Article

Soil physical properties and their relationship with plasticity in a system under traditional tillage and no tillage

Jazmín María de los Dolores Hernández-Sánchez[1]
Benjamín Figueroa-Sandoval[2§]
Mario R. Martínez Menes[1]

[1]Hydroscience Program-*Campus* Montecillo-Postgraduate College. Mexico-Texcoco Highway km 35.5, Montecillo, State of Mexico, Mexico. CP. 56230. (hernandez.jazmin@colpos.mx; mmario@colpos.mx). [2]Innovation Program in the Management of Natural Resources-*Campus* San Luis Potosí-Postgraduate College. Iturbide 73, Salinas de Hidalgo, San Luis Potosí, Mexico. CP. 78600.

[§]Corresponding author: benjamin@colpos.mx.

Abstract

Tillage systems generate changes in soil properties, such as particle size distribution (DTP), structure and content of organic matter (MO), which in turn alters plasticity (limits of Atterberg), property that provides information on the mechanical behavior of the soil. The objective of this work was to evaluate the relationships between the Atterberg limits, the DTP and the MO content in a soil under traditional tillage (LT) and no tillage (NL). The samples were taken from the topsoil. For both plots the liquid limit (LL), plastic limit (LP), plasticity index (PI), MO content and DTP were determined. The NL presented a higher proportion of macroaggregates with respect to microaggregates compared to LT (89.16 and 85.59% respectively). There were no significant differences ($p< 0.05$) in the MO content between treatments, being higher for LT (4.2%) compared to NL (4.1%), as a result of which under the NL system there is a crop rotation that decreases the surface residue, while under LT the incorporation of crop residues is carried out. The LL and IP presented correlation with the clay content (0.6 and 0.4 respectively), but not for the MO content and contrary to what the literature indicates. It is concluded that the content of MO by itself, is not a sufficient indicator of the Atterberg Limits, for which it is recommended that for future investigations the degree of decomposition, quality and disposition of the MO with respect to the mineral particles of the soil matrix.

Keywords: Atterberg limits, organic matter, particle size distribution, tillage.

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Introduction

Soil is one of the main components of agroecosystems as it is the basis for food production, being fundamental its management, proper use and conservation (Navarro, 2010). The aim of tillage systems is to modify soil-air and soil-water relationships by altering the soil structure (Marcano, 1998, cited by Delgado *et al*., 2010). One way to quantify the changes associated with tillage, to design best management practices, are the indicators of the quality of the current state of the soil (Panayiotopoulos *et al*., 2004).

The particle size distribution (DTP), structure, porosity and organic matter (MO) content determine water retention and flow, soil aeration, temperature, shrinkage-expansion, plasticity and resistance. All these properties influence the growth and development of the roots (Gliñski and Lipiec, 1990), while some of them determine the susceptibility of the soil to compaction and erosion (Panayiotopoulos *et al*., 2004).

Regarding the mechanical properties of soils, relationships between soil consistency, MO content and clay have been reported. The Atterberg limits [lower plastic limit or plastic limit (LP) and upper plastic limit or liquid limit (LL)] are defined as a range in the moisture content in which the soil has a plastic consistency (Campbell, 1991).

The soil under a moisture content below the LP presents a fragile behavior, while, above a moisture content of the LL, the soil behaves like a liquid and can flow (Keller and Dexter, 2012). The difference between the LL and LP is called the plasticity index (IP). According to Terzaghi *et al*. (1988) Atterberg limits are necessary to evaluate the long-term effects of land use and the impact of tillage on the mechanical behavior of the soil.

The objective of this work was to evaluate relationships between the Atterberg limits, the DTP and the MO content in a soil under traditional tillage (LT) and no tillage (NL), under the hypothesis that tillage alters the mechanical behavior of the soil by modifying the boundaries of Atterberg in response to the change in content of MO and DTP.

Materials and methods

The study was conducted in the fall of 2016 at the *Campus* Montecillo of the Postgraduate College, Texcoco, State of Mexico, located at 19° 28’ 4.26” North latitude and 98° 53’ 42.18” West longitude, at an altitude of 2 250 m. The average annual precipitation is 550 mm, the soil is a *Typic ustifluvent* (Gutiérrez and Ortiz, 1999) of alluvial and lacustrine origin, with a slightly drained, migajon loamy clay texture. The land under NL has been maintained in this system for 19 years, a period during which the amount of waste remaining on the surface of the soil has been low or nonexistent; in addition, an agroforestry system [perennial apricot plant (*Prunus armeniaca* L.)] was established with a rotation sequence with annual cultivation of grasses [wheat (*Triticum sativum* Lam.), oats (*Avena sativa* L.) and corn (*Zea mays* L.)], legumes [beans (*Phaseolus vulgaris* L.), broad bean (*Vicia faba* L.) and vetch (*Vicia sativa* L.)] and oilseeds [safflower (*Carthamus tinctorius* L.)] for grain and forage production. For its part, the plot under LT has been planted with a rotation of corn in the spring-summer cycle and oats in the autumn-winter cycle for the same period of time.

21 soil samples were taken for each plot, systematically distributed, to a depth of 10 cm. Once the soil samples were collected, they were air dried for a week and then the following determinations were made: DTP, MO content and Atterberg limits.

The DTP was performed on samples of 1 200 g (dry weight), which were fractionated using a set of 9 sieves (19, 9.5, 4.75 and 2 mm, 825, 425, 250, 149 and 74 μm) and a mechanical stirrer. The agitation time was 5 min for each sample. The material retained in each sieve was weighed and for each size class the proportion of weight retained with respect to the total weight of the sample was calculated. Subsequently, the portion of soil that passed through the sieve of 74 μm (50 g), was used to determine the diameter of the fine fraction, by means of the hydrometer method (Day, 1965) making readings at 40 s, 2 and 4 h. The calculation of the weighted average diameter of the aggregates (DMP) was determined according to Kemper and Rosenau (1986) modified by Pla (1983) (equation 1).

$$DMP= \sum_{i=1}^{n} Di*Pi \quad 1)$$

Where: DMP = weighted average diameter; i= i-th class of particle size; n= total number of particle size classes; Di= average diameter of a given size class. Pi= weight ratio of the ith particle size class. An additional determination of the DTP was made using hexametaphosphate and ultrasound as a dispersant. The soil sample after being dispersed with hexametaphosphate was placed in ultrasound for 15 min and then the traditional hydrometer procedure (Day, 1965) was carried out to determine the fractions of each particle size. The MO content was determined by the method of weight loss by ignition (Salehi *et al*., 2011). The limits of Atterberg were determined according to the traditional method of Casagrande (SRH, 1961; ASTM 4318). While the plasticity index was determined by the difference in percentage between the liquid limit and the plastic limit.

The statistical analysis was carried out with the statistical software Statistical Analysis System (SAS); through which the hypothesis of normality of the data set was proved by the Kolmogorov-Smirnoff test. The basic statistics were obtained (mean, median, mode, maximum, minimum, kurtosis, asymmetry coefficient and variation coefficient) and the determination of Pearson correlation coefficients for each study variable. The model used in the Anova is shown in equation 2.

$$\widehat{Y} = \mu_{ij} + \tau_{ij} + \varepsilon_{ij} \quad 2)$$

Where: $\widehat{Y}$ = observed value; μ_{ij}= mean; τ_{ij}= effect of the treatment; ε_{ij}= experimental error; i= i-th treatment; and j= j-th value.

For the determination of significant differences or not between treatments, a comparison analysis of means was carried out by the Tukey method (α= 0.05).

Results and discussion

Both treatments (NL and LT) have a greater proportion of coarse material (0.25 - >2 mm) with respect to microaggregates (< 0.25 mm), as shown in Table 1. The system under NL presents a greater proportion of macroaggregates (89.16%) than LT (85.59%), with NL being different for average diameters 4.75, 2 and 0.425 mm. The LT has a higher proportion of microaggregates (14.39%) than the NL (10.84), being different only for the average diameters 0.15, 0.06, 0.002 and 0.001 mm. These results agree with Madari *et al*. (2005) in Ferrasoles of Brazil, under different management (NL and LT), Castro *et al*. (2002) in Latosoles and Hontoria (2015). The DMP is greater for NL with respect to LT, which coincides with what was raised by Roth *et al*. (1991) and Castro *et al*. (1998) for Ferrasols under two farming systems, although these authors report significant differences between treatments.

Table 1. Particle size distribution with respect to the average sieve diameter.

Average diameter (mm)	NL (%)	LT (%)	CV (%)
25.4	1 A	0.9 A	117.8
12.57	3.4 A	3.3 A	50.6
4.75	20.7 A	17.5 B	24.3
2	33.6 A	31 B	10.5
0.825	19.5 A	20.9 A	13.6
0.425	10.4 B	11.8 A	18.8
0.25	0.6 A	0.4 A	95
0.149	4.3 B	5.8 A	30.5
0.074	2.7 A	3.8 A	49.4
0.0625	0.6 B	0.7 A	24.2
0.031	2.2 A	2.5 A	22.5
0.002	0.8 B	1.3 A	27.8
0.001	0.2 B	0.3 A	30.5
DMP (mm)	4.1A	3.8A	-

Means with different letter are statistically different (Tukey, $p \leq 0.05$); DMP= weighted average diameter.

On the other hand, Table 2 shows the DTP for each treatment carried out by the conventional method of Bouyoucos (Bou) and Bouyoucos in combination with ultrasound as a dispersant (Bult). For the Bouyocus method a greater proportion of sands and clay is observed in LT compared to NL, the lime content is higher for NL. The previous results, turn out to be inconsistent because the experiment was carried out on the same type of soil, this could be due to the fact that the dispersion method used does not achieve the maximum separation of the particles as they are strongly linked to each other in the case of NL.

Therefore, the determination of particles was carried out again using Bouyoucos, but dispersing the soil with hexametaphosphate and ultrasound, finding that there are no significant differences between the system under NL and LT in any of the fractions of particle size. It is verified that the soil matrix has not changed and the differences obtained between treatments with the method of is due to a greater resistance to dispersion with the traditional Bouyoucos method of the clay particles originated by the most intimately mixed organic matter in the NL.

Videla and Trivelin (2008) indicate that although the dispersion of soils by agitation with water has been used to isolate primarily organic-mineral fractions, this method will not ensure the complete disintegration of microaggregates, mainly in soils with a predominance of bivalent cations (Ca and Mg) and clay of type 2:1 as cementing agents, therefore the combination of both methods is recommended, by ultrasonically submitting the separated mineral constituents of the soil (after dispersion and agitation).

Table 2. Particle size distribution for each treatment (Bouyoucos and Bouyoucos with ultrasound).

	Statistical		Medium	Sd	Asm	CV	Kurtosis	Me	Moda	Máx.	Mín.
Bouyoucos	Sand (%)	NL	14.9 $^{A, B}$	1.5	0.7	9.8	-0.5	13.9	13.9	17.9	13.3
		LT	15.4$^{A, B}$	1.4	-0.4	9.1	0.9	16	16	18	12
	Lime (%)	NL	57.8 $^{A, A}$	2.4	0.3	4.1	0.2	58	59.4	63.4	53.4
		LT	52.3 $^{B, A}$	2.8	0.4	5.4	-0.1	52.7	52.7	58.7	48
	Clay (%)	NL	27.3 $^{B, B}$	2.3	-0.1	8.4	-0.7	26.7	28.7	31.4	22.7
		LT	32.3 $^{A, B}$	2.6	-1.1	7.9	1.6	33.3	33.3	36	25.3
Bouyoucos, Ultrasound	Sand (%)	NL	28 $^{A, A}$	2.6	0.7	9.3	0	28	NS	31.8	25.3
		LT	26.6 $^{A, A}$	2.1	0.7	8	-1.6	25.8	NS	29.6	24.6
	Lime (%)	NL	26.8 $^{A, B}$	1.1	-0.4	4.1	-1.1	26.7	NS	28	25.3
		LT	27.9 $^{A, B}$	5.1	0.2	18.1	-2.9	27	NS	33.6	23
	Clay (%)	NL	45.2 $^{A, A}$	2.7	-0.8	5.9	-1.4	46.7	46.7	47.7	41.4
		LT	45.5 $^{A, A}$	3.7	-0.5	8.2	-3.2	47.4	41.4	48.7	41.4

Means with different letter are statistically different (Tukey, $p \leq 0.05$). The first letter indicates difference between treatments for the same method and the second letter indicates differences between treatments for different methods. Sd= standard deviation; Asm = asymmetry; Me= median.

Unlike most studies on MO that indicate a higher NL content with respect to TL (Logan, 1991, Hernández and López, 2002), in the soil under study there were no significant differences, the MO content being higher for LT compared to NL. The above, associated with the fact that currently in the system under NL the incorporation of residues is not carried out, together with the fact that during the spring-summer period the incorporation of vetch waste (*Vicia sativa* L.) was carried out on the system under LT. According to Kenney *et al*. (2015), the removal of 75% of the waste decreases the C content in the first 5 cm of the soil, with the superficial layer of the soil being more sensitive to the removal of the residues (Jin *et al*., 2015), decreasing the content of MO in all fractions of soil aggregates (Hammerbeck *et al*., 2012).

The average value of LL for LT is higher with respect to NL, presented differences between treatments. The above is related to the clay content for each tillage system, as Keller and Dexter (2012) mention that the mechanical behavior of LL is strongly controlled by the surface area of the particles and therefore LL has a direct relationship with the content of clay in a soil. On the other hand, the IP shows higher average values in LT compared to NL, in addition to presenting significant differences between treatments and relating again to the clay content in the soil (Table 3).

According to Mitchell (1993), cited by Seybold *et al*. (2008), in general, the greater the amount of clay in a soil, the greater the plasticity, shrinkage and potential swelling. On the other hand, the LP is greater for NL with respect to LT, classifying the soil as moderately plastic for both treatments

(Lora, 1998). However, the higher average value for NL indicates that this soil is walkable under a higher water content. The floor of the system under LT is prone to compaction induced by vehicles at a lower water content (Blanco-Canqui *et al*., 2006).

Table 3. Basic statistics for weighted average diameter, Atterberg limits and organic matter content.

Statistical	DMP (mm)		LL (%)		LP (%)		IP (%)		MO (%)	
	NL	LT	NL	LT	NL	LT	NL	LT	NL	LT
Average	4.1^{A}	3.8^{A}	44.9^{B}	48.1^{A}	31.4^{A}	30.5^{A}	13.4^{B}	17.6^{A}	4.1^{A}	4.2^{A}
SD	0.6	0.8	2.5	1.7	2.8	2.9	2.3	3.4	0.3	0.2
Asymmetry	-0.1	0.3	1	0.1	0.5	-0.5	0.1	0.7	-0.1	4.5
CV	13.4	21.1	5.6	3.6	8.8	9.4	17.1	19.1	7.1	4.9
Kurtosis	0.1	-0.7	0.5	-0.7	-0.5	-0.5	-0.7	0.3	8.3	20.6
Median	4.1	3.7	44.4	47.9	30.7	30.9	13.4	16.7	4.1	4.1
Fashion	4	3.8	SN	SN	SN	SN	SN	SN	4.1	4.1
Máx.	5.3	2.6	58.7	51.6	37.5	35.4	13.7	24.9	5	5.1
Mín.	3	5.4	41.4	45	27.6	25	9.2	11.7	3.2	4.1

Means with different letter are statistically different (Tukey, $p \leq 0.05$). DMP= weighted average diameter; LL= liquid limit; LP= plastic limit; IP= plasticity index; MO= organic material.

Table 4 shows the Pearson correlation coefficients obtained; through, the construction of a matrix with the study variables. The LP presents the highest correlation coefficients with respect to the variables studied in comparison with the LL, in contrast to that reported in other studies that show lower correlation coefficients for LP with respect to LL (Dc Jong *et al*., 1990; Seybold *et al*., 2008). The LL shows a high correlation for the content of clay-Bou and IP, negative correlation for the content of lime-Bou like Seybold *et al*. (2008), in addition to showing correlation for sand-Bult content. Similar to Dc Jong *et al*. (1990), the LP has a negative correlation with the IP, there is no correlation with the content of sands and lime s, while the IP shows an average correlation with the clay-Bou content.

Table 4. Correlation coefficients for Atterberg limits, content of sand, lime and clay for both methods (Bouyoucos and Bouyoucos with ultrasound).

	LL	LP	IP	MO	Sand Bou	Lime Bou	Clay Bou	Sand Bult	Lime Bult	Clay Bult
LL	1									
LP	0.3	1								
IP	0.5	-0.7	1							
MO	0	-0.2	0.2	1						
Sand Bou	0.1	-0.2	0.2	-0.2	1					
Lime Bou	-0.5	0	-0.4	0	-0.4	1				
Clay Bou	0.6	0	0.4	0.1	0	-0.9	1			
Sand Bult	-0.5	-0.1	-0.4	-0.3	0	0.1	-0.2	1		
Lime Bult	0.3	-0.1	0.4	-0.1	0.3	0.1	0.1	-0.5	1	
Clay Bult	0	-0.1	-0.1	0.4	-0.4	0.1	0	-0.2	-0.7	1

LL= liquid limit; LP= plastic limit; IP= plasticity index; MO= organic material; Bou= refers to the Bouyoucos; Bult= a Bouyoucos in combination with ultrasound.

Low correlation values were obtained for the MO content and the other variables, with the exception of clay-Bult content. On the other hand, the clay-Bou content in the soil showed a close relationship with the Atterberg boundaries. Studies in British soils report that the clay content in the soil was highly correlated with LL and to a lesser degree with LP (Farrar and Coleman, 1967; Keller and Dexter, 2012; Salahedin, 2013), while Larnev *et al.* (1988) found weak correlations between clay content and LP, contrasting with what was found for the present study.

The correlation coefficients obtained for the MO with respect to LP, LL and IP are not significant. However, the results reported in the literature on the MO content in soil plasticity are inconsistent. Dc Jong *et al*. (1990), found positive effects on the MO, LL and IP, but not for the LP, like Stanchi *et al*. (2009) between the content of MO, LP and LL, but not over IP in mountainous terrain in Italy.

Blanco-Canqui *et al*. (2006), reported that soil management significantly affects soil consistency, finding positive correlations between MO, LL, LP and IP, for agricultural soils. On the other hand, Seybold *et al*. (2008) did not perceive significant effects on MO, LL and IP, as well as Keller and Dexter (2012), who indicate that although there are several studies that demonstrate the relationship between MO content and Atterberg limits. It should be considered that, when referring to the organic matter of the soil, the MO content that has been decomposed and humified *in situ* should be specified and to differentiate it from the newly added MO that may be in fibrous or particulate form and that it can be located differently in the soil matrix.

Conclusions

The soil matrix for both treatments is the same, not observing significant differences between LT and NL when making the determination of particle size distribution using hexametaphosphate as a dispersant in combination with ultrasound, confirming that the combination of methods achieves the maximum fractionation of the mineral particles in the soil. The content of organic matter between treatments, did not contemplate significant differences, being higher for LT compared to NL, the foregoing, related to the non-incorporation of residues in the system under NL and the incorporation of *Vicia sativa* L., during the cycle of spring-summer for LT. The liquid limit, plastic limit and plasticity index examined a greater correlation with the clay content and not with the content of organic matter, concluding that the organic matter per se does not directly influence the Atterberg limits. For subsequent studies, it is recommended to carry out tests that involve the determination of the type of waste, decomposition rate and quality of the organic matter with respect to the mineral particles of the soil.

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