

LINEAR SHRINKAGE EFFECTS UPON A SANDY LOAM SAVANNA SOIL PHYSICAL CHARACTERISTICS

EFFECTOS DE LA CONTRACCIÓN LINEAR SOBRE LAS CARACTERÍSTICAS FÍSICAS DE UN SUELO FRANCO DE SABANA

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ABSTRACT

It is generally accepted that kaolinite clay soil does not shrink. The Venezuelan Monagas states sandy loam soil of savanna having kaolinite clay, that increases with depth, shrinks enough, that from an agricultural point of view produces various effects on soil physical parameters and root adverse soil conditions. The general objective was to determine the linear shrinkage at ambient periods of drying in four soil horizons of a loam savanna soil and its consolidation effects. Methodologically a linear semi-cylindrical mold for soil shrinkage data attainment was used; and, randomized experimental design simple factorial ($7 \times 7 \times 4$) block method, regression variance analysis, the least significant difference (LSD), multiple regressions, all-pairwise comparisons test and response surface were used for statistical analysis. The results showed that linear shrinkage increased from drying periods and soil depth; the maximum soil desiccation occurred between 48 and 60 h drying periods; the wet densities did not vary significantly from drying periods, nevertheless evidently for soil horizons. Soil drying, shrinkage and consolidation, resulted the same soil processes. These soils completely consolidate at around 48 h after a good wetting causing flocculation; indicating, requirement of irrigation every two or three days.

Keywords: Consolidation, consistence, compaction, drying, flocculation, hydraulic conductivity.

RESUMEN

En general se acepta que el suelo con arcillas caoliníticas se contraen poco o no. El suelo franco arenoso de sabana del estado Monagas de Venezuela contiene caolinita, que aumenta con la profundidad, se contrae lo suficiente, que desde un punto de vista agrícola produce varios efectos sobre los parámetros físicos del suelo y las condiciones de crecimiento adecuadas de la raíz. El objetivo general fue determinar los efectos de la contracción lineal en períodos de secado al ambiente en cuatro horizontes de un suelo franco arenoso de sabana. Metodológicamente se utilizó un molde semicilíndrico lineal para evaluar la contracción lineal; estadísticamente un diseño de bloques al azar experimental sencillo factorial ($7 \times 7 \times 4$), el análisis de varianza, la mínima diferencia significativa (MDS), regresiones múltiples, pares de prueba de comparaciones y superficie de respuestas. Se concluyó que la contracción lineal aumentó con los períodos de secado y la profundidad del suelo; la máxima desecación del suelo se produjo entre las 48 y 60 h períodos de secado; la densidad aparente húmeda no varió significativamente con los periodos de secado, pero sustancialmente con la profundidad. El secado del suelo, la contracción y la consolidación son los mismos procesos. Estos suelos se consolidan completamente después de una buena saturación a las 48 h, causando disgregación y pulverización con requerimiento de riego cada dos o tres días.

Palabras clave: Consolidación, consistencia, compactación, secamiento, floculación, conductividad hidráulica.



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INTRODUCTION

Soil volume changes by consolidation due to shrinkage engendered by drying may cause both unfavorable and favorable effects on soils. Clods most commonly form in clay and loam soils when tilling, but some clods can occur in sandy loam soil with high loam content (Berntsen and Berre, 1003; Fryrear, 1984). Tensile stresses and porosity changes developed on drying owing to shrinkage (Armstrong *et al.*, 1999). The effects of soil deformation on the water release characteristic associated with hydraulic properties needed understood (Gallipoli *et al.*, 2003). According to Lutenegeger *et al.*, (2003), linear shrinkage was found connected directly to the clay content. Generally, agricultural soils in the world develop moderate volume changes during wetting and drying. This occurs supposedly provided the soil has fewer 8 % swelling clay. Although moderate, this swelling is highly important to regeneration of soil structure after a given damage. More commonly, when a water deficit occurs, soil water tends to shrink away from interface with water-absorbing roots, creating a gap in the soil-plant-air continuum; as the plant continues to lose water via transpiration, the water drawn from root cells resulting in shrinkage of cell membranes. If these conditions persist, integrity of the cell membrane and the living cell itself may extinguish.

Habitual periods of dryness seem to have become typical in many regions of the world. The effects on soil structure and plants can often be seen. However, the long-term effects of drought on the health and survivability of woody plants are less noticeable (Kujawski, 2001; Dexter, 1988; Taboada, 2000; Whitmore and Whalley, 2009; Low and Margheim 1979; Schafer and Singer 1976; Parker *et al.*, 1982). The origins of soil strength have long been the cause of much debate. Houben and Guillaud (1994); Avrami and Guillaud (2008) and Whitmore and Whalley (2009) described the strength as being a result of electrostatic forces, cementation, capillarity forces and friction. Jaquin (2008) argued that although electrostatic forces describe the attraction between clay platelets, the size of attractive forces between larger particles must result of the liquid bridges between the particles, in addition to the inter-particle friction and interlock (Santamarina *et al.*, 2001; Mitchell, 1993; Ingles, 1962). Warkentin and Yong (2013) indicated that shear strength in soils depends primarily on interactions between particles.

In kaolinite, inter-particle forces of attraction result in a structure or particle arrangement that has the major influence on shear strength. A small but finite volume of water is present in the form of liquid bridges between soil particles in soil structures when water dries. This water is under tension and the pore water pressure magnitude, suction, related to the relative humidity of the surrounding

air (Verruijt, 2005). Soil compaction decreases volume by expelling air from partially saturated or dry soil produces reduction of air pore and increasing the bulk density therefore, water content is not altered and has better shear strength and hence better bearing capacity and soil stability; consolidation process reduces volume by squeezing out water from saturated soil causes reduction of pore water content, and thus decreasing soil particle separation (Warkentin, and Yong, 2013; Verruijt, 2005). A consolidated soil is stronger and denser, and hence requires more energy to till at the same water content as an unconsolidated soil (Panwar and Siemens, 1972). The structure of soils can also change continuously through water menisci forces during drying and wetting cycles (Peng *et al.*, 2007).

The changes in kaolinite/smectite ratio are associated with changes in calculated microspore volumes and swelling capacity in good agreement with preceding studies on clay pastes (Tessier and Pedro, 1980; Diamond, 1970). The decreasing swelling capacity of the microspore volume with increasing clay content was also described by Braudeau and Bruand (1993) and covenant with the observations of Fies and Bruand (1998) on the clay-silt phase. Proof of linear shrinkage seems to have been first experienced by the Texas Highway Department in 1932 (Heidema, 1957) and described as a British Standard BS1377:1990(BSI 1990) test procedure. According to Holtz and Kovacs (1981) shrinkage limit of a soil is the water content at which the soil volume ceases to change, but where the degree of saturation is even essentially 100%. Wherein the rupture different water content continues to decrease the volume remains constant but is a direct measure, true shrinkage limit. The shrinkage limit is the boundary between the semi-solid and solid states in soil consistency, being defined as the minimum water content for which the soil does not shrink its volume even if loss of water occurs. Sridharan and Prakash (1998) defined it as representing the lowest void ratio reached due to evaporation or transpiration from vegetation, below which no volume change takes place. Boivin *et al.*, (2006) defined soil shrinkage as the specific soil volume change about its water content. The general objective consisted evaluating the ratio of linear shrinkage with ambient periods of drying in four soil horizons of a loam kaolinitic savanna soil. The specific objectives were: (a) to find the shrinkage limit at four different depths and seven drying periods, (b) assess wet density quantities and (c) review the concepts of shear stress and consolidation during soil drying periods.

MATERIALS AND METHODS

The experimental analysis sampling held on a sandy loam savanna soil in Monagas state, Venezuela, situated at a height of 147 meters and geographical coordinates of 9°41'33" north latitude and 63°23' west longitude; with an annual rainfall of 1127 mm and a mean annual

temperature of 27.5 °C. Under a typical savanna vegetation: *Curatella American* (Dilleniaceae), *Anacardium occidentale*, *Straw Hairy* (*Trachypogon* and *Axonopas* sp), *Byrsonima crassifolia* Malpighiaceae, *Hyptis suaveolens* Lamiaceae, Grasses, Cyperaceae, etc. The soil area selected belongs to Ultisol group of the family Oxic Paleustults Isohipertérmic in virgin soil conditions. Table 1 shows the physical characteristics and organic matter content of the soil. The particle size is in the range established by Rucks *et al.*, (2004) and CIVIL2121 (2012). Figure 1 illustrates the graphical representation where the fine sands is almost representative, the trend lines show components that vary little for different depths from very fine sands to the right and many smaller diameter components are between 45 and 60 cm depth. These soils occupy a large Venezuelan agricultural area management used for different crops, such as maize, sorghum, cassava and pasture.

Table 1. Physical characteristics and soil organic matter content of the studied agricultural soil.

Components	Size mm	Horizons (cm)				Diameter mm
		0-15	15-30	30-45	45-60	
		%	%	%	%	
Very coarse sand	1	1.031	2.78	3.08	0.58	1.41
Coarse sand	0.5	9.180	14.8	19.32	6.06	0.72
Medium sand	0.098	25.614	22.57	23.17	12.89	0.37
Fine sand	0.053	30.098	18.47	13.20	21.47	0.151
Very fine sand	0.041	12.596	6.01	3.94	10.34	0.07
Arena total		78.448	64.63	61.71	50.34	
Silt		8.400	23.17	24.09	31.46	0.053
Clay (kaolinite)		13.151	12.20	14.2	18.2	0.024
Organic matter		1.632	0.45	0.61	0.37	
Textural class		SL	SL	SL	L	

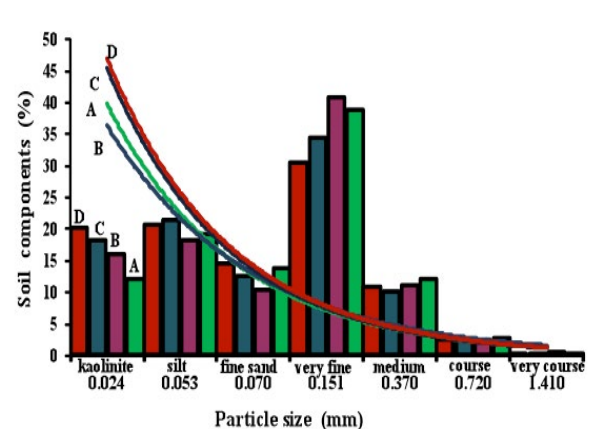


Figure 1. Clay Content, silt, fine sand, very fine sand, medium sand, coarse sand and very coarse sand versus particle size in the four horizons studied. Particle trends size versus depth (displayed with colors) are: (A) 0-15 cm, (B) 15 to 30 cm, (C) 30 to 45 cm and (D) 45 to 60 cm.

The study areas proceeded with a random sampling with excavation of ten test pits and ten repetitions spaced at 30 m with an area of 100 by 80 cm (Figure 2). Separately extracted samples in the field at depths of 0-15, 15-30, 30-45 and 45-60 cm. Metal cylinder volume (VT) with known weight (MC), inserted in the Umland, introduced into the soil taking care not to disturb the sample and weighed to yield the soil wet weight (MT). The samples then placed in plastic bags, wrapped with aluminum foil, labeled and registered before being taken to the laboratory. A crumbled quota of the mixed material, used in determining the physicochemical components; and the rest passed through sieve number 10 (2 mm) for the shrinkage test. Triaxle test used to find the relations of the soil shear tensions.



Figure 2. Soil removal carried out with the Umland sampler at different depths.

Bulk density (ρ_s), wet density (ρ_h), water content (w), dry mass (M_s), wet mass (M_T) and water mass (M_w) of the specimen (for free ambient drying periods w_{Li} and oven drying w_{Es}) were found using the following equations where V_T is the mold volume for straightforwardness:

$$s = \frac{M_s}{V_T} \quad (1)$$

$$r_h = \frac{M_T}{V_T} = \frac{M_s + M_w}{V_T} \quad (2)$$

$$w = \frac{M_T - M_s}{M_s} * 100 \quad (3)$$

One hundred and ninety-six (196) equal semi-cylindrical aluminum containers according to the specifications shown in Figure 3 built with features model 1377 1975 BSI (British Standards Institution) (25mm diameter X 12.5 mm X 140 mm), identified, weighed and volume and length determined. Soil samples around 150 g of the material passing the sieve of 425 μ m granulometric fraction. The proportion of material passed through the 425 μ m sieve (BS sieve), expressed as a percentage of the dry soil mass. The samples positioned in the bowl of plain glass and thoroughly mixed with distilled water using pallets until the mixture became a homogeneous paste with a hydrometric degree approached the liquid limit; then, placed in the molds and under the same environmental conditions. Seven (7) samples taken with randomly evaluation stages and introduced in the oven at a temperature of 110 $^{\circ}$ C, as follows: zero hour, 12 hours, 24 hours, 36 hours, 48 hours, 60 hours and 72 hours. Samples by stage, after 24 hours, removed from the oven, allowed to cool outdoor then measured and weighed.

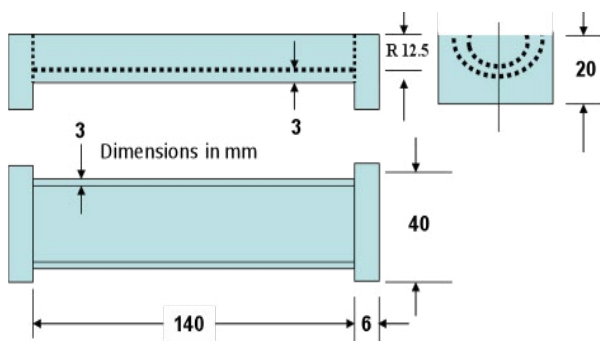


Figure 3. Schematic semi cylindrical mold of radius (R) made to test the soil linear shrinkage.

Linear shrinkage (LS) (%) based on the initial length of the sample of soil of mold length (LM) (mm), the length of the dry soil sample (LDS) (mm) and linear volume

shrinkage (LCV) (%) as indicated by Equations 3, 4 and 5 (Holtz and Kovacs (1981); Head (1994); Heidema (1957); Agus *et al.*, 2011):

$$LS = \frac{LM - LDS}{LM} * 100 = \left(1 - \frac{\text{length of dry soil sample}}{\text{length of the soil sample or mold}}\right) * 100 \quad (4)$$

$$LCV = w - \left(\frac{0.5 * \pi * 12.5^2 * (LM - LDS)}{M_s} \rho_w\right) * 100 \quad (5)$$

$$LCV = w - \frac{(VHS - VDS)r_w}{M_s} * 100 \quad (6)$$

A randomized block experimental design simple factorial (7*7*4) with forty-nine (49) treatments: seven drying period, seven replications and four soil depths employed for the analysis of wet density. The experimental units handled were a hundred and ninety-six (196). Statistically employing, regression analysis of variance (ANOVA), the least significant difference (LSD), multiple regressions and all-pairwise comparisons test.

RESULTS AND DISCUSSIONS

Figure 4 exhibits the mold soil sample linear shrinkage length at different depth, observing that shrinkage augmented with depth. The kaolinite, silt, fine and very fine sand content increased with depth (Table 1). The volume shrinkage was from 12% to 14.66% at 12 h ambient drying period at 60 cm depth. The linear shrinkage limit was from 2%-4.36% at 48 h ambient drying period for soil samples taken at 60 cm depth. The results supported by the analysis displayed in Table 2. Linear shrinkage was highly significantly with respect to depth, drying periods and the combined effect depth*drying.

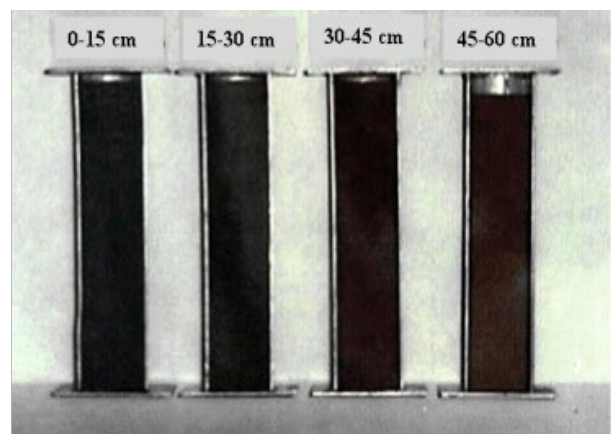


Figure 4. Molds with shrunken soil at different depths

Table 2. Analysis of variance of the shrinkage study on behalf of LS and ρ_h , for four depths, seven drying periods, seven blocks and the combined effect of PRO*SEC of a savanna soil of Monagas State of Venezuela.

Soil Linear Shrinkage (LS)					
Sources	DF	SS	MS	F	P
Block (Blo)	6	0.509	0.085	0.64	0.7020
Depth (PRO)	3	86.074	28.6912	214.61	0.0000
Drying (SEC)	6	156.324	26.0540	194.88	0.0000
PRO*SEC	18	38.531	2.141	16.01	0.0000
Error	162	21.658	0.134		
Total	195	303.095			
Mean: 1.661 %	CV: 22.03		Alfa: 0.05		
Soil Wet Density (ρ_h)					
Sources	DF	SS	MS	F	P
Block (Blo)	6	0.233	0.0388	1.65	0.1374
Depth (PRO)	3	20.317	6.772	287.77	0.0000
Drying (SEC)	6	2.074	0.347	14.69	0.0000
PRO*SEC	18	1.527	0.085	3.60	0.0000
Error	162	3.812	0.024		
Total	195	27.962			
Mean: 2.5109 g/cm ³	CV: 6.11		Alfa: 0.05		

A material is potentially expansive if it exhibits the following properties: a liquid limit of more than 30%, a plasticity index of more than 12%, a linear shrinkage of more than 8% and clay content greater than 12% (Kantey and Brink, 1952). Correia et al., (2004) reported linear shrinkage of $11.35\% \pm 0.08$ for a soil mixture 0.7 clay, 0.15 feldspar and 0.15 quartz; $0.54 \pm 0.06\%$ for a soil mixture of 65.21 kaolinite, 2.28 muscovite, 7.94 montmorillonite and 16.01 quartz. Vsebnosti and Krgovi (2007) stated volume shrinkage values of 18.4% and 15.8% for a clay kind average. Brisbane City Council (2014) informed linear shrinkage of 3% and 5% for friable sandy loam soil capable of being handled when wet but lacking cohesion therefore falling apart when dry. Soa and Ringrose (2000) found in Indonesia and Philippines soils the shrinkage limit values of 0.19%, 0.05%, 0.07% and 0.07%. Moormann and Breemen (1978) notified that drying of a puddled soil usually results in soil shrinkage and cracking especially prominent if expanding clay; but also, be clearly noticeable in kaolinitic soils. Ackroyd (1963) suggested a maximum liquid limit of 25 % and a plastic index of 6 % for the laterites soil samples. In particular, two types of laterites have a linear shrinkage fewer than 10. This revised information backs the results in this study.

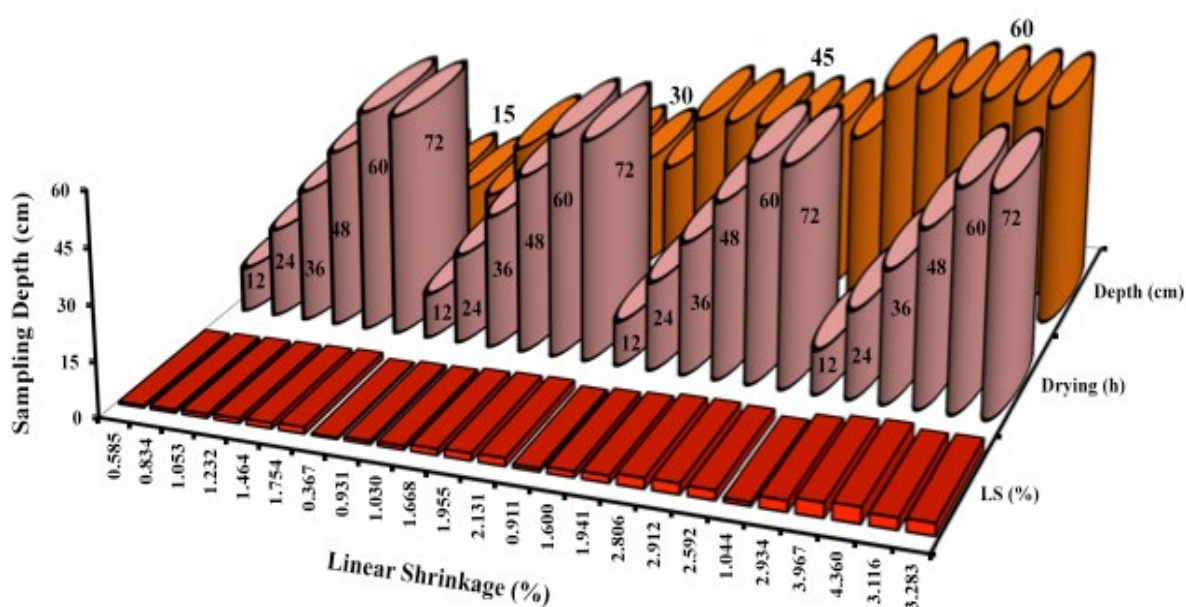


Figure 5. Shows the relationship of linear shrinkage, sampling depth and drying periods. The greater value of the linear shrinkage happened delimited by 36, 48, 60, 72 h dryness and the highest at 48 h period at of 60 cm depth. The statistical analysis revealed in Table 3 sustains the results.

Table 3. LSD All-Pairwise Comparisons Test of LS for four depth (PRO), seven drying Periods (SEC) and the combined effect of PRO*SEC

Depth (PRO) cm	Media %	Group	Drying (SEC) (h)	Media %	Group
60	2.672	A	48	2.517	A
45	1.823	B	72	2.440	A
30	1.154	C	60	2.362	A
15	0.989	D	36	1.998	B
			24	1.575	C
			12	0.727	D
			0	0.00	E
Alpha 0.05					
Critical T Value 1.979					
All 4 means are significantly different					
					Alpha 0.05. Critical T Value 1.979 There are 4 groups (A, B, etc.) in which the means are not significantly different
PRO*SEC EFFECTS					
PRO	SEC	Media	Homogeneous Group		
60	48	4.360	A		
60	36	3.967	B		
60	72	3.283	C		
60	60	3.116	CD		
60	24	2.934	CDE		
45	60	2.912	CDE		
45	48	2.806	DE		
45	72	2.592	E		
30	72	2.131	F		
30	60	1.955	FG		
45	36	1.941	FG		
15	72	1.754	FGH		
30	48	1.668	GH		
45	24	1.599	GHI		
15	60	1.464	HI		
15	48	1.232	IJ		
15	36	1.053	JK		
60	12	1.044	JK		
30	36	1.030	JK		
30	24	0.931	JKL		
45	12	0.911	JKL		
15	24	0.834	KL		
15	12	0.585	LM		
30	12	0.366	MN		
15	0	0	N		
30	0	0	N		
45	0	0	N		
60	0	0	N		
Alpha: 0.05 and Critical T Value: 1.979					
There are 14 groups (A, B, etc.) in which the means are not significantly different					

Figure 6 shows the linear shrinkage limits at different soil sample depth. According to Table 3, the greater values of the mean linear shrinkage happened at 48, 60 and 72 cm depth (significantly different) for 48, 60 and 72 h drying respectively, where the means were not significantly different. A third order polynomial function to describe the relation between the length of the dried sample and the water content managed by regression statistical method. It appears almost that at 45 cm depth resulted a well-structures or biological soil; the others,

seem non-structured soils (Wijaya *et al.*, 2015). Sample shrank length fluctuated from 0 mm (for dried sample length of 140 mm) to about 4 mm (for dried sample length of 136 mm) mm. Table 3 shows LSD all-pairwise comparisons test of linear shrinkage (LS), at four depths (PRO), seven drying periods (SEC) and the combined effect of PRO*SEC. The linear shrinkage with respect to

depth happened that all four means were significantly different and the greatest value occurred at 60 cm depth. With respect to drying periods, occurred that all four means were not significantly different, and the greatest value was at 48 h. The combined effect of PRO*SEC generated 14 groups (A, B, etc.) in which the means were not significantly different.

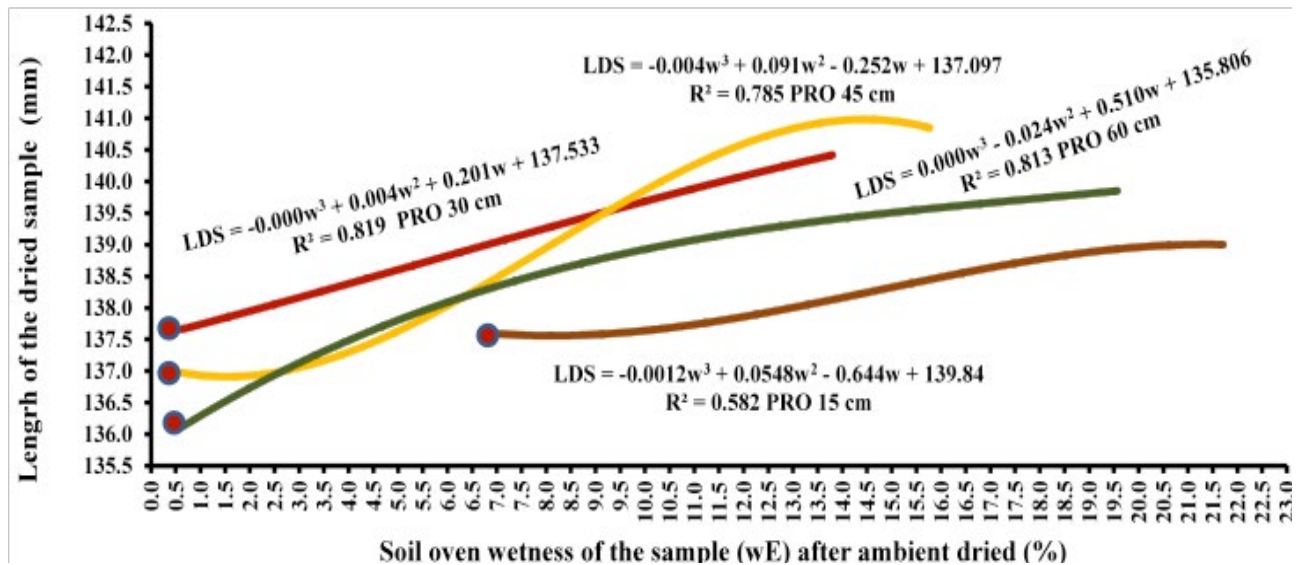


Figure 6. Dried sample length versus wetness of the ambient-dried soil at different depths

Generally, when a swelling and shrinking soil dries out; four shrinkage stages can be distinguished: (1) structural shrinkage, (2) normal shrinkage, (3) residual shrinkage and (4) zero shrinkage (Haines, 1923; Stirr, 1954; Bronswijk, 1991; McGarry and Malafant, 1987; Cornelis *et al.* 2006; Heidema, 1957). Typical over major part of moisture range reached in the field for soils that shrink and swell, structural only occurs over a small part of the range, residual only in very dry conditions and zero when soil particles have reached their densest configuration, volumes cannot decrease any further (Bronswijk, 1991). Bensallam *et al.*, (2012) found that the fourth parts of the shrinkage curve (structural, normal, residual and zero shrinkage) by using only a third degree polynomial equation. Giraldez *et al.*, (1983) used a third order polynomial function to describe the relation between the void ratio and the water content. The model describes the zero, residual and normal shrinkage stages of the shrinkage curve by using two parameters. McGarry and Malafant (1987) and Newman and Thomasson (1979) proposed to use linear functions to describe the three distinct stages of the shrinkage curves: residual, normal and structural shrinkage. Kim *et al.* (1992) handled an exponential and

linear function, which gave the best fits to their data by using three parameters. Tariq and Durnford (1993) used seven parameters to describe the fourth parts of the shrinkage curve. Olsen and Haugen (1998) proposed a second order hyperbolic equation, using in its positive solution to describe the shrinkage curve between the zero and the normal shrinkage, and its negative solution to describe the shrinkage curve from normal to structural shrinkage. Braudeau *et al.*, (1999) suggested a seven-parameter-model for the structural zone divided into a linear and curvilinear zone, including a point of friability. Chertkov (2000, 2003) proposed an expression based on the statistical analogy between crack and the probabilistic microstructure of a matrix consisting only of clay particles. In this study, a third degree polynomial to describe the shrinkage curve.

Figure 7 shows the surface chart of the linear shrinkage versus soil depth and ambient drying. Linear shrinkage increased with drying periods and soil depth. It reached its greater value within 36-60 h for 60 cm soil depth sample. This soil completely consolidates at around 48 h after a good wetting.

$$LS = 0.00144271 * PRO * SEC + 0.000464804 * SEC^2 - 0.0000298792 * PRO * SEC^2 + 0.000015749 * SEC * PRO^2$$

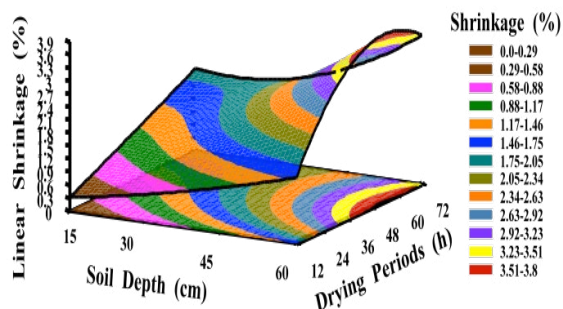


Figure 6. Dried sample length versus wetness of the ambient-dried soil at different depths

The results, obtained with the LSD all-pairwise comparisons test of LS for the combined effects of PRO*SEC shown in Table 3, were statistically analyzed for the dependent variable LS by the stepwise regression with backward choice method; P-to-enter: 0.05, P-to-remove: 0.05. The Independent variables handled were: PRO, SEC, PRO*SEC, PRO², SEC², PRO*SEC², PRO²*SEC, PRO²*SEC²; conformed with twenty-eight (28) rows for each column (28X15 matrix). The parameters selected statistically, and the analysis of variance, shown in Table 4.

Table 4. Parameter selected by the stepwise regression

Parameter Selected	Estimate	Standard Error	T Statistic	P-Value
PRO*SEC	0.001	0.0003	4.77	0.0001
SEC ²	0.0005	0.0001	4.12	0.0004
PRO*SEC ²	-0.00003	0.000003	-8.87	0.0000
PRO ² *SEC	0.00002	0.000005	2.91	0.0077

Multiple regression method backward selection P-to-enter 0.05 and P-to-remove 0.05 examined. The model analysis of variance with 5 freedom degree held with a P-value of 0.0000. Since the P-value is less than 0.05, that term is statistically significant at the 95.0% confidence level. R-squared = 98.0 percent, R-squared (adjusted for degree of freedom) = 97.8 percent, standard error of estimate = 0.31, mean absolute error = 0.3224 Durbin-Watson statistic = 1.29 and lag 1 residual autocorrelation = 0.294. There are 3 studentized residues greater than 2, none greater than 3. There are 2 points with more than 3 times the average influence value, but none with 5 times. There are 4 data with unusually large DFITS values.

The output shows the results of fitting a multiple linear regression model to describe the relationship between LS and eight (8) independent variables. The fitted equation

model is:

$$LS = 0.00144 * PRO * SEC + 0.000465 * SEC^2 - 0.0000299 * PRO * SEC^2 + 0.0000158 * PRO^2 * SEC$$

Jegade and Olaley (2013) found the linear shrinkage values was below 7% while kaolinite predominated the soil clay mineral. According to Gidigas (1973) kaolinite, is a non-expansive clay mineral and the low linear shrinkage value (3.70–6.50) show inactive and non-expansive soil. Boivin *et al.*, (2004); Diamond (1970); Tessier and Pedro (1980) exposed that soil samples showed different shrinkage properties according to clay type and clay content and that changes in kaolinite/smectite ratio associated with changes in calculated microspore volumes and swelling.

The graph of LS versus drying period, wet density (Equation 2) and soil depth presented in Figure 8 shows that soil texture cognate with soil depth is the variable most influential on shrinkage with the highest values at drying period between 24 and 60 hour and its relation with highest soil wet density values. The wet density is the measure of soil volume decrease due to soil water descent by evaporation. Wet density is the physical densification of an agricultural soil considering its constant humid state. Furthermore, consolidation by drying consists on water lose by evapotranspiration. This might well denote that the studied soil dries totally in less than three sunny days, requiring irrigation.

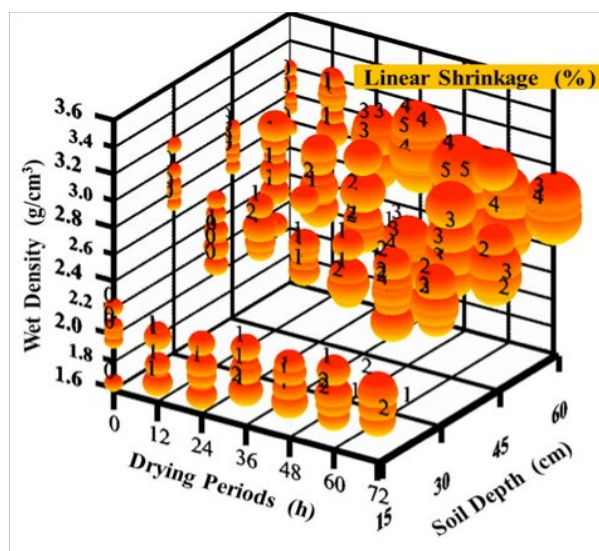


Figure 8. Linear shrinkage (LS) versus ambient drying periods under shade (SEC), wet density (ph) and soil depth (PRO).

Table 8. Shows LSD all-Pairwise comparisons test of the wet density (ρ) for four depths (PRO), seven drying periods (SEC) and the combined effect of PRO*SEC.

Depth (PRO) cm	Media	Group g/cm ³	Drying (h)	Media	Group g/cm ³
60	2.802	A	0	2.703	A
45	2.659	B	12	2.574	B
30	2.616	B	36	2.534	B
15	1.966	C	24	2.529	BC
Alpha 0.05			72	2.449	CD
Critical T Value 1.975			60	2.412	D
			48	2.374	D
There are 3 groups (A, B, etc.) in which the means are not significantly different from one another			There are 4 groups (A, B, etc.) in which the means are not significantly different from one another.		
PRO*SEC EFFECTS					
PRO	SEC	Media	Homogeneous Group		
60	12	3.001	A		
60	0	2.991	A		
30	0	2.927	AB		
45	0	2.902	ABC		
60	36	2.873	ABC		
60	24	2.800	BCD		
45	12	2.793	BCD		
45	24	2.763	CDE		
30	24	2.673	DEF		
60	72	2.668	DEFG		
45	36	2.658	DEFGH		
30	36	2.657	DEFGH		
60	48	2.653	DEFGH		
60	60	2.631	EFGHI		
45	72	2.601	EFGHI		
30	12	2.573	FGHI		
45	60	2.542	FGHI		
30	48	2.511	GHIJ		
30	60	2.498	HIJ		
30	72	2.476	IJ		
45	48	2.352	J		
15	72	2.052	K		
15	0	1.993	KL		
15	48	1.981	KL		
15	60	1.978	KL		
15	36	1.949	KL		
15	12	1.931	KL		
15	24	1.879	L		
Alpha 0.05		There are 12 groups (A, B, etc.) in which the means are not significantly different from one another.			
Critical T Value 1.975					

Figure 9 results from the combined effect PRO*SEC data of Table 8 indicating surfer plot of the wet density (ρ), with maximum values

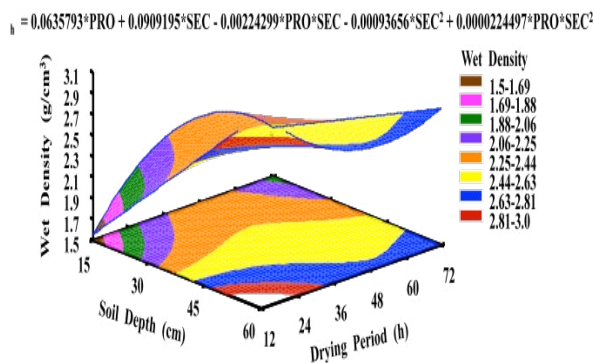


Figure 9. Surfer wet density (ph) plot versus soil depth (PRO) and ambient drying periods under shade (SEC).

The obtained results with the LSD all-pairwise comparisons test of ph for the combined effects of PRO*SEC shown in Table 9; were statistically analyzed for the dependent variable ph by the stepwise regression with the backward selection method with P-to-enter of 0.05 and P-to-remove of 0.05. The Independent variables were PRO, SEC, PRO*SEC, PRO², SEC², PRO*SEC², PRO²*SEC, PRO²*SEC², PRO*SEC³; twenty-eight (28) rows for each column (a matrix of 28X9). The parameters selected statistically and the analysis of variance, shown in Table 9.

Table 9. Para meter selected by the stepwise regression

Parameter	Estimate	Standard Error	T Statistic	P-Value
PRO	0.064	0.004	14.524	0.0000
SEC	0.091	0.018	5.0768	0.0000
PRO*SEC	-0.00	0.000	-4.58349	0.0001
SEC ²	-0.01	0.000	-3.13776	0.0046
PRO*SEC ²	0.00	0.000	2.9368	0.0074

The dependent variable ph surface chart statistically analysis by the stepwise regression, excluding constant. Method: backward selection, P-to-enter: 0.05, P-to-remove: 0.05. The Independent variables introduced were: $ph=f(\text{PRO}, \text{SEC}, \text{PRO}*\text{SEC}, \text{PRO}^2, \text{SEC}^2, \text{PRO}*\text{SEC}^2)$. $ph=0.0635793*PRO+0.0909195*SEC-0.00224299*PRO*SEC-0.00093656*SEC^2+0.0000224497*PRO*SEC^2$. 0.0000-P value for the model. The model analysis of variance with 5 freedom degree held with a P-value of 0.0000. Since the P-value in the ANOVA table is less than 0.05, that term is statistically significant at the 95.0% confidence level. R-squared = 97.83 percent, R-squared (adjusted for degree of freedom) = 97.45

percent, standard error of estimate = 0.41, mean absolute error = 0.26, Durbin-Watson statistic = 2.37 and lag 1 residual autocorrelation = - 0.20.

The surface plot of the wet density versus soil wetness and soil drying period presented in Figure 10 illustrates that soil wet density maximum values happened around 7 and 11.5% soil wetness and drying period of 12 to 48 h; decreasing after 48 h period, when occurs the soil the liquid limit at around 17% soil wetness. The crumbling happens nearby 2.5% wetness.

$$h = 0.373253*w + 0.0724095*SEC - 0.0043014*w*SEC - 0.0132786*w^2 - 0.000515984*SEC^2$$

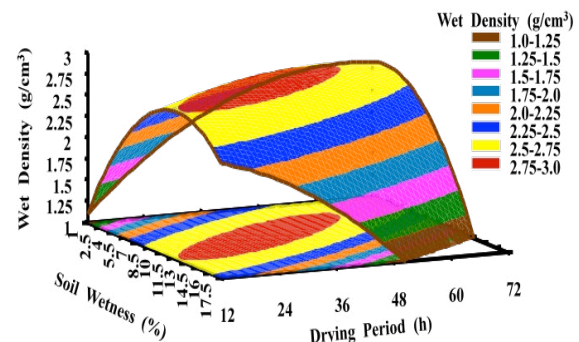


Figure 10. Surfer wet density (ph) plot versus soil wetness (w) and ambient drying periods under shade (SEC)

It might be observed in Figures 9 and 10 that the wet density affected only by depth. Notice in Table 6 and Table 9 that the relationship resulted strong and yet not significant with respect to depth and drying periods, where at zero drying the wet density reached a value closed to 72 h drying. It might be inferred that drying causes consolidation instead of compaction. This argument finds support by results published: Fahey, (1914) expressed that soil shrinkage attributable to drying is just a consolidation process. Casanellas *et al.*, (2003) specified that consolidation of the crust is attributable to soil drying. Whitmore and

Whalley (2009) indicated that in agricultural soils, it is the capillary forces between particles that give soil its strength. These forces engendered by the matric potential, especially with the existence of fine capillaries filled with water producing stronger forces triggering stronger soils. Bresson and Moran (1995) specified that an increase in soil bulk density may also be due to a structured collapse induced by wetting and drying, which is often called natural compaction or hard setting. Singh (2011) expressed that the greater the soil dispersion,

the lower is the hydraulic conductivity. The high rates obtained for bulk density supposed when preparing the mold. High clay content facilitates puddling. Soils with predominantly kaolinitic clay are more difficult to puddle than those with montmorillonitic clay. Behera *et al.*, (2009) concluded that puddling increased bulk density of the soil and decreased hydraulic conductivity. Water retention in puddled soils accords with amount of organic carbon and silt plus clay content. Silty clay loam soil retained more water than, clay loam, loam and sandy clay loam soils at all suctions. The decrease in hydraulic conductivity due to puddling was greater in sandy loam and clay loam soils than in clay soil (Singh, 2011). Naphade and Ghalydya, (1971) indicated that hydraulic conductivity of field of laterite sandy loam

soils puddle, decreased, and the bulk density increased from 1.401 to 1.692 g·cm⁻³.

Figure 11 discloses that wet density resulted greater at 60 cm soil depth for any values of drying period and linear shrinkage. In Figure 12 the highest values of wet density for drying period 24-48 h and linear shrinkage of 2 %; all this, demonstrating that wet density performance resulted possibly to volume reduction due to water content reduction by consolidation in the drying process. At the beginning the wet soil mass (MT) with greatest value; after consolidation started, MT started to decrease due to lose of water; that is the reason of the highest value of ρH. Before the LS reached 2 % the wet density varied with up and down; and after 2 % soil linear shrinkage, the wet density increased steadily.

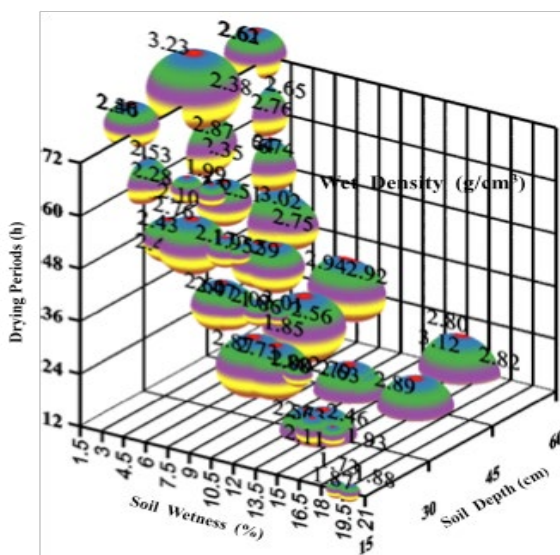


Figure 11. Wet density versus drying periods, soil wetness and soil depth

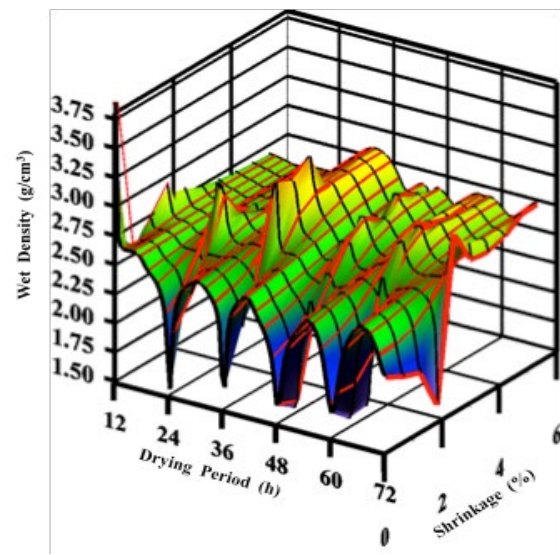


Figure 12. Soil wet density versus soil drying period and Shrinkage

The dependent variable ρ_h surface chart statistical analysis by the stepwise regression, excluding constant. Method: backward selection, P-to-enter: 0.05, P-to-remove: 0.05. $\rho_h = 1.32851 \cdot LS + 0.0696958 \cdot SEC - 0.233143 \cdot LS^2 - 0.00089811 \cdot SEC^2$. 0.0000 model P value. The analysis of variance 0.0000 model P-value of all independent variables. Since the P-value in the ANOVA table is less than 0.05, that term is statistically significant at the 95.0% confidence level. R-squared = 94.1 percent, R-squared (adjusted for degree of freedom) = 93.1 percent, standard error of estimate = 0.62, mean absolute error = 0.46, Durbin-Watson statistic = 0.47

and lag 1 residual autocorrelation = 0.76.

Figures 13 and 14, exposes the relationship of shear resistance, of the studied soil, with soil bulk density and wetness obtained with the triaxle. The regression analysis shows low significance of shear resistance with respect to bulk density (bulk density includes soil air porosity and wet density embraces total porosity, air and water; which characterizes the real agricultural soil), and higher significance with respect to soil wetness; indicating, that soil wetness influences more soil shear resistance than bulk density; supporting the influence consolidation criteria effects on soil shear.

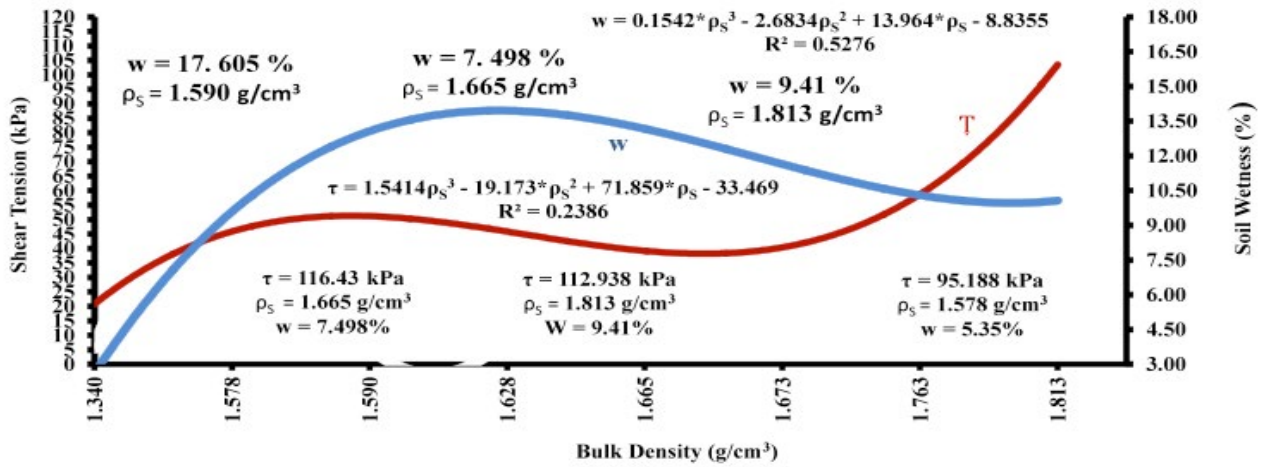


Figure 13. Shear tension (τ) and soil wetness (w) versus bulk density.

The dependent variable ρ_h surface chart statistical analysis by the stepwise regression, excluding constant. Method: backward selection, P-to-enter: 0.05, P-to-remove: 0.05. $\rho_h = 1.32851 * LS + 0.0696958 * SEC - 0.233143 * LS^2 - 0.00089811 * SEC^2 - 0.0000$ model P value. The analysis of variance 0.0000 model P-value of all independent variables. Since the P-value in the ANOVA table is less than 0.05, that term is statistically significant at the 95.0% confidence level. R-squared = 94.1 percent, R-squared (adjusted for degree of freedom) = 93.1 percent, standard error of estimate = 0.62, mean absolute error = 0.46, Durbin-Watson statistic = 0.47

and lag 1 residual autocorrelation = 0.76.

Figures 13 and 14, exposes the relationship of shear resistance, of the studied soil, with soil bulk density and wetness obtained with the triaxle. The regression analysis shows low significance of shear resistance with respect to bulk density (bulk density includes soil air porosity and wet density embraces total porosity, air and water; which characterizes the real agricultural soil), and higher significance with respect to soil wetness; indicating, that soil wetness influences more soil shear resistance than bulk density; supporting the influence consolidation criteria effects on soil shear.

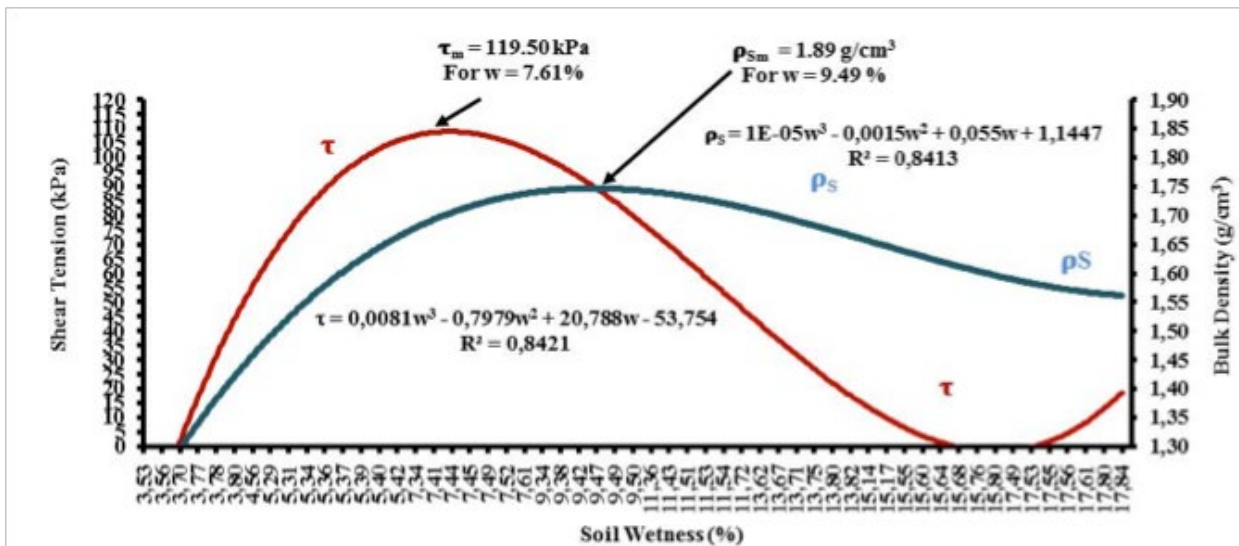


Figure 14. Shear tension (τ) and bulk density versus soil wetness (w)

Bearing in mind that, as soil compaction generates soil air (oxygen) expulsion, soil volume decrease, bulk density increase, soil stability and water retention; and, soil consolidation, owed to shrinkage caused by natural soil drying, produces soil water lose, soil flocculation, soil volume decrease, soil consistence and increase of shear strength owed to soil moisture reduction through an optimum,. Compaction causes soil stability with oxygen reduction and consolidation causes soil resistance by shear tension with water decrease. The results for the studied soil expose that wet density gets a maximum between 36 and 48 h drying between 4 and 6 % shrinkage, wetness about 7.5% and 10.0% and 60 cm soil depth. The bulk density had the same tendency. Also, soil wetness influenced density more than drying periods. The densification increase is only due to soil water porosity reduction and soil volume decrease. Then soil consolidation due to shrinkage does not cause compaction. According to Terzaghi (1943) consolidation is any process that involves a decrease in water content of saturated soil without replacement of water by air. According to Fabiola *et al.*, (2003) and Nawaz *et al.*, (2003) soil densification can occur naturally by the drying and wetting process called soil consolidation. According to Coder (2000) consolidation process leads to increased internal bonding and soil strength as more particle to particle contacts exist and elimination of pore space. Hossne *et al.*, (2012) reported optimum soil shear strength between 41 and 120 kPa for soil moisture ranging from 7% to 8% for silt loam soil and sandy loam. Hossne *et al.*, (2009) specified bulk density of 1.84 g/cm³ for soil wetness ranging 7% to 9 %, and 1.39 g/cm³ for 3 % soil wetness for silt loam soil, and sandy loam soil.

For soil wetness below around 6%, the bulk density reduction and the soil structure, crumbles or flocculates. The optimum compaction values between 8.74% to 11.60 % soil moisture produced an optimum bulk density near soil field capacity and below the plastic limit. Rajaram and Erbach (1999) found that soil strength, cohesion and soil aggregate size, increased with the degree of drying stress. However, the soil bulk density did not change significantly with the drying stress of a clay-loam soil. Consolidation changes soil erodibility as strength and density increases (Dickinson *et al.*, 1982).

CONCLUSIONS

The shrinkage of this soil exists causing clods and flocculation appearances, however low linear shrinkage increased to drying periods and soil depth, and reached its greatest value of 24-60 h increasing from soil depth samples. The linear shrinkage did not cause bulk density and wet density variations on drying periods; however, noticeably about depth. No relations found between optimum values of shear tension and bulk density. In soil drying, shrinkage and consolidation are the same processes. Irrigation for this soil, every other day, at least. More investigation is necessary to specify soil shrinkage and consolidation effects on soil densification and resistance status.

GRATITUDES

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