

Original Research Article

Use of Brachiarias in the improvement of physical and chemical attributes of a Yellow Oxisol

ABSTRACT:

This study aimed to evaluate the effect of the cultivation of five species of grasses of the genus *Brachiaria* (*B. decumbens*, *B. ruziziensis*, *B. brizantha*, *B. humidicola* and *B. brizantha* CV MG-5) in physical and chemical properties and in the formation and stabilization of aggregates of a Yellow Oxisol. The test with the grasses in the absence and presence of fertilization was conducted in the ~~property~~ Chã de Jardim ~~area~~, belonging to the Centro de Ciências Agrárias-UFPB, located in the county Areia-PB. The experimental design was in randomized blocks, with subdivided parcels, in factorial scheme 5 x 2 x 4, with four repetitions, being: five species of Grass (Braquiarias), two conditions of mineral fertilization with NPK (absence or presence) and four depths of soil samples collection (0-5, 5-10, 10-20, 20-30 cm), totaling 40 subplots of 5.0 x 5.0 m, with 3 repetitions, totaling 120 sampling points. The grasses favored the formation of aggregates and contributed to their stability. *Brachiaria brizantha* is the most suitable grass to raise the organic matter content of an oxisol without mineral fertilization.

Keywords: soil aggregation, grasses, pasture fertilization, organic matter.

1- INTRODUCTION

The inadequate choice of fodder, the misuse of soil conservation practices, the lack of maintenance of soil fertility and the high rate of animal stocking are the main causes of soil degradation. These factors alter the physical properties of the soil, being the main causes of its compaction [1]. The compression process reduces the density and macroporosity of the soil, increases the resistance of this to the root growth, in low humidity conditions, and reduces its oxygenation, when humid [2].

~~Therefore,~~ Pastures can protect and improve the physical characteristics of the soil [1]; moreover, some plants, such as the Brachiarias are known for the ability to penetrate the compressed layers of the soil. Another contribution of the grasses is related to the growth of roots in the soil profile, which promotes the increase of the organic matter content, acting in the formation of stable aggregates, because the organic matter and the stability of aggregates have a strong correlation, as noted by [3;4]. The root system in the soil profile, in the process of growth, promotes the approximation of the particles as the roots make pressure on the mineral particles in their advance through the porous space. The absorption of water by the roots, also provides drying in the region adjacent to the root systems, promoting an increase in the cohesion force among the particles, favoring the **aggregation** of the soil [5].

However, despite the large extent of areas cultivated with *Brachiaria* species, it can be stated that the available information still represents little in the universe of situations in which the genus *Brachiaria* is ~~inserted~~ grown? [6]. *Brachiaria* is one of the most widely used forages in Central Brazil and among its favorable agronomic characteristics stand out: High yields of dry matter and low soil fertility tolerance, high nutritional value and high resistance to stresses [7].

Comment [T1]: Not clear, rephrase

Although the number of forage species available in Brazil is high, the genera *Brachiaria* and *Panicum* are the most important, with the predominance of 80% of pasture areas cultivated in the country [8]. The Paraíba has a total pasture area of 1,471,069 ha, of which, the county of Areia, in the Brejo region, ~~participates with~~ contributes 6,791 ha, of this area, 797 ha are pastures planted in degraded areas [9].

Due to the lack of information for correct management of pastures, which are currently in low production capacity due to the lack of nutrient replacement [10], it is necessary to adopt practices that enable to maximize the forage production respecting soil resilience. In this context, [10] suggested that the expectation is that the forage plant be used more rationally, through the use of specific methods of management, capable of making available for pastures, a continuous and expressive production, with greater competition in agribusiness, throughout the agricultural system.

In view of the above, this research aimed to evaluate by means of physical and chemical attributes, the effect of the cultivation of five varieties of *Brachiaria*, on the quality of a Yellow Oxisol, as well as the formation and stabilization of aggregates in this soil.

2- MATERIAL AND METHODS

The soil used for the realization of the experiment is classified as Yellow Oxisol [11] and was collected in the experimental area Chã do Jardim, located in the county of Areia-PB, belonging to the Center of Agrarian Sciences of the Federal University of Paraíba, with coordinates 6°58'12"S 35°42'15"W and at an altitude of 620 m.

The climate of the region, where the experiment is installed, according to the classification of Köppen, is type As', Tropical subhumid (hot and humid), with a rainy season in the autumn-winter period, with greater rainfall in the months of June and July [12]. In the county of Sand-PB, ~~inserted in~~ of the region of the Brejo Paraibano according to the data of the meteorological station of the CCA/UFPB (average of 30 years), the average annual temperature is 24.5 °C, the average annual relative humidity is 85% and the average annual rainfall precipitation is 1,400 mm, being concentrated in more than 75% in the months of March and August.

The experimental area was prepared for ~~implantation~~ establishment of the test with ploughing and grading, for planting the grasses at the beginning of the year 2005. Five species of the genus

Brachiaria were chosen, including: *Brachiaria decumbens*, *Brachiaria humidicola*, *Brachiaria ruziziensis*, *Brachiaria brizantha*, *Brachiaria brizantha* cultivate MG5 and distributed in experimental portions of 10.0 m of Length by 5.0 m of breadth. For five years, after this period the grasses were subjected to successive cuts of the aerial part, every 35 days.

The experimental design adopted was randomized blocks, with subdivided parcels, in factorial scheme 5 x 2 x 4, referring to five species of *Brachiaris*, two conditions of mineral fertilization with NPK (absence and presence) and four depths (0-5, 5-10, 10-20, 20-30 cm) and four repetitions/replications, totaling 40 subplots of 5.0 x 5.0 m and 120 sampling points.

Soil samples, for each treatment, were collected in the months of June to July 2011, in each subparcels (absence and presence of mineral fertilization) by treatment (*Brachiaria*). Undeformed Undisturbed soil samples were collected at the depths (0-5, 5-10, 10-20 and 20-30) for the physical and chemical determinations of the soil.

The density of the soil was determined for each depth, with three repetitions, using the methodology of the paraffin Clod [11]. The separation of the aggregate size of the soil by dry screening was carried out according to the methodology of [13]. With the results, the aggregate diameter classes were determined: 9.52-2.00, 2.00-1.00, 1.00-0.50, 0.50-0.25, 0.25-0.106, 0.106-0.053 and < 0.053 mm and the weighted average diameter of dried aggregates (DMPAs) [13].

The separation of soil aggregates size by wet sieving was performed, using a sieve set with mesh diameter of: 9.52, 2.00, 1.00, 0.50, 0.25, 0.106, 0.053 and < 0, 053mm, through the methodology described by [14], adapted by [15].

Subsamples of approximately 50 g were moistened, by capillary, for a period of 24 hours, through the use of plastic containers, perforated in its lower part, containing cotton and filter paper inside, to facilitate the damping and placed on a tray with water. After the damping, the subsamples were transferred to plastic tubes of 21 cm in length and 9.5 cm in diameter, containing 50 ml of water and stirred for 2 minutes at 16 rpm in a rotary agitator. Then the contents of each tube were placed in a sieve set with mesh diameter of: 9.52, 2.00, 1.00, 0.50, 0.25, 0.106, 0.053 and < 0, 053mm, to obtain the size of aggregates in the classes: 9.52-2.00; 2.00-1.00; 1.00-0.50; 0, 50-0.25; 0.25-0.106; 0.106-0.053 and < 0, 053mm and obtaining the weighted average diameter of wet aggregates (DMPAu) after kiln drying.

The determination of the stability of aggregates was carried out through using the ratio of the weighted average diameter of wet and dry aggregates (DMPAu/DMPAs), according to [13].

After obtaining soil density and soil aggregation by dry and damp, soil samples were destorroadas for physical determinations (particle density and soil porosity) and chemical properties.

Comment [T2]: Not clear, rephrase

Soil chemical analyses were carried out in the Laboratório de Química e Fertilidade do Solo do Departamento de Solos e Engenharia Rural do CCA-UFPB and they consisted of: PpH in water in proportion 1:2.5 (soil/water) and the levels of phosphorus, potassium, calcium, magnesium, exchangeable acidity, potential acidity, total organic carbon and soil organic matter, as well as the sum of bases, the ability to exchange cations and the saturation by bases, following the methodologies of [12]

The averages obtained for the Brachiarias x Brachiarias treatments were compared by the "F" test and the averages compared to each other by the ~~of~~ Tukey test to 5% probability, for the results obtained for the treatments Brachiarias x witness, the averages were compared to each other by the Dunnett test at 5% probability.

Comment [T3]: Not clear, is this control?

3- RESULTS AND DISCUSSION

For the evaluated treatments, the pH of the soil obtained significant values in relation to the witness, the only one that did not obtain significant value was the Brachiaria ruziensiensis with mineral fertilization (Table 1).

Table 1. Values of the chemical determinations of the oxisol cultivated with the different grasses in the presence and absence of mineral fertilization

Treatments	Mean squares							
	pH	P	K	Ca	Mg	Al	SB	M.O.
	-----mg.dm ⁻³ -----			-----cmol _c .dm ⁻³ -----			g.kg ⁻¹	
Witness	4,47	5,63	16,58	0,94	0,78	0,69	1,79	32,48
Grass	With fertilization							
<i>B. decumbens</i>	5,29*	10,36	18,78	1,53	1,03	0,45	2,66	28,13
<i>B. brizantha</i>	5,15*	9,04	20,69	1,50	1,10	0,55	2,69	30,78
<i>B. humidicola</i>	5,21*	9,22	15,54	1,38	1,01	0,46	2,30	29,86
<i>B. brizan. MG5</i>	5,22*	13,00	13,82	1,62	0,91	0,38	2,54	28,90
<i>B. ruziensiensis</i>	4,88	6,17	19,42	1,10	0,88	0,85	1,90	29,83
	Without fertilization							
<i>B. decumbens</i>	5,64*	3,32	17,65	1,41	0,96	0,45	2,46	27,75
<i>B. brizantha</i>	5,32*	3,603	18,44	1,34	1,03	0,46	2,44	26,84*
<i>B. humidicola</i>	5,47*	6,77	13,01	1,13	0,65	0,43	2,04	25,64*
<i>B. brizan. MG5</i>	5,15*	2,29	10,30	1,33	0,78	0,49	2,16	26,66*
<i>B. ruziensiensis</i>	5,28*	4,35	16,22	0,92	0,65	0,56	1,60	28,29

* Significant and superior to the witness, by the Dunnett test, at a level of 5% probability

Comment [T4]: Replace commas by decimal points

Comment [T5]: Rephrase. Is this the same as Control?

The elevation of the soil pH can be attributed to the adsorption of the H^+ in the functional groups of organic compounds of plant residues [16] and to the biological oxidation potential of organic anions, which are released in greater quantity in Beginning of the decomposition of the waste [17].

[18] affirm that such ph values may be linked to the presence of cations (Ca^{2+} and Mg^{2+}), as a consequence of the increase in pH values and the levels of basic cations in the surface layer of soils, there were observed low average concentrations of exchangeable aluminium and low acid exchangeable. Similar results were observed by [2] when observing that the use of organic matter for oxisol recovery did not influence the increase in the pH of the soil.

With regard to the contents of organic matter, significant values were observed in the treatments with *Brachiaria brizantha*, *humidicola* and *brizantha* MG5 both without fertilization, which presented lower values than the witness (table 1). This fact can be explained by the low fertility of the soil, of this experiment, since the grasses, require the nutrients from the soil for its development, intensifying the activity of the microorganisms [19] and consequently higher consumption of organic matter available in the soil. In the areas studied under the direct planting system, due to the cover of the soil by the straw in a direct planting system promoted an increase of the organic matter in the surface layers of the soil [20].

The use of grasses of the genus *Brachiaria*, increased the fertility of the Oxisol, even if it did not Interfering significantly (Table 1). These results are associated with rapid soil coverage by grasses and rapid nutrient recycling [21]. The use of grasses in the recovery of degraded areas is highlighted, because since it has the root system fasciculated is able to form infiltration channels, improving the storage of water, as well as decompression of the soil [22].

Comment [T6]: Rephrase, not clear

The values obtained for soil bulk density, particle density and porosity for the analyzed treatments, depths and absence and presence of mineral fertilization in the different *Brachiaris* analyzed are ~~found~~ presented in Table 2. It is observed that for the values relating to bulk density there was significant difference when the fertilization associated with *B. decumbens* and *B. rizuziensis* was carried out. However, no significant values were presented between particle density and total porosity by the Dunnet test at 5%. Soil and particle density were significant by the Tukey test at 5% for depth, regardless of the type of *Brachiaria* used and the presence or absence of fertilization, so that the superficial layer differed from the others (Table 2).

Comment [T7]: Bulk density

Table 2. Soil bulk density, particle and total soil porosity values for evaluated treatments

Determinações Properties determined			
Treatments	Soil density	Particle density	Total porosity
	g cm ⁻³		%

Witness	1,45	2,65	45,4
<i>B. decumbens</i> SA	1,41	2,66	47,1
<i>B. decumbens</i> CA	1,40*	2,68	47,8
<i>B. brizantha</i> SA	1,42	2,65	46,4
<i>B. brizantha</i> CA	1,40	2,66	47,2
<i>B. humidicola</i> SA	1,40	2,69	48,0
<i>B. humidicola</i> CA	1,42	2,65	46,4
<i>B. brizantha</i> MG 5 SA	1,42	2,68	47,1
<i>B. brizantha</i> MG 5 CA	1,42	2,68	47,0
<i>B. ruziziensis</i> SA	1,41	2,66	47,0
<i>B. ruziziensis</i> CA	1,36*	2,65	48,7
<hr/>			
0 – 5 cm	1,38 b	2,63 b	47,5 a
5 – 10 cm	1,40 a	2,67 a	47,6 a
10 – 20 cm	1,41 a	2,67 a	47,2 a
20 – 30 cm	1,42 a	2,67 a	47,0 a

Comment [T8]: Rephrase

* Significant and superior to the witness, by the Dunnett test, at a level of 5% probability; WoutF (without fertilization), WF (with fertilization). Averages followed by the same lowercase letter in the column, do not differ from each other by the Tukey test at 5% probability.

Comment [T9]: The commas are decimal points

Comment [T10]: rephrase

In the results obtained in Table 2, the lowest bulk and particle density values were found in the depths 0-5 cm, thus showing that the root systems of the grasses influence positively, due to the greater amount of roots in the surface layer. On the other hand, as the analyzed depth increases, the soil tends to become denser. Lower density in the superficial layer was also observed by [22] in Oxisol red distroférico typical very clay.

Comment [T11]: Replace by: a typical clayey red Oxisol

According to [23], the smallest density observed in the most superficial layer may be related to the higher density of roots of the crops used and to the higher content of organic matter. These results are in accordance with those observed by [24] in-observing who observed an increase in the density of the soil in depth in which the treatment, with the smallest average, was observed found in the soil with pasture. These authors agree that this lower soil density, in the more superficial layers, may be due to the higher deposition of organic matter.

In relation to the species of Brachiarias, there was a difference when comparing the average values obtained for the bulk density (Table 2). According to [25], the use of grass with growth in clump favors the compaction of the soil, for facilitating more its exposure to the animal trampling. However, as the *Brachiaria* presents prostrate habit, the soil cover becomes more expressive and consequently favoring its protection. The same was verified when compared the average soil bulk

density values for the treatments with and without fertilization. The particle density values were not influenced by the grasses (Brachiarias) or fertilization (Table 2), being affected only in terms of the depth analyzed, differing from the superficial layer of the others, precisely the one with the highest levels of organic matter (Table 1). Particle density is a physical attribute of the soil that is not affected by the soil texture, being only affected by the source material and the organic matter content of the soil [26].

As noted in the research, [27] agree to verify that variability in organic matter content in Oxisol can reduce particle density values. Higher particle density values were observed in the surface layer of the soil by [28] due, also to the higher organic carbon content on the surface. In relation to the total porosity according to in function of the grasses used in the research, it is understood that the values are very similar for the different grasses, for the condition of fertilization and for the depths analyzed and, therefore not presenting significant differences ($P < 0.05$). However, it is observed that among the grasses there was a variation of 47.6% (*Brachiaria decumbens*) to 46.6% (*Brachiaria brizantha* MG5) and that the total porosity values decreased with the evaluated depth, ranging from 47.5% (0-5 cm layer) to 47.0% (Layer of 20-30 cm). This may indicate, according to [29] that small changes in particle density, can reduce the pore space of the soil, even not in a meaningful way.

The values obtained for the weighted average diameter of dry aggregates (DMPAs) and Damp (DMPAu) and stability of the soil aggregates under the different grasses (DMPAu/DMPAs), for the analyzed treatments, depths and fertilization levels are presented in Table 3.

Table 3. Values of the weighted average diameter of dry aggregates (DMPAs) and Damp (DMPAu) and of aggregate stability (DMPAu/DMPAs) for the different grasses analyzed without and with fertilization NPK

Treatments	Determinations			
	DMPAs	DMPAu	DMPAu/DMPAs	Scattered clay
	-----mm-----			g/kg
Witness (S. Gram.)	2,090	1,033	0,494	26,62
<i>B. decumbens</i> SA	3,004*	2,021*	0,672*	25,64
<i>B. decumbens</i> CA	3,382*	2,309*	0,682*	22,44
<i>B. brizantha</i> SA	3,024*	2,135*	0,705*	22,83
<i>B. brizantha</i> CA	3,146*	2,177*	0,692*	23,01
<i>B. humidicola</i> SA	3,144*	2,005*	0,637*	24,54
<i>B. humidicola</i> CA	3,161*	2,214*	0,700*	19,49
<i>B. brizantha</i> MG5 SA	2,964*	2,041*	0,688*	25,46

Comment [T12]: rephrase

<i>B. brizantha</i> MG5 CA	3,135*	2,230*	0,711*	26,01
<i>B. ruziziensis</i> SA	2,978*	2,176*	0,730*	25,28
<i>B. ruziziensis</i> CA	3,071*	2,609*	0,849*	22,59

* Significant and superior to the witness, by the Dunnett test, at a level of 5% probability; WoutF (without fertilization), WF (with fertilization)

Comment [T13]: Please be careful with the use of commas instead of decimal point

Comment [T14]: Rephrase with control

Of these results, it is observed that for the values concerning the DMPAs and DMPAu there was a significant difference when compared to the value of the witness treatment (without grass and without fertilization) by the test Dunnett to 5%.

Comment [T15]: Rephrase with control

According to the averages obtained it can be observed that there was an improvement in the aggregate of the soil, whether it is DMPA obtained by dry or wet via and stability of the aggregates (Table 3). Although the treatments are being compared statistically with the witness control, the presence of mineral fertilizer influences those without fertilization and exception made only for the stability of the aggregates using the *Brachiaria brizantha*.

The average obtained for the DMPAu/DMPAs ratio was very low for the grass-free treatment (witness control), thus showing the low stability of the soil aggregates under this treatment (Table 3). [13] affirmed that grasses can be used as recovering plants of soil structure in degraded areas, because they have a higher density of roots and better distribution of the root system in the soil, favouring the link of the contact points between mineral particles and aggregates, which contributes to the formation and stability of the aggregates. They also added that the greater the relationship DMPAu/DMPAs (near 1) the greater the stability of the aggregates of the soil in water and, those with values closest to zero, represent aggregates highly susceptible to destruction in the presence of water. By the values of the DMPAu/DMPAs relationship obtained in the treatments with the use of grasses (Brachiarias) for five years, independent of the mineral fertilization (Table 3), there were elevations in the values when compared with that of the witness control.

4- CONCLUSIONS

1. The greatest values DMPAu and DMPAs and the DMPAu/DMPAs relationship for treatments with Brachiarias indicate that grasses favor the formation of aggregates and contribute to their stability;

2. *Brachiaria ruziziensis* reduces soil bulk density values;

3. *Brachiária brizantha* is the most suitable for raising the organic matter content of an oxisol without mineral fertilization.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

5- REFERENCES

- [1] Flávio Neto, J.; Severiano, E.C.; Costa, K.A.P.; Guimarães Junnyor, W.S.; Gonçalves, W.G.; Andrade, R. Biological soil loosening by grasses from genus *Brachiaria* in crop-livestock integration. **Acta Scientiarum. Agronomy**, v. 37, n. 3, p. 375-383, 2015.
- [2] Bonini, C.S.B. ; Alves, M.C. ; Montanari, R. Recovery of the structure of a degraded red Latosol using sewage sludge. *Revista Brasileira de Ciências Agrárias*, v.10, n.1, p. 34-42, 2015.
- [3] Borges, C.S., Ribeiro, B.T. ; Wendlingh, B. ; Cabral, D.A. Soil aggregation, organic carbon and CO₂ emission in areas under different uses in the Cerrado, Triângulo Mineiro region. *Environment & Water - An Interdisciplinary Journal of Applied Science*, v.10, n. 3, p. 660-675, 2015.
- [4] Gazolla, P.R. ; Guareshi, R.F. ; Perin, A. ; Pereira, M.G. ; Rossi, C.Q. Fractions of soil organic matter under pasture, no-tillage system and crop-livestock integration. *Semina: Agrarian Sciences*, v. 36, n. 2, p. 693-704, 2015.
- [5] Zonta, E.F.C.B. ; Goi, S.R. ; Rosa, M.M.T. ; Fernandes, M.S. Root system and its interactions with the edaphic environment. Mineral nutrition of plants. Viçosa, MG, Brazilian Society of Soil Science, p. 8-28, 2006.
- [6] Lima, V.M.P. ; Oliveira, G.C. ; Serafim, M.E. ; Curi, N. ; Evangelista, A.R. Optimum water range as an indicator of improvement of the structural quality of degraded latosol. *Brazilian Journal of Soil Science*, v.36, p. 71-78, 2012.
- [7] Arroyave, C. ; Barceló, J. ; Poschenrieder, C. ; Tolrà, R. Aluminum-induced changes in root epidermal cell patterning, a distinctive feature of hyperresistance to Al in *Brachiaria decumbens*. *Journal of inorganic biochemistry*, v. 105, n.11, p.1477-1483, 2011.
- [8] Fernandes, C.D. ; Valério, J.R. ; Fernandes, A.T.F. Threats Presented by the Current System of Production of Seeds to Agriculture in the Transmission of Diseases and Pests. In Threats presented by the current system of production of seeds to agriculture in the transmission of diseases and pests, **WORKSHOP ON FORESTRY SEEDS**, p.55-68, 1999.
- [9] Brazilian Institute of Statistics and Geography. Agricultural census 2006: preliminary results: IBGE, 2006.
- [10] Euclides, V.P.B.; Montagner, D.B.; Barbosa, R.A.; Nantes, N.N. Manejo do pastejo de cultivares de *Brachiaria brizantha* (Hochst) Stapf e de *Panicum maximum* Jacq. **Ceres**, v. 61, 2015.
- [11] Embrapa, Solo. Manual of soil analysis methods. Rio de Janeiro: Embrapa Solos, 2010.
- [12] Jacomine, PKT 1972. Exploratory survey: soil recognition of the State of Paraíba: Ministry of Agriculture, 1991, EPE.

- [13] Silva, I.F. ; Mielniczuk, J. Evaluation of soil aggregation status affected by agricultural use. In Evaluation of soil aggregation status affected by agricultural use, Brazilian Journal of Soil Science, p. 313-319, 1997.
- [14] Tisdall, J.M. ; Cockroft, B. ; Uren, N.C. The stability of soil aggregates as affected by organic materials, microbial activity and physical disruption. Soil Research, v.16, n.1, p.9-17, 1978.
- [15] Carpenedo, V. ; Mielniczuk, J. State of aggregation and quality of aggregates of Purple Oxisols, submitted to different management systems. Brazilian Journal of Soil Science, v. 14, n. 2, p. 99-105, 1990.
- [16] Miyazawa, M. ; Pavan, M.A. ; Calegari, A. Effect of plant material on soil acidity. Brazilian Journal of Soil Science, v.17, p. 411-416, 1993.
- [17] Helyar, K.R. The management of acid soils. In Plant-soil interactions at low pH, 365-382: **Springer**.
- [18] Ribeiro, A.C. Recommendations for the use of correctives and fertilizers in Minas Gerais: 5. Approximation: Soil Fertility Commission of the state of Minas Gerais, 1999.
- [19] Santos, E.D.G. ; Paulino, M.F. ; Queiroz, D.S. ; Valadares Filho, S.C. ; Fonseca, D.M. ; Lana, R.P. Deferred pasture evaluation of *Brachiaria decumbens* Stapf. : 1. Chemical-bromatological characteristics of forage during drought. Revista Brasileira de Zootecnia, v.33, p.203-213, 2004.
- [20] Silva, A.A. ; Galon, L. ; Ferreira, F.A. ; Tironi, S.P. ; Ferreira, E.A. ; Silva, A.F. ; Aspiazi, I. ; Agnes, E.L. No-tillage system and its impact on Brazilian agriculture. Revista Ceres (Brazil) .Jul-Ago, v. 56, n. 4, p.496-506, 2009.
- [21] Marchini, Débora C, Tseng C Ling, Marlene C Alves, Silvio Crestana, Sebastião N Souto Filho and Otton G de Arruda 2015. Organic matter, infiltration and tomographic images of Oxisol in recovery under different types of management. R. Bras. Eng. Agríc. Environmental, v. 19, n. 6, p. 574-580, 2015.
- [22] Genro Júnior, S. A. ; Reinert, D. J. ; Reichert, J. M. ; Albuquerque, J. A. Physical attributes of a Red Latosol and productivity of crops grown in succession and rotation. Ciência Rural, v.39, p.65-73, 2009.
- [23] Reinert, D.J. ; Albuquerque, J.A. ; Reichert, J.M. ; Aita, C. ; Andrada, M.M.C. Soil density critical limits for root growth of cover crops in Red Argissolo. Brazilian Journal of Soil Science, v.32, n. 5, p. 1805-1816, 2008.
- [24] Custódio, G.D. ; Ribon, A.A. ; Fernandes, K.L. ; Hermógenes, V.T.L. ; Barros, L.R. Soil Density and Relative Density-Indicators of the Physical Quality of a Yellow Latosol Under Different Pasture and Native Forest Management. Digital Field, v.10, n. 1, 2015.
- [25] Imhoff, S.; Silva, A.P. & Tormena, C.A. Spatial heterogeneity of soil properties in areas under elephant-grass short-duration grazing system. **Plant Soil**, 219:161-168, 2000.
- [26] Santos, A. C. ; Ferreira, E. M. ; Araujo, L. C. ; Chemical and physical properties of soils in areas under pasture in cerrado of Northern Tocantins. Revista Acadêmica Agrária e Ambiental, v. 7, p. 55-63, 2009.

[27] Rosales, M.A .; Oliveira, O.S .; Moura, M.A .; Lourdes, E.G. Influence of continuous organic and mineral fertilizations on soil fractions of humic substances. *Ceres*, v. 46, n. 263, p. 67-81, 1999.

[28] Silva, V.L.B .; Martins, P.F.S. Physical properties of the soil and coffee root system, conilon variety, under different spacing. *Journal of Agricultural Sciences / Amazonian Journal of Agricultural and Environmental Sciences*, v.53, p.96-101, 2011.

[29] Bonini, C.S.B .; Alves, M.C. Physical quality of a red Latosol recovering for seventeen years. *Brazilian Journal of Agricultural and Environmental Engineering*, v.16, n. 4, p. 329-336, 2012.

UNDER PEER REVIEW