Aggregation Index in Representative Soils of the Paraiba State – Brazil in Different Stages of Pedological Development

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Abstract

The stability of soil aggregates is an important physical parameter as it mainly influences the flow of water and air in the soil. In this sence, the research aimed to determine the stability aggregates index in six representative soil classes in the Paraíba State-Brazil at different stages of pedological development. The soil classes analyzed is localized on the Microregions of the Curimataú Occidental (Ferrasol, Planosol, Leptosol, Arenosol) and Brejo Paraibano (Acrisol, Lixisol), on the Paraíba state, Brazil. At depths of 0-5 cm, 5-10 cm and 10-20 cm was collected three undeformed soil samples were collected per mini trench (one per depth), making a total of 15 samples per soil class and 90 total samples. In each soil class was analysed: chemical parameters, granulometrics parameters, stability of agregates, Weighted average diameter via wet sieving (DMPAu) and Weighted average diameter via dry sieving (DMPAs); agregate stability index (IEA). For the conditions that research was developed can conclude that: The IEA values *tended to increase with clay contents in all soil classes; Among the less developed soils, the IEA values were better in the Planosol soil, denoting that there is a probable relationship with the low contents of K, Na and Al; In the more developed soils, the high values of Na and Al may have contributed to the lower IEA in the PVd, while the lower values may have contributed to the higher IEA in Ferrasol and Lixisol soils.*

Keywords: Planosol; Ferrasol; Acrisol; Lixisol; Leptosol; Arenosol

1. 1. Introduction

Aggregate stability is one of the important physical parameters in soil quality assessment and is related with the organic carbon contents, quantity and quality of the clay fraction, moisture, edaphic meso and macrofauna, in addition to the use and management of the soil. In a short period of time, the soil aggregates stability can change under the influence of crop systems and is probably more related to changes in organic constituents than total organic matter content. In the case of long periods, the stability of the aggregate decreases, since the organic matter is also reduced, as it is used as a source of energy by soil microorganisms. However, in soils with continuous input of organic material in the surface and subsurface layers, the stabilizing effect takes longer due to the more intense biological activity, such as forest environments, agroforestry systems, non-degraded pastures, which results in products that perform role in the formation and stabilization of aggregates.

In the case the formation of soil aggregates, considering the physical, chemical and biological effects, those arising from the decomposition of organic material (of the plants and the edaphic fauna exudates) besides those who may have suffered the action of mechanical compression by roots and/or hyphae, are called biogenic aggregates. Now considering the action of external physical agents that caused changes and additions to its formation, such as wetting and drying cycles, physical soil compression, especially those with clayey texture, in addition to organo-mineral interactions, we call these physiogenic aggregates. Those whose origin is related to the processes that formed the first two, but do not fit specifically into either of the two previous situations, we call intermediate aggregates.

To MERGEN JÚNIOR (2013), evaluating aggregate genesis in systems with no-till (SPD), conventional tillage (SPC), pasture and secondary forest, the physiogenic aggregates formation pathway prevails over the biogenic aggregates formation pathway, regardless of the land use system evaluated. The SPC disfavors the formation of biogenic aggregates, while the SPD, to maintain of plant residues on the soil and the absence of revolving the same result in better physical and chemical conditions, with a subsequent increase in soil fauna, resembles the area of forest as to the mass of biogenic and physiogenic aggregates. The pasture area favored the greatest formation of biogenic aggregates without comparison to other areas.

According to MARTINS (2008), the decomposition of plant residues, the release of exudates by plant root systems and the effect that plants exert on soil microorganisms are forms of influence of plants on soil aggregation. In turn, microorganisms indirectly influence the stability of soil aggregates through the release of organic compounds (gums and mucilages) or directly, such as the joining of small aggregates by fungal hyphae.

SILVA et al. (2009) evaluated different areas of Luvisol in the Cabrobó-PE desertification core considering three current stages of the areas: Conservation, moderately degraded and intensely degraded. The authors concluded that the indices of aggregation and stability of the aggregates in water were efficient in differentiating the areas submitted to increasing levels of degradation and can be used as indicators of the quality of these soils.

Given the above, this research aimed to determine the stability aggregates index in six representative soil classes in the Paraíba State-Brazil at different stages of pedological development.

2. Material and Methods

2.1 Location of soil classes, regional climatology and current use of soils

a) Municipality of Cuité – PB: Located in the Microregion of Curimataú Occidental, with a Bsh climate model (semi-arid with summer rains) according to the Koppen classification (Brazil, 1972). The average rainfall over the last eight years in the region was 567.1 mm and average annual temperature of 26º C (AESA, 2016).

Soil Classes:

LA - Ferrasol (USDA, 1999) located on the flat top of the Chapada da Serra do Cuité – PB at geographic coordinates 6º58'32.1"S and 35º43'19.2"W.

Current use: Corn crop (*Zea mays*) under rainfed conditions, being the initial soil preparation in the conventional way. After harvesting, the soil spends most of the time uncovered, since the crop remains are used to feed medium and large animals;

SX - Planosol (USDA, 1999), located on the right bank of BR 104, 15.7 km from the entrance of the seat of the municipality of Cuité at geographic coordinates 6º37'23.2 "S and 36º08'46"W.

Current use: limited to sparse vegetation with the presence of some *Prosopis juliflora* (Sw.) DC., in addition to the presence of some medium-sized animals, however, for most of the year the soil surface remains uncovered.

b) Municipality of Pocinhos – PB: located in the Microregion of Curimataú Occidental, with a Bsh climate model (semi-arid with summer rains) according to the Koppen classification (Brazil, 1972). The average rainfall over the last eight years in the region was 406 mm (AESA, 2016) and average annual temperature of 23 to 32ºC.

Soil classes:

RL - Leptosol (USDA, 1999). Located on the right bank of BR 412, at geographic coordinates 7° 9'17.59"S and 36°7'3.10"W.

Current use: vegetation has been removed and the soil surface is uncovered for most of the year.

RQ - Arenosol (USDA, 1999), located on the right side of PB-121 approximately 7.7 km away from the county seat at geographic coordinates 7°9'18.24"S and 36° 02'57.24"W.

Current use: Crops under rainfed conditions, mainly maize (*Zea mays*) and beans (*Phaseolus vulgaris*), however, the removal of crop residues is carried out for animal feed and the soil surface spends most of the year without cover.

c) Municipality of Areia – PB: located in the Microregion of Brejo Paraibano, climate model of Koppen is As' (hot and humid with rain from autumn to winter) (Brazil, 1972). In the municipality, the average annual rainfall over the last eight years was 1,319.8 mm (AESA, 2016), with an average annual temperature of 22ºC.
Soil class:
PVd - Acrisol (USDA, 1999). The area is located at CCA/UFPB at geographic coordinates 6º58'32.1"S and 35º43'19.2"W.
Current use: Natural pasture with Brachiaria decumbens with the soil surface covered throughout the year.

d) Municipality of Alagoa Grande – PB: located in the Microregion of Brejo Paraibano, climate model of Koppen is As' (hot and humid with rain from autumn to winter) (Brazil, 1972). In the municipality, the average annual rainfall over the last eight years was 875.4 mm (AESA, 2016), with an average annual temperature of 24ºC.
Soil class:
PVe - Lixisol (USDA, 1999). The area is located on a side road on the right side of PB-079 towards the headquarters of the municipality of Alagoa Grande, at a distance of 1.33 km from the aforementioned highway, at geographic coordinates 7º01'55.4"S and 35º38'48.8"W .
Current use: With grasses and legumes that followed the removal of sugar cane (Saccharum officinarum), keeping the soil surface covered throughout the year.

2.1 Collection and analysis of the soil samples

At depths of 0-5 cm, 5-10 cm and 10-20 cm: three undeformed soil samples were collected per mini trench (one per depth), making a total of 15 samples per soil class and 90 total samples.
In the physical of soils laboratory , the soil samples was air drying, then went sieved in a 9.52 mm mesh. Of each sample (by soil class and depth), two subsamples of 50g each were taken, where one being placed in an aluminum can intended for drying in an oven at 105ºC, to obtain the moisture content and; the second sample was placed on filter paper inside a plastic container containing cotton and distilled water aiming at moistening of the aggregates by capillary action for a period of 24 hours. Then went this samples were stirred on a rotary shaker for 2 minutes at 16 rpm, then went transferred to beakers with the volum complet of 1000 ml distilled water with subsequent determination of the silt and clay contents by densimetry (Bouyoucos 1951 modified by Day, 1965) .

2.2 Separation of aggregates via wet sieving

Then, all the beakers contents was transferred individually to a set sieves with diameters mesh: 2.00; 1.00; 0.500; 0.250; 0.106 mm in the vertical oscillator containing water in its interior. The sets of sieves were subjected to vertical oscillation for 15 minutes at a speed of 42 oscillations per minute, simulating the process of wetting and drying of the soil by capillary action and the resistance of the aggregates to remain with the same diameter or subdivide into other sizes smaller under the action of water.
After the vertical oscillation process, the material retained in each sieve was transported to aluminum cans

and placed to dry in an oven at 105 ºC for a period of 24 hours. Then, the mass and percentage of stable aggregates in each class were weighed and determined, where the class less than 0.053 mm in diameter was obtained by reading silt+clay dispersed in water, while the class from 0.106 to 0.053 mm was obtained by the difference between the total mass of the sample and the sum of the other fractions.

2.3 Separation of aggregates via dry sieving

The dry separation of the aggregates aimed to evaluate how it were distributed in different classes before the wet separation process. It consisted of placing subsamples of 50 g of soil with particle diameter smaller than 9.52 mm in a set of sieves with diameters mesh: 2.00; 1.00; 0.500; 0.250; 0.106; mm coupled to a produtest vibrator, for one minute. Then, the content retained in each sieve was weighed and their respective masses corrected for dry mass in an oven at 105 ºC.

2.4 Weighted average diameter of soil aggregates

The weighted average diameter of the water-stable aggregates (DMPAu) and obtained by dry means (DMPAS) was calculated by summing the products between the average diameter of each aggregate fraction and the proportion of the sample mass in each class, in relation to the total mass of the sample, obtained through the ratio of the mass of aggregates retained in each sieve to the total mass of the sample corrected in terms of moisture.

2.5 Determination aggregates stability of the soil

The Aggregates stability of the soil was determined by separating aggregates wet and dry following the method described by TISDALL et al. (1978), adapted by CARPENEDO & MIELNICZUCK (1990), where the weighted average diameter values of the aggregates were obtained in the two sieving conditions: Weighted average diameter via wet sieving (DMPAu) and Weighted average diameter via dry sieving (DMPAs).

2.6 Determination of aggregates stability index (IEA)

The aggregate stability index (IEA) in each soil class was determined through the DMPAu/DMPAs ratio established by SILVA & MIELNICZUK (1997), where values of this relationship, the closer to 1 (um) the greater the resistance of the aggregates to disaggregation energy.

3.2 Percent Distribution of size of aggregate

The table 2 contains the percentage distribution of aggregate mass by diameter classes obtained through dry and wet sieving for the six soil classes at depths of 0-5 cm, 5-10 cm and 10-20 cm.

Table 2. Percentage distribution of aggregate mass obtained by dry and wet sieving at different depths

Soil classes	Aggregates size classes, mm													
	> 2,00		2,00 - 1,00		1,00 - 0,500		0,500 - 0,250		0,250 - 0,106		0,106 - 0,053		< 0,053	
	ds	ws	ds	ws	ds	ws	ds	ws	ds	ws	ds	ws	ds	ws

	0 - 5 cm													
LA	15,5	14,8	13,0	10,4	23,0	20,9	27,1	18,3	15,8	18,3	4,2	5,7	1,3	2,9
PVd	40,7	18,4	12,1	10,8	22,9	20,9	15,7	18,7	6,6	18,5	1,0	4,5	0,9	2,4
PVe	37,8	3,4	19,3	6,3	16,0	10,9	13,3	18,2	9,2	31,9	1,7	12,9	2,6	6,6
SX	38,2	4,5	10,7	7,1	11,3	12,6	14,7	17,2	14,1	31,6	4,0	10,3	6,9	10,3
RL	11,7	1,7	6,5	4,7	17,6	13,8	27,2	26,7	24,8	19,6	7,7	18,7	4,4	10,8
RQ	7,6	1,8	5,6	3,3	17,3	14,1	28,9	22,4	24,6	32,4	6,6	10,8	9,4	6,1
	5 - 10 cm													
LA	27,2	10,9	12,3	14,4	20,6	25,1	22,7	16,8	12,5	14,2	2,8	7,8	1,7	4,0
PVd	37,8	11,7	20,5	15,2	24,2	26,5	11,3	17,7	4,5	15,1	0,8	4,8	0,8	2,3
PVe	40,7	2,3	17,8	6,7	17,3	12,0	12,6	19,2	7,7	30,7	1,7	13,4	2,0	6,9
SX	34,6	7,9	12,1	8,3	12,4	12,3	15,1	17,1	13,7	29,6	3,8	9,40	8,0	5,9
RL	17,1	2,2	7,4	3,9	17,3	14,8	25,4	21,3	21,8	25,1	6,2	18,7	4,7	10,8
RQ	7,5	0,7	5,5	3,7	18,6	14,2	31,1	23,8	27,1	26,0	6,8	15,5	3,3	8,8
	10 - 20 cm													
LA	21,7	10,9	14,1	13,3	22,5	23,6	24,3	15,2	12,0	19,1	4,2	9,7	0,9	5,9
PVd	35,6	10,8	20,0	13,2	23,8	23,5	12,7	15,1	5,5	19,0	0,6	7,7	1,5	4,6
PVe	41,6	7,9	17,4	6,2	16,3	12,5	12,9	18,1	7,9	33,5	1,7	4,9	1,9	2,6
SX	31,8	3,6	10,5	6,0	13,3	11,6	16,8	16,7	13,1	29,1	4,8	16,7	9,4	4,9
RL	19,3	1,4	7,0	4,3	16,1	14,3	24,5	24,2	22,5	29,9	6,6	11,9	3,8	7,3
RQ	16,8	0,5	9,8	3,0	21,7	13,8	26,2	26,3	18,6	27,8	4,4	11,5	2,2	6,7

Where: LA – Ferrasol; PVd – Acrisol; PVe – Lixisol; RL – Leptosol; RQ – Arenosol; SX – Planosol; ds – dry sieving; ws – wet sieving

In Acrisol and Lixisol, as well as in Planosol, both under low moisture content (dry sieving), there was greater resistance to disaggregation with a tendency to maintain a higher percentage of aggregates in the >2.00 mm diameter class in all the depths, while in the other classes there was a greater fragmentation to classes with smaller diameters. However, as this method does not allow distinction between recently formed aggregates those others have already suffered a stabilization process, this resistance does not yet represent the state of soil aggregation (SILVA, 1993).

The submission to the wetting and drying process, through wet sieving, caused a fragmentation of this aggregates in smaller macroaggregates (1.00 - 0.500 mm and 0.500 - 0.250 mm) and microaggregates (0.250 - 0.106 mm) in all soil classes and depths. Considering the texture of these soils, associated with the low content of organic matter and the conventional management system, the fragility of these aggregates can be seen, reporting the need for changes in the use and management systems of these soils to promote improvements in the formation of stable aggregates , which according to BASTOS et al. (2005), there are several factors that interfere, among these, the main ones are: clay type and content, polyvalent metals, calcium carbonate, iron, aluminum and manganese oxides and hydroxides, organic exudates of plants, organic substances from the action of microorganisms and other organic compounds.

The accumulation of aggregates in diameter classes <1.00 mm occured due to their stability to rapid wetting, not being destroyed by agricultural practices, since they are constituted by particles from 2 to 20μm in diameter, joined by cementing agents, according to SILVA (1993) and TISDAL & OADES (1982).

3.3 Weighted average diameter of aggregates obtained by dry sieving (DMPAS) and wet sieving (DMPAu)

Table 3. Values of weighted average diameter of aggregates in different classes obtained by dry sieving (DMPAS)

Soil Classes	DMPAs, mm					
	Depht, cm					
	0-5 cm	SD	5-10 cm	SD	10-20 cm	SD
LA	1,323	0,30	1,973	0,55	1,634	0,44
PVd	2,948	0,84	3,084	0,78	2,597	0,75
PVe	2,766	0,78	2,707	0,83	3,098	0,86
SX	2,617	0,84	2,791	0,73	1,535	0,75
RL	0,770	0,28	1,530	0,36	1,470	0,41
RQ	0,793	0,15	0,825	0,16	1,013	0,40

Where: $DMPA_S$– Weighted average diameter of aggregates obtained by dry sieving; SD – standard deviation ; LA – Ferrasol; PVd – Acrisol; PVe – Lixisol; RL – Leptosol; RQ – Arenosol; SX – Planosol

The weighted average diameter of the aggregates obtained by dry sieving indicates the current state of soil aggregation prior to wet sieving, that is, it allowed us to verify the size of these aggregates under conditions of low humidity and without suffering severe disaggregation actions, without indicate however whether if those aggregates were newly formed or not.

In this sense, observing table 3, it can be seen that the Arenosol presented the lowest DMPAs values at all depths, corroborating the textural results of the two soils. The standard deviation values show the low dispersion between the values utilized in the DMPAs. Therefore, the formation of these aggregates is linked to other factors, such as those previously highlighted by TISDALL & OADES (1982), CHAN et al. (2001) and BOENI (2007), since the predominance of the sand fraction, followed by silt and low clay fraction in these soils, showed a probable reduction in the electrochemical activity between the particles.

In the Ferrasol, the DMPAs values were very close, also demonstrated by the standard deviation. The results are in agreement with the contents of the granulometric fractions determined in this soil, portrayed in the percentage distribution of the aggregates obtained dry sieving . However, these results could be better with the adoption of use and management practices available in research for these soils, such as those obtained by ALMEIDA et al. (2014) evaluating Paceae cespitosa and decumbent under NPK fertilization in the aggregation of an Oxisol in the microregion of Brejo Paraibano. Although the authors did not verify statistical differences between the results found for DMPAs, these alone were greater than those found in this research, thus denoting the importance of correct use and management of the soil.

The Acrisol and Lixisol presented DMPAs values higher than those of the Leptosol and Arenosol, even was observed through the standard deviation data a marked variation by depth . These high values can be attributed to the probable effect of the textural aspect, especially the clay contents, as according to SILVA et al. (2014) soil texture affects stability and the formation of aggregates, and high clay on the soil contents favor aggregation.

For VEZZANI & MIELNICZUK(2011), the greater presence of clay contribute to increase the approximation of soil particles. SANTOS et al. (2010), evaluating soil physical and chemical attributes of areas under grazing in the microregion of Brejo Paraibano in Acrisol, also found high values of DMPAs and inferred that sandy horizon hinder the physical protection of organic matter, hindering the formation of aggregates.

In Arenosol, the DMPAs values were similar to those of the Acrisol and Lixisol, following the same behavior with regard to the relationship with the soil texture. In this soil, considering the climatic conditions in which it is found, in the Curimataú region of Paraíba, what may have contributed to the formation of these aggregates is what describes HARRIS et al. (1966) and BAVER et al. (1973), who report that the soil when dry there is a contraction of its colloids and dehydration of organic cements, which tends to increase aggregation.

In addition, SILVA & MIELNICZUCK (1997), evaluating cropping systems and soil characteristics affecting aggregate stability, observed little variation between DMPAs values between soils, cropping systems and analyzed depths and stated that the results obtained are due to the method employee, which does not distinguish aggregates recently formed from those who, in addition to being formed, have undergone a stabilization process.

In table 4, the data referring to the weighted average diameter of the aggregates obtained by wet sieving (DMPAu) are presented. Comparing the values of these with the ones in table 3 it turns out to be minors. According to SANTIAGO (1997), this occurs due to the dry aggregates when subjected to wetting and the mechanical action of sieving, they undergo changes, with greater effects, precisely in those of larger diameter, which contribute to increase the amount of aggregates classes by smaller diameter and, consequently, decrease DMPAu values.

Table 4. Values of weighted average diameter of aggregates in different classes obtained by wet sieving (DMPAu).

Soil classes	DMPAu, mm					
	Deph, cm					
	0-5 cm	SD	5-10 cm	DS	10-20 cm	SD
LA	1,250	0,287	1,120	0,217	1,070	0,228
PVd	1,050	0,380	1,440	0,237	1,130	0,225
PVe	0,460	0,074	0,520	0,054	0,410	0,115
SX	0,636	0,225	0,541	0,084	0,511	0,067
RL	0,380	0,048	0,420	0,058	0,370	0,044
RQ	0,340	0,047	0,390	0,037	0,360	0,039

Where: $DMPA_u$– Weighted average diameter of aggregates obtained by wet sieving; SD – standard deviation ; LA – Ferrasol; PVd – Acrisol; PVe – Lixisol; RL – Leptosol; RQ – Arenosol; SX – Planosol

Also in that table, it was observed that the Ferrasol was the one with the most stable aggregates, since the values of DMPAu presented were close to those of DMPAs, that is, the fragmentation to smaller aggregates after wet sieving was small, allowing to infer that in this soil may have been influenced by the predominant particle size fractions, as well as the residual effect of the use of the soil.

The Acrisol e Lixisol, in addition to the Planosol, were the ones with the lowest values of DMPAu, demonstrating that their structural units were quite vulnerable to disaggregation under the action of water. This denotes the need for improvements in the conditions of use and management of the soil in order to reduce the direct impact of raindrops on the surface of these soils, as well as reducing the direct incidence of sunlight, favoring plant development and microbial activity for formation and stabilization of aggregates, thus having a structural improvement.

Observing the DMPAu values for RL and RQ and comparing them with the DMPAs values in table 3, the fragility of their structural units can also be seen, since the fragmentation of larger to smaller aggregates, after wetting and wet sieving, were in the range of 51 to 75%.

The disaggregation in the Arenosol can be explained mainly by the area being used with a conventional tillage system, planting in rainfed condition sand removal of cultural remains from the area. Added to this, there is the distribution of particle size fractions, where there is a predominance of particles of sand fraction (in greater quantity), silt and finally clay. In this sense, electrochemical activities in this soil tended to be very low and, added to the use and management system, corroborated the low values of DMPAu.

According to TERASI et al. (2014) evaluating the variation in aggregate stability and its relationship with soil vulnerability along a slope in northwestern Paraná, the elevation of the sand fraction of the A and C horizons of these soils is a characteristic that implies an increase in instability of soil aggregates and the susceptibility to erosion.

In table 5 there is results refers to values of the aggregate stability index (IEA) in water on the soil classes. There was a wide variation in IEA values at all depths and soil classes (Table 5). Among the more developed soils, LA and PVe presented better average values IEA, being in the first 5 cm where the most stable aggregates occurred. Of the less weathered soils, only SX presented a good IEA, however, only in the first 5 cm. The low stability of aggregates in these soils may be directly related to their texture and to the low levels of organic carbon, since, according to WOHLENBERGET al. (2004), organic molecules act in the stages of formation and stabilization of aggregates, in addition to serving as a source of energy for microorganisms, which are important aggregation agents.

Except in the classes Acrisol and Lixisol, in the other classes of soils, the areas had their coverage removed, with no remaining cultural remains, corroborating the low levels of organic carbon found, which due to the predominantly sandy texture of these soils, contributed to low formation of stable aggregates in water, consequently reducing the DMPAu/DMPAs ratio.

Considering the influence of chemical and physical characteristics on the stability of soil aggregates, table 6 summarizes these relationships as an aid in interpreting the IEA results observed in soils, according to the degree of development.

Table 5 Minimum, maximum and average values of the aggregate stability index (IEA) in water

Soil classes	Deph (cm)	Values of IEA		
		Min	Max	Aver ± SD
PVd	0-5	0,40	0,68	0,55 ± 0,05
	5-10	0,35	0,70	0,47 ± 0,06
	10-20	0,20	0,79	0,47 ± 0,10
PVe	0-5	0,63	0,98	0,83 ± 0,07
	5-10	0,53	0,97	0,72 ± 0,08
	10-20	0,28	0,91	0,66 ± 0,12
LA	0-5	0,89	0,99	0,92 ± 0,02
	5-10	0,47	0,75	0,61 ± 0,05
	10-20	0,44	0,95	0,66 ± 0,11
RQ	0-5	0,39	0,62	0,52 ± 0,05
	5-10	0,31	0,71	0,46 ± 0,07
	10-20	0,15	0,42	0,28 ± 0,05
RL	0-5	0,24	0,81	0,47 ± 0,11
	5-10	0,18	0,70	0,36 ± 0,09
	10-20	0,21	0,42	0,31 ± 0,04
SX	0-5	0,82	0,99	0,89 ± 0,03
	5-10	0,48	0,72	0,58 ± 0,04
	10-20	0,46	0,90	0,66 ± 0,09

Where: Min – Minimum value; Max – Maximum value; *SD – standard deviation*; LA – Ferrasol; PVd – Acrisol; PVe – Lixisol; RL – Leptosol; RQ – Arenosol; SX – Planosol

Table 6. Auxiliary chemical and physical parameters in the interpretation of IEA values of the studied soils

Soil classes	K^+	Na^+	Ca^{+2} + Mg^{+2}	Ca^{+2}	Mg^{+2}	Al^{+3}	CO	Sand	Silt	Clay	IEA
	$mmol_c dm^{-3}$						$g\ kg^{-1}$				-
	Developed soils										
LA	19,76	2,11	58,63	36,8	21,8	0,06	13,32	626	189	186	73
PVd	3,16	7,89	34,17	26,0	8,2	1,04	18,84	732	93	175	50
PVe	5,45	1,00	38,93	25,5	13,5	0,21	16,86	543	124	333	74
	Undeveloped soils										
RQ	16,16	2,11	56,47	22,6	33,9	0,04	16,23	735	138	126	42
RL	18,63	1,80	56,93	40,1	16,9	0,08	14,22	795	120	85	38
SX	5,66	1,24	156,83	108,1	48,8	0,01	15,67	656	175	169	71

Where: LA – Ferrasol; PVd – Acrisol; PVe – Lixisol; RL – Leptosol; RQ – Arenosol; SX – Planosol; CO – organic carbon; IEA: aggregate stability index.

Considering the influence of chemical and physical characteristics on the stability of soil aggregates, table 6 summarizes these relationships as an aid in interpreting the IEA results observed in soils, according to the degree of development. It was observed that in more developed soils the IEA was directly linked to the sand and clay contents, with little influence of the organic carbon contents.

Even though PVd presented a higher quantity of organic carbon than PVe and LA, its low clay and high sand contents, in relation to the other two, contributed to the low IEA. The importance of the clay fraction in these soils, with regard to aggregation, is due to the predominance of kaolinite, a clay mineral in the 1:1 group, which, due to its characteristics, allows for better aggregation for these soils.

According to PEDROTTI et al. (2003), tropical soils show, in general, the predominance in the mineralogical composition of the clay fraction, clay minerals of 1:1 type and iron and aluminum oxides, which results in a tendency towards greater aggregation than soils with high levels clay minerals of the group 2: 1 and low in iron and aluminum oxides.

Adding to these results, it was observed through the chemical characteristics of these soils that the presence in greater amounts of Ca^{+2} + Mg^{+2} and the low values of Na^+ may have contributed to the better aggregation of LA and PVe. According to OLIVEIRA et al. (2012), these cations influence the flocculation and dispersion processes of clays, and according to DONTSOVA & NORTON (2001), when there is a predominance of Ca^{+2} in relation to Mg^{+2} the flocculation process is favored due to the smaller radius of Ca^{+2} hydration corroborate for a closer approximation of the clays, thus increasing the resistance to disaggregation and raising the IEA values.

In this sense, the effects of Na+ on clays dispersion may have occurred with greater intensity in PVd, since the found this cation contents in relation to PVe and LA were 7.89 and 3.7 times higher, respectively. Also in that table and in less developed soils, it was found that the high levels of organic carbon and clay found in the SX and RQ provided to theses best IEA values, with the SX standing out in relation to the RQ and RL.

Regarding the chemical characteristics of these soils, it was found that the presence of the highest amounts of Ca+2 + Mg+2 in the SX, where the proportion of the Ca+2 in relation to Mg+2 was 2.21:1 , corroborating probabely for best IEA value. Although silt contents were higher than clay, allied to the predominance of the sand fraction, it was observed that the combination of higher contents of CO and clay provided better stability, where SX stood out from the others.

In this sense, the results are in agreement with those obtained by OLIVEIRA et al. (2012), studying factors related to erosion susceptibility in soil samples from a typical dystrophic Litholic Neosol in Rio Grande do Sul, found that the higher clay and OM values (determinated from organic carbon values) in the native forest treatment partially explained the greater stability of the aggregates (IEA), as well as the Ca+2 and Mg+2 ratio in relation to soil CTC. Therefore, considering that the proximity of the IEA value of the unit indicates better stability (SILVA & MIELNICZUCK, 1997), it was found that the soil classes PVd, LA and SX were found to be soils with better aggregates stability and the soil classes PVd, RQ and Rl with greater susceptibility to disaggregation, that is, with more instability.

BOCHNER et al. (2008) evaluated the stability of aggregates and the relationship with the litter chemical characteristics of two Haplic Planosols (one gleissolic and the other arerenic), where the first under secondary forest (FS) and the second with Carapa guianensis (PA) and *Mimosa caesalpinaefolia* (PM). According to the authors, in the area with secondary forest, the IEA was higher than the other areas, being twice the values verified for the PA and PM areas, and they attributed the results to the quality of the litter and the content of organic carbon present in it.

Assessing organic matter in Solodic Eutrophic Haplic Planosol under management systems in irrigated rice cultivation in southern Brazil, ROSA (2010) reported that total organic carbon contents and physical fractions of soil organic matter did not correlate with diameter weighted average of soil aggregates obtained by wet sieving in systems with conventional tillage, showing that OM is not contributing to the stabilization of soil aggregates and/or soil aggregation in these systems. The intense soil disturbance realized by this cultive system provoked the breaking of the aggregates, exposing the organic matter, which reduced the physical protection and the time of contact all the organic fraction with the mineral so that there was interaction between them.

VENDRUSCOLO et al. (2011) evaluating physical properties of an Ferrasol and an Acrisol compared to four types of soils in Paraíba, found an IEA of 0.95 for the Ferrasol. According to the authors, the result can be attributed to the fact that the studied area has a large contribution of organic matter, coming from the native forest associated with the cycling of nutrients in these sites and for this reason as it is not a cultivation area, there is a greater contribution of organic carbon maintaining the system balance, mainly on the physical properties of the soil.

5. Conclusion

For the conditions that research was developed can conclude that:

- The IEA values tended to increase with clay contents in all soil classes;
- Among the less developed soils, the IEA values were better in the Planosol soil, denoting that there is a probable relationship with the low contents of K^+, Na^+ and Al^{+3};
- In the more developed soils, the high values of Na^+ and Al^{+3} may have contributed to the lower IEA in the PVd, while the lower values may have contributed to the higher IEA in Ferrasol and Lixisol soils.

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7. References

ALMEIDA, A. V. D. L. Caracterização morfológica, química e físico-hídrica de Neossolos Regolíticos no Agreste Meridional de Pernambuco. 2014. 75p. (Dissertação de Mestrado). Garanhuns: Universidade Federal Rural e Pernambuco, 2014.

AESA – AGÊNCIA EXECUTIVA DE GESTÃO DAS ÁGUAS DA PARAÍBA. Precipitações acumuladas no estado da Paraíba por município. Disponível em. Acessado em 23 de janeiro de 2016.

AGUIAR, M. I. Qualidade física do solo em sistema agroflorestal. 2008. 89 p. (Dissertação de Mestrado). Viçosa: Universidade Federal de Viçosa, 2008.

BASTOS, R.S.; MENDONÇA, E.S. ALVAREZ, V.H. CORRÊA, M.M. Formação e estabilização de agregados do solo decorrentes da adição de compostos orgânicos com diferentes características hidrofóbicas. Revista Brasileira de Ciência do Solo, v. 29 n. 1,. 2005.

BAVER, L. D.; GARDNER, W. M.; GARDER, W. R. Física de suelos. México: Hispano-Americana, 1973. 529 p. il.

BOENI, M. Proteção física da matéria orgânica em Latossolos sob sistemas com pastagens na região do Cerrado brasileiro. 2007. 152 p. (Tese de Doutorado). Porto Alegre: Universidade Federal do Rio Grande do Sul, 2007.

BRASIL. Ministério da Agricultura. Escritório de Pesquisa e Experimentação. Equipe de Pedologia e Fertilidade do Solo. I. Levantamento exploratório de Reconhecimento dos Solos do Estado da Paraíba. II. Interpretação para uso agrícola dos solos do Estado da Paraíba. Rio de Janeiro: 1972. 683 p. (Boletim Técnico, 15; SUDENE. Série Pedologia,

CARPENEDO, V.; MIELNICZUK, J. Estado de agregação e qualidade de agregados de Latossolos roxos, submetidos a diferentes sistemas de manejo. Revista Brasileira de Ciência do Solo, v. 14, p. 99-105, 1990.

CHAN, K. Y.; BOWMAN, A. M.; SMITH, W.; ASHLEY, R. Restoring soil fertility of degraded hardsetting soils in semiarid areas with difference pastures. Australian Journal of Experimental Agriculture, Collingwood, v. 41, p. 507-514, 2001.

DAY, P. R. Particle fractionation and particle size analysis. In: A. Black, ed Methods of Soil analysis . Agronomy: 9:545-567, 1965.

DONTSOVA, K.; NORTON, L. D. Effects of exchangeable Ca:Mg ratio on soil clay flocculation, infiltration and erosion. In: Stott, d. e. Steinhardt, G. C. (ed). Sustaining the global farm. In: International Soil Conservation Organization Meeting, 10, Proceedings, 2001. P.24-29.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. 2. Ed. Brasília: Embrapa Produção de Informação, 2013, 353 p.

FERREIRA, C. R.; SILVA NETO, E. C.; PEREIRA, M. G.; GUEDES, J. N.; ROSSET, J. S; ANJOS, L. G. C. Dynamics of soil aggregation and organic carbon fractions over 23 years of no-till management. April 2020, Soil and Tillage Research 198:9. Disponível em : https://www.researchgate.net/publication/338559033_Dynamics_of_soil_aggregation_and_organic_carbon_fractions_over_23_years_of_no-till_management .

HARRIS, R. F.; CHESTERS, G.; ALLEN, O. N. Dinamics of soil aggregation. Advance of Agronomy., New York, v. 18, p. 107-169, 1966.

MERGEN JUNIOR, C. A.; LOSS, A.; COSTA, E. M.; PEREIRA, M. G.; BEUTLER, S. J. Gênese de agregados sob diferentes sistemas de uso do solo. Disponível em: https://www.sbcs.org.br/cbcs2013/anais/arquivos/102.pdf

MARTINS, M. R. Carbono orgânico e polissacarídeos em agregados de um Latossolo Vermelho eutrófico em sequências de culturas sob semeadura direta. 2008. 59 p. (Dissertação de Mestrado). Jaboticabal: Universidade Estadual Paulista "Júlio de Mesquita Filho". 2008.

MONTEIRO, A. L. Caracterização mineralógica de solos representativos do estado da Paraíba. 2010, 139 p. (Dissertação de Mestrado). Areia: Universidade Federal da Paraíba, 2010.

OLIVEIRA JUNIOR, J. A. S.; SOUZA, E. S.; CORREA, M. M.; LIMA, J. R. S.; SOUZA, R. M. S.; SILVA FILHO, L. A. Variabilidade espacial de propriedades hidrodinâmicas de um Neossolo Regolítico sob pastagem e caatinga. Revista Brasileira de Engenharia Agrícola e Ambiental. v.18, n.6, p.631–639, 2014.

OLIVEIRA, F. P. O.; BUARQUE, D. C.; VIERO, A. C.; MERTEN, G. H.; CASSOL, E. A.; MINELLA, J. P. G. Fatores relacionados à suscetibilidade da erosão em entressulcos sob condições de uso e manejo do solo. Campina Grande: Revista Brasileira de Engenharia Agrícola e Ambiental. v.16, p.337-346, 2012.

PEDROTTI, A.; FERREIRA, M. M.; CURI, N.; SILVA, M. L. N.; LIMA, J. M.; CARVALHO, R. Relação entre atributos físicos, mineralogia da fração argila e formas de alumínio no solo. Viçosa: Revista Brasileira de Ciência do Solo, v. 27, 20

ROSA, C. M. Matéria orgânica em Planossolo Háplico sob sistemas de manejo no cultivo do arroz irrigado no Sul do Brasil. 2010.94 p. (Tese de Doutorado).Pelotas: Universidade Federal de Pelotas, 2010.

SANTIAGO, R. D.; Agregação do solo: efeito de diferentes gramíneas na formação e estabilização. 1997. 64 p. (Dissertação de Mestrado). Areia: Universidade Federal da Paraíba, 1997.

SANTOS, G. G.; MARCHÃO, R. L.; SILVA, E. M.; SILVEIRA, P. M.; BECQUER, T. Qualidade física do solo sob sistemas de integração lavoura pecuária. Pesquisa Agropecuária Brasileira, Brasília, v.46, n.10, p.1339-1348, out. 2011.

SILVA, H. P. Mapeamento das áreas sob riscos de desertificação no semiárido de Pernambuco a partir de imagens de satélite. 2009. 173 p. (Tese de Doutorado). Recife: Universidade Federal Rural de Pernambuco. 2009.

SILVA, I. F.; MIELNICZUK, J. Avaliação do estado de agregação do solo afetado pelo uso agrícola. Revista Brasileira de Ciência do Solo, v. 21, p. 313-319, 1997.

SILVA, I. F. Formação, estabilidade e qualidade de agregados do solo afetados pelo uso agrícola. 1993. 126p. (Tese de Doutorado). Porto Alegre: Universidade Federal do Rio Grande do Sul, 1993.

SILVA, A. S.; SILVA, I. F.; BANDEIRA, L. B.; DIAS, B. O.; SILVA NETO, L. F. Argila e matéria orgânica e seus efeitos na agregação em diferentes usos do solo. Santa Maria: Revista Ciência Rural, v.44, n. 10, 2014.

TERASSI, P. M. B.; SILVEIRA, H.; BONIFÁCIO, C. M. Variação da estabilidade de agregados e as suas relações com a vulnerabilidade dos solos ao longo de uma vertente na região noroeste do Paraná. Maringá: Boletim de Geografia, v.32, p.166-176, 2014.

TISDALL, J. M.; OADES, J. M. Organic matter and water-stable aggregates in soil. Journal of Soil Science, n.33, p.141-162, 1982.

USDA - UNITED STATES DEPARTMENT OF AGRICULTURE. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. Disponível em: HYPERLINK "https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051232.pdf"

VENDRUSCOLO, J.; RIBEIRO, T. S.; MESQUITA, F. O.; ALVES, A. S.; SANTOS, G. A. Propriedades físicas de um Latossolo e Argissolo comparados a quatro tipos de solos na Paraíba – Brasil. Revista Verde, Mossoró, v.6, n.4, p.204-212, 2011.

VEZZANI, F. M.; MIELNICZUK, J. Agregação e estoque de carbono em argissolo submetido a diferentes práticas de manejo agrícola Viçosa: Revista Brasileira de Ciência do Solo,v.35, n.1, 2011.

WOHLENBERG, E. V.; REICHERT, J. M.; REINERT, D. J.; BLUME, E. Dinâmica da agregação de um solo franco-arenoso em cinco sistemas de culturas em rotação e em sucessão. Viçosa: Revista Brasileira de Ciência do Solo. v.28, p. 891-900, 2004.

A.B. Smith, C.D. Jones, and E.F. Roberts, “Article Title”, Journal, Publisher, Location, Date, pp. 1-10.
Jones, C.D., A.B. Smith, and E.F. Roberts, Book Title, Publisher, Location, Date pp. 20-30.

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