

LONG-TERM EFFECT OF CONVENTIONAL MANAGEMENT ON PROPERTIES OF A SANDY SOIL

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ABSTRACT

In Venezuela the sustainable food production and environmental quality is threatened by soil degradation in the Venezuelan plains. Scarce information of the main types and processes of soil degradation these soils are available. As a support to near future management decisions, the objective of this work is to assess the impact of long-term effect of conventional management on several physical and chemical soil properties, soil penetration resistance and soil water infiltration in a sandy soil with different agricultural managements on the Mesa de Guanipa. Soil samples were taken in a stratified-random unaligned grid. There are significant differences between forest and conventional land use in the phosphorous content (P^{3+}) calcium (Ca^{2+}), magnesium (Mg^{2+}), soil organic matter (SOM), penetration resistance (PR) and soil infiltration. However, there are no significant differences for the bulk density (ρ_b) between managements. These differences are associated to conventional management that affect the physical qualities, especially the adverse consequences in the soil mechanical resistance and infiltration capacity of sandy soils in the Mesa de Guanipa. PR in the subsoil of intensively cultivated soil exceeds the value of no-tillage more than 2 times. The average effective penetration is 0.27 cm/blows for the disturbed soil and 0.39 cm/ blows for the undisturbed. Initial and final soil infiltration rate of the no-tillage exceeds the value of tillage in 2 and 5 times, respectively. The adoption of conservation practices is crucial for their sustainability on the medium and long term.

Keywords: Tillage, Soil infiltration, Dynamic cone penetrometer, Effective penetration.

INTRODUCTION

Production of all crops involves the use of some type of tillage system. On the one hand, the tillage system may be very simple, involving either digging or punching holes to sow seeds. On

the other hand, it may be a complex system comprised of primary tillage and several secondary tillage operations before and after crop establishment, with different machinery and equipment.

The growing demand for food for the population has led to the intensive exploitation of agricultural soils; generally based on mechanization with tractors and plows unsuitable for one or another soil condition. According with FAO (1994), one of the main causes of soil degradation in Latin America is unquestionably the application. Of inadequate tillage techniques, with the consequent decline of physical, chemical and biological soil properties, the decrease in agricultural yields and more importantly, the deterioration of the environment.

In Venezuela also there is the trend of degradation of agricultural soils, whose severity is due to excessive use of machinery and inputs (fertilizers and pesticides), among other aspects (Pla, 1990; Mogollón and Comerma, 1994; Mazzani, 1999; Lozano et al., 2002 and Rodríguez et al., 2003).

Conventional tillage carried out in Venezuela is very complex due to the optimal water content conditions necessary for primary and secondary tillage. In addition, the opportune operational times are very short, creating bottlenecks in the production process due to the rain factor; also involves high costs. The disc harrow is the most common implement in agricultural fields, generally used for secondary tillage, due to inadequate friability conditions, timely operation time, relatively cheaper purchase price, ease use and maintenance, easier and faster weed control, as well as lime application (Hossne, 2006).

The region of the plains occupies the central part of Venezuela, represent an area of 260000 km², about 5 percent of the total area of the country (Cárdenas et al. 2000). In its eastern portion, the area of the Mesa de Guanipa, Anzoátegui State, have a marked pattern in terms of frequency and variability of the rainfall, a large underground aquifer and around 300 thousand hectares of very coarse-textured soil destined to agricultural activities for agricultural production companies, which have a high degree of mechanization.

According with Bruand et al. (2005), sandy soils are often considered as soils with physical properties that are easily defined; however they are far from being simple. This is particularly the case for sandy soils in the tropics where they are subjected to a cycle of wetting and drying associated with seasonality. In this respect, small changes in composition lead to significant differences of physical properties.

Sandy soils are often considered as structurally inert because of their massive structure and the absence of shrink-swell properties (Lesturgez et al., 2005). In contrast, unlike other soils, the elementary fabric can be easily loosened by tillage practices. Thus greater porosity can be produced easily by tillage but its stability is very weak and compaction by wheels or other actions can produce a dense structure with adverse physical properties. This leads to a decrease

in the water retention properties and hydraulic conductivity, an increase in the resistance to penetration and sensitivity to surface crusting (Bruand et al. (2005).

Soil compaction affects important surfaces in the Venezuelan plains, fundamentally those that are highly mechanized, restricting root development and the movement of water in the soil profile. The structure of sandy soils can be easily affected by mechanical compaction over a large range of scales (Bruand et al., 2005). The low stability of aggregates causes the formation of surface crusting and consequently affects the water movement, causing a degradation of the soil structure. The main source of pollution is associated with commercial agriculture, while the excessive use of fertilizers and pesticides cause health problems, superficial contaminations, underground water bodies and losses of biodiversity (López et al., 2015).

The aim of this paper was to assess the impact of long-term effect of conventional management on some physical, chemical, mechanical and hydraulic properties of a sandy soil of the Mesa de Guanipa.

2. MATERIALS AND METHODS

2.1 Soil type

The soils are classified in the order Entisol, subgroup Quartzipsamments (USDA Soil Taxonomy) and Arenosols (World Reference Base) enclosed in the zone of influence of the Orinoco basin, in the Mesa de Guanipa, south of the Anzoátegui State, Venezuela. They are highly weathered soils under savanna vegetation. In common they have very sandy surface layers, variable increases in clay with depth, low base saturations, a predominance of kaolinitic clays and sands dominated by quartz (Comerma and Chirinos, 1997). The phenomenon of compaction is manifested in the agricultural areas of the Mesa de Guanipa (López et al., 2015).

It has very coarse-textured soils with low water retention capacity, risks of wind erosion and the impact of raindrops and runoff, which reveals their great fragility and vulnerability. The soil acidity, as a natural condition, makes it susceptible to degradation due to acidification processes, which can be activated if they are not taken into account as part of agricultural managements.

2.2 Sites and management practices description

Comparisons are made between two areas with the same soil type, but under different agricultural managements (distance between sites: 100 m).

2.2.1 Disturbed soil

In the area under conventional management (8°50'48.1"N; 64°12'6.6"W) during more than 30 years (0.8 ha), tillage has been carried out at any time of year, without a consensual analysis taking into account the climate and the soil characteristics, such as optimal water content for tillage. Tillage operations involve mechanical inversion of soil and the use of disc harrow as a

tillage implement for soil preparation and weed control. The boom of these tillage practices coincides with the rainy season. The crop rotations are nonexistent and the burning of plant residue favors the soil erosion processes by wind and water and degrade the soil structure. Central pivot irrigation system is employed without taking into account the efficient water use.

2.2.2 Undisturbed soil

The study includes non-mechanized area (8°50'43.4"N; 64°11'59.2"W) in a mixed forest (0.53 ha) by more two decades, without machinery traffic.

2.3 Weather characteristics

The large region of the Venezuelan plains belongs to the tropical-equatorial climatic zone. Annual mean temperature behavior is relatively constant (Figure 1). In contrast, precipitation constitutes the meteorological variable with the greatest intra and inter-annual variability (López et al., 2015). Total amount of annual precipitation is 1520 mm with a typical pattern in the Mesa de Guanipa. The rainy season is from April to October with maximum values in July and August, during this period the relative humidity is high. The dry season is from November to March, with minimum precipitation values in January, February and March, during which the relative humidity is low and evaporation reaches its maximum values, inducing a water deficit.

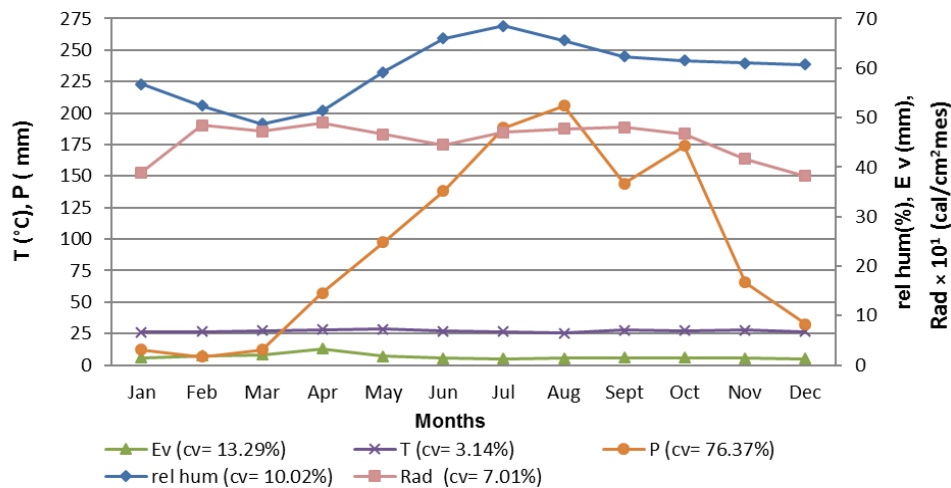


Figure 1: Monthly values of weather data in the Mesa de Guanipa. Evaporation (Ev), temperature (T), precipitation (P), relative humidity (rel hum), radiation (Rad) and coefficient of variation (cv). (Adapted from 16 years (1998-2014) of meteorological variables reported by INIA Agrometeorological Network, El Tigre, Anzoátegui, Venezuela)

Figure 2 allows us to synthesize the historical water deficit period from November to March and water excesses from April to October. This provides clarity concerning the scenarios and

complexities in the use of agricultural machinery and its consequences for the sandy soils in the Mesa de Guanipa.

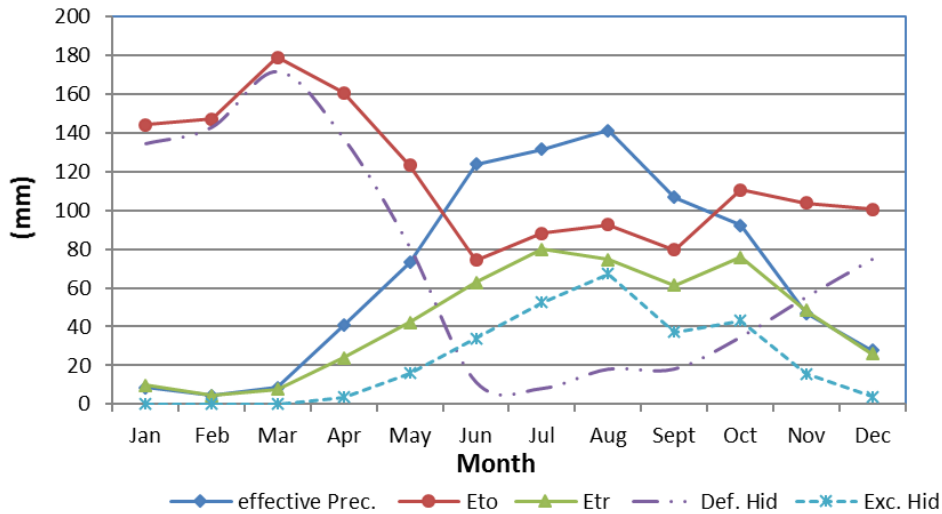


Figure 2: Water balance in the Mesa de Guanipa.

(Adapted from 16 years (1998-2014) of meteorological variables reported by INIA Agrometeorological Network, El Tigre, Anzoátegui, Venezuela).

2.4 Experimental design

For the selection of the points was imposed in the disturbed area a stratified-random-unaligned grid (Webster and Oliver, 1990) which combines the advantages of a regular grid and randomization. For this purpose, a main regular grid with 36 nodes was superimposed (Fig 3), made up of cells 17 m wide by 18 m long. The length and height of the cells serve the purpose of keeping the same proportions relative to the dimensions of the plot (≈ 0.8 ha). As a result, 25 sampling points were chosen into the mechanized area. Experimental design is focused on applying geostatistical techniques for the study of variability, for example, map generation for penetration resistance, which is a research aim much more ambitious. In contrast, 10 sample points were chosen randomly in the non-mechanized soil.

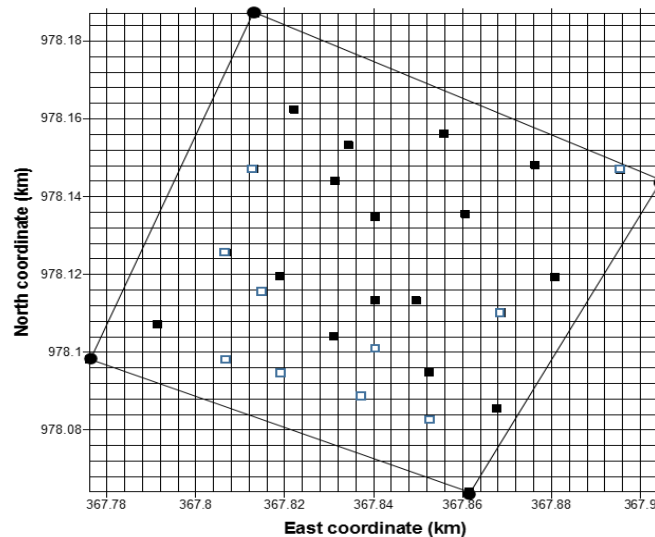


Figure 3: Site locations in the soil under conventional management. The dark circles represent the area boundary and the squares represent the sampling points. The unfilled squares are sampling points with a particular mechanical resistance behavior from 20 to 30 cm depth.

2.5 Soil properties measured

Selected physical, chemical, mechanical and hydraulic soil properties are shown in the Table 1. The experiment was conducted in the dry season. Soil samples were taken at 10–15 cm to avoid the effect of disturbances that are common close to the soil surface.

Table 1: Soil properties measured, symbol, determination method and quantification units.

Soil properties	Symbol	Method	Units
Particle size distribution	Sand, Silt, clay (USDA scheme)	hydrometer	%
Gravimetric moisture content	θ_g	Gravimetric	g g ⁻¹
Soil Organic Matter	SOM	Walkley and Black (1938)	%
Bulk density	ρ_b	Cylinder	g cm ⁻³
Phosphorus extractable	P^{3+}	Olsen extracted with NaHCO ₃ 0,5 M pH 8,5; SGCL-IA-001	mg kg ⁻¹
Calcium	Ca^{2+}	Morgan Mod extracted with (CH ₃ COONa) 0,125 M	mg kg ⁻¹
magnesium	Mg^{2+}	pH 4.2 and. Soil: Solvent ratio Extrac.1:2	
pH	pH	electrode pH meter soil water ratio 1:2,5SGCL-AI-002	-
Penetration resistance	PR	dynamic cone penetrometer (DCP)	MPa
Infiltration	infiltration	double-ring infiltrometer (Bouwer 1986)	mm hr ⁻¹

Dynamic cone penetrometer (DCP) have a cone penetrometer with a base area of $5.06 \times 10^{-4} \text{ m}^2$, cone angle 60° , free fall distance of 0, 6 m, total mass of 7 kg and impact of 2.3 kg, respectively. Number of blows were registered at 5 cm intervals up to 35 cm depth. The readings were translated into PR values using formulation 2.1 (Stolf, 1991).

$$PR = \frac{M}{(M + m)} \frac{Mgh}{Ax} + (M + m) \frac{g}{A} \tag{2.1}$$

A- basal area of the cone

g- gravity acceleration constant

h – height above the anvil (plate of impact)

M- mass of impact (kg)

m- mass of frame (unconsidered M)

x- penetration distant by impact or effective penetration (mm/impact)

The double ring infiltro meter is placed in both plots at 15 cm depth in order to distinguish possible physical peculiarities, properly of resistance to penetration. The technique is particularly suitable for surface soils that are strongly affected by compaction. A key aspect of this research is the fact of clarifying the management effects. This purpose is satisfied comparing the set of physical, chemical, mechanical and hydraulic properties measured in both areas. Measured parameters were examined using different procedures of the statistical package SPSS 16.0. In the ANOVA, Levene's test (homogeneity of variance test), as well as Brown-Forsythe, and Welch (robust tests of the equality of means) to test the hypothesis that several means are equal.

3. RESULTS AND DISCUSSION

3.1 Soil physical and chemical properties

Table 2 show the general statistics of the measured properties at both plots.

Table 2: Descriptive statistics for the disturbed and non-disturbed soils.

Variables	Disturbed					Non-disturbed					P value
	N	μ	Mín.	Max.	C. V (%)	N	μ	Mín.	Max.	C.V (%)	
sand (%)	25	91.60	88.00	94.00	1.78	10	84.40	80.00	92.00	5.68	0.000
Silt (%)	25	6.40	4.00	10.00	25.52	10	12.00	6.00	16.00	29.81	0.002
clay (%)	25	2.08	2.00	4.00	19.23	10	4.00	2.00	6.00	31.62	0.020
$\rho_b(\text{g}\times\text{cm}^{-3})$	25	1.62	1.36	1.84	6.60	10	1.61	1.50	1.68	4.30	0.452
$\theta_g(\times 10^{-1}\text{g}\times\text{g}^{-1})$	25	0.87	0.05	1.47	47.70	10	1.43	0.76	1.80	29.16	0.826
P ($\text{mg}\times\text{kg}^{-1}$)	24	17.17	6.00	58.00	69.92	10	6.00	5.00	7.00	23.57	0.001

Ca (mg× kg ⁻¹)	25	76.20	22.00	128.00	45.78	10	50.40	47.40	52.80	18.81	0.000
Mg (mg× kg ⁻¹)	25	96.84	48.00	159.00	34.13	10	27.80	22.10	31.50	18.29	0.000
S.O.M (%)	25	0.91	0.62	1.15	16.10	10	3.68	2.46	5.98	32.73	0.000
pH _{H2O} (-)	25	5.47	4.80	6.10	6.97	10	6.80	6.30	7.20	5.70	0.003
θ _g _0-20 cm(×10 ⁻¹ g×g ⁻¹)	25	0.04	0.01	0.15	82.10	10	0.89	0.13	3.36	55.52	0.000
θ _g _20-30 cm(×10 ⁻¹ g×g ⁻¹)	25	0.18	0.06	0.37	47.41	10	0.35	0.18	0.57	45.15	0.056

p: probability that the null hypothesis of equal measurement means between managements from anANOVA.

The percentage of sand, silt and clay is typical of the particle size distribution reported for regional soils (Comerma y Chirinos, 1997). Both experimental sites differ in relation to their textural composition and the chemical variables measured. The coefficient of variation indicates a greater dispersion in the fractions to the undisturbed plot. The composition of particle size is one of the properties subject to greater temporal stability, therefore the differences are due to the spatial variability.

In the case of bulk density and its gravimetric water content there are no significant differences between managements. Other studies have found similar evidences (Dao,1996; Martinez et al., 2008). Ismail et al. (1994) reported no significant difference in bulk density between tilled and untilled soils and Mubarak et al (2005) conclude that several properties, including bulk density, are not significantly different between long and short cultivation time and native vegetation.

Contrasting effects of soil management's experiments in ρ_b are common. According to Strudley et al. (2008) the general trend of no-tillage is to increase macropore connectivity while generating inconsistent responses in total porosity and apparent density, compared to conventional practices.

The lowest CVs (<10%) are found for pH and bulk density. The CV of exchanges bases in the sandy soil under conventional managements were more than twice that of conserved sandy soil.

3.2 Soil mechanical properties

The number of blows with the impact mass of the DCP with depths is shown in Figure 4, which gives an idea of the contribution of energy transformed into a penetration work, whereas higher energetic requirements lead to greater penetration resistance.

In many cases the value of the number of blows is equal to zero, which is due to the weak soil structure in the first centimeters, favoring that the penetrometer searches various centimeters without the assistance of impact mass, helped only with the weight of instrument in vertical position.

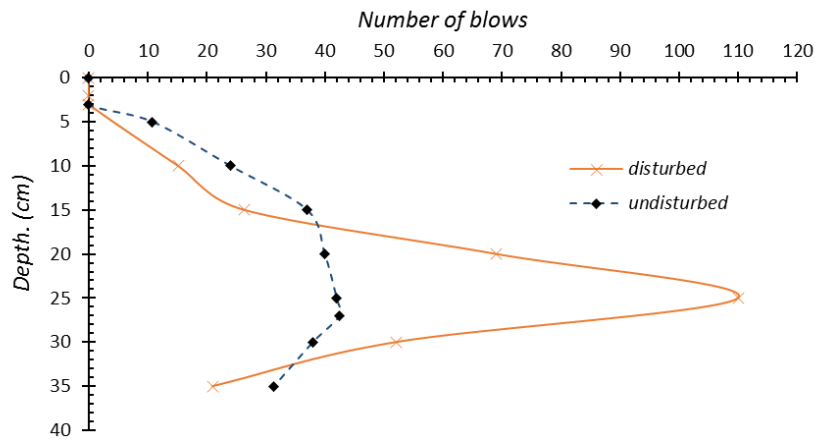


Figure 4: Number of blows of the mass of impact registered with DCP.

The number of blows experiences a tendency to increase with depth, which is more accentuated in the disturbed soil. In this soil the average value of blows registered between 15 and 20 cm is 70 blows, from 20 to 25 cm it is 106 blows and it decreases to 50 blows until 30 cm. In contrast, the values in the undisturbed soil are 36 blows at 15 cm and they diminish after 25 cm. DCP readings from 10 to 30 cm are different between managements (at a significance level of 99%).

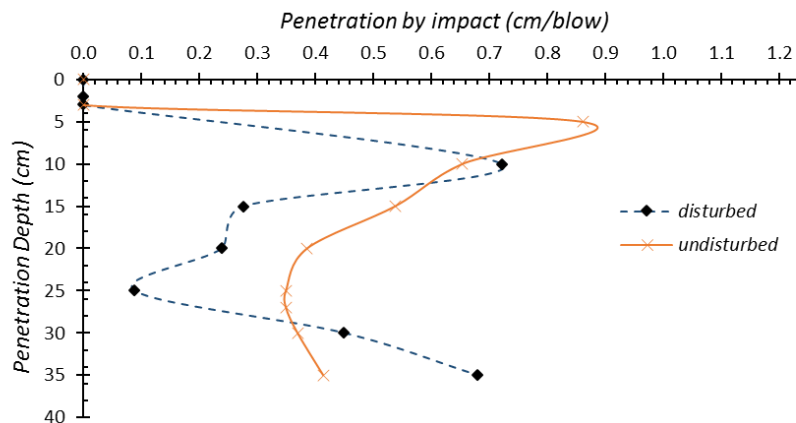


Figure 5: Penetration by impact registered with DCP.

The penetration distance by blows (cm / blows) or effective penetration of the conical tip for each blow of the impact mass in free fall is presented in Figure 5. The effective penetration from 10 cm exceeds 0.6 cm / blow in both plots, which in the disturbed case diminishes appreciably between 15 and 30 cm. The average effective penetration is 0.27 cm / blows for the disturbed plot and 0.39 cm / blows for the undisturbed, which obey to average forces of 4.99 N/m² and 1.28 N/m², respectively. This can give an idea of the soil restrictions in both plots to the root growth.

Figures 4 and 5 reveal the occurrence in both plots of different degrees of opposition to being penetrated by the conical tip, which clearly speaks of the existence of greater resistance to penetration in the disturbed plot under conventional management, although these are not registers universally handled in the literature. Therefore, is convenient to translate the registers into RP values with the expression 2.1.

The experimental evidence of registering a number of blows equal to zero in the first centimeters is considered in this expression, reporting a value of RP different from zero, called static pressure (Figure 6). Although, the impossibility of measuring soil resistance values below this pressure constitutes a limitation in the formulation (Stolf et al., 2005). Additionally, the register can differ if different impact mass or cone area are chosen for the same soil.

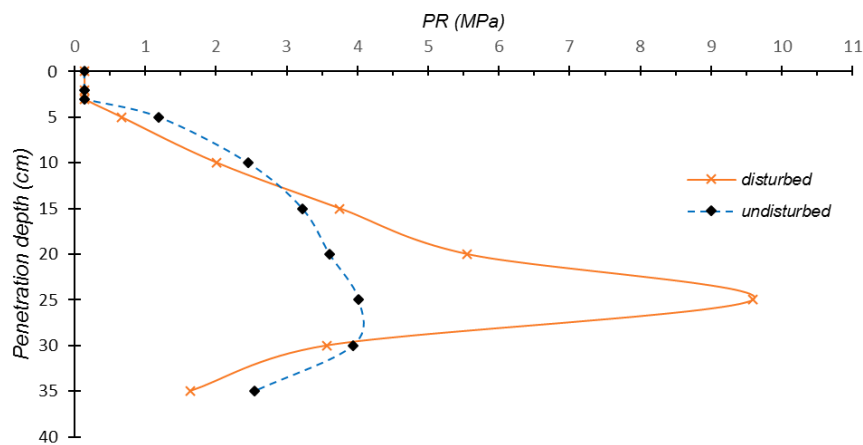


Figure 6: Penetration resistance calculated with the formulation derived by Stolf (1991).

The associated resistance value to the static pressure due to the weight of the penetrometer is equal to 0.14 MPa. A simple Anova proved that the number of blows and PR are not statistically different between managements at soil depths minor to 10 cm. In the rest of soil depths there are significant differences between managements This is justified by the soil structure and the reaction of DCP represented by the number of blown used in the calculus of PR.

3.3 Soil infiltration

The soil infiltration values were measured in both areas (Figure 7), showing a significant difference in infiltration ($p < 0.01$) between experimental sites.

The conserved soil initially infiltrates around 200 mm / hr, twice the value obtained in the soil under conventional management. When the infiltration rate decreases asymptotically this

difference increases 3.5 times. When the air in the pores is replaced by water, then it infiltrates more slowly from the soil surface, tending towards the steady-state infiltration rates, which typically occur when soil is nearly saturated.

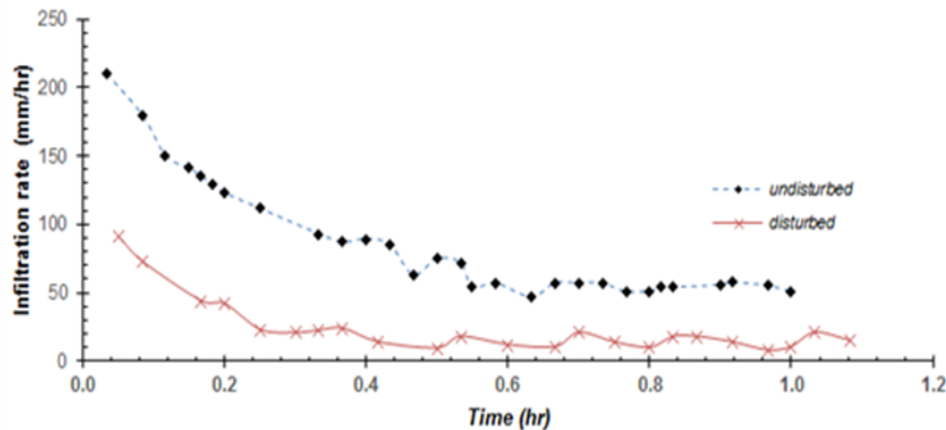


Figure 7: Infiltration rate measured with the double- ring infiltrometer.

The presence of a fine textured layer within the soil profile prevents the flow of water, even a coarse textured layer can delay infiltration in a short period of time. The soils of the Mesa de Guanipa are characterized by having an argillic horizon at depths greater than 40 cm, but this is a source of controlled variability in the comparisons. According to Strudley et al. (2008), soil texture and soil surface conditions (e.g., cover) are independent of time at the scale of individual infiltration events, these characteristics can be assumed to be constant during the event.

To give an idea, after the soil sample were obtained water was tentatively poured into some of the holes in the mechanized plot, observing the permanence of this volume of water beyond than expected for sandy soils, characterized by being very well drained, which suggested carrying out infiltration measurements in both plots under study.

DISCUSSION

4.1 Interaction between soil properties and managements

To support the changing values of physical and chemical properties we also compared the measured values in representative soil profiles obtained by INIA-Anzoátegui with our corresponding values (Table 3) and generated maps.

We must pay attention to the higher values of ρ_b for the disturbed soil (Figure 8), indicating a close packing of elementary soil particles in soils that have been subjected to continuous cultivation. The relatively high ρ_b becomes evident from statistics (Table 2) and represents

another issue of concern. Very small porosities are generally observed in sandy soils of the tropics (Lamotte et al., 1997; Lesturgez et al., 2005).

There are wide zones of the disturbed area, mainly at its southeast part (Figure 8), where the interpolated values of bulk density are higher than 1.7 g cm^{-3} . Also higher values are reported by Bennie and Botha (1986) when recorded $1.7 < \rho_b < 1.8 \text{ g cm}^{-3}$ in the 0-20 cm layer under wheel tracks and in the 20-40 cm layer. Also Aggarwal et al. (1991) recorded $1.75 < \rho_b < 1.82 \text{ g cm}^{-3}$ in the 15-20 cm layer after several years of high puddling in a sandy loam soil.

In this sense, several reports confirm an interval from 1.6 to 1.7 g cm^{-3} how the critical value of bulk density in sandy soils (Jones, 1983; Pla, 1995; Griffith, 1977 and Reinert et al., 2001). In our study, approximately 60 percent of the values measured under conventional managements are higher than 1.6 and 28 percent are higher than 1.7 g cm^{-3} , which is a factor limiting the root growth. Also it was corroborated in situ that the major root density of undesirable vegetation is located around 15 cm depth. Many extended crops in the region (Maize, bean, cassava, peanut) have maximum root depth between 0.5 to 1.5 m (Allen et al., 1998).

The magnitude of chemical soil properties in the disturbed soil double the referents for these soils (Table 3), but not in the undisturbed case. The soil under conventional managements have a distinctly higher phosphorous, magnesium and calcium content. The magnesium is the base with major predominance in the soil exchange complex in disagreement. With local studies (Comerma and Chirinos, 1997, Inder/INIA., 2012 and López et al., 2015).

Table 3: Chemical properties in soil of Mesa de Guanipa, Soil laboratory INIA-Anzoátegui (Inder/INIA, 2012).

Variable	values
pH	4,5-5,1
phosphorous	<5 µg/g
Calcium	10 - 70 µg/g
Magnesium	5 - 60 µg/g
Potassium	10 - 30 µg/g
Iron	0,5 - 30 µg/g
Couper	0,1 - 0,7 µg/g
Manganese	0,5 - 12 µg/g
Zinc	0,1 - 1 µg/g
Organic matter	0,1 - 1,3 %
Aluminium exchange	0,1 - 1,0 meq/100 g
Electric Conductivity	0,1 - 0,3 dS/m

INIA: National Institute of Agricultural Research

The differences are associated with the agricultural management, abundant fertilizers and amendments, more aimed to supply the crops requirements than amending acidity. The

inappropriate use of fertilizers, the high permeability of these soils, their low cation absorption capacity and biodegradation are the responsible for the decline in soil quality and increase the risks of agro-contamination. This reaffirms other studies that judge agricultural management in Venezuela (Pla, 1990; Rodriguez et al. 2003;) and that affirm the existence of serious soil degradation problems (Lugo-Morin, 2007).

The SOM is very low, and in some cases practically negligible, it represents another issue of agricultural soil under intensive managements. The SOM and the average pH under conventional managements agree with those reported in local studies (Comerma and Chirinos, 1997, Inder/INIA, 2012 and López et al., 2015). In contrast, conservation practices can increase the organic matter content alike to the soil under permanent forest.

The comparison for pH (Table 2) show evidence of the increase of pH in going on in these conserved sandy soil over the last decades, which is not common in the region of Mesa de Guanipa. The causes of the differences in pH for NT seem less clear. One hypothesis appoint to non-irrigation can explain such differences. In the region pH ranging from 5.1 to 5.3 (Silguera et al., 2014), which is the main water quality parameters in disagreement with the norms (reported in Official Gazette N° 36.395/1998 of Bolivarian Republic of Venezuela). The pH tendency under conservation managements is very important for alimentary independence because current values under conventional managements affects pH-sensitive of several crops.

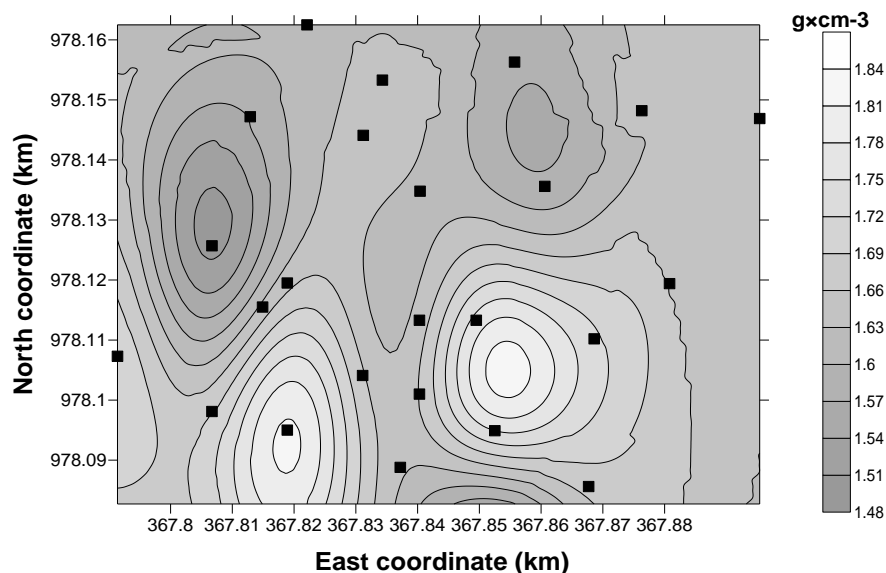


Figure 8: Kriged Map of bulk density in the disturbed soil at 10-15 cm.

4.2. compaction and tillage

The subsoil compaction is a serious problem because it is expensive and difficult to alleviate and it has been recognized as a serious form of the soil degradation. According to our evidences, in 8 of the 25 sampling points in the 0.8 ha of disturbed soil were not possible register readings beyond 20 cm depth due to the high soil mechanical resistance and the insufficient energy of impact provided by the instrument. In these cases, the number of blows recorded was very high and the penetration by impact insignificant.

The PR is highest in the subsoil layer (> 20 cm) probably because this layer supports the wheels of the tractors during ploughing. Figure 3 show that these points are located at the limits of the area. Therefore, the traffic and the proximity to the turning areas of the agricultural machinery affected the soil physical condition, leading to formation of a prominent compacted layer. Conventional management during 30 years are enough time to accumulate the combined effect of the traffic load at this soil depth. According to López et al. (2015) the presence of plow layer at depths between 15-30 cm is common feature in heavily mechanized areas of the Venezuelan plains. Lesturgez et al. (2005) also find the presence of a compact layer located at 20-40 cm depth in a sandy soil of Thailand.

In the disturbed soil until 20 cm depth average PR ranging from 0.14 to 5.55 MPa when the water content ranged from 0.001 to 0.015 g×g⁻¹ and until 35 cm depth ranging from 1.63 to 9.6 MPa when the water content ranged from 0.018 to 0.037 g×g⁻¹. The coefficient of variation was 78.72 % and 152 %, respectively, representing the variability in PR. In contrast, at the undisturbed area in all range of soil depth PR register values between 0.14 to 4.02 MPa at a variation of water content from 0.013 to 0.336 g×g⁻¹. There are significant differences on water content associated with PR between managements (Table 2).

The low water content potencies the soil mechanical resistance (inversely related) in both areas, which is elevated in disturbed area by the variation of the other soil characteristics linked with soil structure and tillage (e.g. porosity, assemblage of the elementary particles) and explain that PR reaches inevitably high values.

Panayiotopoulos and Mullins (1985) for pure sand materials showed that these air-dry and nearly saturated sands were always found to pack more closely under a given load than the same sand at any water content. According with Bruand et al. (2005), a decrease in water content would increase frictional and cohesion forces from field capacity to intermediate water content, smaller water contents increase the frictional forces alone, disappearing the cohesion forces.

Kukul and Aggarwal (2003) recorded at field capacity a penetration resistance ranging from 3.0 to 4.5 MPa in the compacted layer and Smith et al. (1997) showed in a sandy loam soil that resistance to penetration on compressed soil cores increase from 1 to 5 MPa over a range of

water content of only 4 % by mass. These results are more alike with PR behavior in undisturbed soil than in the disturbed.

In correspondence, To and Kay (2005) in the development of PTF from the disturbed and undisturbed data set report PR measured by cone penetrometers in the range to 8MPa. Even 60 of them were lost because the measurement of PR was beyond the maximum measuring capacity of the transducer (12.000 kPa).

Figure 9 shows the PR regionalized in disturbed soil. With the calculated values between 20-35 cm we built a semivariogram, performed spatial interpolation, and generated maps. Insights about the spatial relationships between the bulk density and PR are provided in Figure 8 and 9.

In the same disturbed points stated above are reported higher values, although in most of them the PR is above the critical values (7.2 MPa) for sandy soil with clay content between 5 and 10 % (Chaudhari et al., 2013).

We must mention that the calculated values do not take into account the value corresponding to the friction force between the stem of the equipment and soil. This unconsidered force is dependent on the relationship between the length and diameter of the stem in contact with the soil and the basal area of the cone (Ramos et al., 2014). Furthermore, the root adaptability under current physical conditions is not taken into account in the study. However, it is more appropriate to pay attention to the physical evidence and trends aggravated by the conventional managements, which have been correctly interpreted by the DCP.

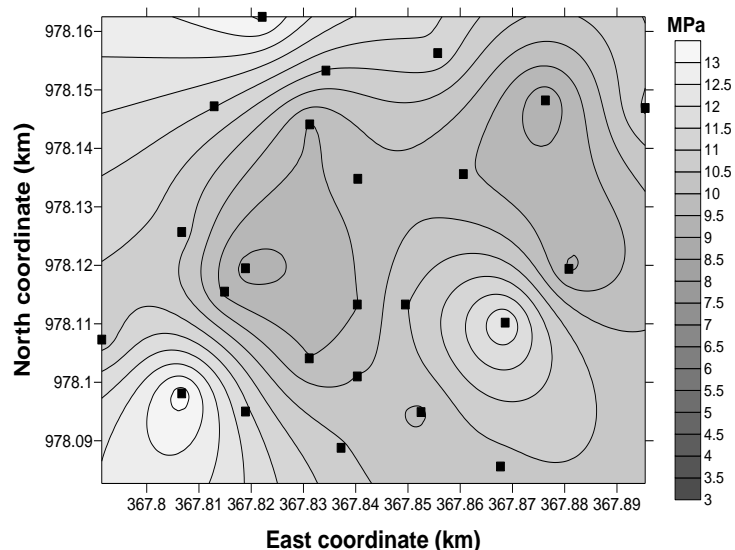


Figure 9: Kriged Map of penetration resistance in the disturbed soil at 20-30 cm.

It is difficult to provide clear guidelines about how the observed patterns are affecting root or crop growth and yields under the current conventional managements, but the adoption of conservation practices is crucial for their sustainability on the medium and long term.

4.3 soil infiltration and managements

Many usual tillage operations in the region induce through a succession of traffic loads the usual massive aspect in the soil profile. It is occurring at varying depths. Is common to observe plow pans, harrow pans and traffic pans (López et al., 2015). Mechanical compaction in sandy soils affects the large pores down to the small pores that result from the arrangement of the skeleton particles (sand and silt) within the clay fraction, which is possible because of the small cohesion between the skeleton particles (Bruand et al. 2005). According to Poiseuille's law, water flow rate in the tubular pores is proportional to the square of the pore diameter.

In this sense, mechanical compaction influences the soil infiltration. For a better compression, the stabilized infiltration rate is a function of the pore configuration and must remain stable over time unless the structure is altered by machinery traffic. In this study, the water infiltrates faster in the conserved soil than in the intensively tilled and massively compacted soil. Also Azooz and Arshad (1996 and 2001) measured a significantly lower infiltration rate under conventional tillage than in no-tillage in silty and silty sandy soils of northwestern Canada.

The infiltration rates in highly permeable soils must be high. Values above 100 mm/hr are invariably associated with coarse textures, while below 50 mm / hr they are associated with groups of medium and fine textures (Diamond and Shanley, 1998). The infiltration rate measured in the mechanized soil are in disagreement with data showed by these authors. In addition, it does not satisfy the steady infiltration rates given for general soil textural groups (Hillel,1998). According this author sandy group must exceed 20 mm/hr. In the conventional managements the soil infiltration capacity decreased and consequently its values are not typical of its textural group.

When rainfall occurs at a rate that exceeds the soil's infiltration capacity, runoff moves downslope or ponds on the surface of level land. When runoff occurs on bare or poorly vegetated soil, erosion occurs. Runoff promote leaching nutrients, chemicals, and soil, resulting in decreased soil productivity, offsite sedimentation of water bodies, and diminished water quality.

Pitt et al. (1999) obtained that the structural state is the main cause of infiltration differences for a high number of sandy soils grouped by wet, dry and compaction, as well as the fact that the initial and final average infiltration velocity of the non-compacted exceeds the value of compacted in 3 and 8 times, respectively.

In contrast, according to Agrawal and Kunar (1976), Agrawal et al. (1987), Agrawal (1991) and Arora et al. (2005) the compaction that reduces the volume and continuity of large pores, would

increase water retention and reduce water infiltration and saturated hydraulic conductivity in highly permeable deep sandy soils. Compaction would save irrigation water by 15-36% and increase productivity by 30-50%. In this sense, Martinez et al. (2008) report that soil water infiltration and coarse porosity decreased under NT as compared to CT. Although it can disappear rapidly and constitute an apparent advantage.

It is necessary to carry out future studies to evaluate the soil water availability and crop yields, to categorically discern if the current penetration resistance and infiltration capacity, induced by the use and handling of machinery, constitute desired effects or not for crops planted in regional soils.

CONCLUSIONS

There are significant differences between disturbed and no-disturbed sandy soil in the phosphorous content, calcium, magnesium, organic matter, soil compaction resistance and infiltration rate. These differences are related to conventional managements that affect the soil attributes of agricultural soils in the Mesa de Guanipa. Bulk density and penetration resistance exceed critical values in several sites, therefore representing limiting factors. However, there are no significant differences for the bulk density between managements. The increasing penetration resistance and decreasing soil infiltration are the most concerning degradation problems in the regional soils.

Soil degradation must be reversed with tillage operations to loose condensed and impermeable soil horizons that restrict or prevent root penetration, movement of fluids, and activities of soil organisms, without burning crop residues to provide the incorporation of plant cover and organic matter while helping to mitigate erosive processes and stabilize the infiltration capacity during the occurrence of meteorological events, as well as carrying out irrigation planning that takes into account the climatic characteristics and crop water requirements.

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