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SUGARCANE ROOT UNDER REGULAR SOIL WATER CONTENT, COMPACTION, IRRIGATION AND SHEAR STRESS

CRECIMIENTO RADICULAR DE LA CAÑA DE AZÚCAR BAJO HUMEDECIMIENTO REQUERIDO, COMPACTACIÓN, RIEGO Y TENSIÓN CORTANTE

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ABSTRACT

Sugarcane is an important agricultural crop of the area, where the soil is incompressible and alterable. The effects of soil compaction, irrigation frequencies, and shear stress influence on a sandy loam soil sugarcane (*Saccharum officinarum* L) root development were studied when subjected to different treatments of soil water content. The objectives of this study were to measure the effects of: (*a*) water content and compaction over root length and root penetration under soil water content requirements, and (*b*) shear stress and normal tension on root growth. The methods were: the Proctor test, water meters, watering frequency, 30x30x1.5 cm plastic cylinders, distributed in randomized block in simple factorial arrangements, four levels of compaction per layer (0, 12, 24, and 36 blow), four soil water contents through four irrigation frequencies (daily, inter-day, every two days, and every three days), and the water amount of 10% to 13% with mean value of 11.78% was taken up. Among the findings: (*a*) Root length between 30 and 100 cm, (*b*) Root penetration between 7 and 26 cm, with mean rate 20.42 cm. In conclusion, the sugarcane root structure was positively influenced by water content more than compaction; the dependent variables root length as well as root penetration showed no significance difference with respect to the independent variables studied.

KEY WORDS: Savanna soil, Proctor method, root length, root penetration.

RESUMEN

La caña de azúcar es un importante cultivo agrícola de la zona, donde el suelo es incompresible y alterable. Se estudiaron los efectos de la compactación del suelo, frecuencias de riego y la influencia de la tensión cortante sobre el desarrollo radicular de la caña de azúcar (*Saccharum officinarum* L) en un suelo franco arenoso sometido a diferentes tratamientos de contenido de agua. Los objetivos fueron medir los efectos de: (*a*) el contenido de agua y la compactación sobre la longitud y penetración de las raíces bajo los requisitos del contenido de agua del suelo, y (*b*) el esfuerzo cortante y la tensión normal en el crecimiento de la raíz. Los métodos fueron: la prueba Proctor, medidores de agua, frecuencia de riego, cilindros de plástico 30x30x1,5 cm, bloques al azar en arreglo factorial simple, cuatro niveles de compactación por capa (0, 12, 24 y 36 golpes), y agregado de cuatro contenidos de agua (10% al 13% con el valor medio de 11,78%) a través de cuatro frecuencias de riego (diarios, interdiarios, cada dos días, y cada tres días). Entre los resultados: (*a*) la longitud radicular entre 30 y 100 cm, (*b*) la penetración de las raíces entre los 7 y 26 cm, con una tasa media de 20,42 cm. En conclusión, la estructura de la raíz de la caña de azúcar fue influenciada positivamente por el contenido de agua más que la compactación. Las variables dependientes longitud y penetración de la raíces, no mostraron diferencias significativas en relación con las variables independientes estudiadas.

PALABRAS CLAVE: Suelos de sabana, método Proctor, longitud radicular, penetración radicular.

INTRODUCTION

Sugarcane is a relevant crop for agroindustry in Venezuela. Growing sugarcane involves the use of agricultural machinery in all crop stages. The pressure of the heavy tractor, harvester traffic and agricultural implements in the crop inter-rows, causes compaction and affects soil structure. Soil drying causes consolidation and soil resistance by increasing shear strength. The wetting and drying in this region produces undesirable soil changes. The investigation accomplished on soil samples of a sugarcane cultivation field to study the effects of soil compaction on root growth under standard soil water content with regular irrigation. Studies by many researches demonstrated that increases in soil bulk density, caused by soil compaction, restricted root growth: Trouse and Humbert (1961); Monteith and Banath (1965); Trouse (1965); Camilotti *et al.* (2005); Silva *et al.* (2006a, 2006b); Soares *et al.* (2014). Wood (1965) demonstrated restriction of sugarcane root growth caused by impeded drainage resulting from soil compaction. Hare (1962), and Juang and Ghara (1971) indicated reduction in nutrient uptake by sugarcane with increasing bulk density affected by soil compaction. The consequences of soil compaction on root growth is well-known; but also, soil compaction increases soil water

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retention and soil swelling causing removal of consolidation attributable to drying effect and reducing shear tension. Trujillo (2014) showed on sandy loam soils that field capacity increased with the rise of soil compaction. Hossne (2008) concluded that bulk density is inversely correlated with soil humidity. The general objective was to find the root length (RL) and root penetration (RP) of sugarcane correlated with soil compaction and irrigation periods of a loam savanna soil. The specific objectives were: (*a*) to find the root length and penetration influenced by four compaction levels and four irrigation periods managed with recommended water requested and, (*b*) the influence of shear stress and normal loading on root length and penetration.

The study essentials related to the soil terramechanic and structural alterations with soil wetness, and its effects on plant' roots system development. Bulk density is an indicator of soil compaction. Densification of soil by removing air voids by rearrangement of soil particles without outflow of water. Fine grain soil needs more water to reach greatest rate and coarse grain soil needs less water to reach maximum value. Bulk density typically increases with soil depth (Freitag 1971, McKibben 1971, Kunnemann and Wittmuss 1976, Wells and Burt 1984, Batey 1990, Ngunjiri and Siemens 1993, Wood *et al.* 1993, Abu-Hamdeh and Al-Jalil Hamin 1999, Borůvka *et al.* 2002). Hossne *et al*. (2009, 2012) detailed for silt loam, and sandy loam soils a bulk density of 1.84 g*cm^{-3} for soil wetness ranging 7% to 9%, and 1.39 g*cm^{-3} for 3% soil wetness; also, for soil wetness bellow around 6%, followed reduction of the bulk density, and the structure of the ground crumbled or flocculated; The maximum compaction values occurred between 8.74% to 11.60% soil moisture; that produced a maximum bulk density near soil field capacity and below the plastic limit. Soil consolidation, produced by shrinkage in natural soil drying, generates increase of shear strength. 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*. (2013) soil densification can occur naturally by the drying and wetting process called soil consolidation. Coder (2000) showed that consolidation process leads to increased internal bonding and soil strength, as more particle to particle contacts increased eliminating pore space. Hossne *et al*. (2012) reported for silt loam and sandy loam soils, maximum soil shear strength between 41 and 120 kPa for soil moisture ranging 7% to 8%. Rajaram and Erbach (1999) found that soil strength, cohesion and soil aggregate size, increased with the degree of drying stress. Abdulrahman (2011), revealed that wetting and drying cycles increases the collapse tendency for clayey soils, and reducing collapse tendency for silty or sandy soils.

MATERIALS AND METHODS

The study done with material obtained from the farm land "Las Delicias", in the municipality of Santa Barbara, Monagas State, Venezuela. According to Nuñez (1985), Santa Barbara, Monagas State, located 170 meters above sea level 9°38' north latitude and 63º38' west longitude; with an annual rainfall of 750 mm and an average temperature of 26.10° C, consisting of a typical savanna vegetation with predominance of plant species as grasses (*Trachypogon*) and some woody species (American *Curatella*, *Byrsominia* sp.). The soil has the following features: flat relief and gently undulating with a slope of 1 to 4%, sandy texture on clay medium texture, drainage from an excessively drained to moderately drained soil, pH from 5.1 to 5.3, low fertility and low humidity retention (Guzmán 1981). Santa Barbara municipality has access roads, electricity, availability of water in surface and groundwater. It has weather from dry forest to tropical dry forest soils. The Delicias farm has a clay (kaolinite) content of 8.2%, silt 13.5%, sand 78.4%, organic matter of 0.61% and an aF textural class. Figure 1 illustrates the sample collection procedure. Figure 2 shows the proctor method applied in soil compaction.

Figure 1. Las Delicias farm, municipality of Santa Barbara, preparation of the area to take soil samples.

Figure 2. Proctor equipment, used to induce soil compaction.

The experimental units grouped with 64 containers of PVC (Polyvinyl Chloride) 1.5 cm thick, 30 cm in diameter, 30 cm deep and 0.019 m^3/cylinder of soil deposited in each cylinder. See Figure 4, and Figure 5. The employed statistical randomized block design test handled with factorial arrangement (4x4) and four replicates, where the factors were compaction and irrigation frequency; compaction established by several blows per layer (0, 12, 24, 36) and irrigation frequency periods (F_1, F_2, F_3, F_4), specified by: F_1: daily, F_2: interday, F_3: every two days, F_4: every three days; C_1: 0 blow/layer, C_2: 12 blows/layer, C_3: 24 blows/layer, C_4: 36 blows/layer; which generated different apparent densities averaging 1.36 g/cm^3, 1.39 g /cm^3, 1.41 g/cm^3 and 1.44 g/cm^3, respectively. The quantity of water supplied per period was 1.5l of water and a medium soil wetness of 11.78% registered. The blows with the Proctor hammer (Fig. 2) applied by layers (three layers) (Fig. 4), achieved with Proctor method requirements. The establishment of the experiment counted with five (5) sugarcane buds seeded, see Figure 3, for a total amount of 320 buds placed in the 64 containers; two (2) left after sprouting by choosing the more vigorous seedlings per container, allowing 128 seedlings, and transplanting where the sprouted plants did not function. The dry soil sample passed through a sieve Nº 10 mesh 2 mm diameter, for homogenizing the particle size for compaction or reduction in the pore spaces out as uniform in all experimental units. To set the soil amount per cylinder, the average weight of ten cylinders capacity, taken randomly from the 64 cylinders, a total soil mass of 27.57 kg resulted; packing with 8.19 kg of soil each layer. The amount of fertilizer used, based on 180-120-180 kg/ha of NPK, was 7.47 g/cylinder for formula 15-15-15 applied. The fertilizer, evenly mixed to the cylinder, added at the last layer of soil. The shear strength of the soil in triaxial compression depends on the stresses applied, strain rate, and the stress history experienced by the soil. The shear characteristics measured using the triaxial test apparatus.

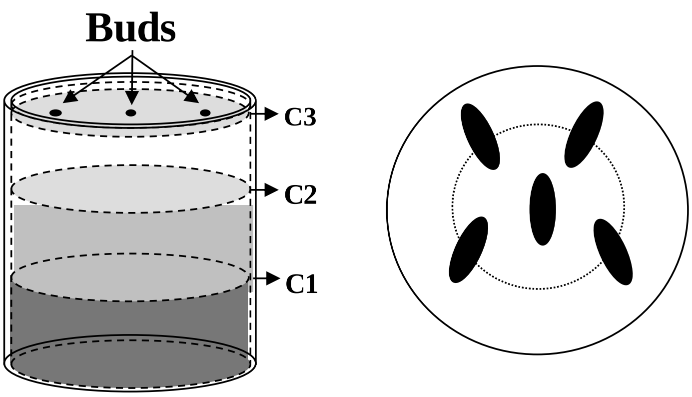

Figure 3. Buds plantation in the cylinders and soil layers.

Figure 4. Development of the sugarcane plants twenty days later.

RESULTS AND DISCUSSION

Figure 5 displays the surface plot of the soil water treatment versus irrigation frequencies, and soil compaction levels. Observing slight variability with higher values for irrigation frequency every three days with compaction between 0 blow and 36 blows with statistics no significant difference. Espinoza (1970) found that the field capacity ranged between 12% and 13%, with a mean value of 12.6 for 0 to 0.5 m soil depth. Trujillo (2014) registered that the field capacity increased with the increase of soil compaction. The work utilized four repetitions or block (I, II, III, IV), four soil humidity levels (10%, 11%, 12%, 13%), four levels of compaction with 0, 16, 32 and 48 blows per layers (three layers) or 0 kN, 0.71 kN, 1.43 kN, 2.14 kN compaction levels. The mean field capacity for the range of humidity was 11.78%. Hossne *et al.* (2009, 2012) reported that maximum compaction values resulted between 8.74 and 11.60% soil gravimetric moisture, when compared with field capacity of these soils, inferring that the maximum compaction occurs near or within the field capacity and below the plastic limit. There shall always be air and little resistance for root development. The vibrational effects caused by the drops of rain, tractors, agricultural implements, and drying/wetting conditions, all favor compaction and erosion.

$$w = 11,736813 + 0,170563*F^2 - 0,054519*F*C + 0,001281*F*C^2 - 0,402438*F + 0,100542*C - 0,002434*C^2$$

F = 3.669 P= 0.004 R^2 =71% Mean 11.78%

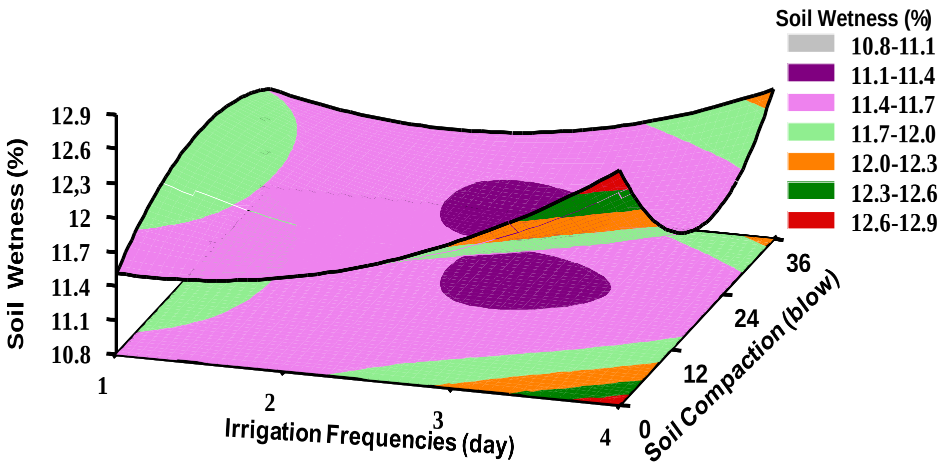

Figure 5. Soil water content dry basis versus irrigation frequencies and soil compaction.

Figure 6 shows grown plants after sixty (60) days of the experiment time, subjected to two compaction steps and two irrigation frequencies. The root growth reached the bottom of the container. Ongin'jo and Olweny (2011) concluded it is economical to harvest crop at the age of nine months in Kenya coastal region. Mequanent and Ayele (2014) concluded that 20 months was optimum harvest age of sugarcane varieties grown on clay soil. Supported result by statistical analysis.

Figure 6. Sugarcane plant growth subjected to 36 blow compaction level and every three-day-irrigation (C_4F_4) and 24 blow compaction level and interday irrigation (C_4F_1).

The analysis of variance in Table 1 shows that root length and root penetration resulted no significantly with respect to compaction, irrigation frequencies and the combined effect C*F; root length and root penetration affected significantly with respect to block only.

Table 1. Analysis of variance of the root length (RL) and Root penetration (RP), for Blok, Compaction, irrigation frequencies and the combined effect of C*F of a savanna soil of Monagas State of Venezuela.

Root length (RL)					
Sources	DF	SS	MS	F	P
Block	3	4510.7	1503.56	4.04	0.0125
Compaction (C)	3	1949.9	649.95	1.75	0.1707
Irrigation Frequencies (F)	3	2030.9	676.96	1.82	0.1569
C*F	9	3562.9	395.88	1.06	0.4064
Error	45	16727.7	371.73		
Total	63	28782.1			
Mean			74.073		
CV	26.03		Alfa: 0.05		
Soil Root Penetration (RP)					
Sources	DF	SS	MS	F	P
Block	3	216.99	72.3303	3.72	0.0180
Compaction (C)	3	115.25	38.4155	1.97	0.1314
Irrigation Frequencies (F)	3	2.55	0.8505	0.04	0.9877
C*F	9	44.19	4.9095	0.25	0.9839
Error	45	875.82	19.4626		
Total	63	1254.79			
Mean			20.417		
CV	21.61		Alfa: 0.05		

The LSD all-pairwise comparisons test in Tables 2 shows no significance difference of the dependent variable RL about the independent variables F, C, and F*C. Root systems are generally elastic in their response to adverse physical conditions; restriction of root enlargement subjected to mechanical impedance possibly compensated by an increase in root diameter and branching of the root structure (Atkinson and Mackie-Dawson 1991). Hossne *et al*. (2015) established that root development was largely influenced by soil moisture content. Consequence of the compaction attributable to the volume change caused by Proctor hammer drops, showed their influence; but, possibly to reduced air availability.

Table 2. LSD All-Pairwise Comparisons Test of RL for soil compaction (C), irrigation frequencies (F) and the combined effect of C*F.

Compaction (C) blow	**Average**	**Group**	**Irrigation Frequencies (F)**	**Average**	**Group**
36	83.194	A	3	81.600	A
12	73.516	AB	2	77.328	AB
0	70.719	AB	4	69.569	AB
24	68.866	B	1	67.797	B
Alpha 0.05. Critical *t* Value 2.014			Alpha 0.05. Critical *t* Value 2.014		
There are 2 groups (A and B) in which the means are not significantly different from one another.			There are 2 groups (A and B) in which the means are not significantly different from one another.		

C*F EFFECTS

C	F	Average	Homogeneous Group
12	3	92.250	A
36	1	87.500	AB
36	2	86.813	AB
0	3	83.250	ABC
12	2	80.750	ABCD
36	4	79.650	ABCD
0	2	79.000	ABCD
36	3	78.813	ABCD
24	4	74.375	ABCD
24	3	72.088	ABCD
24	1	66.250	ABCD
0	4	65.750	ABCD
24	2	62.750	BCD
12	1	62.563	BCD
12	4	58.500	CD
0	1	54.875	D
Alpha 0.05 Critical *t* Value 2.014		There are 4 groups (A, B, etc.) in which the means are not significantly different from one another.	

The root length maximum values appeared for irrigation frequencies between 2 and 3 and compaction blows 0 and 12; also, for irrigation frequency 4 and compaction blow 36, and irrigation frequency 1 and compaction blow 36.

With Figure 7 drafted using the combined effect C*F data shown in Table 3. RL practically did not change with irrigation and compaction. The root length highest values appeared for irrigation frequencies between 2 and 3 and compaction blows 0 and 12; also, for irrigation frequency 4 and compaction blow 36; likewise, for irrigation frequency 1 and compaction blow 36. Smith *et al*. (2005) revealed that the size and distribution of the root is strongly caused by the spreading and availability of soil water, causing differences in the crops to exploit deeper soil resources. Soares *et al*. (2014) concluded that the soil compaction degree above 93%, corresponding to a bulk density of 1.30 g*cm^{-3}, severely restricted the sugarcane root development; but, no link with soil water content.

Trujillo *et al.* (2010) concluded around frequencies of irrigation and soil compaction levels influence on concentrations of chlorophyll, carotenoids, and relative water content electrolytes washing. Watering frequency was significant for the variables evaluated, and soil moisture resulted influential on soya growth more than soil compaction. Conlin and van den Driessche (1996), Buttery *et al.* (1988) and Blouin *et al.* (2008); expressed that compaction influenced seedling growth and biomass at dry water content, but not at moist or wet water contents in lodgepole pine and beans. The moist and wet water contents seem to have decreased the strength of the soil and alleviated the effects of compaction. As compaction increased at dry water content, average needle length, and new root mass decreased. Blouin *et al.* (2008) illustrated how the effects of soil compaction, alleviated for some soil types if the high soil water content is satisfactory throughout the conifer growing season. The studied soils in the wet treatment was not saturated, this is a common problem with many forest soils after compaction, soils are poorly drained and saturated for lengths of time. Future work should include treatments with higher levels of water content. Day *et al.* (2000) concluded that silver maple roots can expand moderately in compacted soil when high soil water content decreases soil strength; dogwood was unable to take advantage.

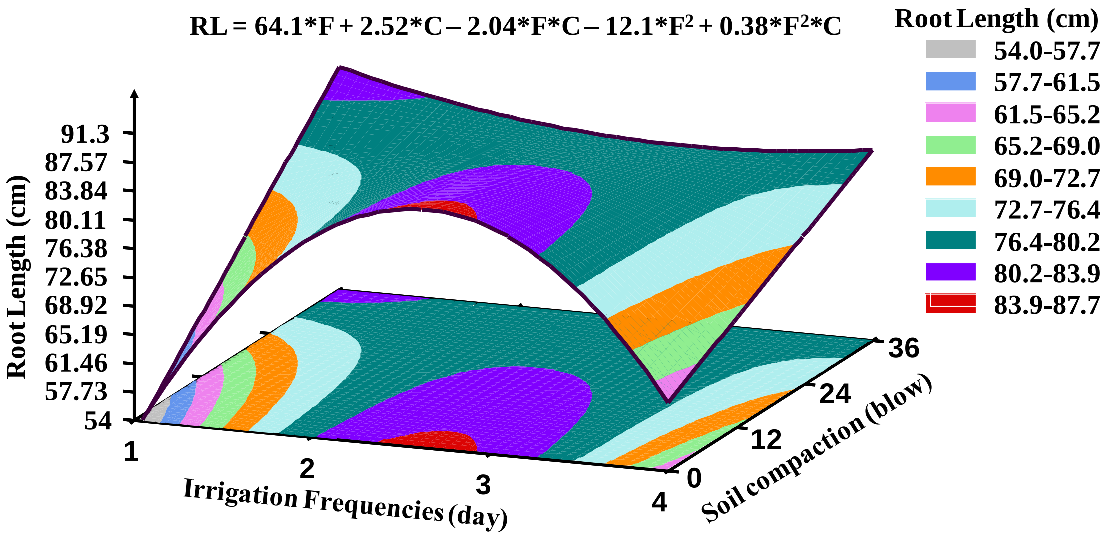

Figure 7. Root length versus irrigation frequencies and soil compaction.

Tables 4 and 5 show the standard *t* values and analysis of variance for the equation RL = 2.52*F + 64.1*C – 2.04*F*C – 12.1*F^2 + 0.38*F^2*C. The function RL = f (F, C) constructed of both irrigation frequencies (F) and compaction levels (C). A table with nine columns created with sixteen (16) average values for the following terms: RL, F, C, FC, F^2, C^2, FC^2, F^{2}C, F^{2}C^2. Multiple Regression with dependent variable RL, independent variables F, C, FC, F^2, C^2, FC^2, F^{2}C, F^{2}C^2 applying stepwise regression method: backward selection with 0.05 P-to-enter and 0.05 P-to-remove. R-squared = 99.2 percent, R-squared (adjusted for degree of freedom) = 99.0 percent, Standard error of estimate = 7.85, Mean absolute error = 4.81, Durbin-Watson statistic = 1.75 and a Lag 1 residual auto correlation = 0.0244. Subsequently the *P*-value in the ANOVA table was lesser than 0.05, the variables at the 95.0% confidence level were statistically significant. The R-Squared statistic indicates that the model as fitted explains 99.2% of the variability in RL column.

Table 4. Standard *t* values obtained with 5 terms.

Parameter	Estimate	Error	Statistic	*P*-Value
F	2.52	0.487	5.18	0.0003
C	64.1	4.96	12.9	0.0000
F*C	-2.04	0.478	-4.27	0.0013
F^2	-12.1	1.44	-8.4	0.0000
F^2*C	0.38	0.101	3.75	0.0032

Table 5. Analysis of variance.

Source	**Sum of Squares**	**Degree Freedom**	**Mean Square**	**F-Ratio**	***P*-Value**
Model	8.9E4	5	1.78E4	289.06	0.0000
Residual	677.0	11	61.6		
Total	8.97E4	16			

The LSD all-pairwise comparisons test in Tables 6 shows no significance difference at all the dependent variable RP with respect to the independent variables F, C, and F*C.

Table 6. LSD All-Pairwise Comparisons Test of RP for soil compaction (C), irrigation frequencies (F) and the combined effect of C*F.

Compaction (C) blow	**Average (cm)**	**Group**	**Irrigation Frequencies(F) (day)**	**Average (cm)**	**Group**
0	22.591	A	4	20.634	A
12	20.469	AB	3	20.525	A
36	19.328	B	2	20.409	A
24	19.281	B	1	20.100	A
Alpha 0.05. Critical *t* Value 2.014			Alpha 0.05. Critical *t* Value 2.014		
There are 2 groups (A and B) in which the means are not significantly different from one another.			There are no significant pairwise differences among the means.		

C*F EFFECTS

C	F	Average (cm)	Homogeneous Group
0	4	23.250	A
0	1	23.025	A
0	3	22.700	A
0	2	21.387	A
12	4	20.788	A
12	2	20.725	A
12	3	20.688	A
24	3	20.575	A
36	1	20.338	A
36	2	20.025	A
24	4	19.688	A
12	1	19.675	A
24	2	19.500	A
36	4	18.813	A
36	3	18.137	A
24	1	17.363	A
Alpha 0.05 Critical *t* Value 2.014		There are no significant pairwise differences among the means.	

Figure 8 sketched using the combined effect C*F data onto Table 6. The RP practically did not change from irrigation and compaction. The highest values of RP observed for irrigation frequencies of 2 and 3, for compaction blows 0 and 12; also, for irrigation frequency 1 and compaction blow 36. Soares *et al*. (2014) concluded that soil penetration resistance is a property influenced by the soil water content and horizontal and vertical uniformity of the soil water content during the sampling period. The apparent effect on penetration resistance greatly associated with soil management. Soil properties can affect RP values, among which water content deserves attention. According to Cunha (2002), many studies carried out, showed no conclusive measurement of influence of water content of RP variation in dissimilar soils, or a result if water additions influence coefficient of variation on RP data onto a given soil. Some researchers assume that field capacity is ideal for determining the RP (Henderson 1989, Arshad *et al.* 1996.). Assis *et al.* (2009) disagreed, stating that water decreases the possibility to detect differences in the results.

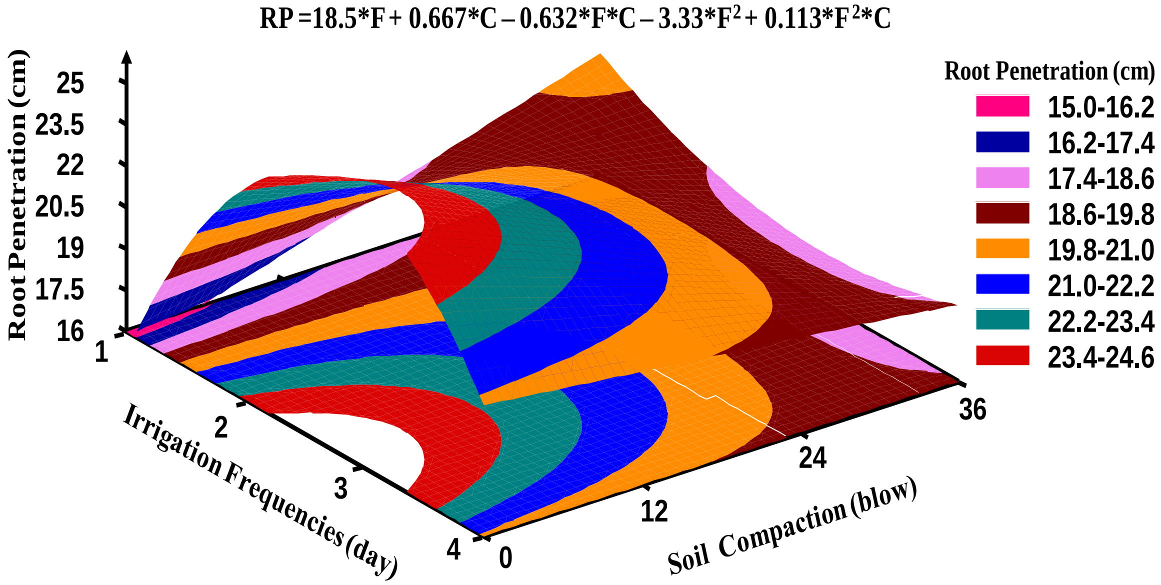

Figure 8. Root penetration versus irrigation frequencies and soil compaction.

Tables 7 and 8 show the standard T values and analysis of variance for the equation RP = 18.5*F + 0.667*C – 0.632*F*F – 3.33*F^2 + 0.113*F^2*C. The function RP = f (F, C) constructed of both irrigation frequencies (F) and compaction levels C. A table with nine columns created with sixteen (16) average values for the terms: RP, F, C, FC, F^2, C^2, FC^2, F^2C, F^2C^2. Multiple Regression with dependent variable RP, independent variables F, C, FC, F^2, C^2, FC2, F^2C, F^2C^2 applying stepwise regression method: backward selection with 0.05 *P*-to-enter and 0.05 *P*-to-remove. R-squared = 98.5 percent, R-squared (adjusted for Df) = 97.9 percent, Standard error of estimate = 3.03, Mean absolute error = 1.67, Durbin-Watson statistic = 1.89 and a Lag 1 residual auto correlation = 0.0163. The *P*-value in the ANOVA table is lesser than 0.05, a statistically significant relationship between the variables at the 95.0% confidence level exist. The R-Squared statistic indicates that the model as fitted explains 98.5% of the variability in Colum RP. The adjusted R-squared statistic is more suitable to compare with models with diverse numbers of independent variables, is 97.9%.

Table 7. Standard T values obtained with 5 terms.

Parameter	Estimate	Error	Statistic	P-Value
F	18.5	1.91	9.68	0.0000
C	0.667	0.188	3.55	0.0046
F*C	-0.632	0.184	-3.43	0.0056
F^2	-3.33	0.557	-5.98	0.0001
F^2*C	0.113	0.0392	2.89	0.0148

Table 8. Analysis of variance.

Source	Sum of Squares	Degree Freedom	Mean Square	F-Ratio	*P*-Value
Model	6.61E3	5	1.32E3	144.09	0.0000
Residual	101.0	11	9.17		
Total	6.71E3	16			

Figure 9 shows the dependent variable RL and RP affected by experimental treatment and bulk density, and their relations to shear tension and normal loading (sketched according to Table

9). Soil shear resistance is an inverse function of soil moisture, had no influence when applied irrigation frequencies that produced the greatest soil moisture. The highest values of RL happened to treatments C_4F_1 and C_4F_2 at low shear stress and low normal load, and high bulk density. With treatments C_2F_2 and C_2F_3 at higher shear stress, normal loading and bulk density; happened to that C_2F_2 and C_1F_3 at mean shear stress, normal loading and high bulk density. Root penetration (RP) influenced slightly by soil compaction, see in Figure 9. All the highest bulk density quantities happened to higher compaction levels (C_4), and among the C_4F_1 was the lowest. All the results were not statistically significant. Soil water content of plant requirement made difference. Several studies have shown that penetration resistance (PR) between 1.0 and 3.5 MPa (Taylor and Gardner 1963, Beutler and Centurion 2004a,b, Beutler *et al.* 2006) and macro porosity lower than 0.10 $m^3 \cdot m^{-3}$, are restrictive and can impede root growth and development (Centurion *et al.* 2007). Azevedo (2008) found that PR values between 1.5 and 9.6 MPa did not restrict sugarcane root growth for considerable heterogeneity of soil structures, allowing root growth even in presence of compacted layers. This confirms that root growth and distribution are also affected by the soil structure, be it undisturbed or disturbed by human activity (Ralisch *et al.* 1994, Tavares *et al.* 2001, Baquero *et al.* 2012). Mitchell and Berry (2001) expressed that as soil strength is inversely along to water content, it is important to have soil water contents at field capacity when conducting tests of soil strength using a probe. Hossne *et al.* (2003) concluded that soil moisture was the index that best affected soil resistance when compared to the inter-particle friction or internal friction and the apparent cohesion. These soils containing kaolinite, silt and a high percentage of sand have cohesion, and the friction angle has more influence on shear tension than the apparent cohesion. Edison *et al.* (2014), experimenting with correction of soil penetration resistance values according to soil water content that interfered with the accuracy of penetrometers and its applicability evaluating soil compaction. They found that the difference of the manual and auto modes was directly proportional to the water content in the soil; the drier the soil the greater was the difference between the two modes. Hossne (2004) indicated not consider bulk density as index of root penetration; if not as, an index of air porosity or compaction, because bulk density, apparent cohesion and angle of internal friction are inversely proportional altered by soil moisture. Soil moisture is the key component in root length and the real rate of radical penetrability.

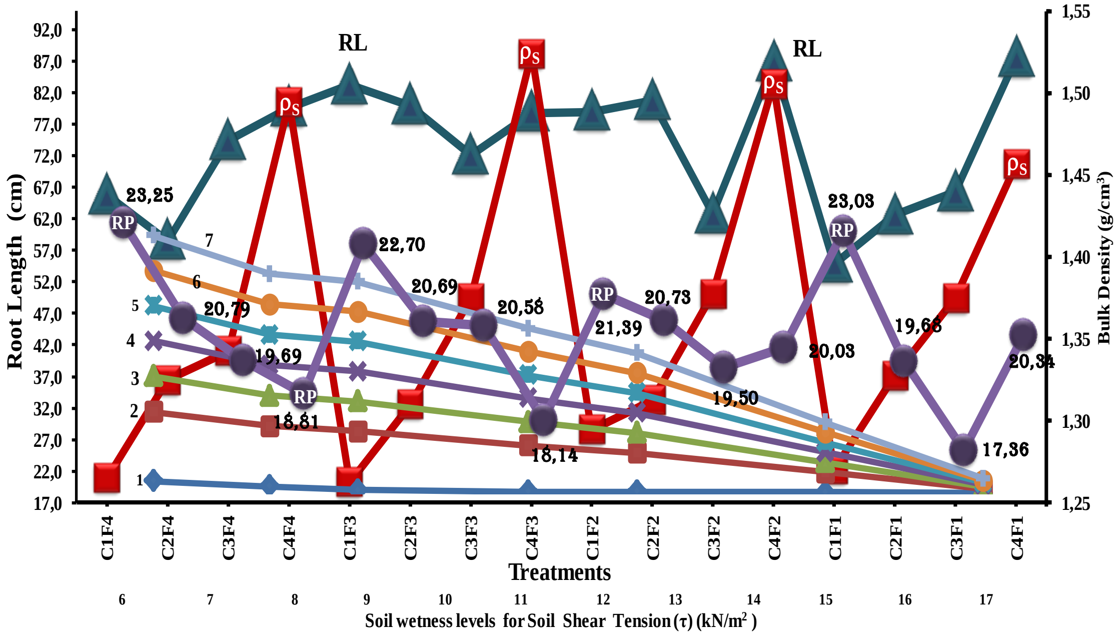

Figure 9. Root length and penetration versus treatment, bulk density and shear tension (τ) and normal load (σ) effects.

Table 9. Shear tension (τ) versus soil water content and normal load (σ).

Line number (Fig. 9)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
σ ($kN \cdot m^{-2}$)	0	340	512	684	856	1028	1200
% w				**τ ($kN \cdot m^{-2}$)**			
6.10	46.87	302.82	432.30	561.78	691.26	820.74	950.22
7.67	27.51	249.29	361.49	473.68	585.88	698.07	810.27
8.85	14.31	231.45	341.30	451.14	560.99	670.84	780.69
11.15	9.11	179.14	265.15	351.16	437.18	523.19	609.20
12.62	8.01	152.36	225.38	298.41	371.43	444.45	517.48
15.16	6.36	79.10	115.90	152.70	189.50	226.30	263.09
17.29	2.36	17.75	25.53	33.31	41.10	48.88	56.66

CONCLUSIONS

The sugarcane root system was more positively influenced by soil water content more than soil compaction; no significance difference occurred of the dependent variables RL and RP regarding the independent variables studied, influenced by the effect of soil wetness. Soil shear resistance decreased from the increase in soil water content and bulk density, varied all along the treatments with the highest values at maximum compaction blows with no significance difference. Soil wetness varied slightly throughout the experiment in irrigation periods and soil compaction levels; the highest values observed at zero compaction blows and maximum compaction blows. On recommend irrigation period applications that maintain the soil wetness requirement corresponding with the area and soil texture.

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