Cana de açúcar: Indicadores de fertilidade física e vulnerabilidade do solo em Tucumán, Argentina

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Introduction

Soil compaction is a major issue on physical soil degradation (Pagliai et al., 2003). This phenomenon alters the structure of cultivated soils, modifying several key properties of soil production and its health (Soane and van Ouwerkerk, 1994; Chan et al., 2006). Excessive compaction levels may have detrimental effects over the seedlings and radical development, water infiltration and runoff. Moreover, causes a reduction in oxygen diffusion favoring denitrification (Czyz, 2004).

Soane y van Ouwerkerk (1994) conclude that the intensity of compaction it is due to two different factors: (1) load applied and (2) soil mechanical resistance, which is related to texture, water content and aggregation. Furthermore, Trautner and Arvidsson (2000) informs that tensions observed in an expansive loamy clay soil, subjected to loads of 14 tn per axis, varied from 300 to 650 kPa at 0.3 m depth and from 70 to 270 KPa at 0.7 m, depending on the moisture content.

Induced soil deformations are maximum when are applied over conventional tillage rather than minimum tillage soils, this is related to a low soil mechanical resistance (J. Lipiec, R. Hatano, 2003; Horn and Baumgartl, 1999; Horn and Rostek, 2000). Therefore, it is important to control transit impact to maintain acceptable levels of compaction (Alakukku et al., 2003) or “transitability”.

Several methods have been developed to study compaction effects over the soil quality (Alakukku et al., 2003; Lipiec and Hatano, 2003) and exists a growing interest on improve their diagnosis precision (Cavalieri et al., 2008). Terzaghi (1936) uniaxial compression test, it is used to characterize soil compressibility (Figure 1).

Various methods are used to determine precompression stress (Dawidowski and Koolen, 1994; Arvidsson and Keller, 2004; Imhoff et al., 2004), and it is noted that significant errors in the estimation can be made if the curve tends non-linear at high tensions. Some authors (Keller et al.

2004) do not consider said fragment on their determinations, or make statistical adjustments using polynomial or sigmoidal functions (Baumgartl and Köck, 2004; Gregory et al., 2006).

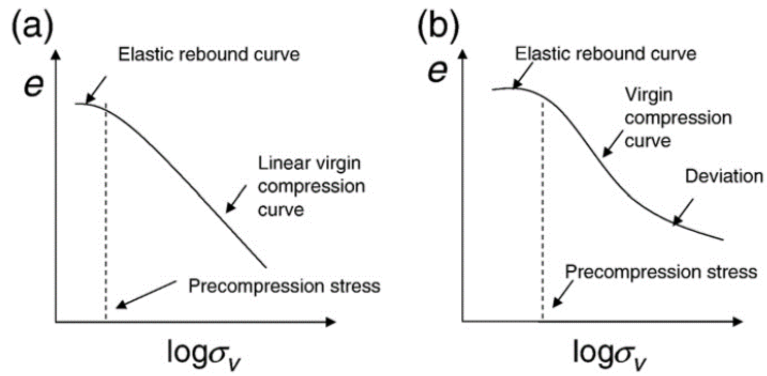

Figure 1: principal shapes of strain-load curves: bi-linear (a) and S-shaped curves (b).

Precompression stress is considered by numerous authors as the capacity of soils to support loads and consequently, as the risk of compaction of cultivated soils (Veenhof and McBride, 1996; Horn and Fleige, 2003; Imhoff et al., 2004; Rucknagel et al., 2007). For other authors, it is an indicator of soil mechanical resistance and stability (Arvidsson et al., 2001; Berli, 2001).

Strictly, precompression tension represents the load history that soil has resisted in its geological development, while the angle of the segment called "virgin compression curve" would indicate and estimate the risk of compaction (Terzhagui y Peck, 1976; Juárez Badillo y Rico Rodríguez, 1972). Nevertheless, there is an almost unanimous opinion that if the applied loads are less than the preconsolidation tension, soils is deformed and recovers elastically. If, on the other hand, the loads exceed the preconsolidation stress, the deformation suffered in the soil (at the expense of the reduction of its porous space) is irreversible (Lebert and Horn, 1991).

The objective of this work is to determine the efficiency of the cultural activities normally used in the main industrial crops using indicators of physical soil fertility and soil vulnerability, in particular, by the uniaxial compression test.

Methods

Tests were realized using unaltered soil samples, which were extracted before the implantation of the treatments on June of 2013, using 110 mm stainless steel hoop cores (Figure 2). Experimental site was conducted as a traditional long-term sugarcane monoculture. Two years before the treatments, the site was ploughed and a soybean crop was sowed. Soil profile and the result of the textural analysis of the experimental site are detailed in Table 1.

Soil samples were taken from A and Bt1 horizons, as those are the densified layers in experimental site, and all sites evaluated at Tucumán province (TESOURO et al., 2012 SATCA). Soil strain-load curves were obtained following a protocol based in the ASTM D

2435 03 methodology, using a uniaxial compression apparatus developed in the Laboratorio de Terramecánica e Implantación de Cultivos (IIR - CIA - INTA Castelar) (Figure 2 b).

TABLE 1: Soil horizons sequence and textural classes of the experimental site.

Depth (cm)	0 - 5	5 - 25	25 - 40	40 - 62	62 - 85
	Ap	**A**	**Bt1**	**Bt2**	**BC**
Sand (%)	20,7	20,7	18,7	14,7	14,7
Silt (%)	46,0	46,0	42,0	46,0	70,0
Clay (%)	33,3	33,3	39,3	39,3	15,3
Texture	Clay Loam	Clay Loam	Silty Clay Loam	Clay Loam	Silty Loam

Figure 2: a) Stainless steel hoop cores, a soil sample and a soil sample as is brought from field test, before flushing. b) Uniaxial compression apparatus.

The soil samples were soaked for 48 hours in order to reach the saturation state before being subjected to vertical pressures of 6, 19, 34, 62, 113, 210, 400, 760 y 1478 kPa. More evaluation pressures were added when it was considered needed. The time of application was the necessary one to allow the drainage of excess water from the soil sample from both sides (up and down) of the core. Soil sample deformation was measured with a digital micrometer, with a minimum resolution of 0.01 mm. The deformation of the soil sample was plotted as a function of the logarithm of the time. Voids ratio were established as a function of the logarithm of the pressure and, from this function, It was determined the load-strain ratio, maximum curvature point, the soil precompression stress and the compression indexes of all unaltered soil samples.

Results and discussion

Strain-load relations observed in Figures 3a and 3b shown that precompression stress was practically identical in both cases and of minimum magnitude, between 13.5 y 14.5 kPa. This values implies a brief range of tensions in which soil reacts elastically, over this threshold values soils deformation are irreversible. Horizon A performance when superficial loads are applied, obey to its historical management as seen by LEBERT AND

HORN (1991): it can be observed remains of artificial porosity created by 2011 shallow tillage before the implantation of this treatments, tillage also made that layer more susceptible to plastic deformation.

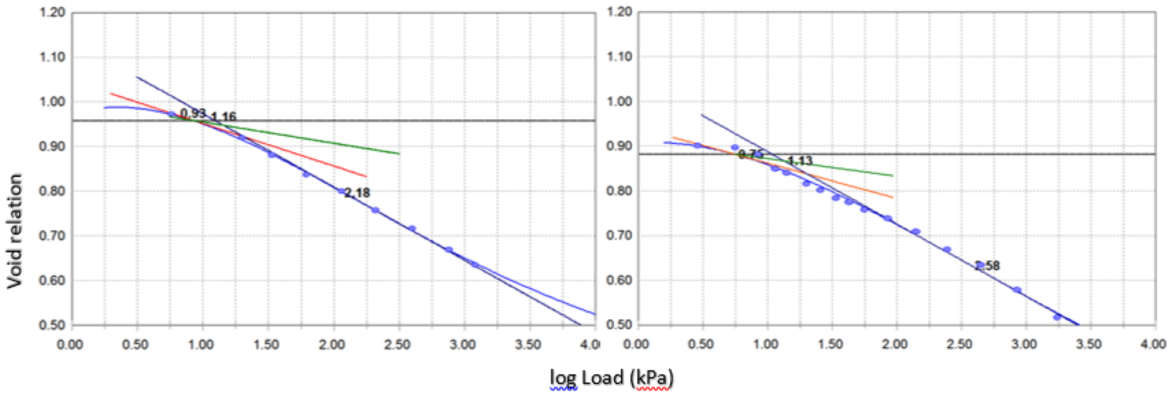

FIGURE 3: Strain-load curve, expressed as void relation, obtained on A horizon (100 to 200 mm of depth). a) soil sample 1; b) soil sample 2

TABLE 2: Principal parameters obtained of strain-load deformation relation of soil samples of A horizon (depth range from 100 to 200 mm).

Sample	Void relation (origin)	Maximum curvature point	Preconsolidation load (Pc)		Void relation at Pc point	Compression index (Cc)	
	cm^3/ cm^3	(log kPa)	(log kPa)	(kPa)	cm^3/ cm^3	($\Delta y/\Delta x$)	(degrees)
1	0.99	0.93	1.16	14.5	0.93	-0.1638	-9.30
2	0.91	0.75	1.13	13.5	0.85	-0.1617	-9.18

A complete different situation stands on BT1 horizon, with historical less disturbance than A horizon. In this case, preconsolidation stresses fluctuated on a range from 80 to 200 kPa, situation that can be appreciated on Figures 4a and 4b. These values should reflect the load of A horizon layer, drying and wetting cycles and anthropic effect.
The 4 kPa pressure exerted by the superior actual layer (Ap and A soil layers summed) was estimated using its thickness (300 mm) and its bulk density (TESOURO et al., 2016). Soil mechanics adhere to that the capilar tensions developed during drying cycles generates the major force involved in soil contraction and provokes an irreversible compression of susceptible soils (SOANE Y VAN OUWERKERK 1994, ARVIDSSON et al., 2001). Neutral load at the beginning of the air inlet (37.2% of gravimetrical humidity) was estimated in 30 kPa. At the end of residual contraction, neutral tension arrived to 140 kPa. Precompression strain-load of one of the samples of Bt1 horizon exceed widely 140 kPa Table 3).

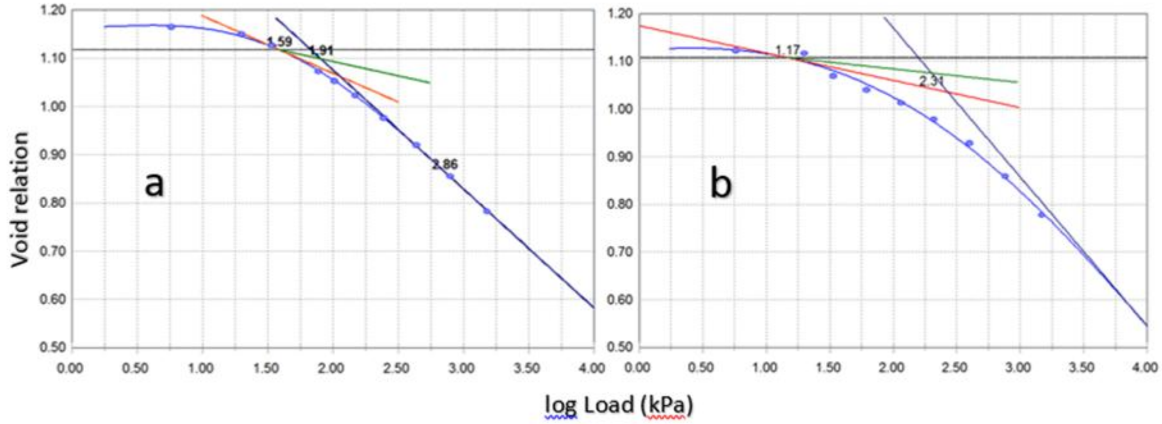

FIGURE 4: Strain-load curve, expressed as void relation, obtained on Bt1 horizon (300 to 400 mm of depth). a) soil sample 1; b) soil sample 2

TABLE 3: Principal parameters obtained of strain-load deformation relation of soil samples of A horizon (depth range from 100 to 200 mm).

Sample	Void relation (origin)	Maximum curvature point	Preconsolidation load (Pc)		Void relation at Pc point	Compression index (Cc)	
	cm^3/ cm^3	(log kPa)	(log kPa)	(kPa)	cm^3/ cm^3	(Δy/Δx)	(degrees)
1	1.17	1.59	1.91	81.3	1.07	-0.2466	-13.85
2	1.13	1.17	2.31	204.2	0.98	-0.3127	-17.36

Conclusions

With this approach, it is possible to determine the maximum loads that can be applied to a sugarcane soil before plastical deformation. A Horizon had a behaviour similar to a refurbished sample, presumably because of its historical heavy tillage action. On those samples it cannot be estimated its load history, and the virgin compression load initiates almost on the origin of its strain-load function. Instead, Bt1 horizon showed precisely its process of consolidation, reducing consequently its stage of elastical deformation.

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