Effect of Agricultural Supplies on the Physical Properties of Tropical Soils

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Abstract - Changes in the texture and structure of the soil, as a result of chemical reactions with fertilizers, are important in the geotechnical field because the soil may have alterations in terms of hydromechanical behavior. For this reason, the effects on the particle size distribution and the Atterberg's limits of a laterite soil and a transition soil were evaluated when mixed with three fertilizers and two limes, very used in Brazil. In addition to these five supplies, three chemical compounds were used, formed from these pure chemical products. The results of this study shown that the interaction between the compounds and the soil, changed the particle size distribution and the liquid and plastic limits, which can affect the mechanical behavior of the soil.

Keywords: disaggregation/deflocculation; texture changes; erosion

1. Introduction

The soil can act by retaining both carbon, an essential element for the development of plants, and other substances, such as poorly soluble fertilizers [1]; in other words, it works as a filter [2]. Over time, the infiltration, deposition, and accumulation of these and other substances affect the quality of the soil and may also act by modifying its structure and, therefore, its behavior and properties [3]. Some characteristics such as mineralogy, clay content, pH, humidity level, temperature, and the presence of other chemical compounds, may influence the behavior of these retained substances and in the own behavior and properties of the soil that shelters them [4], [5].

Some studies have been developed to show the effect of various types of fertilizers on the physical-chemical properties of the different soils under study, such as soils with high organic matter content [6], clay soils to which the crop rotation technique is applied [7], and flooded arable soils from subtropical regions, used to grow rice [8]. The impact on its internal structure, which affects the process of plant development, was also assessed. However, evaluations from the point of view of the interaction between particles, which depend on the level of soil weathering, aggregate stability, and texture changes, are scarce in the literature.

The study presented here is based on the premise that some agricultural supplies change soil conditions, for example, in the case of Potassium Chloride, reducing microbial biomass, inhibiting soil nitrification, and thereby becoming a potential soil biocide [9]. Fertilizers can also affect the texture of tropical soils and the interaction between particles and generate changes in soil properties and behavior. At the same time, it is known that in Brazil and worldwide, the use of fertilizers to increase agricultural production has increased [10], [11] and [12].

Consequently and based on studies carried out where it is verified the alteration of soils, erosive processes and even trigger processes of rupture in slopes submitted to agricultural use can be increased.

Although other studies deserve to be carried out, the analysis presented in this article are based on grain size tests and Atterberg limits, carried out on two soils composing a tropical weathering profile and which were analyzed before and after being subjected to treatments with various types of fertilizers and limes. Urea (Nitrogen), Potassium Chloride, Single Superphosphate (Phosphorus), Calcium and Dolomite lime, and three compounds formed from these pure products were used in the study. For a better understanding of the results, mineralogical analysis of the soils studied was performed.

2. Materials and Methods

Deformed soil samples were collected from the experimental field of the Graduate Program in Geotechnics (PPGG) at the University of Brasilia (15° 45' 56" S, 47° 52' 20" O).

The samples were collected at 1 m and 9 m depth. Based on [13], in this tropical weathering profile at 1 m depth, there is B horizon of oxisols and at 9 m a saprolite horizon, both of dark red color. According to the unified soil classification system (USCS), the 1 m soil corresponds to clay silt of low plasticity and the 9 m soil to silt of low plasticity [14]. In mineralogical terms, the X-ray diffraction (XRD) results presented by [15] indicate that quartz is the main mineral for both depths. Also, the gibbsite and kaolinite are the subordinate minerals of the soil at 1 m; for soil at 9 m, in addition to these two, there is also goethite and muscovite.

The lateritic soil is formed by the particles aggregation generating a high porosity characterized by the presence of macropores between the aggregates and micropores inside them [16]. The transition soil corresponds to a type of intermediate soil between the deeply weathered soil and the saprolitic soil. Its particles may be isolated, weakly aggregated or forming clay packages, for this reason, when using in this text the expression disaggregation for this depth, it will be referring to the disaggregation mechanisms itself and the deflocculation when the particles that are composing the clay packages are separated.

To carry out the different mixtures to be evaluated in this research, 3 pure fertilizers Single Superphosphate, Urea and Potassium Chloride and 2 types of lime, Dolomitic and Calcitic Lime, were used along with three chemical compounds. The first compound called "SUC", results from the mixture in equal parts of Single Superphosphate, Urea, and Potassium Chloride. Adding Dolomitic Lime to the SUC generates the second compound called "SUC + D" and finally, the mixture "SUC + C" results from the addition of Calcitic Lime to the SUC. Phosphorus, nitrogen and potassium are the elements that compose the NPK, a fertilizer widely used in Brazil. The Calcitic Lime, and especially the Dolomitic Lime, are widely used to correct the pH of the soils, and the use of one or the other is almost always linked to regional availability.

In order to preserve the natural conditions as much as possible, the soil was not previously dried for the execution of the tests, since it can affect its textural stability [17], [18], [19], so the soil was used in its natural condition.

The chemicals Potassium Chloride and Dolomitic Lime are generally found in powder form in the Brazilian market, while Urea, Single Superphosphate, and Calcitic Lime come in the form of small spheres. Consequently, the latter three were manually ground until they reached a size less than 0.149 mm, that is, pass the sieve mesh number 100 not to impair the sedimentation test.

The high agricultural supplies content used aimed to evaluate what would be the impact of supplies used with long-term accumulations, in addition to the fact that such concentrations may increase in certain parts of the cultivated areas due to geomorphological and drainage conditions. The percentages used were 2% and 10% also considering the fact that with the advent of direct planting, the dosages are very high in the first centimeters of the soil, and even if these supplies present high solubility, they may affect the most superficial layer at the beginning of its action. Another reason for selecting these contents was thinking that the effect generated by them in these quantities would be more evident and would facilitate the analysis.

In preparing the mixtures, the amount of soil necessary to carry out the test was initially placed in plastic bags. Then, the corresponding content of the chemical compound was added, being adopted 2% and 10% for the particle size test and 10% for the Atterberg limits. The mixture was made until a homogeneous material was observed and left to rest under stable temperature conditions for a period of 24 hours. This rest period was intended to allow the occurrence of chemical reactions and ionic exchange.

The determination of the chemical composition of the soils was made by a laboratory specialized in soil chemical analysis for agricultural purposes.

The tests to determine the granulometric distribution of the soils were carried out according to the Brazilian standard norm [20]. Considering that one of the objectives of the research was to evaluate the textural stability of soils when mixed with agricultural supplies and limes, the following changes were made in the way of carrying out this test:

- According to the standard norm governing this test, the soil to be used must be passed through the sieve mesh #10 (2 mm), but as the previous drying was not carried out, the soil from the depth of 9 m, which was wetter, did not pass through this mesh opening due to the agglomerations of particles forming larger grains, making it necessary, to enable the execution

of the tests, to use the soils in a natural state without passing them through any sieve. This procedure, as will be seen in the granulometry results obtained, was not harmful to the study, since both soils in the natural state did not present particles with diameters greater than 1 mm.

- Considering the fact that wet samples would be used, in the tests, 100g of soil was adopted as quantity and not 70g as established in the standard norm for the types of soil studied. A larger quantity of soil was also used to facilitate the obtainment of readings with the densimeter since the natural soil is rich in aggregates, predominantly the most weathered.

- In sedimentation tests, sodium hexametaphosphate (deflocculant) and the dispersing apparatus were not used as these would disturb the soil state to be analyzed. Therefore, all the tests were made with distilled water only, being manually stirred with a rubber stirrer for two minutes to homogenize the soil-water solution, followed by densimetric readings.

- According to the standard norm, in the sieving test the washing is done with water falling at low pressure, but in this case this washing was done carefully by immersion placing the sieve below the water surface in a larger diameter container containing water. The sieve was gently agitated in the water to avoid disaggregation or mechanical deflocculation of grains in the soil, and possible microaggregations generated by the action of chemical additives during the respective exposure times and/or during the sedimentation test.

The particle size distribution test was carried out for each of the chemical products used to correct the granulometric curves of the different mixtures. The correction consisted of removing the amount of fertilizer or lime that was not solubilized, that is, that was in suspension and that would intervene in the granulometric results of the soil itself.

The determinations of the Liquid Limit (LL) and Plastic Limit (PL) were performed following the procedures established in the standard norms [21] and [22], respectively. For its execution, the norms establish that the soil to be used must pass the sieve mesh number 40 (0.42 mm), but as the soil was with its natural humidity, this was not possible. Therefore, only the visually larger particles were removed to avoid inconvenience during the execution of the tests.

The profoundly weathered tropical soils, such as those from 1 m deep in the analyzed soil profile, are generally characterized by presenting aggregate particles with no defined orientation. On the other hand, in the 9 m deep soil, aggregations in the formation process can be found as well as clay packages and independent clay particles [23]. As the main objective of the study was to evaluate the impact of agricultural supplies and limes on the textural stability of the soil and at the Atterberg limits, the methodological adaptations presented were made.

3. Results

A specialized laboratory carried out the chemical analysis of the samples from the two depths studied. These results are presented in Table 1.

Table 1. Chemical composition of the soils analyzed in their natural state.

Chemical composition	Units	1 m	9 m
Phosphorus (P)	mg dm-3	2,6	0,5
Calcium (Ca)	cmolc dm-3	6	0,1
Magnesium (Mg)	cmolc dm-3	1	0,1
Potassium (K)	cmolc dm-3	5,5	0,01
Sodium (Na)	cmolc dm-3	0,6	0,03
Aluminum (Al)	cmolc dm-3	1	0,6
Acidity (H+Al)	cmolc dm-3	25	4,3
Sum of the bases	cmolc dm-3	13	0,2
CTC	cmolc dm-3	38	4,5
Saturation by bases	%	34	5
Saturation by Al	%	7	71
Saturation by Na	%	5	12
Organic carbon	g kg-1	5,1	0,1
Organic matter (OM)	g kg-1	8,8	0,2
Available Iron	mg kg-1	65,2	29,2

Figure 1 and 2 show the results of granulometry for the soil of 1 m and 9 m of depth mixed with 2% and 10% by weight of the chemical product, respectively. In these figures, it is shown a disaggregation of soil particles generated by the interaction with chemical additives, increasing the clay fraction and decreasing the content of larger grains in different degrees depending on the chemical product used. This phenomenon becomes more intense with the content increasing of fertilizers, affecting even more the texture of the saprolitic soil due to the chemical and structural characteristics mentioned above.

Considering that with the increasing concentration of agricultural supplies, greater is the change in the granulometry of the soil, the effect on the granulometric distribution of the compound SUC (Single Superphosphate + Urea + Potassium Cloride) was evaluated when mixed with Calcitic (C) and Dolomitic (D) Lime. These analyses were performed by adding to the soil 10% of the weight content of the compounds SUC, SUC + D and SUC + C, previously defined. Composing these mixtures, there is, therefore, in the SUC, 3.33% of Single Superphosphate, 3.33% of Urea and 3.33% of Potassium Chloride and in the mixtures SUC + C and SUC + D 2.5% of each of these components. These results are shown in Figure 3.
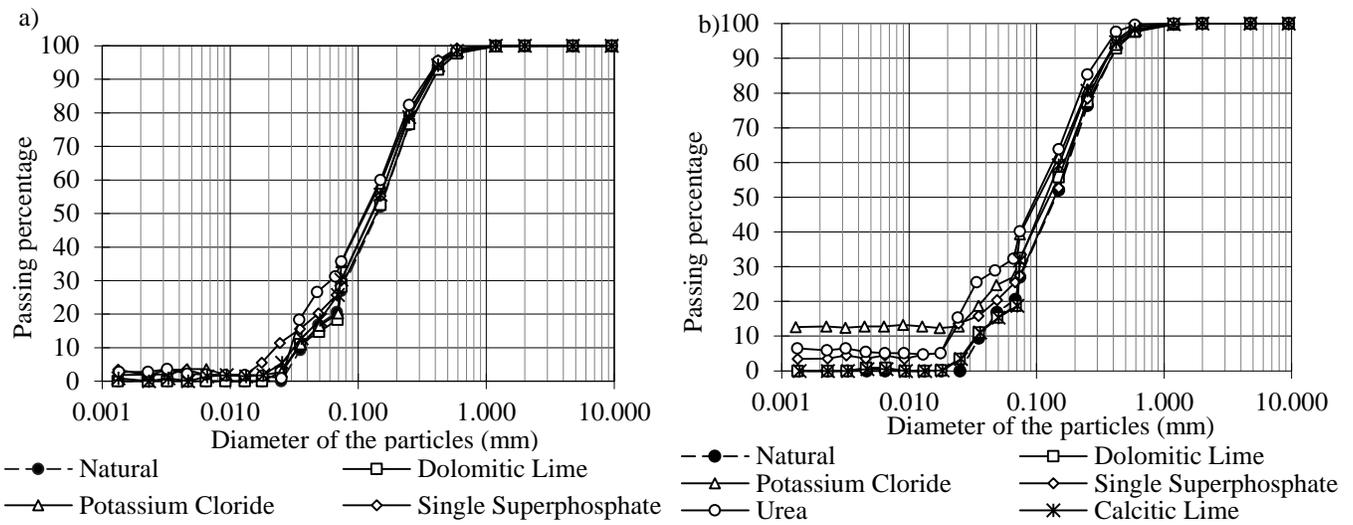
Figure 1. Soil of 1 m depth with (a) 2% and (b) 10% content of pure fertilizers and 24h exposure time.
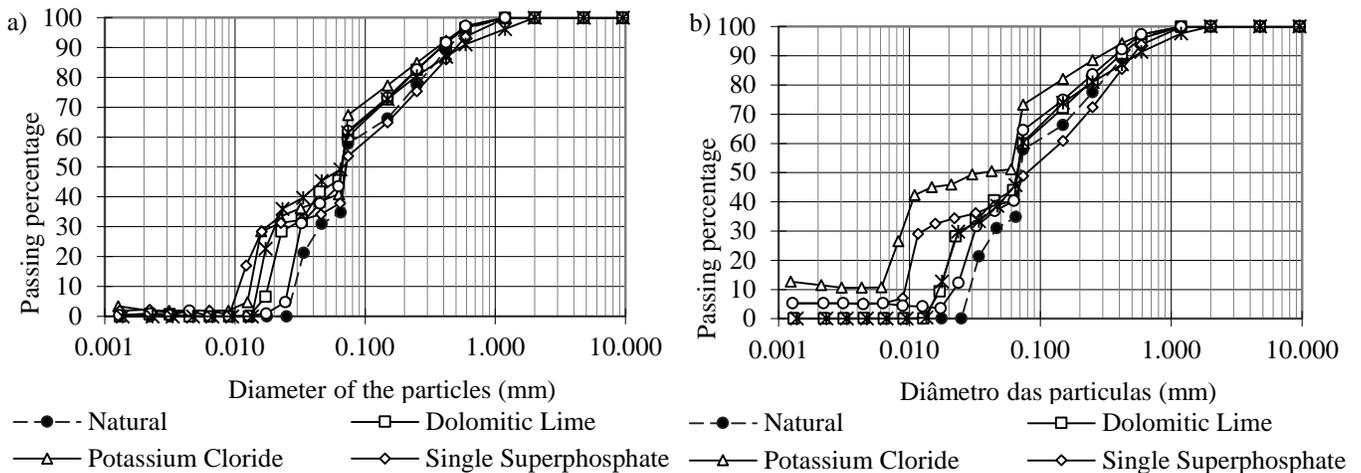
Figure 2. Soil of 9 m depth with (a) 2% and (b) 10% content of pure fertilizers and 24h exposure time.
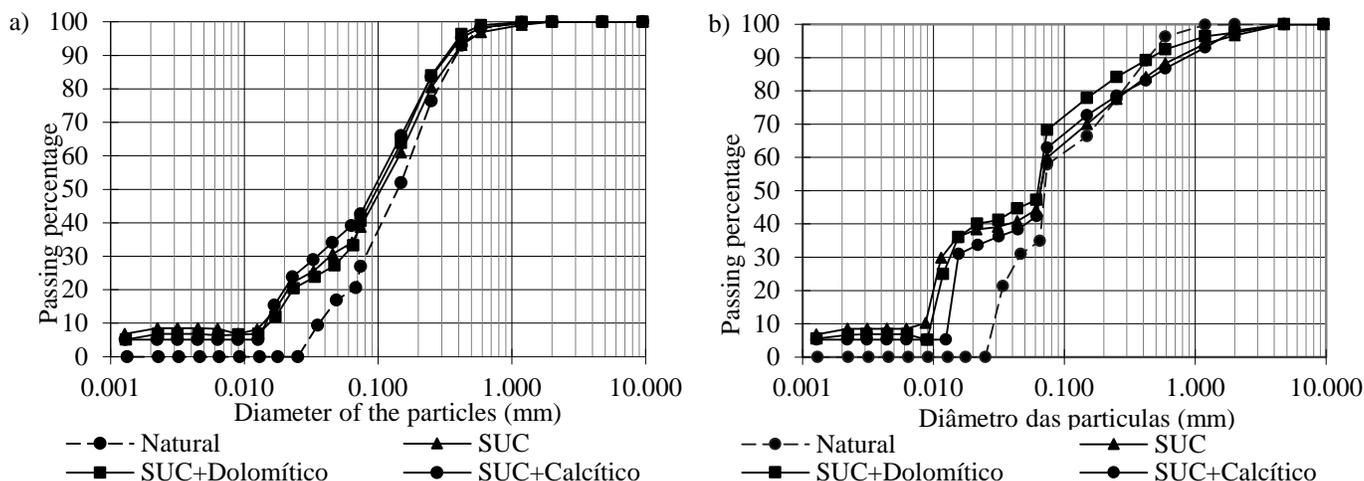
Figure 3. Soil of 1 m (a) and 9 m depth (b) mixed with 10% content of chemical compounds and 24h exposure time.

Table 2 presents the results of the Atterberg limits (LL and PL), for natural soil and for each mixture, with an exposure time of 24h and 10% by weight of each studied compound. The high content adopted aimed to maximize the effect of the additive on soil behavior.

Table 2. Results of Atterberg Limits for natural soil and each mixture evaluated.

	Mistura	1m	9m
	Natural	39 / 22	43 / 33
	Urea	40 / 21	46 / 32
	Dolomític L.	33 / 23	30 / 21
Liquid limit (LL) / Plastic limit (PL)	Single Superp.	29 / 23	27 / 20
	Calcític L.	35 / 24	33 / 20
	Potassium C.	31 / 14	23 / 16
	SUC	32 / 16	29 / 21
	SUC+D	33 / 16	30 / 21
	SUC+C	29 / 18	31 / 22

4. Discussion

Considering the results observed in Table 1 the low base saturation of the 9 m soil, together with the highest acidity value (H + Al), suggests the possibility of a greater ionic exchange during the reactions with chemical additives since it would be presenting smaller amounts of cations saturating the negative charges of the particles than the soil of 1 m depth. These characteristics make the transition soil more structurally sensitive to the presence of agricultural supplies than the lateritic soil.

The cation exchange capacity (CEC) of a soil depends on different factors, including the content of organic matter (higher OM, higher CEC), and the amount and type of clay that is part of the soil structure [24]. It should be noted that as this OM content decreases, CEC becomes more directly dependent on the mineralogical composition of the profile. According to table 1, the soil from 1 m depth has a higher value of both organic carbon and OM, but it is the 9 m depth that presents the highest CEC value. This is due to the fact that the most superficial layer presents a higher degree of weathering, being composed mainly of iron and aluminum oxide-hydroxides and clays of the type 1:1 such as kaolinite, which according to [24], has lower CEC (50 -150 mmolc dm-3) than those of type 2:1 such as Illite (100-500 mmolc dm-3), which is present in the lower layers of the profile studied [15] as is the case of the layer present at 9 m depth. This means that, in this case,

the mineralogical composition is prevailing over the OM content. It should be noted that the presence of a trace of organic matter and organic carbon at 9 m depth, signals the occurrence of migration by water flow through the profile.

Another way of confirming the aforementioned is evaluating the point of zero charge (PZC) of the soils, being in this case 5.7 for 1 m soil and 3.1 for the 9 m soil. It is known that organic matter contributes to the decrease of this indicator while iron and aluminum (gibbsite) oxide hydroxides contribute to its increase [25], for this reason, and considering that in the surface there is a greater amount of iron oxides, hydroxides and gibbsite than the soil of lower layers [15]. The fact that the depth of 1 m presents a higher PZC value even presenting a higher amount of OM, indicates that effectively in this case the mineralogy of soils exerts greater influence on chemical reactions than organic matter.

In lateritic soils the aggregates are more stable due to the weathering action that acted in the formation process and composition. In contrast, in the transition soils, the aggregates are generally still in the formation process and the clay packages have interaction between particles more linked to purely chemical-mineralogical factors. The disaggregation generated and shown in Figures 1 and 2 potentiates the surface erosion and the sealing of the micropores, which can affect the mechanical behavior of the material.

From [15], it is known that kaolinite is present along the studied weathering profile, increasing its content from 19% on the surface to 54% at 8 m - 9 m, depth from which the content tends to stabilize. The decrease in the kaolinite content when it advances to the surface of the ground, it is due to the greater intensity of the weathering that transforms it into gibbsite. Thus, gibbsite, in turn, its presents in a higher content in the most superficial layers, approximately 31% up to 3 m - 4 m deep, layers that regionally correspond to the most active zone, then decreasing to 8% to 9 m and tending to zero from 11 m.

The disaggregation shown in both depths (Figures 1 and 2) is notably greater with Potassium Chloride and, according to the lyotropic series of kaolinite [26], it prefers potassium for ionic exchange more than magnesium or calcium. Consequently, this could justify why Potassium Chloride was the one that generated the most significant changes in soil grain size, mainly in the transition soil, where there is a greater quantity of this clay mineral than in the soil of 1 m depth. It is also noteworthy that the ionic exchange can change the solution charge, making the connections a little weaker between the particles that make up the aggregates, thus facilitating the disaggregation of the soil.

On the other hand, the Single Superphosphate has 10% sulfur in its composition, so there is a possibility that when the soil-fertilizer mixtures come into contact with water, sulfates are generated, which according to [27], accelerate the dissolution of gibbsite. The dissolution process of this mineral would be causing an instability of the aggregates, finally contributing to the disaggregations presented in figures 2 and 3. In a lesser degree of disaggregation, Urea and the Dolomitic and Calcitic Limes follow.

In the results shown in the Figure 3, it is observed that the chemical compounds disaggregate the soil in a similar percentage, mainly in the area of particles with diameters between 0.075 mm and 0.010 mm. The disaggregation effect of compounds, compared with that of pure supplies, tends to be greater in the soil of 1 m. This may be due to the fact that the Single Superphosphate, when in contact with other chemicals, can generate more sulfates, which accelerate the dissolution of gibbsite, causing in this process greater instability of the aggregates. In the 9 m soil, the compounds generate an effect similar to that generated by Single Superphosphate but lesser to that caused by Potassium Chloride, because within their compositions there is only one-third of the amount of Potassium Chloride, in the case of SUC, and a fourth part, in the case of SUC + C and SUC + D, thereby generating less ionic exchange with kaolinite which is found in greater quantities at this depth.

The results presented in Table 2 show a significant decrease in the values of the Atterberg limits of the mixtures in relation to the values corresponding to the natural soil. Based on the analysis presented by [28], the decrease of these limits indicates that there is also a decrease in the resistance since the soils mixed with the fertilizers reach the two limits with lower moisture content. For example, in the humidity corresponding to the natural soil LL, the soil with fertilizers will withstand a smaller number of strokes than that corresponding (25 strokes) for that the open furrow closes, which means lower resistance. Urea was the only fertilizer that presented, at both depths, a higher LL than of the natural soil, indicating greater porosity and, consequently, a higher resistance in the same moisture compared to other mixtures.

From a practical point of view, these results are important, because they would be pointing to an easier release of particles with the superficial flow, which would modify the structure of the soil once it is dry. In the case of a slope, the advance of

the contamination by agricultural supplies can lead to its instability by resistance loss, but this is a topic that deserves further studies. In this case, it is not possible to directly associate these processes to soils with different textures and compositions but rather similar soil in the presence of chemical compounds that could destabilize it.

4. Conclusions

The interaction between compounds and soil particles affected the texture, which can affect the mechanical behavior of the soil.

The chemical-mineralogical composition of the soil is an important factor in the intensity of the effect generated by fertilizers on it.

In the specific case of limes mixed in the lateritic soil, there were no significant variations in the results of granulometry neither in the PL; instead, the LL decrease by approximately 5%. On the contrary, in the 9 m deep soil, there was a decrease in the minimum particle diameter, from 0.025 mm to 0.013 mm. Also, it was generated an increase in the percentage that passes of several particle diameters, mainly with the calcitic lime with the dosage of 2% reaching differences of up to 36% with the soil without treatment.

Specifically, in lateritic soil, Potassium Chloride at 2% content presented a behavior very similar to the natural soil, but with 10%, it presented a considerable disaggregation reaching for particle diameters less than 0.02 mm a difference of 12% of passing material with respect to the untreated soil. In the case of mixtures with Single Superphosphate and Urea, the disaggregation was evident for some particle sizes being the difference in percentage with the natural soil approximately 10%. For the soil of 9 m depth, Urea did not generate significant differences along the entire granulometric curve. Contrary to what was obtained with Single Superphosphate, where there was disaggregation between the diameters of particles 0.03 mm and 0.009 mm, being the maximum difference with the natural soil of 32% when the dosage of 10% of chemical product is used. Potassium Chloride was the fertilizer that generated the greatest disaggregation along the entire curve, which is more pronounced with the dosage of 10%, reaching a difference of up to 49% of material that passes comparing to the natural soil. Finally, in the mixtures with the 3 compounds, the disaggregation effect was similar, being higher in the dosage of 10% and having between 35% and 40% additional of particles between 0.05 mm and 0.01 mm.

For all mixtures were obtained values of the Atterberg limits much lower than those of the natural soil, this difference is of approximately 10% for limestones and 7% for all fertilizers. In the specific case of Urea, the limits were very similar to those of the natural soil.

The agricultural supplies and limes used, altered the physical properties of the two types of soils evaluated, generating mainly disaggregation.

Acknowledgements

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