REVISTA ESPAMCIENCIA para el agro

PHYSICAL PROPERTIES AND ROOT ENVIRONMENT TENDENCIES DURING WETNESS AND DRYING PERIODS

TENDENCIAS DE LAS PROPIEDADES FÍSICAS Y AMBIENTE RADICULAR DURANTE PERÍODOS DE HUMEDECIMIENTO Y SECADO

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Abstract

Soil wetness has important agricultural implications. Reasons for the upsurge soil moisture in situ monitoring increase. Data interpretation is severely limited without soil property data. The agricultural soils need, thermodynamically, proper irrigation for plant physiological processes. The objective was to investigate soil physical parameters disturbance by soil wetness interrelated with root growth in a savanna loam soil. Experimental units consisted of (a) 9 polyvinyl cylinders, 15.24 cm in diameter and 20 cm height, with a soil volume of 2.50 kg/cylinder for infiltration estimations (b) 48 square glass container 3x15x15 cm for root growth assessments and 18 porometers for porosity evaluations. Statistical analysis under a randomized block design with three replications and three factors: humidity with five levels (3, 6, 9, 12 and 15%), soil depth (0-15, 15-30 and 45-60) and compaction with three levels (0, 13 and 26 blows). Soil shear and density are independent soil variables; but also, both are wetness dependent. The infiltration effect on bulk density and shear tension resulted in inversely proportionally. The soil apparent dry densities (bulk density) or wet, are dynamic variables that change with natural drying processes. Soil water retention rises as bulk density increases. Root growth offers weightier variability with respect to shear than versus bulk density. Root growth showed its greatest at lower shear tension, lower bulk density and daily and every two days of irrigation. Irrigating this soil every two or three days will give progress to roots. Wetness is the fulcrum of all other soil properties for plant existence requirements.

Keywords: Response surfaces, proctor test, root soil environments.

Resumen

La humedad del suelo tiene importantes implicaciones agrícolas, que promueve el monitoreo in-situ. Los suelos agrícolas requieren, termodinámicamente, riego para los procesos fisiológicos de las plantas. El objetivo fue evaluar la alteración de los parámetros físicos por la humedad, interrelaciones con el crecimiento de la raíz. Las unidades experimentales consistieron en (a) nueve cilindros de polivinilo, 15.24 cm de diámetro, 20 cm de altura y 2.50 kg de suelo, (b) 48 contenedores de vidrio 3x15x15 cm y 18 porómetros. Un diseño de bloques al azar con tres replicaciones y tres factores: humedad con (3, 6, 9, 12 y 15%), profundidad del suelo (0-15, 15-30 y 45-60) y compactación de (0, 13 y 26 golpes). La tensión cortante y la densidad son variables independientes; subordinadas por la humedad. El efecto de la infiltración sobre la densidad aparente y la tensión cortante resultó inversamente proporcional. La densidad seca aparente y la humedad del suelo, son variables dinámicas que cambian con los procesos de secado. La retención de agua en el suelo aumenta a medida que aumenta la densidad aparente. El crecimiento de la raíz ofrece una variabilidad más importante con respecto a la tensión cortante que a la densidad. El crecimiento de la raíz mostró mayor intensidad a menor tensión cortante, menor densidad y riego cada dos días. Irrigar cada dos o tres días contribuirá al progreso de la raíz. La humedad es el apoyo de todas las propiedades del suelo para la existencia de la planta.

Palabras clave: Superficie de respuestas, prueba Proctor, ambiente radicular.

INTRODUCTIÓN

The agricultural soils need, thermodynamically, proper irrigation for plants respiration and photosynthesis processes; but also, it alters soil wetness stages overflow, soil shear resistance, compaction gage density, shrinkage, drying, soil water retention, and porosity among others; that furthermore, all variables, jointly or not, affect roots development and plant life. Dryness is not a simple stress cause; the agronomic practice that investigates climate adaptation changes must take into account multiple aspects in the stress induced by insufficient water as well as other interacting stresses. Soil wetness produces categorical soil variations for shear tension, bulk density, photosynthesis, transpiration processes, chemical properties, and soil structure changes. The hypothesis contemplates investigating soil wetness effects upon compaction, shear tension, soil structure and their interrelations including adequate root environment. Compaction is always erroneously related to soil strength; actually, its effect is soil stability by pore reduction and a strong air (oxygen) decrease.

Rajarama and Erbachb (1999) working on clay loam soil subjected to three different degrees of drying stress, showed that soil strength, indicated by a cone penetration resistance and soil aggregate size, increased with drying stress degree. However, the compaction soil bulk density index did not change much with drying stress. Burlinsky and Sergiel (2014) in their conclusion pointed out, that changes in soil wetness content, subjected to mechanical impacts, affected soil density stronger. Hossne (2008) in his conclusion indicated that savanna soil bulk density altered and varied inversely proportionally with soil wetness. The microporous capillary water, most but not all, is available for plant growth. Hygroscopic water, very thin films around soil particles, form a tight bond, is unavailable to plant. Capillary forces acting on microporous exert more force than water on macroporous. Soil structure is changing continuously due to wetness and external and internal forces.

The general objective consisted in evaluating the savanna sandy loam soil properties and root environment rearrangement behavior with wetness and drying action. The investigation was specifically accomplished evaluating the influences of soil wetness upon shear tension, and bulk density, bulk density upon wetness, wetness, and bulk density upon shear, soil stratum or depth, wetness, and drying periods upon bulk density, depth, wetness and linear shrinkage upon bulk density, wetness upon shear, and bulk density for the upper and bottom layers of the container experimental unity, wetness and bulk density on microporosity, macroporosity, and soil water retention capacity, and root length growth associations with bulk density, shear, wetness, shear-wetness, and bulk density-wetness.

MATERIALS AND METHODS

Sampling collection was accomplished on a sandy loam savanna soil in Monagas State, Venezuela, situated at a height of 147 m, and geographical coordinate 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 ºC. Under typical savanna vegetation: *Curatella american* (Dilleniaceae), *Anacardium occidentale*, *Trachypogon*, and *Axonopas* sp, *Byrsonima crassifolia Malpighiaceae*, *Hyptis suaveolens* Lamiaceae, Grasses and Cyperaceae among others. The soil area selected belongs to a Ultisol group of the family *Oxic Paleustults isohipertermic* in virgin soil conditions. Table 1 shows the soil physical characteristics and organic matter content. The particle size is in the range established by Rucks *et al*., (2004) and CIVIL2121 (2012). Figure 1 shows the region where the fine sand is almost representative. These soils occupy a large Venezuelan agricultural area occupied for the exploitation of many items such as maize, sorghum, cassava, and pasture. The lab study achieved in the Soil Physical and Mechanical Laboratory of the Oriente University, Nucleus of Monagas, Maturin; campus located according to UTM E482908.31 N-1076748.00 and E-482924.24 N-1076752.51.

Table 1. Texture and organic matter soil content analysis in Jusepin, Monagas State.

Components	Soil horizons (cm) 0-15	15-30	45-60	Diameter
	%	%	%	(Average) mm
Very coarse sand	1.01	1.31	0.20	1.41
Coarse sand	6.18	5.71	2.69	0.72
Medium sand	19.1	14.26	13.34	0.37
Fine sand	32.38	24.77	26.33	0.151
Very fine sand	15.0	13.11	15.81	0.07
Total sand	73.67	58.66	58.37	
Silt	16.13	17.14	29.43	0.053
Clay (kaolinite)	10.2	24.2	12.2	0.024
Organic matter	1.20	0.61	0.45	
Textural class	SCL	SCL	SCL	

Source: Labsea, UDO Monagas

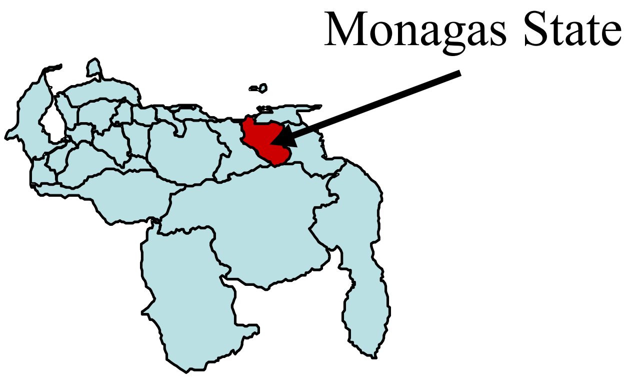


Figure 1. Venezuelan states map. Sampling side position

The experimental infiltration unit (Figure 2) equipped with 9 polyvinyl cylinders, 15.24 cm diameter and, 20 cm heights. A volume of 2.50 kg soil deposited. A millimeter scale tape stuck to the cylinder wall, allowed the infiltrated water height readings. 15 ml of water applied to all the containers at each irrigation time. The water poured into the cylinders through a textile cover to avoid soil disturbances of the falling water.

Figure 2. The employed experimental unit and the Proctor hammer in the infiltration analysis

The measurements consisted of determining the sheets of water infiltrated rates in the cylinders for different time intervals ranging between 1 and 60 minutes, with at least 10 readings to keep up the same number of observations and thus the data comparison. The amount of water was previously determined by a test using ten containers filled with air-dried soil without compaction, to avoid saturation in those treatments; daily watering recommended. The soil compaction steps performed, with three compaction layers, under the standard Proctor (commonly called the standard Proctor compaction test, ASTM, 2009). The bulk density inverse (Vt/Ms) is the soil specific volume (ν), or dry apparent density inverse. Dry bulk density was used instead of wet soil bulk density because the last is an ever-changing entity due to soil evaporation under natural conditions, but the last is the real agricultural soil state. Statistical analysis carried out consisted of a randomized block design with three replications with two factors, wetness with five levels (3, 6, 9, 12 and 15%) and compactions with three levels (0, 13 and 26 blows) (Leiva, 2011; Smith, 2011; Vásquez, 2011).

The root growth experimental data was carried out by studying the courgette seedlings (*Cucurbita pepo* L) root growth. The test units made up of forty-eight (48) square glass containers, 5 mm thick, 3x15x15 cm, with an opening in the lower part of the side covers to allow water out. The dry soil passed through a No. 10 soil test model No. CB-810 with 2 mm mesh diameter. The amount of soil per container was established through a weighing average of 10 containers, resulting in a total dry soil mass of 330.0 g/container. The employed modified Proctor has a total mass of 1.83 kg, 0.63 kg hammer weight, 78.5 cm total hammer fall length, and 30 cm used to drop in the experiment. Figure 3 shows the container and the plant root growth after 15 days for cero compaction and every-day irrigation (Maita, 2016).

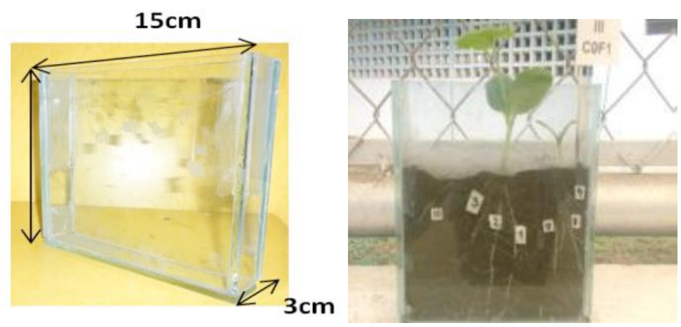


Figure 3. Experimental container and courgette root developing under zero compaction and every-day irrigation after 15 days.

The porometer was used for determining macroporosity, microporosity, wetness retention capacity, dry density and gravimetric wetness in dry base (%). The eighteen (18) porometers units consisted of plastic cylinders of PVC of 7.62 cm diameter, 15 cm length, with eight (8) holes of 5 mm of diameter in the base covers with 800 g average of soil per cylinder. The statistical test employed was a randomized block design with four blocks, nine treatments consisting of three wetness levels (3, 8 and 13%) and three compaction levels of 0, 10 and 20 strokes/layer, and two repetitions per experimental unit; extended with an analysis of variance with factorial arrangement (3x3) of random blocks and regression analysis between the variables MAP, MIP, WRC, ρ_S and w with a level of significance of 0.05 (Rocca, 2017).

The Durbin Watson statistic tests autocorrelation considered always between 0 and 4. If the Durbin–Watson statistic is substantially less than 2, there is evidence of positive serial correlation. As a rough rule of thumb, if Durbin–Watson is less than 1.0, there may be cause for alarm. If >2, successive error terms are negatively correlated (Montgomery *et al*., 2001). The variables and some procedure terminology employed are presented in Table 2.

Table 2. Nomenclature

ANOVA	Analysis of variance
CO	Compaction (blow)
DP	Drying period (h)
IF	Irrigation frequency (day)
LS	Linear shrinkage (%)
MAP	Macroporosity (%)
MIP	Microporosity (%)
max	Variable maximum value (Sub index)
min	Variable minimum value (Sub index)
Ms	Dry soil mass. g
op	Variable optimum value (Sub index)
PRO	Soil depth or horizon (cm)
PVC	Polyvinyl chloride
RL	Root Length (cm)
Vt	Total soil volume. cm^3
w	Soil wetness (%)
WRC	Wetness retention capacity (%)
v	Specific volume. cm^3/g
τ	Shear tension (kPa)
ρ_S	Bulk density (g/cm^3)

RESULTADOS Y DISCUSIÓN

The Proctor test blows and wetting regimen data, obtained from eight (8) units randomly chosen, did not produce remarked soil physical properties changes in the upper and bottom experimental vessel soil samples layers, shown in Figure 4. The effects in layers 0 to 20 cm depths of the experimental unit yielded minimum dissimilarity results for τ and ρ_S versus w; possibly indicating that wetting affected physical properties alike regardless of soil depth or texture. Wetness altered τ and ρ_S differently and independently, showing no relations between them. The equations, shown in Figure 4 reveal nearest employed root growth conditions. The statistical analysis presented in Tables 3 and 4 validates the last statement.

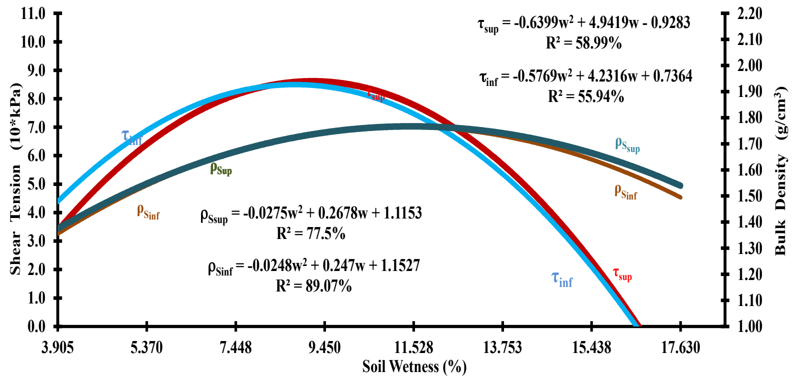


Figure 4. Shear tension and bulk density versus soil wetness. Results in the upper (sup) and bottom (inf) layers of the experimental units.

Table 3. The curve fit statistical regression analysis for Figure 4 data, with eight (8) average total cases, disclosed slight variation effects for τ versus w.

Receptacle upper layer		
Quadratic model of best fit: $\tau = 19.014*w - 1.129*w^2$		0.000 ANOVA significance
Coefficient correlation significance: 0.006 (w) and 0.011 (w^2)		
$R^2 = 78\%$	Adjusted $R^2 = 71\%$	τ_{op} = 80.06 kPa for $w_{op} = 8.42\%$
Receptacle bottom layer		
Quadratic model of best fit: $\tau = 19.7*w - 1.178*w^2$		0.009 ANOVA significance
Coefficient correlation significance: 0.005 (w) and 0.009 (w^2)		
$R^2 = 79\%$	Adjusted $R^2 = 72\%$	$\tau_{op} = 82.36$ kPa for $w_{op} = 8.36\%$
With a slight higher difference, expected, occurring in the bottommost		

Table 4. The curve fit statistical regression analysis for figure 4 data, with eight (8) average total cases, disclosed no variation effects for ρ_S versus w.

Receptacle upper layer		
Quadratic model of best fit: $\rho_S = 0.335*w - 0.15*w^2$		0.000 ANOVA significance
Coefficient correlation significance		0.000 (w) and 0.000 (w^2)
R^2 = 98.9%	Adjusted $R^2 = 98.6\%$	ρ_{Sop} = 1.87 g/cm^3 for $w_{op} = 11.17\%$
Receptacle bottom layer		
Quadratic model of best fit: $\rho_S = 0.335*w - 0.15*w^2$		0.000 ANOVA significance
Coefficient correlation significance		0.005 (w) and 0.000 (w^2)
R^2 = 98.9%	Adjusted $R^2 = 98.5\%$	$\rho_{Sop} = 1.87$ g/cm^3 for $w_{op} = 11.17\%$
With no difference between the upper and bottom layers		

The total data of τ and ρ_S versus w, graphed (Figure 5) and analyzed statistically (Table 5, 6 and 7), show alike tendency with Figure 4 results. The dependent variables τ and ρ_S values, after its maximums, decreased with respect to w around 8% and 11% soil wetness correspondingly.

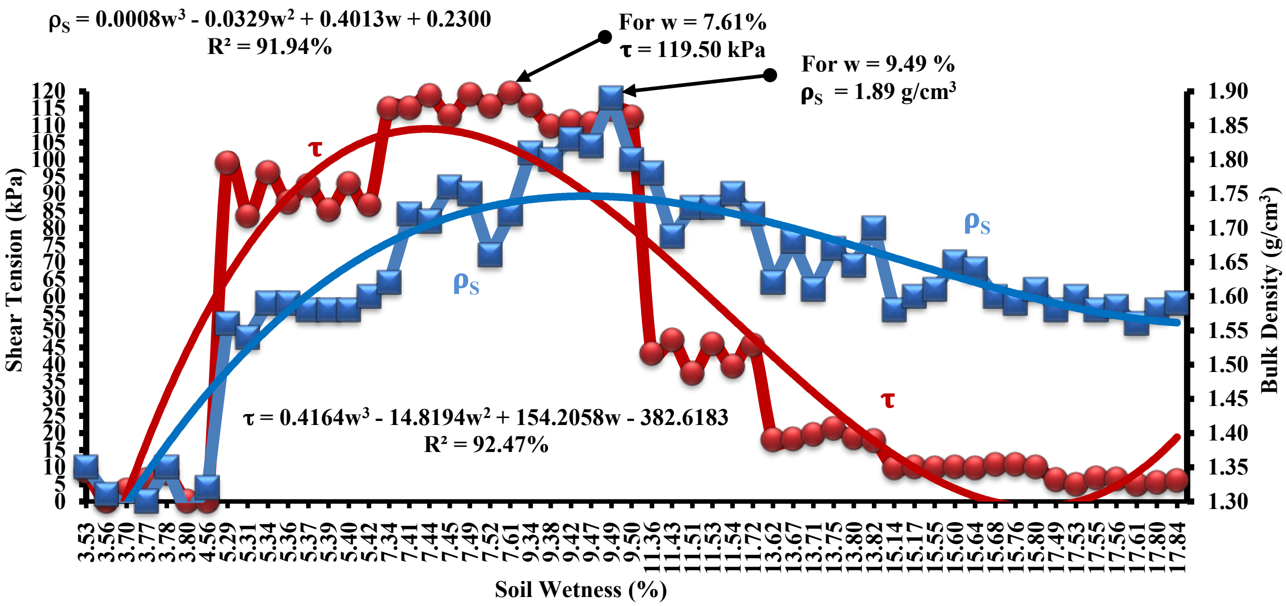


Figure 5. Shear tension and bulk density versus soil wetness.

Table 5. The relations of τ and ρ_S versus w analyzed with Excel.

τ versus w	
Disclosed that the dependent variables τ presents an increase with respect to w	
τ presents an increase with respect to w, with τ_{max}= 116.22 kPa for w_{op} = 7.71% and τ_{max}= - 3.52 kPa for w_{op} = 16.02%	
R^2 = 92.47%	tendency to zero when oriented to 17% wetness
the savanna soil liquid limit The soils liquid limit is important information to predict landslides	
ρ_S versus w	
For ρ_S versus w presented a maximum of 1.76 g/cm^3 for w_{op} equal to 9.16%	
R^2 = 91.94%	ρ_{Smin} = 1.46 g/cm^3 for w_{op} = 18.26%

Table 6. Multiple regression of τ versus w, ρS, w*ρS , ρS2, w2, ρS2*w, ρS*w2.

τ = - 478.88*w + 35.82*w*ρ_S + 0.29*ρ_S^2 + 367.88* w^2 – 28.27*ρ_S*w^2	
0.0000 ANOVA regression significant	R^2 = 98.47% and adjusted R^2 = 98,35%
Correlation coefficients significant 0.0000, 0.0000, 0.0357, 0.0000 and 0.0000 respectively Durwin-Watson 2.21	

Table 7. The curve fit regression analysis of ρS and τ versus w with 55 data.

ρ_S versus w		
Quadratic model of best fit: ρ_S = 0,001*w^3 – 0,041*w^2 + 0,479*w		0.000 ANOVA significance
Coefficient correlation significance 0.006 (w), (w^2) and (w^3)		R^2 = 99.9%
Adjusted R^2 = 99.9%		ρ_{Smax} = 1,72 g/cm^3 w_{op} = 8,45% ρ_{Smim} = 1,16 g/cm^3 w_{op} = 18,87%
τ versus w		
Quadratic model of best fit: τ = 19.695*w – 1.178*w^2		0.009 ANOVA significance
Coefficient correlation significance		0.000 (w) and (w^2)
R^2 = 78.7%	Adjusted R^2 = 77.9%	τ_{op} = 81.63 kPa for w_{op} = 8.40%.
τ and ρ_S curves cross point, the resulted values for τ = 80.69 kPa and for ρ_S = 1.691 g/cm^3		

Shear depends on particle-particle and particles/water-particle attraction; and density most on macroporosity reduction. Hossne (2008) concluded that the studied soil ρ_S varied inversely proportionally to w; it changed with natural and stove drying processes. The data performance revealed that shear and density are soil variables independent of one another; but also, both were wetness dependents. Soil water retention raised as bulk density increased. Andrew *et al.* (2009) revealed that capillary forces between agricultural soil particles produce its strength; the more fine capillaries filled with water the stronger the soil. The plant height increased with increasing air-filled porosity in a wet year and decreased with increasing soil mechanical resistance in a dry year. 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 1.84 g/cm^3 ρ_S for w ranging from 7% to 9 %, and 1.39 g/cm^3 for 3 % for silt loam soil, and sandy loam soil. For w below around 6%; the bulk density and shear decreased, the soil structure crumbled or flocculated. Hossne (2008) reported, for savanna soils, that ρ_S decreases with increasing soil volume and increases or decreases with w variation with a pronounced decrease between 4 and 7%, and 13% onwards. The ρ_S crests were obtained for lesser volume and low w. Fuentes and Seguel (2013) found that shear strength proved dependent on internal tensions and external stresses in the tested soils. In general, in air-dried samples, the strength of the aggregates is considerably great. The difference in cohesion between soil cores and single aggregates decreased significantly because of wetness effect. The processes involved in aggregate formation related mainly to soil shrinkage and swelling occurred by drying and wetting seasonal cycles (Semmel *et al.*, 1990), as well as biotic agents (Kay and Angers, 2002). The results suggest that soil texture, bulk density, shear tension, and water content are the most important physical properties because they accounted for much of the soil physical properties. Pan *et al.* (2012) found the same results but only for soil texture, bulk density and air-dried water content.

Further examination of τ variability with respect to ρ_S and w (Figure 6) shows τ constant variation with respect to ρ_S changes; but, pronounced w influence; this back up the already results presented. The functions τ, and w, are the measure of soil resistance; a compacted soil firmness (ρ_S) endures as long it is dry.

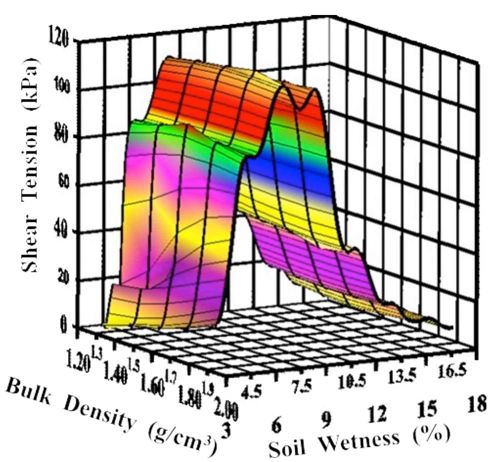
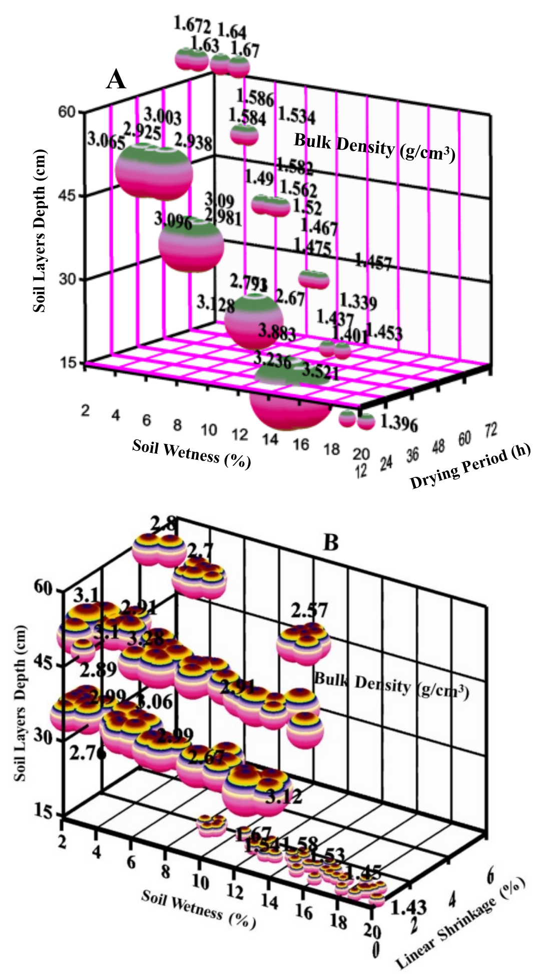


Figure 6. Shear tension versus bulk density and soil wetness.

Examining ρ_S versus soil DP, LS and soil PRO, Figures 7 A and B (figures in four dimensions where the diameter of the spheres represent the variable ρ_S), show that drying and shrinkage affected ρ_S as expected due to porosity reduction caused by soil and water particles attraction, and increasing with PRO owed to soil texture changes, possibly related to the kaolinite content increase, organic matter decrease, and coarse sand decrease. The diameters of the spheres represented ρ_S size, proportionally. The lowest ρ_S happened at 12-24 h DP. Soil wetness exceptional influences on bulk density occurred between 24 and 48 h DP, and LS between 2% and 6 %. Bulk density is the compaction evaluation gauge, commonly employed by civil engineering that indicates soil porous reduction, oxygen content decrease, and stability. The soil loses resistance and compaction at low dryness less than 6% wetness for sandy loam when soil particle loses it capillary strength changing to a dusty soil. The optimums for ρ_S and τ occurred at 9.49% and 7.61% wetness respectively (Hossne *et al.* 2009, 2012).



Figures 7. (A) Bulk density correlated with soil layers, wetness and drying periods. (B) Bulk density versus soil layer, wetness and linear shrinkage.

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The soil aggregation and breakdown is more intense in undisturbed soil due to successive wetting and drying cycles that favor new pores creation. Structural changes took place due to internal (shrinkage) and external forces (compaction) which affected the hydraulic behavior of these soils (Dorota *et al.* 2008). Rigid or incorrectly considered non-swelling soils are usually coarse-textured, poor organic matter and hard to till. Pore rigidity, as one of the major boundary conditions, is always assumed to exist. Under in-situ conditions, the assumption validity is questionable and strongly depends on the climate, land use, soil type, and management. Changes of water content or water potential will alter porosity for structured or homogeneous soils irrespective of geological origin and clay mineralogy (Horne *et al*. 2014). They also have low aggregate stability, a high module of rupture, and low resilience after given damage (e.g. compaction by agricultural traffic). They are considered having hard-set behavior after several years of disc plowing; a hard plow pan developed in the subsoil (Taboada, 2003). Generally, most agricultural soils in the world develop only moderate volumetric changes during wetting and drying. This occurs provided the soil has less 8 % swelling clays (Dexter 1988). Although moderate, this swelling is highly important to soil structure regeneration after given damage. According to Rattan *et al*. (2005), an increase in soil bulk density leads to inhibited root development, poor gaseous exchange and anaerobiosis. Excessive runoff lowers availability of stored water in the root zone and sub-optimal or supra-optimal soil temperatures and poor aeration exacerbates the problem of reduced water uptake. For a given bulk density, soil strength decreases with increasing soil moisture content. For a given soil moisture content, soil strength increases with increasing soil bulk density, but this never happens because soil wetness is an agricultural soil dynamic property. Organic matter promotes good soil structure growth and decreases soil bulk density binding soil particles together as aggregates so they are not as easily cracked, split, or compressed (Wortmann and Jasa, 2009). In general, fine-textured soils at low moisture content show high strength. Bulk density generally increases with a decrease of aggregate size. Two principal aggregate properties are strength and hydrophobicity.

Soil porosity is responsible for physical, terramechanics actions, water retention changes during irrigation or rain, and soil DP. The bulk density analysis and soil wetness effects on MIP, MAP, and WRC are illustrated in Figures 8, 9 and 10 (Rocca, 2017). Figures 8 A and B showed MIP responses with ρ_S and w changes, and Table 8 that encloses the statistical analysis responses that validated its behaviors.

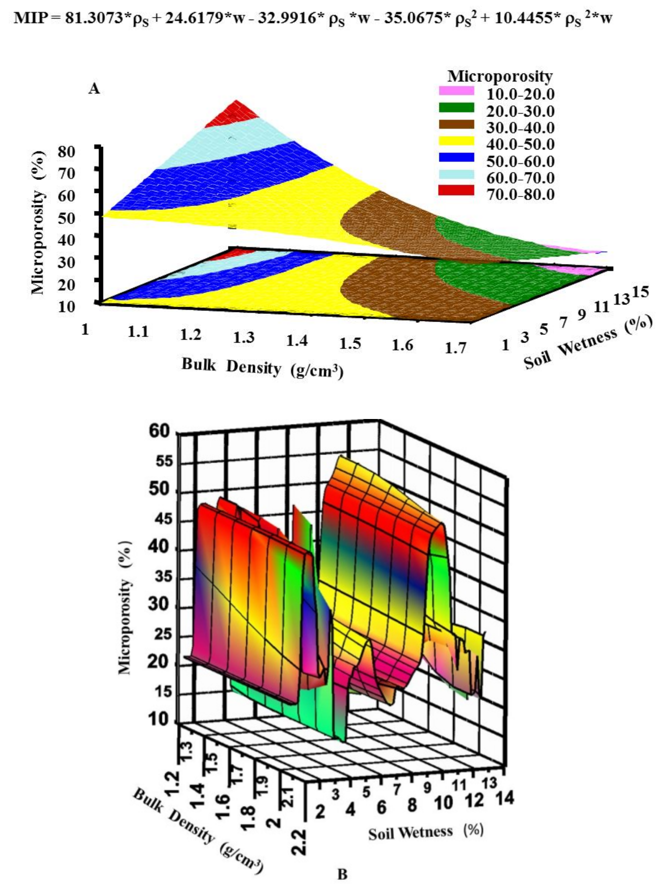

Figure 8. Soil microporosity versus bulk density and wetness.

Table 8. Soil microporosity statistical analysis including multiple regression and curve fit analysis.

Applying multiple regression on the dependent MIP, Figures 8 A and B, versu w, and ρ_S	
MIP = 81.31* ρ_S + 24.62*w – 32.99* ρ_S *w – 35.07* ρ_S^2 + 10.45* ρ_S^2*w	
0.0000 ANOVA regression significant	R^2 = 96.67% and adjusted R^2 = 96.47%
Correlation coefficients significant 0.0000 for all coefficients	Durwin-Watson =1.03
MIP versus ρ_S and w regression analysis curve fit with 55 total cases	
MIP versus ρ_S	
Quadratic model of best fit: MIC = – 25.21* ρ_S^2 + 62.14* ρ_S	0.000 ANOVA significance
Coefficient correlation significance	0.006 (ρ_S) and 0.000 (ρ_S^2)
R^2 = 98.9%	Adjusted R^2 of 98.8%
MIP versus w	
Quadratic model of best fit: MIC = 9.82*w – 0.59*w^2	0.009 ANOVA significance
Coefficient correlation significance 0.000 (w, w^2)	R^2 = 83.8%, Adjusted R^2 = 83.4%
Differentiating both equations: ρ_{Sop} = 1.23 g/cm^3, MIP_{op} = 38.30% and w_{op} = 8.33%, MIP_{op} = 40.89%	

Microporosity decreased for ρ_S high values and decreased with w rises. As water content increased, soil particles ware separated until particle attraction ruptured. At soil consistency liquid limit value, soil runoff occurred. The insert ρ_{Sop} and w_{op} values in the surface equation generated a MIP_{op} of 45.32 cm^3.

Table 9. Soil macroporosity statistical analysis including multiple regression and curve fit analysis

Applying multiple regression on the dependent MAP, Figures 9 A and B, versu w, and ρ_S	
MAP = 8,19528*w + 7,28924*ρ_S - 9,69946*w*ρ_S - 3,56308*ρ_S^2 + 2,81698*w*ρ_S^2	
0.0000 ANOVA regression significant	R^2 = 86.7% and adjusted R^2 = 86.9%
Correlation coefficients significant 0.0000 for all coefficients	Durwin-Watson =1.45
MAP versus ρ_S and w regression analysis curve fit with 55 total cases	
MAP versus ρ_S	
Quadratic model of best fit: MAP = - 5.333*ρ_S^2 + 10.805*ρ_S	0.000 ANOVA significance
Coefficient correlation significance 0.000 (ρ_S^2)	0.000 (ρ_S) and
R^2 = 71.7%	Adjusted R^2 = 71.1%
ρ_{Sop} = 1,03 g/cm^3, MAC_{op} = 5,47%	
MAP versus w	
Quadratic model of best fit: MAP = − 0.041*w^2 + 0.784*w	0.009 ANOVA significance
Coefficient correlation significance and 0.007 (w^2)	0.000 (w)
R^2 = 48.3%	w_{op} = 9.56%, a MAP_{op} of 3.75%
Inserting in the surface equation the optimum values of ρ_S and w, MAP = 15.14%	

Figures 9 A and B showed MAP responses with ρ_S and w changes, and table 9, that encloses its statistical analysis, show MAP responses that support its behaviors.

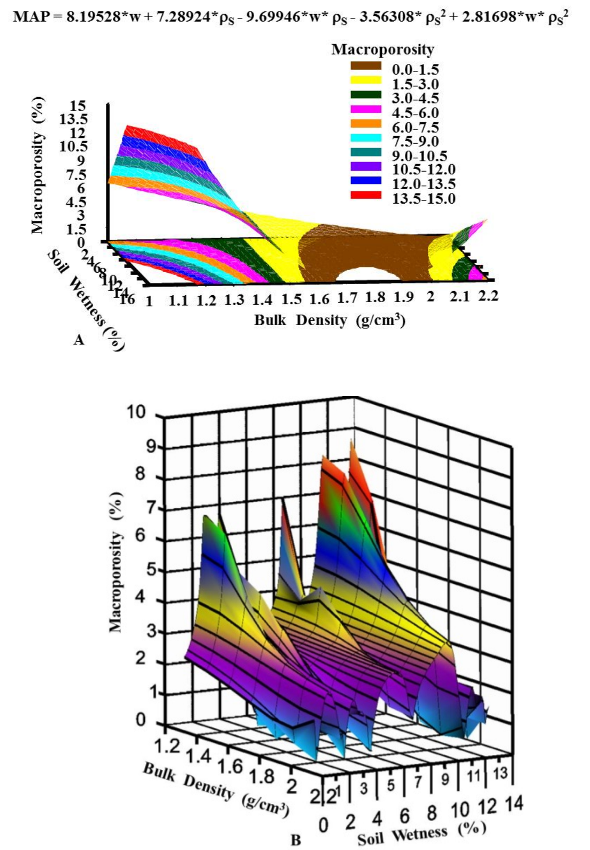

Figure 9. Soil macroporosity versus soil wetness and bulk density.

The ρ_S increase caused soil porosity to decrease. Macropores, essential for soil water and air movement, are primarily affected by compaction. Research has suggested that most plant roots need more than 10 percent air-filled porosity to thrive (Duiker, 2004). The average 8.95% optimum w caused MIP and MAP larger values. Hossne *et al.*, (2012, 2009) reported that at 8% w average occurred optimum τ and ρ_S for silt loam soil and sandy loam. Hossne *et al.* (2009) found that the average values were: 19.63% for the air-filled voids volume, 63.13% for solidity and 1.66 g/cm^3 for bulk density. The maximum and minimum values were for the air-filled voids volume: 45.14% for 3% w and 9.17% for 13% w, for solidity: 69.96% for 7% and 9% w, and 49.88% for 3% w, and for bulk density: 1.84 g/cm^3 for 7% and 9% w, and 1.39 g/cm^3 for 3% w.

Figure 10 shows WRC responses with varied ρ_S and w values. Table 10 includes the statistical analysis showing WRC responses that supported figure 10 behaviors.

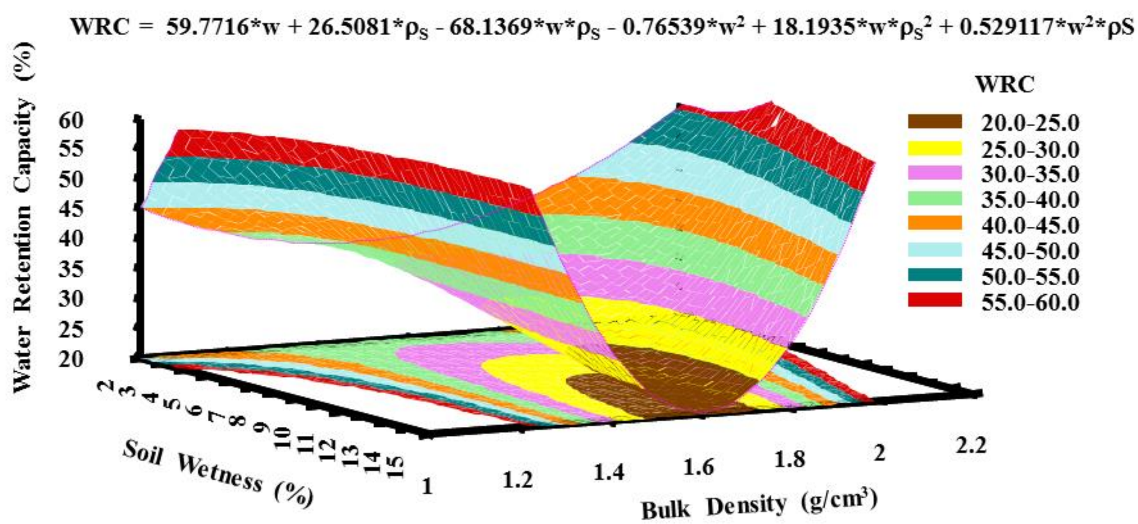

Figure 10. Soil water retention versus soil wetness and bulk density.

Table 10. Soil wetness retention capacity statistical analysis including multiple regression and curve fit analysis.

Applying multiple regression on the dependent WRC, Figures 10, versu w, and ρ_S	
WRC = 59.7716*w + 26.5081*ρ_S - 68.1369*w*ρ_S - 0.76539*w^2 + 18.1935*w*ρ_S^2 + 0.529117*w^2*ρ_S	
0.0000 ANOVA regression significant	R^2 = 96.96% and adjusted R^2 = 96.73%
Correlation coefficients significant 0.0000 (w, ρ_S, w*ρ_S), 0,0004 (w^2), 0.0000 (w*ρ_S^2) and 0.0001 (w^2*ρ_S)	Durwin-Watson =1.6
MIP versus ρ_S and w regression analysis curve fit with 55 total cases	
WRC versus ρ_S	
Linear model of best fit: WRC = 24.127*ρ_S	0.000 ANOVA significance
Coefficient correlation significance	0.000 (w, w^2, w^3)
R^2 = 90.3%	Adjusted R^2 = 89.9%
WRC versus w	
Cubic model of best fit: WRC = 0.132*w^3 – 3.118*w^2 + 21.419*w	0.009 ANOVA significance
Coefficient correlation significance 0.007 (w^2)	0.000 (w) and
R^2 = 48.3%	w_{op} =5.07%, a WRC_{op} = 45.55%, and for w_{op} = 10.68; WRC_{min} = 33.91%

The observations on MIP, MAP, and WRC analysis showed a remarked influence of ρ_S upon MAP, WRC, and MIP; but, for MIP w revealed some effect. Trujillo (2014) reported that field capacity increased with increasing soil compaction. Hossne (2008) stated that the wilting point and WRC were around 6% and 12% correspondingly. The WRC varied from 7.68% to 12.01%, increasing with soil depth. Hossne *et al.* (2009) concluded that compaction optimum values versus w occurred between 8.74% and 11.60%; compared with the WRC values, the maximum compaction occurred, near or within, the field capacity and below the plastic limit. There will always be air and little resistance to root development.

Extrapolating concatenation of root length (RL) with the independent variables ρ_S, τ and irrigation frequencies (IF), shown in Figure 11, revealed that w due to irrigation period every day, and every two day caused the greatest RL values overcoming the effects of ρ_S and τ which produced independent influences (Maita, 2016). The results pitched red in Figure 11, are corroborated statically by the analysis presented in Table 11.

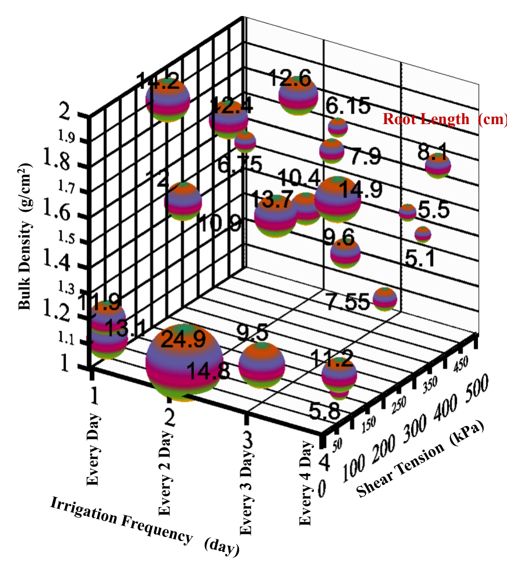

Figure 11. Root grows length versus bulk density, shear tension and irrigation frequencies.

Table 11. Soil root length statistical analysis including multiple regression and curve fit analysis.

Applying multiple regression on the dependent RL, Figures 11, versus IF, τ and ρ_S	
$RL = -1.471*IF + 13.468*\rho_S - 0.20*\tau$	
0.0000 ANOVA regression significant	$R^2 = 87.78\%$ and adjusted $R^2 = 87.8\%$
Correlation coefficients significant 0.012 (IF), 0.000(ρ_S) and 0.003(τ)	Durwin-Watson =1.256
MIP versus ρ_S and w regression analysis curve fit with 55 total cases	
RL versus τ	
Power model of best fit: RL = $\tau^{0.450}$	0.000 ANOVA significance
Coefficient correlation significance	0.000 (τ)
$R^2 = 94.1\%$	Adjusted $R^2 = 94.0\%$
RL versus IF	
Cubic model of best fit: $RL = 22.79*IF - 10.427*IF^2 + 1.314*IF^3$	0.000 ANOVA significance
Coefficient correlation significance 0.000 (IF, IF^2, IF^3)	$R^2 = 92.4\%$ Adjusted $R^2 = 91.9\%$
RL versus ρ_S	
Quadratic model of best fit: $RL = 18.018*\rho_S - 6{,}631*\rho_S^2$	0.000 ANOVA significance
Coefficient correlation significance 0.000 (ρ_S, ρ_S^2)	$R^2 = 88.8\%$ Adjusted $R^2 = 88.3\%$
$\rho_{Sop} = 1.36$ for $RL_{op} = 12.24$ cm	

Factors that affect tilth formation are the stability of soil aggregate particles, pore space, water content, aeration degree (oxygen), water infiltration rate, and drainage (Britannica, 2015; Whiting, 2015). Roots only grow where the soil tilth allows for adequate levels of soil oxygen. Agricultural soil compaction affects oxygen permanency that could be prevented by keeping suitable wetness and zero tillage. Hossne and Salazar (2003) and Salazar (1999) stated that wetness between 12% (field capacity) and 14% (plastic limit), makes the soil susceptible to compaction; also that, requiring any type of tillage, proceed in the friable perimeter below the plastic limit, the friability index is about 9% water content.

The soil wetness affected soil compaction and shear for the various sandy soils texture deviations; at the same time, the root environment. Table 12 presents the analytical relations of w versus IF, RL versus IF, RL versus τ, RL versus ρ_S, τ versus ρ_S, ρ_S versus w, τ versus IF, and ρ_S versus IF. The root growth offers weightier variability with respect to shear stress than versus bulk density. Root length significantly diverged as τ increased and scantily did versus ρ_S,. Preserving irrigation according to wetness soil requirement keeps shear tension and bulk density low. Longer RL happened with IF 1-2 days where τ offers the highest value of 266.63 kPa, ρ_S of 1.6. Suitable applications of irrigation changed the effects of physical and terramechanics soil constraints.

Table 12. Relations of w versus IF, RL versus IF, RL versus τ, RL versus ρ_S, τ versus ρ_S, ρ_S versus w, τ versus IF, and ρ_S versus IF

w versus IF	
$w = 1.91*IF^3 - 13.21*IF^2 + 23.95*IF$ $IF_{op} = 3.36$ (IF = 3-4) , $w_{op} = 3.88$ $IF_{op} = 1.24$ (IF = 1-2), $w_{op} = 13.02$	ANOVA regression significance 0.000. Unstandardized coefficient significance 0.000 for IF, IF^2 and IF^3. Adjusted $R^2 = 92.4$
RL versus IF	
$RL = 22.79*IF - 10.43*IF^2 + 1.31*IF^3$ IF = 3.75 (3-4), RL = 8.13 IF = 1.54 (1-2), RL = 15.17	ANOVA RL versus IF regression significance 0.000. Unstandardized coefficient significance 0.000 for IF, IF^2 and IF^3. Adjusted $R^2 = 91.9$.
RL (cm) versus τ (kPa)	
$RL = \tau^{0.450}$	ANOVA regression significance 0.000. Adjusted $R^2 = 94.0$. Unstandardized coefficient significance 0.000 for τ.
RL versus ρ_S	
$RL = -6.631*\rho_S^2 + 18.018*\rho_S$ $\rho_{Sop} = 1.36$ g/cm^3 $\Rightarrow$ $RL_{op} = 12.24$	ANOVA regression significance 0.000. Unstandardized coefficient significance for ρ_S and ρ_S^2 0.000. Adjusted $R^2 = 88.3$. Bulk density affects root length with very slight variability, contrary to the effect of shear tension.
τ versus ρ_S	
$\tau = -771.93*\rho_S^3 + 2454.83*\rho_S^2 - 1727.49*\rho_S$ $\tau' = -2315.79*\rho_S^2 + 4909.66*\rho_S - 1727.49$ $\rho_{Sop} = 0.445$ g/cm^3 and 1.6775 . The value 0.445 inexistent $\tau_{op} = 366.15$	ANOVA significance 0.000. Unstandardized coefficient significance for ρ_S^3, ρ_S^2 and ρ_S 0.000. $R^2 = 94.6$ adjusted $R^2 = 94.3$. Bulk density affects shear with variability.
ρ_S (g/cm^3) versus w (%)	
$\rho_s = -0.014*w^2 + 0.314*w$ $\rho_s' = -2*0.014*w + 0.314$ $\rho_s' = 0 \Rightarrow w_{op} = 11.21 \Rightarrow \rho_{sop} = 1{,}76$	ANOVA regression significance 0.000. Unstandardized coefficient significance for w and w^2 0.000. Adjusted $R^2 = 95.1$.
τ versus IF	
$\tau = 22.425*IF^3 - 171.533*IF^2 + 383.572*IF$ $\tau' = 67.275*IF^2 - 343.066*IF + 383.572$ IF = 3.444 τ = 202.50 IF = 3-4 IF = 1.65 τ = 266.63 IF = 1-2	ANOVA regression significance 0.000. Unstandardized coefficient significance 0.000, 0.009 and 0.041 for IF, IF^2 and IF^3. Adjusted $R^2 = 68.7$.
ρ_S versus IF	
$\rho_S = 0.118*IF^3 - 0.924*IF^2 + 2.171*IF$ $\rho_S' = 0.354*IF^2 - 1.848*IF + 2.171$ $IF_{op} = 1.78$ (IF 1-2) $\rho_{Sop} = 1.60$ $IF_{op} = 3.43$ (IF 3-4) $\rho_{Sop} = 1.34$	ANOVA regression significance 0.000. Unstandardized coefficient significance 0.000 for IF, IF^2 and IF^3. Adjusted $R^2 = 95.8$.

All plants require adequate water and nutrients supplies; without a minimum, growing in hard soil or pots, a signal from the roots is the growth rate of the shoot. According to Passioura (2002) a soil physical property that affects the plant growth rate without affecting water availability and nutrients is that of the size of the pores through which the roots grow. Donald, Kay and Miller (1987), and Alexander and Miller (1991) sieved aggregates of different sizes from a loam and found that maize plants growing in pots filled with the smallest of the aggregates grew substantially better than plants growing in the larger aggregates when the diameters of the inter-aggregate spaces probably exceeded that of the roots, the inter-aggregate spaces presumably had diameters about one-fifth of that of the aggregates. Another stress reason, the soil air-filled porosity, may also cause harmful effects on plant growth (Voorhees *et al*., 1975; Drew, 1990; He *et al.,* 1996; Grichko and Glick, 2001; Zou *et al.,* 2001). As the total air-filled porosity decreases to 10% or less, the oxygen diffusion rate into the soil, causes roots injury and function inability (Engelaar and Yoneyama, 2000). Plants roots require water, nutrient and pore space for oxygen. The Durbin Watson statistic tests autocorrelation evaluations resulted between 1 and 2, indicating autocorrelation between the dependent and independent analyzed variables. Root length obtained its optimum value of 14.20 cm for τ_{opt} of 268.91 kPa at w_{opt} of 10.6%, and Lr_{opt} of 12.24 cm for ρ_{Sopt} of 1.36 g/cm^3; without much variability with density changes: 1.76 g/cm^3 for ρ_{Sopt}, 11.21% for w_{op}. The soil wetness presence makes a pronounced effect. Shear effects root growth more pronouncedly than bulk density. Rigid or erroneously considered non-swelling soils are usually coarse-textured, poor organic matter, and hard to till. Pore rigidity, as one of the major boundary conditions, is always assumed to exist. For in situ conditions validity of this assumption is questionable and strongly depends on the climate, land use, soil type, and management. The regression curve fit analysis caused ρ_{Sop} = 1.90 g/cm^3 for w_{op} = 11.27%, τ_{op} = 82.32 kPa for w_{op} = 8.36%.

CONCLUSIONS

All soil physical or terramechanics properties are dynamic. The shear tension, wetness function, is the measure of soil resistance. The compacted soil firmness endures as long it is dry. On infer that shear and density, are soil variables independent from one another. Soil water retention and wetness rise as bulk density increases. Infiltration varies wetness, shear resistance, bulk, and wet density, and structure; all at the same time. The soil loses resistance and compaction at low dryness less than 6% wetness for sandy loam when soil particles lose their capillary strength changing to a dusty soil. Preserving irrigation according to wetness soil requirement keeps shear tension and bulk density low. The effects in the upper and bottom sample layer (0 and 20 cm depths) yielded minimum dissimilarity results (increasing very slightly with depth) through the experiment test for τ and ρ_S versus w; possibly indicating, that wetting causes alike physical properties changes regardless of soil depth or texture.

Soil bulk density alters and varies inversely proportional to soil wetness, changes with natural drying processes, in the stove, depth and from place to place. The lowest ρ_S happened at 12-24 h DP. Soil wetness exceptional influences on bulk density occurred between 24 and 48 h DP and linear shrinkage between 2 and 6. Examining bulk density versus DP, linear shrinkage and soil depth showed that drying and shrinkage affect bulk density as expected due to porosity reduction caused by soil and water particles attraction, and, increasing with depth owed to soil texture changes, possibly related to the increase of kaolinite content, decrease of organic matter and decrease of coarse sand.

Root growth offers weightier variability with respect to shear than versus bulk density. Root length showed its greatest growth at lower shear tension, lower bulk density and daily and every two-days irrigation; but also, resulted in good development for every and two days irrigation for higher values of shear and bulk density. Irrigating this soil every two or three days will give good root progress. Wetness is the fulcrum of all other soil properties for plant existence requirements.

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