

# The Influence of Oxisol Physics Parameters on Dry Matter Production in Grasses of *Brachiaria* Genus

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## Abstract

The aim of this study was to assess the correlation between physical attributes of a Yellow Oxisol and the shoot dry matter production in grasses from the *Brachiaria* genus in the Brejo region, in Paraíba. The experiment has been conducted since 2005 in an experimental area of the Center of Agricultural Sciences of the Federal University of Paraíba, Areia-PB (6°58'12" S; 35°41'15" W and 573 m altitude). The experimental design adopted was that of randomized complete blocks (RCB) with 4 treatments and 4 replications. T1- *Brachiaria decumbens* Stapf.; T2- *Brachiaria brizantha* (Hochst) Stapf.; T3- *Brachiaria humidicola* (Rendle) Schwickerdt Vr.; T4- *Brachiaria brizantha* MG5 cv. Vitória. The soil in the

experimental area was characterized as Dystrophic Yellow Oxisol with clay-sandy texture. Soil samples with disturbed and undisturbed structure were collected within the 0.0-0.10 m layer. The shoot dry matter of grasses was collected in October of 2018. The analyzed variables were: bulk density (BD), compaction degree (CD), total porosity (TP), macroporosity (Ma), microporosity (Mi), field capacity ( $\theta_{FC}$ ), permanent wilting point ( $\theta_{PWP}$ ), available water content ( $\theta_{AWC}$ ), soil aeration capacity (SAC), mean weighted diameter of wet and dry aggregates (Wet and Dry MWD), aggregate stability index (ASI) and saturated hydraulic conductivity ( $K_{\theta}$ ). The Student's t-test and Pearson's correlation analysis ( $p < 0.05$ ) were performed. It was concluded that dry matter production was positively influenced by  $\theta_{FC}$  and  $\theta_{PWP}$ . And the increase of the average values of BD, CD, Wet and Dry MWD favored the increase of shoot dry matter production by grasses.

**Keywords:** Agreste of Paraíba, *Poaceae*, leaf area, soil physical quality, correlation

## 1. Introduction

Cattle is one of the main sources of profit for Brazil, considered a job and revenue promoter, for its strong participation in the national and international economic scenario. In total, there are 221.1 million animals spread in 190 million hectares of pastures, both natural and cultivated (ABIEC, 2018). It is an activity with low production costs as it demands no big investments and is possible to be executed with low use of agricultural implements, when compared to other activities, such as agriculture (Ferreira; Ferreira Neto, 2018).

However, the reduced usage of agricultural implements in the pastures involves issues that can greatly impact the animal production, especially when combined with the increasing soil degradation, leading to losses that significantly reduce the productivity of such activity (Dias Filho, 2014), apart from compromising the environmental sustainability (Silva et al., 2017a; Nascimento et al., 2019). Estimations show that 50% of Brazilian pastures are degraded, these are 95 million hectares which are located mainly in the North, Northeast and Central-West part of the country (Dias Filho, 2014).

The lack of soil maintenance and the loss of productivity are key-factors in the degradation of pastures, which combined to intense animal trampling unleash physical processes that make this activity less and less competitive (Macedo et al. 2000; Silva et al. 2011a). Soil compaction is one of the most common and least desired among physical processes within a pasture, because it involves mechanisms that lead to negative alterations in soil structure, with higher density and compaction degree, reduction of total porosity and rate of water infiltration (Lima et al., 2013). The impact in the soil may compromise the growth of grasses, as a result of a mechanical barrier caused by compacted layers, resulting in a smaller portion of soil being explored by the roots and consequently less water and nutrients absorption by the plants (Richart et al., 2005).

The negative effects of changes in the physical attributes of the soil on plant development are well known and find back up on scientific literature, especially related to soil compaction. Among the effects, are reductions in roots density, specific surface and dry mass (Leonel et al. (2007), reduction in roots mean diameter and impediment to root growth (Mazurana et al.,

2013; Valadão et al., 2015), leaf area reduction (Foloni et al., 2003), reduction in plant's height and lower aerial biomass production (Santos et al., 2013; Labegalini et al., 2016; Rosa et al., 2019) and lower levels of N, P, Ca and Mg in leaves (Valadão et al., 2017).

Grasses from *Brachiaria* genus have been used in pastures for being adaptable to the different edaphoclimatic conditions of Brazil. However, it is still unknown to which extent variations in the physical attributes of the soil may compromise its growth, especially concerning shoot dry matter production under the edaphic conditions of the Brejo microregion in Paraíba. It is noted a necessity for studies, especially in the long run, aiming to evaluate the correlation between physical attributes of the soil and the productive characteristics of the *Brachiaria* genus, as literature lacks information on this topic.

Therefore, it was aimed in this study to evaluate the linear correlation between physical attributes of a yellow oxisol and the shoot dry matter production of grasses belonging to the *Brachiaria* genus, in the microregion of Brejo in Paraíba.

## 2. Material and Methods

### 2.1 Characterization of the Experimental Area

The experiment has been conducted since 2005 in experimental area of the Center of Agricultural Sciences of the Federal University of Paraíba, in Areia (PB). The city is located within the Brejo microregion and in the Agreste of Paraíba mesoregion (6°58'12"S; 35°41'15"W and 620 m of altitude).

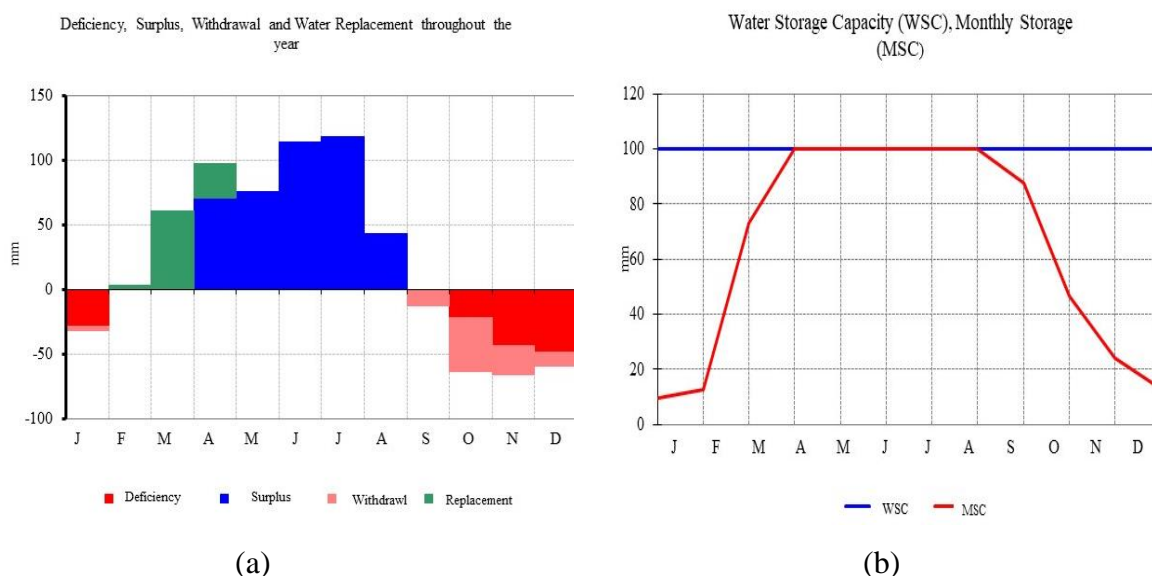


Figure 1. Soil water balance and water storage capacity for 2018, Areia-PB

According to Köppen classification, the predominant climate in the municipality is As' – tropical, hot and humid, with rains during autumn and winter and mean annual precipitation of 1400mm (Almeida et al., 2014). The annual mea

n temperature is 24.5 °C and the relative humidity of the air in average of RH is 80.0%; as for the rain season, 62% occurs between April and July (Lima et al., 2014). Soil water balance and water storage capacity for the January-December period of 2018 are shown in Figure 1, according to methodology proposed by (Rolim et al., 1998).

The soil in the experimental area was characterized as Dystrophic Yellow Oxisol with clay-sandy texture (Santos et al., 2018). In table 1, the physical characterization of the soil of the experimental area is presented.

Table 1. Soil physical characterization of the experimental area, in the 0.00-0.10 m layer under grasses

Layer	Sand	Silt	Clay	CDW	FD	PD	BD	TP
-- m --	----- g kg <sup>-1</sup> -----			----- g cm <sup>-3</sup> -----		m <sup>3</sup> m <sup>-3</sup>		
0.00-0.10	574	69	357	14	961	2.58	1.22	0.50

PD = Particle density, BD = Bulk density, TP= Total porosity, FD = Flocculation Degree, CDW = Clay dispersed in water

As for the chemical characterization of the experimental area's soil, the analysis determine the following values: pH= 5.3 (H<sub>2</sub>O 1: 2.5); Ca<sup>2+</sup>= 1.89 cmol<sub>c</sub> dm<sup>-3</sup>, Mg<sup>2+</sup>= 1.43 cmol<sub>c</sub> dm<sup>-3</sup>, Al<sup>3+</sup>= 0.30 cmol<sub>c</sub> dm<sup>-3</sup>, H+Al<sup>3+</sup>= 8.33 cmol<sub>c</sub> dm<sup>-3</sup>, SB= 3.46 cmol<sub>c</sub> dm<sup>-3</sup>, CEC= 11.79 cmol<sub>c</sub> dm<sup>-3</sup>, Na<sup>+</sup>= 0.06 cmol<sub>c</sub> dm<sup>-3</sup>; SOM = 49.52 g kg<sup>-1</sup>; P= 1.82 mg dm<sup>-3</sup> e K<sup>+</sup>= 28.37 mg dm<sup>-3</sup>.

## 2.2 Experimental Design and Characterization of Analyzed Variables

The experimental design adopted was that of randomized complete blocks (RCB) with 4 treatments and 4 replications (4x4). The assessed treatments were the following: T1- *Brachiaria decumbens* Stapf.; T2- *Brachiaria brizantha* (Hochst) Stapf.; T3- *Brachiaria humidicola* (Rendle) Schwickerdt Vr.; T4- *Brachiaria brizantha* MG5 cv. Vitória.

The grasses were planted in 2005 in experimental plots measuring 10 x 5 m, therefore 50m<sup>2</sup> of usable area; plots were one meter apart and blocks were two meters apart. Characterization relating growth habit and shoot dry matter production of grasses are presented in Table 2.

Table 2. Growth habits and shoot dry matter production of *Brachiaria* genus grasses

Grasses	Growth habit	Dry matter production
		Mg ha <sup>-1</sup>
<i>Brachiaria decumbens</i>	Decumbent	1.55**
<i>Brachiaria brizantha</i>	Caespitose	3.38**
<i>Brachiaria humidicola</i>	Stoloniferous	1.37**
<i>B. brizantha MG-5 Vitória</i>	Caespitose	2.38**

\*\*Results obtained by Silva et al. (2019), in the experimental area under dry farming system.

In the year of implantation (2005), 553 kg ha<sup>-1</sup> of NPK mixture (60-80-45) was fertilized in the experimental plots, with the following nutrient sources: ammonium sulfate (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, triple superphosphate P<sub>2</sub>O<sub>5</sub> and potassium chloride KCl. The fertilizer was sowed at the beginning of the rain season, just after pruning and standardizing the grasses, repeating the process until 2010 (Almeida et al., 2014). After that the experiment was conducted annually but with no fertilizer addition.

### 2.2.1 Determination of Shoot Dry Matter of Grasses

The shoot dry matter samples were collected in November 2018 at three random spots in the experimental plots, adding up to 48 sampled points (12 points per treatments, 4 points per plot) using a wooden template measuring 0.30 x 0.21m (0.063 m<sup>2</sup>). Subsequently, the samples were put to dry in an air cycling oven at ± 65 °C for 72 hours until constant weight was reached. Finally, the samples were weighed in analytical scale to determine the shoot dry matter (kg ha<sup>-1</sup>).

### 2.2.2 Soil Sampling for Traits Analysis and Determination

The undisturbed soil samples used to determine the physical attributes of the soil were collected using an Uhland sampler, 0.05 m high and 0.05 m diameter (98.17 cm<sup>3</sup>) at the center of each experimental plot. Then, the samples were sent to analysis to the Laboratory of Soil Physical Analysis of the Federal University of Para íba. For the determination of the mean weighted diameter of wet and dry aggregates, soil samples of preserved structure were collected, using straight shovel, for subsequent breaking and sieve screening for aggregates separation (9.52 mm mesh).

The analyzed variables were: bulk density (BD), compaction degree (CD), total porosity (TP), macroporosity (Ma), microporosity (Mi), field capacity ( $\theta_{FC}$ ), permanent wilting point ( $\theta_{PWP}$ ), available water content ( $\theta_{AWC}$ ), soil aeration capacity (SAC), mean weighted diameter of wet and dry aggregates (Wet MWD and Dry MWD), aggregate stability index (ASI) and saturated hydraulic conductivity (K<sub>θ</sub>).

Bulk density (BD) was determined by the ratio between dry soil mass/ soil sample volume, according to the methodology proposed by Blake & Hartge (1986). Thus, it was possible to calculate the compaction degree of the soil (Equation 1), defining the percentage of soil compaction in relation to its maximum, using  $1.85 \text{ g cm}^{-3}$  as the maximum restrictive value of BD for a medium texture Oxisol (Suzuki et al., 2007).

$$CD = (BD / 1.85 * 100) \quad (1)$$

Where: CD is the compaction degree and BD is the bulk density. Total porosity (TP) was determined by the humidity corresponding to the soil saturation volume, as described in the equation (2):

$$TP = (MSS - Mds) / CV \quad (2)$$

Where: TP is the total porosity of the soil ( $\text{m}^3 \text{ m}^{-3}$ ), MSS is the mass of saturated soil, Mds is the mass of dry soil and CV is the cylinder volume. Microporosity (Mi) was determined in a tension table by applying the -6 kPa potential in saturated soil samples, as suggested by Teixeira et al. (2017). Macroporosity (Ma) was obtained through the difference between (TP - Mi).

Soil Aeration Capacity was determined following methodology proposed by Reynolds et al. (2007). Matrix potentials of  $\Psi_m$  -10 kPa and -1500 kPa were used to determine humidity in the field capacity ( $\theta_{FC}$ ) and the permanent wilting point ( $\theta_{PWP}$ ), as described in Teixeira et al. (2017). Through the relation ( $\theta_{FC} - \theta_{PWP}$ ), the available water content for plants was obtained ( $\theta_{AWC} - \text{m}^3 \text{ m}^{-3}$ ).

Saturated hydraulic conductivity ( $K_\theta - \text{cm h}^{-1}$ ), was determined in undisturbed soil samples, using permeameter of constant charge and calculated through the following equation:

$$(K_\theta) = Q \times L / A \times H \times T \quad (3)$$

Where: ( $K_\theta$ ) – is the saturated hydraulic conductivity ( $\text{cm h}^{-1}$ ), Q – is the water volume percolated and collected in a measuring cylinder ( $\text{mL}^{-1}$ ), L – is the soil block height (cm), A – is the cylinder area ( $\text{cm}^2$ ), H – is the height of the soil block + water sheet (cm) and T – is the time in hours of percolated water volume collection.

The determination of the mean weighted diameter of wet aggregates (Wet MWD) and mean weighted diameter of dry aggregates (Dry MWD) were performed according to methodology proposed by Kemper & Chepil (1965), with variations proposed by Carpenedo & Mielniczuk (1990) and Silva & Mielniczuk (1997), where the principle is to evaluate the resistance offered by the aggregates when submitted to oscillations in both wet and dry sieves. The aggregate stability index (ASI) was calculated through the Wet/Dry MWD ratio.

The clay dispersed in water was obtained by granulometric analysis of the soil, according to the densimeter method of Bouyoucos (Teixeira et al. 2017), but with no use of chemical dispersant. For the total clay, the previous procedure was performed, however using sodium hydroxide (NaOH – 1N) as a dispersant agent and mechanical agitation as physical dispersant. The flocculation degree was obtained according to the following:

$$FD = \text{Clay-CDW} / \text{Clay} * 1000 \quad (4)$$

Where: FD is the flocculation degree of the soil ( $\text{g kg}^{-1}$ ), Clay is the clay content dispersed in sodium hydroxide – NaOH ( $\text{g kg}^{-1}$ ), and CDW is the clay content dispersed in water ( $\text{g kg}^{-1}$ ).

### 2.3 Statistical Analysis of Data

The Student's t-test and the Pearson's correlation analysis were performed at ( $p < 0.05$ ), using R statistical software (R DEVELOPMENT CORE TEAM, 2013).

### 3. Results and Discussion

Figure 2 shows the correlation data between bulk density (a) compaction degree (b), and shoot dry matter production (DMP) of *Brachiaria* grasses. Through the analysis of the images it is possible to state that there was no statistically significant variation between BD x DMP and CD x DMP ( $p < 0.05$ ).

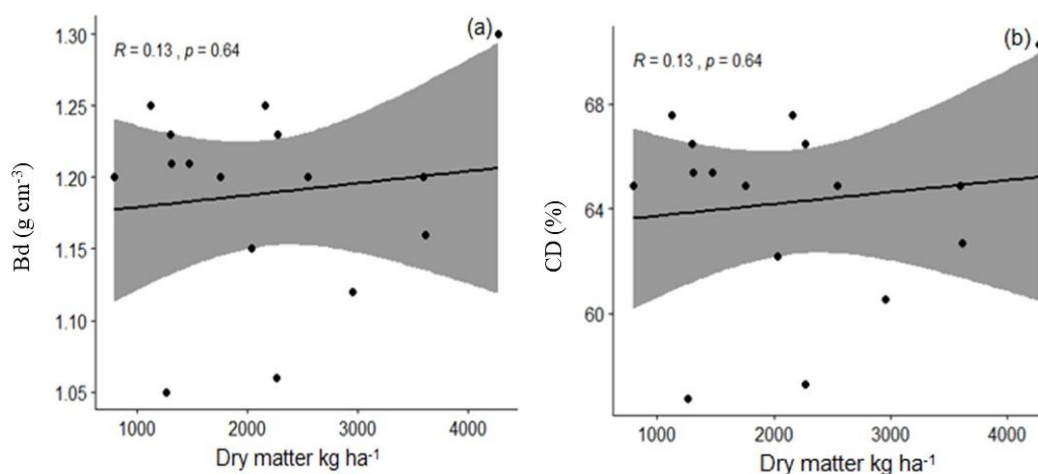


Figure 2. Linear correlation of bulk density (a) and compaction degree (b) with shoot dry matter production (DMP) in grasses of *Brachiaria* genus

Correlation values were low, with  $R = 0.13$  for BD x DMP and  $R = 0.13$  for CD x DMP. The mean values showed strong dispersion in relation to the straight line for both evaluated attributes, as a result of the spatial dependence of the CD to the mean values of BD. The dry matter production was not affected by the attributes, maintaining a slight growth trend as the average values of the attributes increased.

The result found in this study was different from that found by Vitória et al. (2012), working with linear and spatial correlation between *Brachiaria brizantha* productivity and soil physical attributes. They observed that soil density is inversely proportional to grass dry matter production, for density values ranging between 1.21 and 1.87  $\text{g cm}^{-3}$ .

The results observed in Figure 2 (a) and (b) show that density values of 1.05 - 1.30  $\text{g cm}^{-3}$  and compaction degree values of 60.0 - 68.0% have no negative influence in shoot dry matter production. It is also observed that BD was within the limit range for medium texture Oxisols, which according to Reichert et al. (2007) is between 1.20 and 1.40  $\text{g cm}^{-3}$ . Therefore, it can be stated that the BD and CD values presented in Figure 2 do not restrain the development



and productivity of grasses. Even with the increase in the mean value of these variables, dry matter yield tended to increase, exceeding the average of 4 tons per hectare for all four *Brachiaria* cultivars.

The linear correlation analysis between soil microporosity (Mi) and macroporosity (Ma) with shoot dry matter production (DMP) is shown in Figure 3 (a) MI x DMP and (b) Ma x DMP.

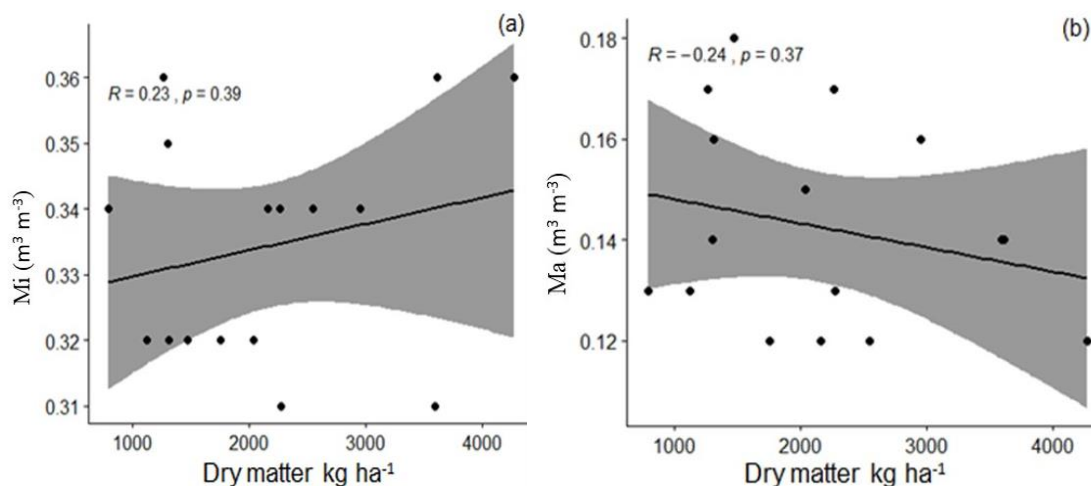


Figure 3. Linear correlation of microporosity (a) and macroporosity (b) with shoot dry matter production (DMP) in grasses of *Brachiaria* genus

There was no significant linear correlation ( $p < 0.05$ ) between Mi x DMP ( $p = 0.39$ ) and Ma x DMP ( $p = 0.37$ ). As for the correlation values, Figure 3 shows (a)  $R = 0.23$  for Mi x DMP and (b)  $R = -0.24$  for Ma x DMP. Both  $R$  values are considered weak, meaning they have little influence on dry matter production in grasses.

However, microporosity and macroporosity showed inverse linear trends, increasing for Mi x DMP and decreasing for Ma x DMP (Figure 2). These results emphasize that microporosity, despite its low correlation with dry matter production, does not affect grass yield. This statement is confirmed by Figure 3 (a), which shows the increase in DMP as a function of the increase in soil microporosity.

This result is due to the importance of microporosity for water availability to plants, since much of the water retained in the soil is present in the micropores. For Dexter et al. (2004) and Barros et al. (2016), the core function of micropores is to retain water and make it available for plants. The solubilization of nutrients also depends on the moisture level of the soil (micropores), which is where a large amount of essential nutrients for plant development is contained.

The reduction in shoot dry matter production as soil macroporosity increases (Figure 3b) is related to a rise in soil aeration capacity (SAC) and a decrease in the volume of retained water. This factor is evidenced by the weak, but negative correlation between Ma x DMP ( $R = -0.24$ ). The mean values of macroporosity were  $0.16 - 0.18 \text{ m}^3 \text{ m}^{-3}$  and the highest yield of dry matter production was found for  $0.14 - 0.16 \text{ m}^3 \text{ m}^{-3}$  (Figure 3b), with loss in DMP along time. From these results, we can draw that, for the soil condition dealt in this study, keeping macroporosity

levels around  $0.15 \text{ m}^3 \text{ m}^{-3}$  is enough to achieve a good dry matter production for grasses of the *Brachiaria* genus.

Figure 4 (a) shows Pearson's linear correlation analysis between soil aeration capacity (SAC) and shoot dry matter production of *Brachiaria* grasses. In Figure 3 (b), the result of the linear correlation analysis between total porosity (TP) and dry matter production (DMP) is observed.

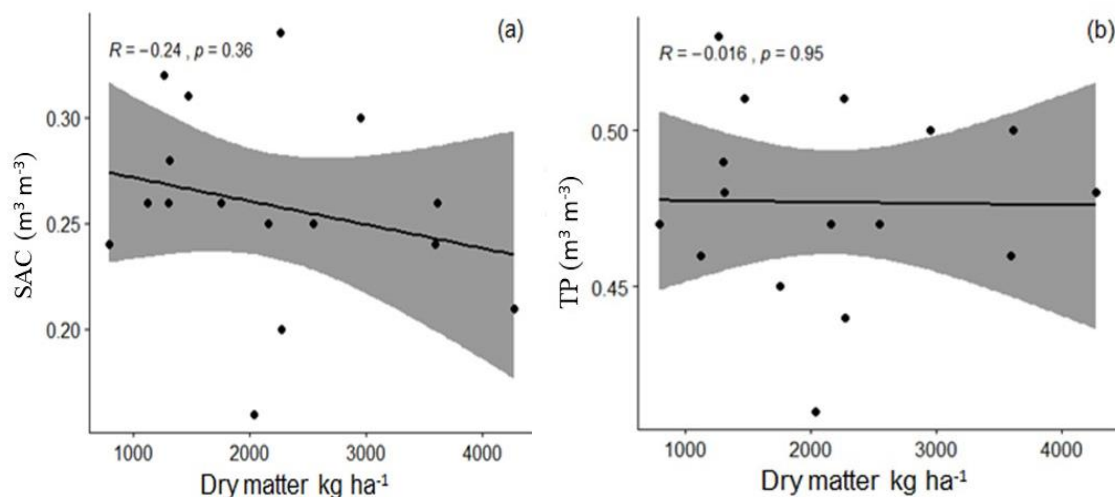


Figure 4. Linear correlation of soil aeration capacity (a) and total porosity (b) with shoot dry matter production (DMP) in grasses of *Brachiaria* genus

There is a weak negative correlation between SAC x DMP ( $R = -0.24$ ,  $p = 0.36$ ) and an almost nonexistent correlation between TP x DMP ( $R = -0.016$ ,  $p = 0.95$ ). Both correlations were not statistically significant. However, it is observed that there was a reduction in DMP with increasing soil aeration capacity, especially when the average SAC values exceeded the  $0.30 \text{ m}^3 \text{ m}^{-3}$  limit (Figure 4a).

This finding matches the data analysis verified by Reynolds et al. (2002), Tormena et al. (2002) and Assis et al. (2015). For them the SAC required for the proper development of plants should be in between  $0.10$  and  $0.34 \text{ m}^3 \text{ m}^{-3}$ , because, below or above these limits, numerous damages to plants occur due to problems related to water retention in the soil and low gas diffusion around the rhizosphere.

In the case of grasses, the negative effects were observed when the average values of SAC tended to increase, approaching the limit value of  $0.34 \text{ m}^3 \text{ m}^{-3}$ . According to Sojka (1992) and Klein et al. (2008), there are many negative effects that an imbalanced SAC could have on plants, mainly because they act directly on plant physiology, with emphasis on stomatal closure, plant wilting, root necrosis, obstruction to xylem water flow and nutritional and hormonal imbalance in plants.

Figure 4 (b) shows an extremely weak negative correlation between TP x DMP ( $-0.016$ ). It is emphasized through this result, that total porosity is not a limiting factor to the shoot dry matter production in grasses. The mean values were in the range of  $0.45$  to  $0.50 \text{ m}^3 \text{ m}^{-3}$ , so we can consider it suitable for good soil operation.

The lack of response of grasses to TP is explained by the fact that this variable is composed of a sum of numerous pore classes, such as macroporosity, microporosity, aeration porosity, bioporosity, cryptoporosity, among others. And as shown in Figure 4 (a and b), the behavior of microporosity and macroporosity are divergent on dry matter production, thus reflecting on the low representativeness of TP on the DMP variable.

Total soil porosity is vital for soil functioning in the physical, chemical and biological realms, however, Klein & Libardi (2002) and Silva et al. (2017b) point out that the importance of this attribute is not only in its volume, but also in the way pores are distributed in the diameter, becoming a key factor in soil fertility and crop productivity, as it interferes with factors such as drainage, available water content to plants, nutrient absorption, root penetration, aeration and temperature.

Figure 5 (a) shows the results of the correlation analysis between available water content ( $\theta_{AWC}$ ), (b) field capacity ( $\theta_{FC}$ ) and (c) permanent wilting point ( $\theta_{PWP}$ ), with the dry matter production of grasses.

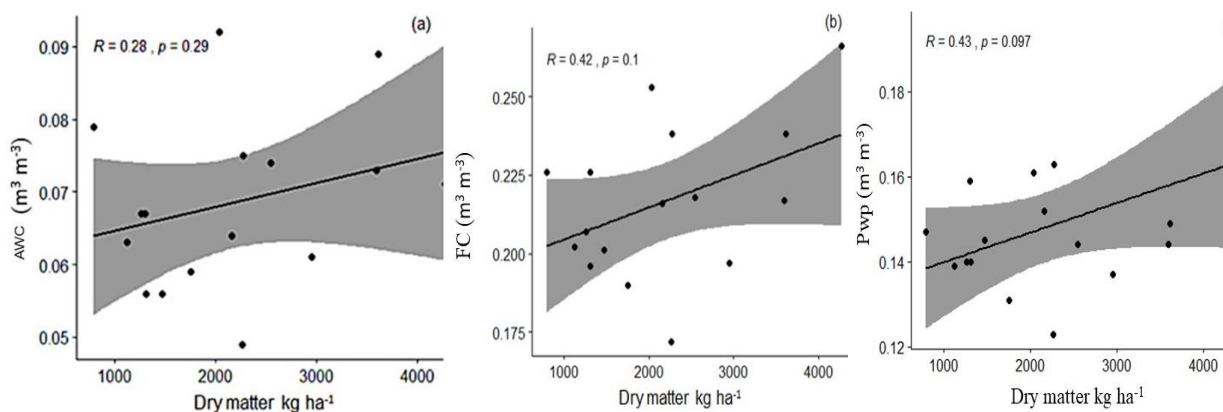


Figure 5. Linear correlation of available water content (a), field capacity (b) and permanent wilting point (c) with shoot dry matter production (DMP) in grasses of *Brachiaria* genus

Positive linear correlation values between  $\theta_{AWC}$  x DMP ( $R = 0.28, p = 0.29$ ),  $\theta_{FC}$  x DMP ( $R = 0.42, p = 0.10$ ) and  $\theta_{PWP}$  x DMP ( $R = 0.43, p = 0.097$ ) are noted.  $\theta_{AWC}$  presented a weak positive correlation, but  $\theta_{FC}$  and  $\theta_{PWP}$  presented moderate correlation with grass dry matter production, demonstrating its importance for plant development.

Although the statistical analysis did not show significant correlation values between these attributes and DMP, it is emphasized that there was a mutual increase in DMP and the mean values of  $\theta_{AWC}$ ,  $\theta_{FC}$  and  $\theta_{PWP}$  (Figure 5 a, b, c). Water retained in the subsurface layers of the soil possibly favored the maintenance of dry matter production by grasses, because they have an abundant root system and so they are able to absorb promptly available water from deeper soil layers.

And despite the water restriction imposed by the soil, it is observed that available water content values in the 0.05 to 0.09  $m^3 m^{-3}$  range, were not restrictive to grass dry matter production (Figure 5). Pezzopane et al. (2015), evaluating *Brachiaria brizantha* response mechanisms to

water stress, observed that there was a reduction in biomass production and leaf area, as well as an increase in the number of roots in deeper soil layers, as a function of soil moisture reduction.

It is estimated that fifty percent of the total water volume retained in the soil (available water content), is readily available to plants. In this case it can be stated that the grass species *Brachiaria decumbens* Stapf., *Brachiaria brizantha* (Hochst) Stapf., *Brachiaria humidicola* (Rendle) Schwickerdt Vr. and *Brachiaria brizantha* MG5 cv. Vitória, maintain a linear increase in dry matter production, even with low water content in the soil (Figure 5, a, b and c). For Aspiazú et al. (2010), the biomass production in water-restricted grasses occurs due to their metabolism (C4), being therefore efficient in water use.

Saturated hydraulic conductivity ( $K_{\theta}$ ) showed a weak negative correlation with grass dry matter production ( $R = -0.37$ ,  $p = 0.16$ ). It can be observed (Figure 6) a decreasing linear correlation with DMP as saturated hydraulic conductivity increases.

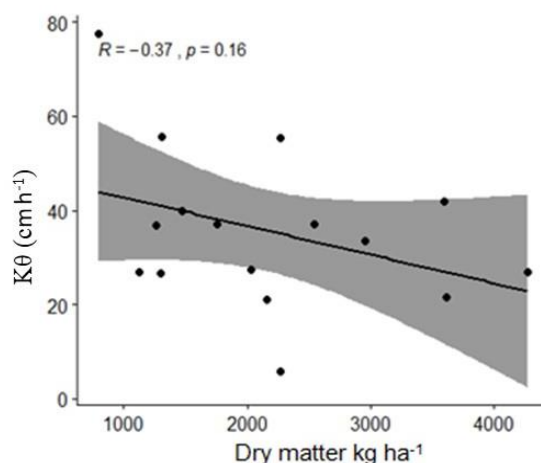


Figure 6. Linear correlation of saturated hydraulic conductivity with shoot dry matter production (DMP) in grasses of *Brachiaria* genus

The average values of saturated hydraulic conductivity were between 0 to 80 cm h<sup>-1</sup> with strong data dispersion in relation to the main line. It can be observed in Figure 6 that the minimum value of dry matter production was pronounced when ( $K_{\theta}$ ) approached 40 cm h<sup>-1</sup>, indicating that, although beneficial, water in large volumes may compromise development and productivity of grasses.

From all evaluated attributes, it is observed that the most representative negative correlation value was observed for  $K_{\theta} \times \text{DMP} = -0.37$  (Figure 6). Several factors are involved in this result, as saturated hydraulic conductivity depends on soil texture and porosity, especially macroporosity (Mesquita & Moraes, 2004). This result suggests that saturated hydraulic conductivity was favored by increased soil macroporosity (Figure 2b) and both attributes were negatively correlated with grass dry matter production.

Therefore, it can be affirmed that the increase in porous spaces larger than 0.05 mm (Ma) increases the aeration capacity of the soil and reduces the contact surface of the roots with the soil solution, compromising the absorption of nutrients, which sometimes accumulate in the

subsurface layers of the soil. This may reduce the response of grasses to dry matter production due to the large volume of voids and smaller contact surface at the root-soil-solution interface, where water and nutrients are contained. Hara et al. (2019) observed a reduction in hydraulic conductivity with an increase in the root system of *Urochloa brizantha*. According to them, the reduction in  $K_{\theta}$  is due to the fact that, with the increase of the root system, there is a consequent reduction in the soil macroporosity, which increases again after the root system dries out.

Figure 7, shows linear correlation values of mean weighted diameter of dry (a) and wet (b) aggregates and of aggregates stability index (c) with shoot dry matter production in grasses.

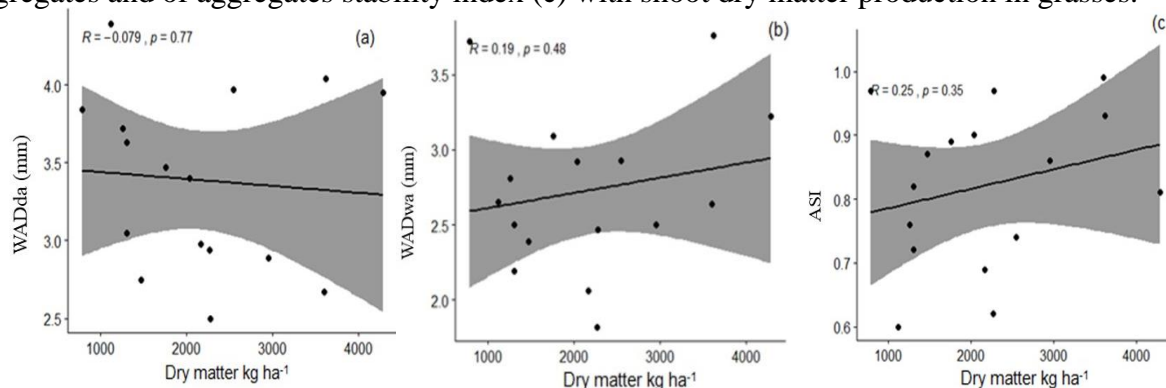


Figure 7. Linear correlation of Wet MWD (a), Dry MWD (b) and ASI (c) with shoot dry matter production (DMP) in grasses of *Brachiaria* genus

There was a weak negative correlation between the mean weighted diameter of dry aggregates (Dry MWD) and grass shoot dry matter production (DMP) ( $R = -0.079$ ,  $p = 0.77$ ) and diameter values ranged from 2.5. to 4.0 mm. Mean weighted diameter of wet aggregates (Wet MWD), showed a weak positive correlation with DMP ( $R = 0.19$ ,  $p = 0.48$ ) and the mean diameter values ranged from 2.0 to 3.5 mm.

For the aggregate stability index (ASI), it was observed that there was a weak positive correlation with DMP ( $R = 0.25$ ,  $p = 0.35$ ) and mean values ranged from 0.6 to 1.0. With the exception of Wet MWD, the other attributes (Dry MWD and ASI) positively favored dry matter production as their mean values increased (Figure 7, b and c). Regarding the ASI, the mean values between 0.6 and 1.0 indicate that the evaluated soil presents an adequate degree of stability, having a positive effect on the DMP. Wet MWD and ASI are used as soil quality indicators, for predicting possible structural disturbances and their positive correlation with DMP confirm that soil conservation is essential for plant development, being related mainly to root development and shoot production.

High aggregate stability is essential for plant establishment, especially in terms of diameter, as it has a strong influence on the development of the root system, which under unfavorable conditions loses the ability to penetrate the intra-aggregate pores (Camargo & Alleoni, 2006). Soils with a high aggregate stability index favor the establishment and development of the root system of plants, reflecting on the green and dry matter production of grasses. And as there is a direct relationship between the roots of plants and the formation of aggregates (Salton et al. 2008), it is clear that over time there is a balance within the system, where the

input of organic matter is sufficient for the production of dry matter.

Preservation of soil physical attributes, especially aggregates, is an efficient way to generate straw, allowing greater mulching over the soil (Silva et al., 2011b). In addition, there is a direct relationship between leaf area and soil root volume, which in grassy pasture areas contributes to aggregate formation (Salton et al., 2008) and improvements in structure and other emerging properties of the soil (Mielniczuk et al., 2003).

Thus, it can be affirmed that the high production of dry matter by grasses is directly correlated with the physical attributes of soil quality, especially those related to soil water availability. Table 3 shows the average values of the soil physical attributes that were used to evaluate the correlation with shoot dry matter production in grasses.

Table 3. Significance level, mean and correlation values for physical variables correlated with grass shoot dry matter production

Variable	Unit	Mean Value	<i>R</i>	<i>p</i>
TP		0.47	-0.16	0.95
Ma		0.14	-0.24	0.37
Mi		0.32	0.23	0.39
$\theta_{FC}$	$m^3 m^{-3}$	0.216	<b>0.42</b>	0.10
$\theta_{PWP}$		0.148	<b>0.43</b>	0.097
$\theta_{AWC}$		0.068	0.28	0.29
SAC		0.25	-0.24	0.36
BD	$g cm^{-3}$	1.18	0.13	0.64
CD	%	64.25	0.13	0.64
Wet MWD	mm	2.73	0.19	0.48
Dry MWD		3.38	-0.079	0.77
ASI	-----	0.807	0.25	0.36
$K_{\theta}$	$cm h^{-1}$	35.65	<b>-0.37</b>	0.16

Wet MWD= Mean weighted diameter of wet aggregates; Dry MWD = Mean weighted

diameter of dry aggregates; ASI = Aggregates stability index;  $\theta_{FC}$  = Field capacity;  $\theta_{PWP}$  = Permanent wilting point;  $\theta_{AWC}$  = Available water content;  $K_{\theta}$  = Saturated hydraulic conductivity; TP = Total porosity; Ma = Macroporosity; Mi = Microporosity; SAC = Soil aeration capacity; BD = Bulk density; CD = Compaction degree; R = Correlation value; p = Significance value.

Favorable attributes to dry matter production in grasses include bulk density, compaction degree, microporosity, available water content, field capacity, permanent wilting point, mean weighted diameter of wet aggregates and aggregate stability index (Table 3). The attributes that negatively influenced dry matter production were macroporosity, soil aeration capacity, saturated hydraulic conductivity and mean weighted diameter of dry aggregates.

The total soil porosity had almost no effect on the shoot dry matter production of grasses (Table 3). The positive variables that most influenced DMP were  $\theta_{FC} = 0.42$  and  $\theta_{PWP} = 0.43$ ; and the most representative negative value in relation to DMP was  $K_{\theta} = -0.37$  (Table 3).

## 5. Conclusion

Grass shoot dry matter production decreases with increases in the average values of macroporosity, soil aeration capacity, saturated hydraulic conductivity and mean weighted diameter of dry aggregates.

The increase in the average values of bulk density, compaction degree, microporosity, available water content, field capacity, permanent wilting point, mean weighted diameter of wet aggregates and aggregate stability index favored the increase in shoot dry matter production of grasses.

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