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PHYSICAL AND WATER ATTRIBUTES OF YELLOW LATOSOL IN THE MATOPIBA REGION OF PIAUÍ, BRAZIL

ATRIBUTOS FÍSICOS E HÍDRICOS EM LATOSSOLO AMARELO NA REGIÃO DO MATOPIBA DO PIAUÍ, BRASIL

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ABSTRACT: Knowledge and proper management of soil-water-plant-atmosphere relationships are crucial for promoting sustainable agricultural development. This study aimedto characterize the physical and water attributes of yellow latosols in the MATOPIBA region of Piaui, Brazil. Soil samples were collected from 12 soil profiles, and mini-trenches were opened in each area to collect soil samples with deformed and undeformed structures at different depths. We measured various parameters, including granulometric analysis, bulk density, particle density, macropores, micropores, total porosity, field capacity, permanent wilting point, and available water content. Descriptive statistical analysis, Pearson's correlation analysis, path analysis, and principal component analysis were performed on the data. The results demonstrated that the available water content was directly influenced by the field capacity and soil microporosity within the range of 0.0–0.20 m and 0.20–0.40 m, respectively. From an agronomic perspective, the Yellow Latosol profiles evaluated in the MATOPIBA region exhibit satisfactory physical and physical-hydric attributes for sustainable agricultural development.
Keywords: *Soil porosity, soil water, soil quality indicators.*

RESUMO: O conhecimento e o manejo adequados das relações solo-água-planta-atmosferasão de fundamental importância para promoção de um desenvolvimento agropecuário sustentável. Objetivou-se com o trabalho caracterizar os atributos físicos e hídricos de Latossolo Amarelo na região do MATOPIBA do Piauí, Brasil. Amostras de solo foram coletadas em 12 perfis. Em cada local, foram abertas minitrincheiras e coletadas amostras de solo, com estrutura deformada e indeformada, nas profundidades de: 0,0 a 0,20 m e 0,20 a 0,40 m. Foram determinados: análise granulométrica, densidade do solo, densidade de partícula, macroporosidade, microporosidade, porosidade total, capacidade de campo, ponto de murcha permanente e água disponível. Os dados foram submetidos à análise estatística descritiva, análise de correlação de Pearson e de caminho ou trilha, além de Análise de Componentes Principais. A água disponível foi diretamente influenciada pela capacidade de campo e microporosidade do solo. Do ponto de vista agronômico os perfis de Latossolo Amarelo avaliados na região do MATOPIBA, apresentam atributos físicos e físico-hídricos satisfatórios para o desenvolvimento agropecuário sustentável.

Palavras-chave: *Porosidade do solo, água no solo, indicadores de qualidade do solo*

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INTRODUCTION

The Maranhão, Tocantins, Piauí, and Bahia(MATOPIBA) region encompasses part of the Cerrado biome and is known for its highly productive agriculture, which relies heavily on modern inputs. The predominant soils in the region areyellow latosols, which belong to the Latosol class and account for approximately 31% of the soil in the region. These soils are used primarily for soybean cultivation (DONAGEMA et al., 2016b).

The study of soil physicochemicalattributes is crucial for understanding soil-water-plant-atmosphere relationships, including water storage capacity and availability to plants (MARCATTO, et al., 2016).

Several studies have characterized the physicochemical attributes in the literature (SANTOS et al., 2021; SILVA et al., 2021; ANDRADE et al., 2020a; BRASIL NETO et al., 2018; SCHOSSLER et al., 2018; MORETTI et al., 2018; CASSOL et al., 2017). Fontana et al. (2016) identified several favorable factors for expanding cultivation in the region, including flat to gently undulating relief, soils responsive to agricultural practices, and good crop productivity under intensive and conventional agriculture. Research institutions and stimulus policies have fostered these efforts.

According to Schossler et al. (2018), the effect of converting native areas into agricultural systems on the physical quality of soil is still not well understood because this region is an expanding agricultural frontier. Further studies are necessary to fully characterize this impact.

One way this knowledge is applied is in determining agricultural zoning. Therefore, this study aimed to characterize the physical and hydric attributes of yellow latosol in the MATOPIBA region of Piaui, Brazil.

MATERIAL AND METHODS

The study area was located in the southern Cerrado of Piaui. This region has recently experienced an intensification of the agricultural frontier, with a focus on producing exportable goods such as corn and soybeans (Figure 1.

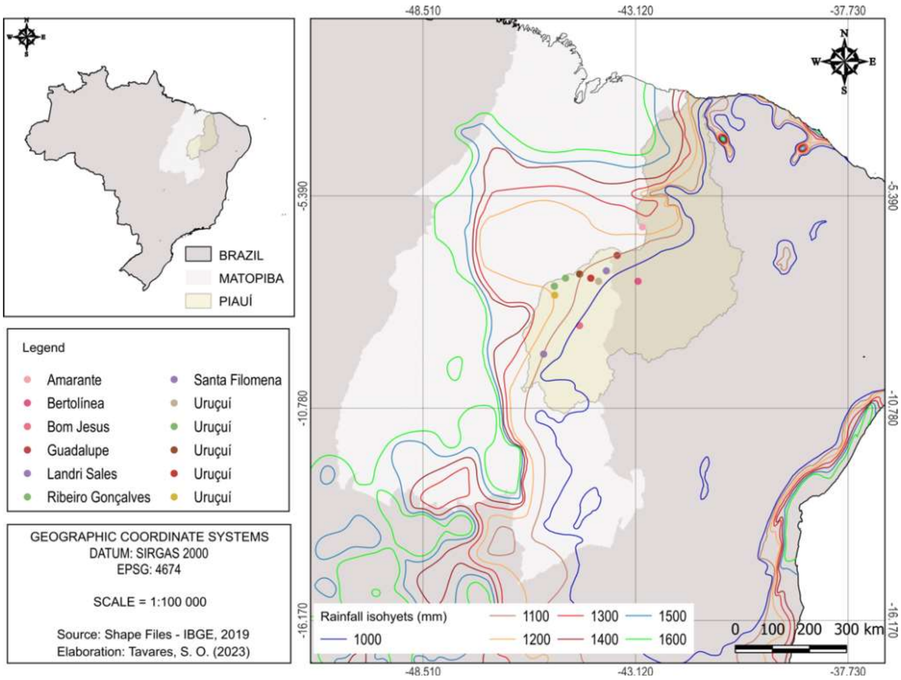

Figure 1. Location of the profiles opened for soil sampling in the study area (State of Piaui)

According to Köppen, the climatic classification of the area is Aw type (warm semi-humid tropical) (ALMEIDA et al., 2019). The isohyet map of the average annual precipitation in Brazil (CPRM, 2011) indicates annual precipitation of 1,200–1,600mm. Soil samples were collected from 12 profiles in the study area. Mini trenches were opened in each area, and soil samples, both disturbed and undisturbed, were collected at depths of 0.0–0.20 m and 0.20–0.40 m, with two repetitions (Figure 2).

Table 1 presents the classifications, locations, and geographical coordinates of the mini-trench profiles that were opened for soil sampling.

Figure 2. Mini trenches opened for soil sampling in the study area (State of Piaui) (Source: RAMOS, 2019).

Table 1. Classifications, location of profiles, and geographical coordinates of the mini-trench profiles opened for soil sampling in the study area (State of Piaui).

Sample	CLASSIFICATION Adapted from Jacomine (1986)	Municipality/Location	Geographical Coordinates SIRGAS 2000	
			Lat.	-06º 54' 4,428"
1	Yellow Latosols	Guadalupe	Long.	-43º 35' 18,305"
			Alt.	201m
			Lat.	-07 17' 36,69734"
2	Yellow Latosols	Landri Sales	Long.	-43 51' 46,07167"
			Alt.	289 m
			Lat.	-07º 33' 33,38919"
3	Yellow Latosols	Bertolínia	Long.	-44º 03' 25,75828"
			Alt.	347m
			Lat.	-07º 28' 48,08688"
4	Yellow Latosols	Uruçuí	Long.	-44º 15' 22,56218"
			Alt.	425 m
			Lat.	-07º 22' 31,14173"
5	Yellow Latosols	Uruçuí	Long.	-44º 32' 23,04246"
			Alt.	376 m
			Lat.	-07 28' 41,18921"
6	Yellow Latosols	Uruçuí	Long.	-44 53' 50,47604"
			Alt.	384 m
			Lat.	-07º 33' 33,38919"
7	Yellow Latosols	Uruçuí	Long.	-44º 03' 25,75828"
			Alt.	347 m

			Lat.	-07º 40' 59,42027"
8	Yellow Latosols	Ribeiro Gonçalves	Long.	-45º 10' 47,96026"
			Alt.	412 m
			Lat.	-07º 54' 42,85666"
9	Yellow Latosols	Uruçuí	Long.	-45º 10' 20,07719"
			Alt.	380 m
			Lat.	-08º 41' 07,66111"
10	Yellow Latosols	Bom Jesus	Long.	-44º 32' 31,78140"
			Alt.	204 m
			Lat.	-06º 10' 38,45239"
11	Yellow Latosols	Amarante	Long.	-42º 56' 54,00534"
			Alt.	124 m
			Lat.	-09º 24’ 27,00700"
12	Yellow Latosols	Santa Filomena	Long.	-45º 27’ 9,30200"
			Alt.	451 m

Lat. = Latitude, Long. = longitude, Alt. = Altitude

The attributes determined included granulometric analysis (clay, silt, fine sand, coarse sand, and total sand). Moreover, bulk density (Bd), particle density (PD), macropores (Mac), micropores (Mic), total porosity (Pt), field capacity (FC), permanent wilting point (PWP), and available water (AW, as calculated using Equation 1) were assessed.

$$AW = (FC - PWP) \quad \text{Eq. 1}$$

Where, AW: available water (cm3 cm-3); FC: field capacity (cm3 cm-3); and PWP: permanent wilting point (cm3 cm-3).

Soil analyses were performed at the Embrapa Meio-Norte soil laboratory following the methods described in the soil analysis manual by Donagema et al. (2011a). The soil selection was based on a pedological map of the state of Piaui established by Jacomine (1986).

To ensure accurate results, we conducted field verifications and calibrations based on the granulometry and physical characteristics of the samples per the Brazilian Soil Classification System (EMBRAPA, 2013). To determine FC, we used the tension table method at a specific matric potential of -10 kPa.

To determine the PWP, we used a Richards pressure chamber at a matric potential of -1500 kPa, following the soil analysis method manual (DONAGEMA et al., 2011a). Studies conducted on Brazilian soils have shown that the classical criterion of the matric potential of -33 kPa should be adjusted to higher potentials, from -10 to -6 kPa, for clayey latosols, especially toxic ones, as they have shown better correlation at these potentials (REICHARDT, 1988; ANDRADE; STONE, 2011c).

Descriptive statistical analysis was performed on the data from all the evaluated attributes by layer. Averages for the two depths, maximum and minimum values, standard deviation, and coefficient of variation were calculated using the Statistic 9.2 software (SAS Institute Inc., 2010). The relationships between variables were determined using Pearson correlations, where $p<0.05$ was considered statistically significant.

Correlations were analyzed using path analysis to estimate direct and indirect effects with the help of computationally applied genes (CRUZ, 2006).

Principal component analysis (PCA) was performed to group similar profiles and visualize variations in the physical and hydric attributes of the soil. The PCA biplot was constructed using the “fviz_pca_biplot” function provided in the FactoMineR package (LÊ et al. 2008). Pearson correlation analyses and PCA were conducted using the R statistical software version 4.1.3 (R Core Team, 2022).

RESULTS AND DISCUSSION

Table 2 describesthe descriptive statistics of soil attributes at depths of 0.0–0.20 m and 0.20–0.40 m, including mean values, minimum values, maximum values, standard deviation, and coefficient of variation.

Table 2. Descriptive statistics of soil attributes with mean values, minimum values, maximum values, standard deviation, and coefficient of variation for depths of 0.0 to 0.2 m and 0.2 to 0.4 m

Soil properties	Depth	Average	Min.	Max.	SD.	CV.
Sand(gkg^{-1})	0,0 – 0,20 m	24	13	50	13	51
	0,20 – 0,40 m	29	15	50	11	37
Silt($g\ kg^{-1}$)	0,0 – 0,20 m	7	2	17	4	58
	0,20 – 0,40 m	7	1	18	5	69
Coarse sand(gkg^{-1})	0,0 – 0,20 m	30	14	47	10	35
	0,20 – 0,40 m	28	9	62	16	57
Fine sand(gkg^{-1})	0,0 – 0,20 m	37	11	53	11	29
	0,20 – 0,40 m	35	11	53	12	34
Totalsand(gkg^{-1})	0,0 – 0,20 m	69	33	84	15	69
	0,20 – 0,40 m	63	32	84	15	24
Bulk density (Mgm^{-3})	0,0 – 0,20 m	1,4	1,1	1,7	0,16	11
	0,20 – 0,40 m	1,5	1,1	1,7	0,16	11
Particle density ($Mgcm^{-3}$)	0,0 – 0,20 m	2,6	1,9	2,8	0,2	9
	0,20 – 0,40 m	2,6	2,0	2,9	0,3	10
Macropores ($cm^3\ cm^{-3}$)	0,0 – 0,20 m	0,13	0,07	0,22	0,05	35
	0,20 – 0,40 m	0,12	0,03	0,23	0,05	46
Micropores ($cm^3\ cm^{-3}$)	0,0 – 0,20 m	0,31	0,24	0,39	0,05	16
	0,20 – 0,40 m	0,32	0,27	0,42	0,05	16
Total porosity($cm^3\ cm^{-3}$)	0,0 – 0,20 m	0,44	0,35	0,51	0,05	11
	0,20 – 0,40 m	0,44	0,40	0,53	0,04	9
FC(cm^3cm^{-3})	0,0 – 0,20 m	0,15	0,10	0,20	0,03	20
	0,20 – 0,40 m	0,15	0,11	0,21	0,03	18
PWP(cm^3cm^{-3})	0,0 – 0,20 m	0,07	0,04	0,10	0,02	35
	0,20 – 0,40 m	0,06	0,03	0,12	0,03	43
AW(cm^3cm^{-3})	0,0 – 0,20 m	0,08	0,03	0,15	0,04	45
	0,20 – 0,40 m	0,09	0,03	0,13	0,04	41

Min.=minimum;Max.=maximum;SD=standard deviation;CV=coefficientofvariation(%); FC = field capacity,PWP=permanent wilting point, AW=Available water.

The coefficients of variation of most soil attributes were high (CV>20%). However, exceptions exist for field capacity, total porosity, micropores, particle density, and bulk density. Pádua et al. (2015) reported that this behavior aligns with the complexity, diversity, and interactivity of the factors and processes that control the physicochemical attributes of soils. In line with these findings, Santos et al. (2021) observed low variation coefficients for physical and hydraulic attributes when assessing different crops in the dystrophic Yellow Latosol in transition areas between the Cerrado and Caatinga in the southwest of Piaui.

The bulk density ranged from 1.1 to 1.7 Mg m-3, with an average of 1.45 Mg m-3 and a standard deviation of 0.16. The macropores ranged from 0.03 to 0.23 cm3 cm-3, with an average of 0.12 cm3 cm-3 and a standard deviation of 39.83. The micropores ranged from 0.24 to 0.42 cm3 cm-3, with an average of 0.32 cm3 cm-3 and a standard deviation of 15.7. The total porosity ranged from 0.35 to 0.53 Mg m-3, with an average of 0.44 Mg m-3 and a standard deviation of 9.56.

Schossler et al. (2018) obtained similar results when evaluating the physical quality of soil in grain production systems in the southwestern region of Piaui, Brazil. The authors observed average values of 1.29 g g-1 for bulk density, 0.27 g g-1 for macropores, 0.17 g g-1 for micropores, and 0.43 g g-1 for total porosity.

Watanabe et al. (2002) suggest that aeration porosity values below 0.10–0.15 m3 m-3 are generally restrictive for crop growth and productivity. Andrade and Stone (2009d) state that the lower limit of macroporosity was approximately 0.10 g g-1, and values of macroporosity/total pore volume less than 0.33 g g-1 are considered ideal.

The field capacity ranged between 0.10 and 0.21 cm3 cm-3, with an average value of 0.15 cm3 cm-3 (SD = 0.03). The permanent wilting point ranged from 0.03 to 0.12 cm3 cm-3, with an average of 0.07 cm3 cm-3 (SD = 0.03). Available water ranged from 0.03 to 0.15 cm3 cm-3, with an average of 0.08 cm3 cm-3 (SD = 0.04). Schossler et al. (2018) reported an average available water value of 0.17 g g-1. Teixeira et al. (2021) classified available water (AW) values in Brazilian soils in m3 m-3 as follows: very low (AW < 0.050), low (0.050 ≤AW <0.075), medium (0.075 ≤AW <0.100), high (0.100 ≤AW <0.125), and very high (AW ≥0.125).

The correlation matrix of the studied variables demonstrated positive and negative relationships with one or more variables (Figures 3A and B). In both sampled layers, available water exhibited a strong positive correlation with micropores, a moderate positive correlation with field capacity, and a moderate negative correlation with clay content, macropores, and permanent wilting point. Additionally, it demonstrated a weak negative correlation with the sand content.

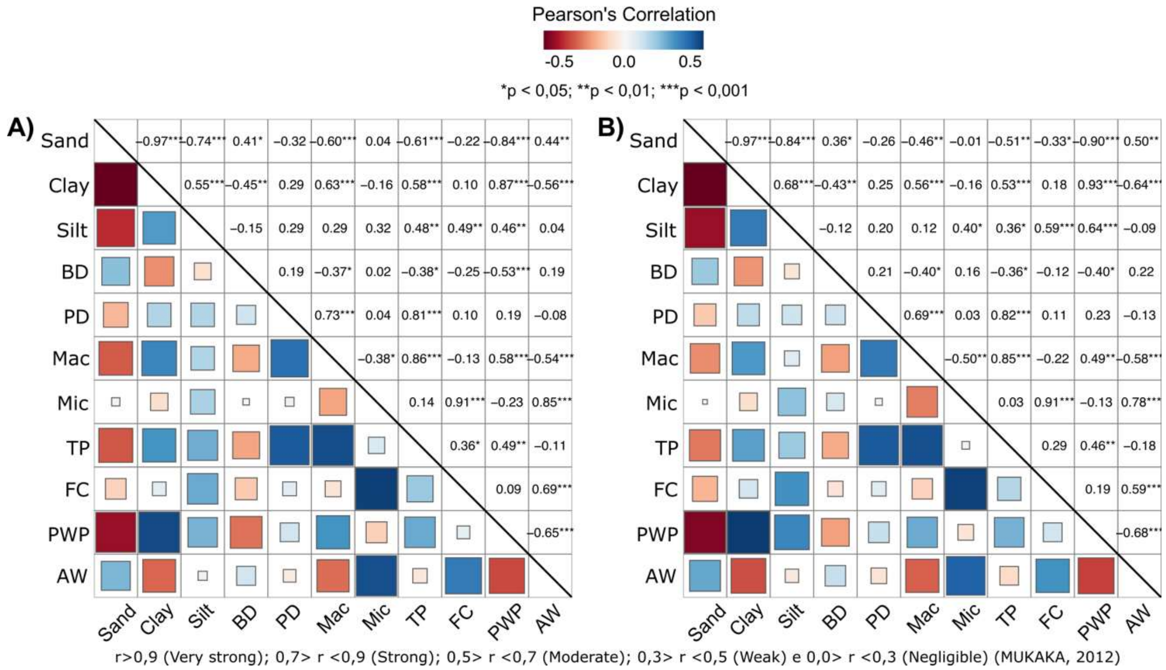

Figure 3. Pearson correlation matrix of physical and physico-hydric attributes in the layers, 0.0-0.2 m (A) and 0.2-0.4 m (B), of a Yellow Latosol in the MATOPIBA region of Piauí, Brazil. Bulk density (BD), particle density (PD), macropores (Mac), micropores (Mic), total porosity (PT), field capacity (FC), permanent wilting point (PWP), and available water (AW).

The field capacity exhibited a strong positive correlation with the micropores in both layers studied. Additionally, weaker correlations were observed between total porosity and silt content, with the strength of the relationship ranging from weak to moderate in both layers. Conversely, it demonstrated a weak correlation with sand content, which was significant in the 0.2–0.4 m depth layer (Figure 2A and B).

Consistent with these results, Andrade et al. (2020b) observed that microporosity has the strongest correlation with available water capacity, followed by bulk density and clay content. The permanent wilting point had the strongest correlation with sand content (-0.92), followed by mesoporosity (-0.65) and bulk density (-0.23).

Significant correlations were observed between permanent wilting points and various soil attributes. A strong to very strong correlation was observedwith clay content, whereas weak to moderate correlations were observed with silt content and macroporosity in both layers. Additionally, total porosity demonstrated a weak correlation with the permanent wilting point. However, the analysis revealed a strong negative correlation between the permanent wilting point and total sand content and weak to moderate correlations with bulk density in the two analyzed layers (Figures 3A and B).

The path analysis results highlighted the variables with the largest direct positive or negative effects on the main variable (AW) (Figure 4).

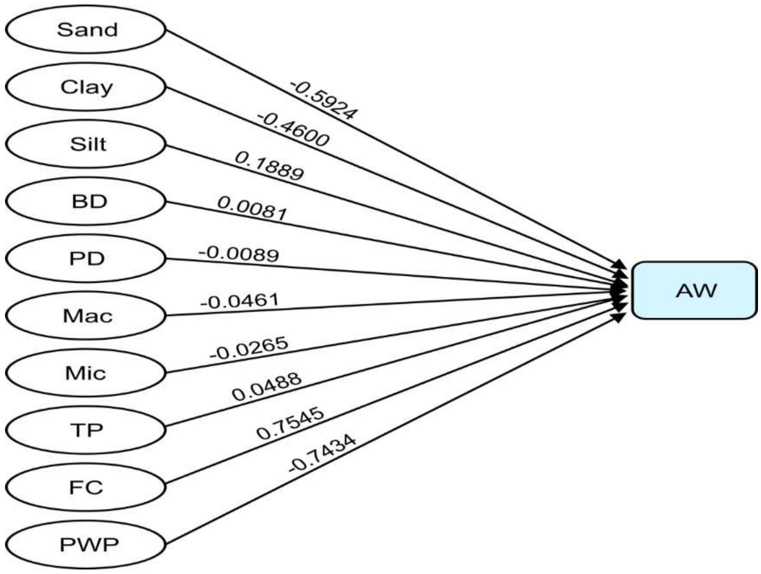

Figure 4. Direct effects of physical and hydric attributes in Yellow Latosol from the MATOPIBA region of Piaui on the available water in the soil. Bulk density (BD), particle density (PD), macropores (Mac), micropores (Mic), total porosity (PT), field capacity (FC), permanent wilting point (PWP), and available water (AW).

The field capacitywas observed to have the most significant and positive influence on available water, indicating that soil profiles with high FC values demonstrated an increase in available water. However, the following attributes negatively affected soil AW: permanent wilting point, sand, clay, and silt. Michelon et al. (2010) reportedthat the total porosity, macropores, micropores, particle density, and bulk density were less important in the direct cause-and-effect relationship with AW when developing pedotransfer functions to estimate water retention in certainsoils of Rio Grande do Sul. The amount of water available for plant absorption is defined as the quantity of water held by the soil between the field capacity and the permanent wilting point (BLASCHEK et al., 2019). According to Michelon et al. (2010), granulometry indirectly affects the determination of soil water availability by influencing the FC and PWP values. Brito et al. (2011) stated that the field capacity has a positive effect on soil moisture retention when the texture becomes clayey. This increased the storage of available water insandy, loamy, and silty loam soils.

Soil texture is a crucial factor that influences moisture retention in the soil. Clayey soils retain much more water than loamy or sandy soils. However, increasing moisture levels at both field capacity and the permanent wilting point does not necessarily result in higher available water content (AL MAJOU et al., 2008; REICHERT et al., 2009).

The principal component analysis allowed us to deduce how certain variables were interconnected to categorize the soil profiles based on two significant principal components (Dim1 and Dim2), which explained a total variance of 69.9% using the 11 studied variables.

The PCA Biplot represents the yellow latosol profiles and variables in specific directions in the two studied layers, 0.0–0.2 m (Figure 5A) and 0.2–0.4 m (Figure 5B). The vector direction indicates the path along which the contribution of the corresponding variable increases. The proximity of the profiles indicated similarity.

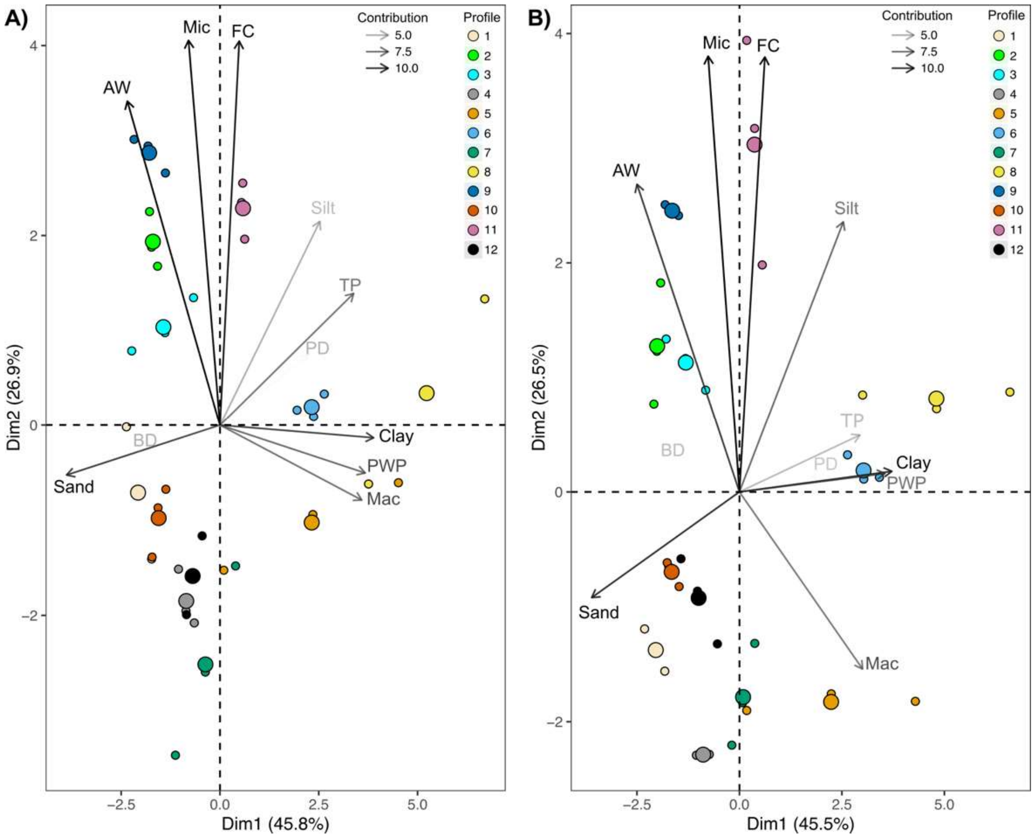

Figure 5. Principal Component Analysis of physical and hydric attributes in the layers, 0.0-0.2 m (A) and 0.2-0.4 m (B), of a Yellow Latosol from the MATOPIBA region of Piaui. Vectors are colored according to the strength of their contributions. Bulk density (BD), particle density (PD), macropores (Mac), micropores (Mic), total porosity (PT), field capacity (FC), permanent wilting point (PWP), and available water (AW).

Profiles 5, 8, 6, and 11 were opposite to profiles 1, 2, 3, 4, 7, 9, 10, and 12, respectively, with respect to Dim1. Regarding Dim2, soil profiles 9, 2, 3, 11, 6, and 8 were grouped on opposite sides of profiles 1, 4, 5, 7, 10, and 12. AW was closely associated with profiles 9, 2, and 3. Additionally, Mic, FC, and AW were positively correlated, indicating that soil profiles with high FC and Mic values tended to have high AW values.

According to Santos et al. (2021), a study evaluating the physical and hydric attributes of dystrophic yellow latosol in transition areas between Cerrado and Caatinga in southwestern Piauí, Brazil, reported that a PCA explained 42.05% and 22.15% of the total data variability on axis 1 and 2, respectively, for a cumulative explained variance of 64.20%.Axis 1 was primarily influenced by gravimetric moisture (0.88), total porosity (0.87), macropores (0.82), and available water (0.76), all with positive eigenvectors, and bulk density (-0.93) with a negative eigenvector.

Granulometry is the characteristic that best describes the water availability in soil. As expected, clay demonstrated a positive correlation, whereas total sand demonstrated a negative correlation because of the specific surface area of the particles. According to Andrade and Stone (2011c), micropores retain most of the water at higher matric potentials (up to -100 kPa) and have the highest correlation coefficient with retained water. This implies that maintaining and monitoring these attributes is crucial for optimizing water availability for crops and pastures.

CONCLUSIONS

Water availability in the soil is mainly influenced by field capacity and soil microporosity. The physical and physico-hydric attributes of the yellow latosol profiles evaluated in the MATOPIBA region are satisfactory for sustainable agricultural development according to agronomic criteria.

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