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Variation of Soil and Water Volumes in Riparian Jungle Soils of Brazil

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Abstract: The objective of this work is to study the relation between humidity, density, porosity and shrinkage of the floodplain soil and riparian vegetation and their ability to store water. For this purpose, two locations for every type of soils were evaluated. Both were placed at the Agronomy University (Faculdade de Ciências Agronômicas) in São Manuel, State of São Paulo, Brazil. The floodplain soil was vegetated with Southern Cattail (*Typha domingensis*). In both places, soil samples were collected from several depths: 0, 30, 60 and 100 cm. Results show that lower soil density values (0.15 g/cm^3) with organic texture and high porosities values (up to 86.2%) were found in samples with the highest organic material content in the floodplain soil. For this field experiment, flood plains soils (characterised as basin gley soils) presented high volumetric instability with a retratibility of 67.49% and higher water storage capacities compared to riparian stands soils (characterised as fluvic neosoils).

Key words: Soil, water, density, porosity, riparian jungle.

1. Introduction

The presence of water in the soil is fundamental for the majority of its natural physical, biological and hydrological processes involved. This is very common in the specific case of the soils of riparian jungle (in Portuguese, mata ciliar) where the presence of water is linked to their natural processes. Riparian jungle ecosystems include vegetation that is settled in river banks. This vegetation plays an important role in the control of detrimental effects of the river rises and helps for the estabilization of river banks. Riparian jungle soils are subject to frequent floods. In the soils of the riparian jungle the biological diversity and water storing is maintained according to Penczak et al. [1]. In these soils, the saturated zone of the microbasin is extended during the rainfall season according to Lima and Zakia [2].

In riparian jungle, several types of soils are included. Fluvisoils is a type of soil that is very common in riparian jungle. Fluvisoils are included in all the continents and climates. With an extension of 350,000,000 ha, these soils supose more than a half of the surface of the tropics: Amazonian basin, the plain of Ganges-India, the Chad lake in Central Africa, Brasil, Paraguay and Argentina. Gley soils are another type of soil included in riparian jungle soils. Gley soils, with a surface of 720,000,000 ha, are azonal soils and are presented in the majority of the climates. These soils are extended from subartic areas in Siberia (Russia), Canada, Alaska, damp temperate soils and subtropical in China and Bangladesh and in tropical zones: Amazones, Africa and Asian Southeast, are reported for IUSS-WRB [3].

The majority of soils are not expansives. Their volume is not increased when water is absorbed.

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Moreover, some types of Argilic soils (with a high quantity of organic matter) are expansives. In these soils, the volume and the soil moisture is increased similarly according to Prakash and Sridharan [4]. In these soils, the more soil moisture is decreasing the more contraction they suffer. This is a reversible phenomenon. The volumetric instability fenomena (contraction and expansion) of soils originated by the change of the proportion of water is complex and it is influenced by several factors such as tipe of soil, climatic conditions and tension states according to Sartori, Tariq and Ferreira [5-7].

There are several conditional factors linked to soil (water retention, air permeability, distribution of clay particles, pososity, mineralogic orientation, cimentation, estratigraphic profile, thick of soil and litological discontinuity, etc.) according to Hunt and Jalbert [8, 9] that were influencing its expansive potential.

Soils that change in volume when they are flooded by water, as collapsible as expansion, demand an extra care regardless of the uses: agricultural, engineering work or both. This performance is inevitable because it is inherent to the soil according to Ferreira [7].

Retraction of a soil is a dependent variable of physical properties as density, porosity and water amount. A soil of a basin retains great amounts of water. A contraction is suffered by these soils when they begin to dry. When water is added soil begins to expand.

Another aspect that has to be observed is that, in expansive or retractive soils, density is altered because of volume variation. A dry volume of soil has to be taken in account in order to determine the density. The case of the volume of a humid soil is different. In most occasions, this aspect is not advertised. For this reason, wrong results for porosity and some doubts about evaluation of density could be generated.

High porosity (66%) evaluating physical soil properties are found in watershed friable soils. They developed some works about hidrogeology of the Paraiba do Sul river basin in a case study of mineralizing areas according to Diniz [10].

The study of soil water movement is very complex because of the heterogeneity of the soil characteristics as density and size, the form and disposition of holes, texture, structure, specific surface, proportion of organic matter, iron oxides, hydraulic properties and other factors according to Jorge and Ferre [11, 12].

The soils that present expansion and contraction an adequate volume for density calculations has to be considered. In this case the real volume of soil has to be considered. Additionally, it has to be taken into account with its volumetric contraction.

Vegetation is fundamental in the maintenance of the conditions of porosity of soils. This factor and the added organic matter generation are basic conditions for root development in the soil. Previous conditions of the use of soil could, in general, modify the characteristics of infiltration according to Lima [13].

Basin soils present a high quantity of organic matter and they suffer expansion and contraction. Organic soils present low values of density and high porosity. In this case, these soils change to store water and it contributes to the hydrological process of the microbasins. In the micro basins, water sustainability has to be a goal of preservation that is needed for the maintenance of ecosystems according to Rodrigues [14]. An adequed soil and water management could decrease the degraded zones.

The physic characteristics as expansion and contraction of soils control the water percolation in soil. During rainfall seasons a storing environment is happened. The contraction of soil and the water outflow are developed along the dry season.

This work aims to study the relationship among soil moisture, density, porosity and soil contraction of basin soils, riparian stands and its capacity for water storing. The work is organized as follows: Section 2, the methodology is described in detail, Section 3 offers some results, and finally, Section 4 is devoted to the conclusions.

2. Materials and Methods

2.1 Location of Study Area

The study area is located in the experimental farm of the Faculdade de Ciências Agronômicas-UNESP, São Manuel, São Paulo, Brasil. The hydrographical microbasin is cincunscribed between the next geographical coordinates: 22°45′ to 22°47′ of south latitude and 48°33′24″ to 48°35′34″ of west longitude. The average altitude is 770 m over the sea level.

2.2 Soils of the Experimental Area

Two types of soils are next to one of others. Soils have a sandy texture. They present different characteristics: gley soil is over the basin, and fluvic neosoil is over the riparian stands.

Basin presents a gley soil with 156 g/dm^3 of organic matter, and second IUSS-WRB [3] gley soil has a wide strip of non-consolidated materials, mainly fluvial, with basic to acid mineralogy, in a depressed area, low position in the land and with surface phreatic water. In the riparian stands, a fluvic neosoil with 48 g/dm^3 and organic matter is located. This soil is developed in genetically young alluvial deposits.

2.3 Climate

The climate of the São Manuel, São Paulo, according to Cunha [15] was classified as Cwa, template hot climate (mesotermic) with rainfalls during summer and dry in winter. The average temperature of the hotest month is over 22 °C.

2.4 Collecting Data of Soil Samples

Collecting data were extracted with volumetric rings of 100 cm^3, in vertical direction in two trenchs at 0, 30, 60 and 100 cm deeper, with three repetitions per layer. 24 samples were obtained along two profiles of soil of the riparian stands and the taboa basin (Typha domingensis). In these unaltered samples, the physical characterisitcs as soil moisture, aparent density, density of particles, volumetric shrinkage and water storing were obtained. The samples were collected 60 cm deeper of the soil profile.

2.5 Soil Moisure Determination

Soil moisture refered to dry mass was determined considering humid soil mass (m_u). This parameter is obtained by weighing of samples and refered to dry soil mass (m_s). Dry soil mass is obtained by drying in heater at 105 °C constant mass included. Soil moisture refered to dry mass was obtained by the Eq. 1.

$$Ubs = [(m_u - m_s)/m_s] \times 100 \quad (1)$$

Soil moisture refered to the volume was obtained multiplying soil density by soil moisture refered to dry mass (Eq. 2). Analysis was obtained according to Embrapa [16].

$$\theta = \rho \times Ubs \quad (2)$$

2.6 Determining Density, Density of Particles and Soil Porosity

Soil density (g/cm^3) was calculated by the ratio between dry soil mass (g) and the total volume of humid soil (cm^3). Moreover, for basin soils, a correction in the determination of density is applied, because of the volumetric shrinkage of this soil. In this case, the volume of dry soil is taken into account.

Density of soil particles was obtained by the relation between dry soil mass (g) and the volume of the mineral and organic particles (picnometer method).

Total porosity of soil was calculated using the average values of soil density (ρ_s) and the density of soil particles (ρ_p), by Eq. 3 according to Klar [17].

$$P_s = [1 - (\rho_s/\rho_p)] \times 100 \quad (3)$$

where, P_s = porosity of soil (%); ρ_s = density of soil (g/cm^3); ρ_p = density of the soil particles (g/cm^3). Volumetric soil moisture (θ) is the rate between water volume and soil volume. This parameter is determined by the product of soil moisture and soil density according to Klar [17].

2.7 Volumetric Contraction Determining

Soil samples after retraction maintained an approximately cilindric format with some imperfections. These samples were considered as a cylinder in order to obtain the volume.

According to IUSS-WRB [3], lineal expansion and contraction coefficient is a measure of soil expansion and contraction potential. This is defined as the relation between the size of the sample in saturation moisture and the size of the dry sample.

In this study, the contraction in the base of saturated and dry volume of the sample was determined. The high of the sample was determined by four determinings in different points and the average was calculated.

The ratio of the sample was obtained from circle perimeter of the sample obtained with a line around a circunference of the sample in three different positions. Once the sample perimeter was obtained the average was determined and calculated the ratio of the sample dividing the perimeter by 2π.

According to the relation $V_s = \pi R^2 h$, the dry volume of the samples was determined. Contraction or shrinkage of soil was determined using Eq. 4, according to Rezende [18-20].

$$Rv = [(V_{sat} - V_s)/V_{sat}] \times 100 \quad (4)$$

where, Rv = maximal volumetric contraction (%); V_{sat} = volume of satured soil (cm^3); V_s = dry soil volume (cm^3).

Quantification of water storage along the soil profile was determined 60 cm deeper. The soil moisture was based on volume by the high of profile of soil every 10 cm, according to Eq. 5, according to Reichardt [21].

$$\Delta_s = (\theta^{*} \cdot h) \times 10 \quad (5)$$

where, Δ_s = soil water storing (mm); θ = soil moisture refered to volume (cm^3/cm^3); h = soil profile height (cm).

2.8 Statistical Analysis

Results were analysed using the software SAEG, version 9.1, UFV, 2007. For the variance analysis of the soil water storing the Tukey test was used, with an average comparation of 5% of significance. The porosity results related to average was expressed by the standard deviation and variance.

3. Results and Discussion

3.1 Contraction of Basin Gley Soils

Expansion and contraction of a soil are linked to other physic properties as, for example, the density and absorbed quantity of water during the drying (Fig. 1a). In non-expansive soils, the volume is not increased when the water is absorbed and the contraction is not suffered when they loose soil moisture (Fig. 1b).

In the basin soil, the volume of a dry soil sample is the volume of the volumetric ring. The reason of this is that basin soil suffers contraction after losing soil moisture like drying and after, with water addition, and sample returns to expand (Fig. 1a).

In the riparian stand soil the volume of a dry soil sample is equal to the volume of a volumetric ring. This soil suffers contraction and samples will remain with the same volume (Fig. 1b).

The parameters to obtain the soil contraction were: R = average ratio of dry samples (cm); H = average height (cm); V_s = average volume of the dry sample (cm^3); m = dry soil mass (g); ρ_{as} = obtained density by the ratio between dry mass and ring volume; ρ_{ac} = obtained density obtained by the ratio between dry mass and the volume of dry soil (g/cm^3); ρ_p = density of particles (g/cm^3); R_v = volumetric contraction (%) in Table 1.

Basin soil presented a huge contraction with an average value of 67.5%, with a standard deviation of 4.41 and a variation coefficient of 20.04% (Table 1). Density of basin soil was 0.15 g/cm^3 with organic texture, the density of particles was 1.22 g/cm^3 and a high value of porosity was 86.2% (Table 2). It is verified that the basin soil is retractive, organic and presents a high porosity when it is compared with a riparian stand.

Results of physical-water soil properties of a basin soil of a riparian stand are: moisture mass (m_u), dry mass (m_s), moisture refered to dry mass, percentage and

Fig. 1 Fig. 1a presents the samples of basin gley soil after drying in a heater. The volumetric contraction is evident; Fig. 1b presents the samples of fluvic neosoil of riparian stands after drying in a heater. In this soil there was not contraction.

Table 1 Contraction of basin soil of Paraíso River Farm São Manuel.

Sample	R (cm)	H (cm)	V_s (cm^3)	V_c (cm^3)	m_s (g)	ρ_{as} (g/cm^3)	ρ_{ac} (g/cm^3)	ρ_p (g/cm^3)	R_v (%)	SD† $\bar{x}$	VC‡ (%)
1	2.1	2.4	34.5	101.9	12.5	0.12	0.36	1.22	66.2	4.27	21.9
2	2.2	2.4	37.8	101.9	15.0	0.15	0.40	1.22	62.9	4.64	21.5
3	1.9	2.4	27.5	101.9	17.6	0.17	0.64	1.22	73.0	4.46	19.9
4	2.0	2.4	29.5	101.9	15.7	0.15	0.53	1.22	71.0	4.33	18.8
5	2.0	2.3	30.2	101.9	14.1	0.14	0.47	1.22	70.4	4.51	20.4
6	2.2	2.7	39.2	101.9	14.9	0.15	0.38	1.22	61.5	4.22	17.8
Average	2.1	2.4	33.1	101.9	15.0	0.15	0.46	1.22	67.5	4.41	20.0

†Standard deviation, ‡Variation coefficient.

Table 2 Hydrophysical analysis of basin soil of Paraíso River Farm São Manuel.

Perfil do soil (cm)	m_u (g)	m_s (g)	U_{bs} (%)	U_{bs} -	ρ (g/cm^3)	θ (cm^3)	P (%)	Δ_s (mm)	SD† $\bar{x}$	VC‡ (%)
0	111.6	15.3	626.8	6.27	0.15	0.945	86.3	37.8 c	0.30	0.09
30	115.1	15.0	666.8	6.67	0.15	0.982	86.6	39.3 b	0.34	0.12
60	115.7	15.3	654.7	6.55	0.15	0.985	86.3	39.4 ab	0.30	0.09
100	118.0	15.9	640.1	6.40	0.16	0.998	85.8	40.1 a	0.34	0.12
Average	115.1	15.4	647.1	6.47	0.15	0.978	86.2	39.2	0.32	0.10

Test of Tukey at 5%, †Standard deviation and ‡Variation coefficient.

not percentage (*Ubs*), soil density (ρ), soil moisture refered to volume (θ), soil water storing (ΔS, mm) and soil porosity (*P*), are referred in Tables 2 and 3.

The surface of basin gley soil presents high values of porosity, and the average value is 87.9%, with an average standard deviation of 0.32 and the variation coefficient is 0.10%. The variance analysis was significative 5% for the water storing in a limited layer of soil that does not present significative differences with Tukey test at 5% (Table 2), when it is compared with the average data of the riparian stand of 29.8% of porosity. This difference could be caused to a major quantity of organic matter in the basin. The total amount of stored water in the basin for average dates was estimated at 60 cm deeper. This value was 588.7 mm.

The fluvic neosoil of the riparian stand presents a minor porosity when it is compared with the basin gley soil. Average data of holes in the surface is greater when it is compared with other samples in deep. This is possible to be caused to a greater quantity of organic matter from vegetation in this superficial layer.

Soil density in the surface samples over the riparian stands was 1.30 g/cm^3 and, in profile average value was 1.48 g/cm^3 with heavy texture. In these samples the density of particles of soil was 2.10 g/cm^3. The surface porosity was 38.1% and in the soil profile was 29.5%, with an average standard deviation of 2.4 and a variation coefficient of 7.73%.

The variance analysis was significative at 5% for water storing in the limited layer presented and averages are not statistically different with the Tukey test at 5% (Table 3). Soil surface of riparian stand presents a major porosity when it is compared with the average data of profile with 100 cm deeper. This could be caused to organic matter from the plant residuals. The total amount of stored water in the soil of riparian stands in average data was estimated at 60 cm deeper. The result was 240.8 mm.

The difference between these two types of soil (basin gley soil and fluvic neosoil) of the riparian stand could be observed with a minor density and a major quantity of organic matter. According to the water storing in the soil of two environments the estimation of the water table was determined at 60 cm deeper. In the basin soil was estimated in (588.7 mm). In the riparian stand was estimated in 240.8 mm. In this way, the basin presents an increment of 144.5% when it is compared with the riparian stand soil. The storing capacity of the basin soil is demonstrated. For this reason it is clearly that basin is a remarkable environment as natural water storing. This water could be available for the rivers in critical seasons, as long as dry seasons.

This aspect results in the importance of vegetation *Typha domingensis* in order to improve the water retention capacity of basin gley soil. It is possible to a firm that basin soil, as gley soil type has an excellent quality about the physical and chemical aspects. These properties are related to the great ratio of organic matter. This organic matter is provided by its vegetation and the accumulation of sediments of the edge in the riparian stand vegetation.

It is notable the mutual help of these vegetations to control the temperature, erossion and the improvement of fertility of two soils. Additionally, the edge effect

Table 3 Hydrophysical analysis of riparian stand soil of Paraíso River Farm São Manuel.

Soil Profile (cm)	m_u (g)	m_s (g)	U_{bs} (%)	U_{bs} -	ρ (g/cm^3)	θ (cm^3)	*P* (%)	Δ_s (mm)	SD† $\bar{x}$	VC‡ (%)
0	172.0	132.5	29.8	0.298	1.30	0.387	38.1	15.5 ab	4.82	23.2
30	194.5	157.5	23.4	0.234	1.54	0.362	26.7	14.5 b	1.41	1.98
60	197.5	156.6	26.2	0.262	1.53	0.401	27.1	16.0 ab	1.51	2.29
100	201.0	155.7	29.1	0.291	1.53	0.443	27.1	17.7 a	1.85	3.43
Average	191.2	150.6	27.1	0.271	1.48	0.398	29.8	15.9	2.40	7.73

Test of Tukey at 5%, †Standard deviation and ‡Variation coefficient.

of the riparian stands contributes to the adding of the organic matter, sediments and non-consolidated materials for the basin gley soil. The environment of the basin contributes to the water availability for river during the dry seasons. This is an suitable microclimate for the environment and vegetation of riparian stands.

4. Conclusions

Basin gley soil presents an extremely high value for the volumetric contraction and a high natural volumetric instability. This is a physical property that implies a great capacity of water storing.

Fluvic neosoils of riparian stands do not present volumetric contraction. Although these two types of soils are located nearby, they present very different physical properties.

Low density values and high porosity values of the basin gley soil imply a high content of organic matter in the soil. This occurs in fluvic neosoil of the riparian stands.

The basin gley soil presents a higher value of stored water quantity than the riparian stand soil, because of the high values of the organic matter and the high volumetric instability.

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