2 (compactação × adubação) com quatro repetições e parcelas úteis de 3,6 m^2. Após a escarificação do solo foi passado um trator de 11 Mg na superfície do solo formando os seguintes tratamentos: T_0= sem compactação, T_1= uma passada, T_2= duas passadas, T_4= quatro passadas e T_6= seis passadas do trator no mesmo local. Os tratamentos de adubação foram: sem adubação e adubação para produtividade esperada de 2,5 a 2,9 Mg ha^{-1}. As amostras indeformadas de solo foram coletadas na camada de 0,02 – 0,05; 0,07 – 0,10 e 0,15 – 0,18 m para determinação da macro e microporosidade, densidade do solo e resistência à penetração. A soja foi semeada em dezembro e após 120 dias foram analisados a altura de plantas, número de vagens, massa de matéria seca peso de 100 sementes e produtividade. Com incremento da compactação do solo decresceu o desenvolvimento e produtividade de soja e os efeitos foram mais pronunciados no solo sem adubação, indicando que a adubação aumenta a tolerância da soja à compactação.
Palavras-chave: densidade do solo, resistência à penetração, adubo, produtividade

INTRODUCTION

Since the 1970s, investments in studies on the genetic improvement of cultivars, fertilizers and pesticides for soybean production in Brazil have increased and improved productivity. However, less investment has been applied to understanding the effects of soil compaction on such production. The demand for studies on the effects of soil compaction on soybean has increased since negative effects on yield have been shown (Hakansson & Voorhees, 1998; Ralisch & Tavares Filho, 2002).

Soil compaction usually has been evaluated from traits such as porosity, bulk density (D_b) and penetration resistance (PR) (Tormena et al., 2002; Silva et al., 2004). However, D_b and PR have been the most used traits to infer critical levels for producing crops. PR is directly related to root growth (Letey, 1985) and thus has been preferred as an indicator for soil compaction.

Considering these soil parameters, critical values have been determined for adequate root growth such as: aeration porosity = 10% (Gupta & Allmaras, 1987), D_b = 1.55 Mg m^{-3} for clay loam soils (Camargo & Alleoni, 1997), and PR = 2.0 MPa (Silva et al., 1994; Tormena et al., 1998). In fact, soil root growth is completely inhibited at D_b higher than the critical value of 1.52 Mg m^{-3} in medium loam oxisols supplied with a water content close to field capacity (Fernandez et al., 1995). In a similar way, Beutler & Centurion (2003) found that soybean production in the greenhouse decreased at a PR of 2.2 MPa, in an Oxisol with the same texture and water content at field capacity (0.01 MPa). These authors also observed that in a clayey euthroferric Oxisol, productivity decreased at a PR = 2.8 MPa.

Moreover, some studies have evaluated compaction effects in soils with phosphate fertilization. Thus, Fernandez et al. (1995) found that a D_b = 1.52 Mg m^{-3} inhibits root growth with or without phosphate fertilizers added to the soil. However, in ordinary soil these authors showed that fertilization increased shoot dry matter production. However, few studies have established critical D_b and PR values for several conditions, and the interaction between soil compaction and fertilization has not been addressed to provide critical values for soil physical traits in soybean development. The objective of this study was to compare levels of soil compaction, fertilization, and their interaction on soybean plant characteristics and productivity.

MATERIAL AND METHODS

Study site and soil characterization

This study was carried out in Jaboticabal (21º15’29’’S; 48º16’53’’W, 607 m), State of São Paulo, Brazil. The climate was a Cwa according to Köppen-Geiger’s classification (Brasil, 1960). The daily precipitation during the soybean cycle is shown in Figure 1. The soil type was a medium-textured Typic Haplustox. Particle size distribution was determined in disturbed soil samples, by adding NaOH (0.1 mol L^{-1}) to enhance dispersion, with slow shaking for 16 h; clay content was obtained by the pipette method. At a depth of 0.0-0.2 m, 1 kg of an Haplustox contained 271 g clay, 42 g silt, 687 g sand and had a particle density of 2.82 Mg m^{-3}. Chemical characterization is showed in Table 1 and was obtained as described in Raij et al. (1987).

Experimental Design

This research evaluated soybean (*Glycine max* cv. Embrapa 48) development and productivity according to levels of soil compaction and fertilization. A completely randomized design with a 5 × 2 factorial layout (compaction vs. fertilization) with four replications in each treatment was employed. Each experimental unit (replication) consisted of a useful area of 3.6 m^2.

After cultivation, the soil was compacted at five levels using various numbers of tractor passes: T_0= no compaction, T_1= one pass, T_2= two passes, T_4= four passes, and T_6= six passes. The tractor ran over the entire ground area in each treatment to ensure each part was compacted by its tires. After that, soybean seeds were sown on 10 December 2002 and the fertilizer treatments were applied. After ten days, weeds were removed by hand (roguing) and 20 plants per meter of row were maintained. After 120 days, soybean development and yield parameters were analyzed.

Specific Procedures

Soil Preparation - The soil was scarified down to a depth of 0.30 m and then harrowed. After intense precipitation, the soil was wet up to field capacity (0.01 MPa) and then compaction was imposed.

Soil Compaction - Soil compaction was applied by means of a tractor weighing 11 Mg, with four tires of equal width and inflation pressure. This tractor travelled the designated number of times across the entire surface to be used. Soil samples were collected at depths of 0.02-0.05 m, 0.07-0.10 m, and 0.15-0.18 m, with two replications. These samples were collected in cylinders (53.16 cm^3) subjected to a tension of 0.006 MPa in Richards’ chambers (Klute, 1986) until they reached equilibrium, weighed, and subjected to a tension of 0.01 MPa until equilibrium was reached again. At this stage, penetration resistance (PR) was determined by an electronic penetrometer, with a constant penetration velocity of 0.01 m/min and a cone area of 3.14×10^{-6} m^2, as described by

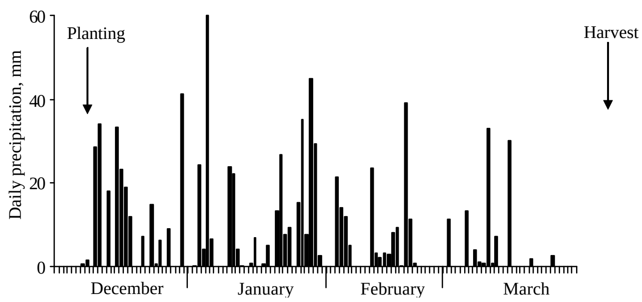

Figure 1 - Daily precipitation during soybean cycle in the 2002/03 growing season.

Table 1 - Chemical properties at two depths of a non-fertilized Haplustox, before soybean sowing.

Depth	pH($CaCl_2$) 0.01 mol L^{-1}	OrganicMatter	P_{resin}	K	Ca	Mg	H + Al	Basis Saturation
m		g dm^{-3}	mg dm^{-3}	---------------	mmol$_c$ dm^{-3}	---------------		%
0.0 - 0.10	5.0	14.0	22.0	2.1	15.0	7.0	22.0	52.0
0.10 - 0.20	5.0	13.0	16.0	1.9	15.0	7.0	20.0	54.0

Tormena et al. (1998). The samples were oven dried at ± 105°C for 24 h and weighed for D_b (Blake & Hartge, 1986), total soil porosity (Danielson & Sutherland, 1986), and microporosity determinations – in Richards' chambers at a tension of 0.006 MPa - (Klute, 1986). Macroporosity was calculated from the difference between total porosity and microporosity.

Fertilization - The two fertilizer treatments consisted of a control (no fertilizer) and ammonium sulphate (50 kg ha^{-1}) + triple superphosphate (125 kg ha^{-1}) + potassium chloride (85 kg ha^{-1}). These levels provided soybean yields of 2.5 to 2.9 Mg ha^{-1} (Raij et al., 1996), while the control treatments gave smaller yields.

Soybean sowing and productivity - After soil compaction, soybean seeds were sown at a depth of 0.05 m and a row spacing of 0.45 m. Soybean development (plant height, number of pods per plant, shoot dry matter per plant, and weight of 100 seeds) and seed yield per hectare were analyzed.

Statistical Analyses - The treatments were compared by ANOVA (5 × 2 factorial layout). When significant effects were found ($P \leq 0.05$), polynomial regressions (linear and quadratic) were tested between the soybean development and PR parameters, and also between soybean yield and D_b.

RESULTS AND DISCUSSION

In all depths and soil compaction levels, the macroporosity values were smaller than 0.10 $m^3 m^{-3}$. A single tractor pass (Table 2; T_1) was enough to reach this value. Macroporosity was lower in treatments with more intense compaction, reaching 0.03 in T_6 at 0.02-0.05 m. Aeration porosities lower than 10% (0.10 $m^3 m^{-3}$) decrease root growth (Gupta & Allmaras, 1987) and soybean root length in up to 50% (Cintra & Mielniczuk, 1983). Although soil compaction usually decreases the size of the root system, it may not affect the supply of water and nutrients to the shoot (Shierlaw & Alston, 1984; Taylor & Brar, 1991; Beutler & Centurion, 2003). Root size reductions above 40% are critical to plant yield (Pabin et al., 1998).

A critical D_b value of 1.55 Mg m^{-3} for this type of soil has been reported by Camargo & Alleoni (1997). In the present study, the treatments showed values lower and higher than this critical level in all compaction levels tested (Table 2). The critical PR of 2.0 MPa (according to Silva et al., 1994 and Tormena et al., 1998) was exceeded in T_1 and T_2 at the two lowest depths and in T_4 and T_6 at all depths. The treatments, however, did not greatly affect soil microporosity.

Soybean development was negatively affected by increasing the number of times the tractor travelled over the soil (T_1 to T_6; ANOVA factorial; $P < 0.01$), which is also shown by the regressions in Figures 2 and 3. PR is more sensitive to the effects of compaction on soybean development, irrespective of soil type (Letey, 1985).

The higher the penetration resistance (PR), the lower the soybean parameters of plant height, dry matter weight, number of pods, and seed weight (Figure 2). Moreover, these effects are represented by negative linear regressions. The negative effects of soil compaction were reduced by fertilization (Figure 2; Table 3). In fact, Fernandez et al. (1995) showed that even in compacted soils, dry matter production for the shoot parts is increased by fertilization, but only until a D_b= 1.30 Mg m^{-3}. When water and nutrients are adequately supplied, the compaction of oxisols might decrease the soybean root system, but production is still not affected, because a reduced root system might supply the shoot with water and nutrients

Table 2 - Soil physical attributes at three depth increments and five levels of soil compaction.

Soil Attribute	Depth	Soil compaction level[1]				
	m	T_0	T_1	T_2	T_4	T_6
Macroporosity (m^3 m^{-3})	0.02 - 0.05	0.28	0.10	0.06	0.05	0.03
	0.07 - 0.10	0.24	0.06	0.05	0.04	0.04
	0.15 - 0.18	0.18	0.08	0.06	0.05	0.04
Microporosity (m^3 m^{-3})	0.02 - 0.05	0.24	0.29	0.30	0.29	0.29
	0.07 - 0.10	0.25	0.29	0.28	0.28	0.28
	0.15 - 0.18	0.28	0.30	0.30	0.29	0.28
Penetration Resistance (MPa)[2]	0.02 - 0.05	0.21	1.00	1.92	3.58	4.57
	0.07 - 0.10	0.32	2.38	2.63	4.40	4.10
	0.15 - 0.18	0.65	2.07	3.65	3.64	4.07
Bulk density (Mg m^{-3})	0.02 - 0.05	1.19	1.54	1.70	1.74	1.80
	0.07 - 0.10	1.31	1.68	1.76	1.82	1.81
	0.15 - 0.18	1.46	1.64	1.74	1.77	1.78

[1]Subscript denotes number of passes of an 11 Mg tractor. [2]Determination at field capacity (tension= 0.01 MPa).

(Nogueira & Manfredini, 1983). In the present study, the applied compaction reduced soybean growth and development, but fertilization always promoted a positive response, even in T_4 and T_6 where D_b reached 1.8 Mg m^{-3}.

Soybean development and yield were affected by the applied compaction but its effects were reduced by fertilization, mainly because it increases soil nutrient availability and absorption by the shorter roots. Soybean yield was also negatively affected when D_b and PR were increased (Figure 3). This effect was also minimized by

Table 3 - Interaction between penetration resistance and fertilizer (ANOVA).

Parameter	Penetration resistance × Fertilizer	
	F-value	LSD
Plant height	0.95^{NS}	4.80
Shoot dry matter	1.89^{NS}	0.42
Number of pods	3.40*	4.81
Weight of 100 seeds	0.90^{NS}	0.97
Yield	3.22*	0.38

NS, *Non significant and significant (P < 0.05).

soil fertilization. Productivity started to decline from D_b = 1.36 Mg m^{-3} and PR = 0.39 MPa in treatments without fertilization. However, this decrease occurred only from D_b = 1.48 Mg m^{-3} and PR = 0.85 MPa in treatments that received the fertilizer, thus corroborating the efficacy of fertilization in reversing the effects of soil compaction and preventing damage from low levels of soil compaction. Furthermore, the crop yield reduction was lower in fertilized soils (T_1= 0.23%; T_6= 49.18%) than in control ones (loss of 25.5% in T_1 and 74.09% in T_6). At the critical D_b (1.55 Mg m^{-3}) and PR values (2.0 MPa), soybean yield is reduced respectively by 2.3 and 5.2% in fertilized soils.

The yield reduction from cultivation in compacted soils is a consequence of a lower rate of cell elongation and increased number of cells, thus enlarging plant root diameter (Benghough & Mullins, 1990). Such a reduction in root length causes exploitation of a smaller soil volume, thus decreasing water and nutrient absorption; this accounts for lower productivity in compacted soils.

In compacted soils, the greater particle proximity to each other facilitates water layer continuity and consequently phosphorus diffusion, until a peak of increased

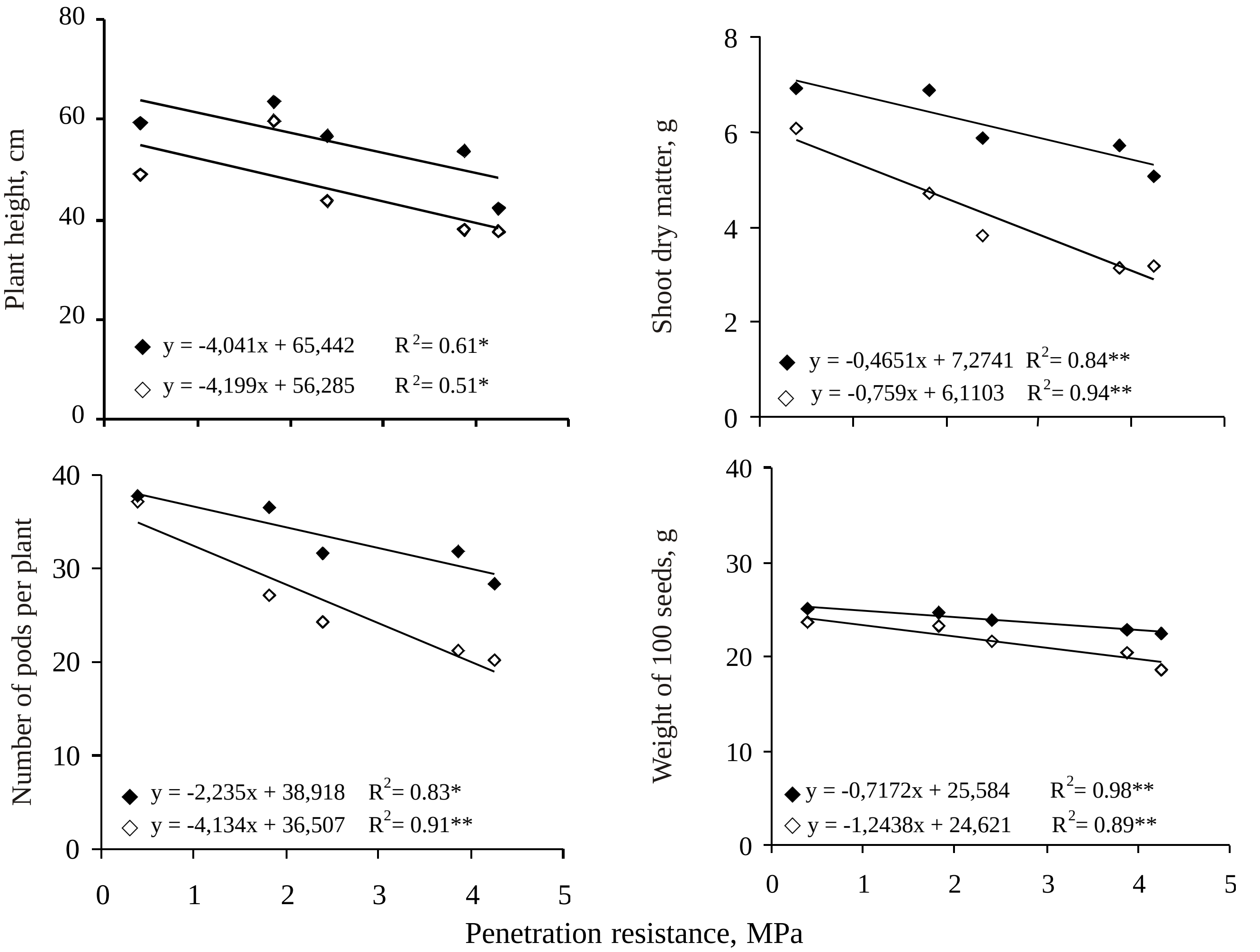

Figure 2 - Regression between penetration resistance and parameters of soybean development in an Haplustox, with (◆) or without (◇) fertilization. 5% (*) or 1% (**) significance levels.

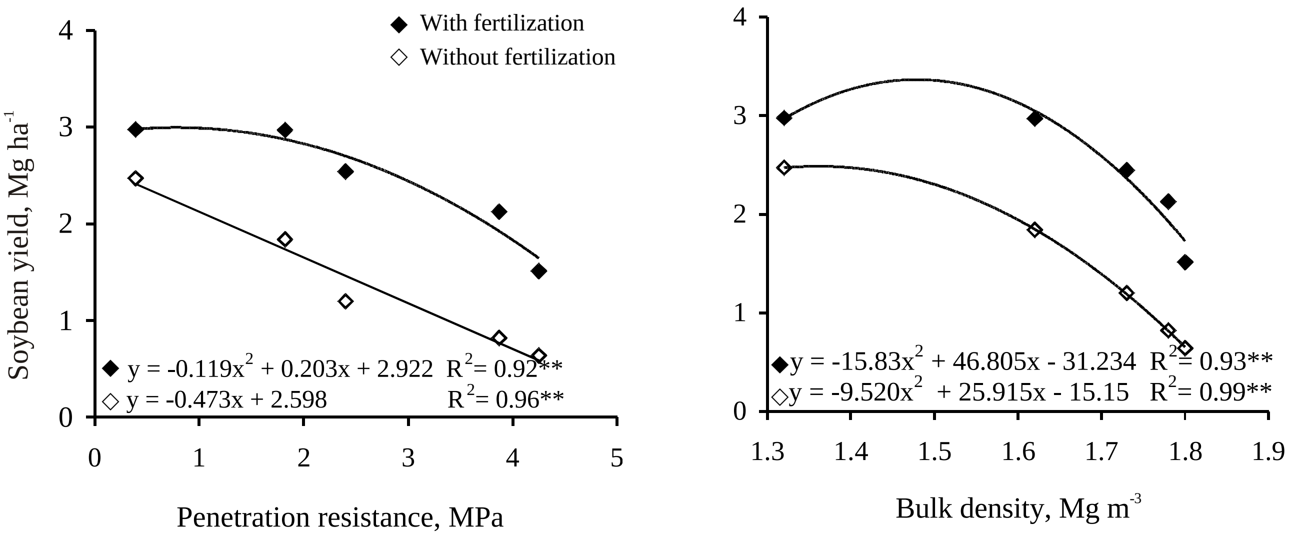

Figure 3 - Regression between penetration resistance and bulk density and soybean yield in an Haplustox, with or without fertilization. 5% (*) or 1% (**) significance levels.

absorption of ions by the roots is achieved (Oliveira et al., 1998). However, the closer distances between soil particles increase both the surface area and phosphate ion interaction along its diffusion course, thus becoming increasingly closer to positively charged surfaces (which adsorb it) (Novais & Smyth, 1999). This implies lower amounts of ions absorbed by roots when the soil is excessively compacted. Consequently, soil compaction is advantageous, since higher phosphorus concentrations will be required for this element to reach the roots, increasing saturation and maintaining an adequate diffusion flow for the plant's demand. In addition, soil compaction promotes quick water and nutrient depletion at the pores occupied by the roots because of the higher resistance of pore walls in compacted soils (Tardieu, 1994).

Considering these effects, a reasonable explanation for the higher tolerance of soybean to fertilized compacted soil found here should take into account an association between fertilizer actions and nutrient availability to the plant, thus facilitating absorption by shorter roots.

Finally, considering the mechanization processes, only one pass of an 11-Mg tractor (T_1) over the soil (with water content close to that retained at a tension of 0.01 MPa), in a fertilized Haplustox, reduced soybean yield by 0.23%, while in non-fertilized soil it was enough to reduce yield by 25.5%.

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