Ciencia & Futuro V. 15 No. 1. Mars-May 2025 p. 1-14 ISSN: 2306-823X
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Received: 20/11/2024/Accepted: 31/01/2025

Evaluation of moisture retention in lateritic soils by applying agrominerals

Evaluación de la retención de humedad en suelos lateríticos mediante la aplicación de agrominerales

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Abstract: The influence of water absorption and retention capacity of the soils of University of Moa's organoponic garden, with the addition of agrominerals, was evaluated. For this purpose, the gravimetric humidity analytical method was applied. The geological materials used in the experimental tests are vitreous tuffs, zeolitized tuffs loaded with ammonia residue, calcilutites and lateritic soil. The results show that calcilutite, having a low porous structure, holds a poor absorption capacity; while tuffs, rich in absorbing minerals, exhibit a higher water retention capacity.

Key words: urban agriculture, natural minerals, agricultural productivity

Resumen: Se evaluó la influencia de la capacidad de absorción y retención de agua en los suelos del organopónico de la Universidad de Moa, con la adición de agrominerales. Para el mismo, se emplea el método analítico de la humedad gravimétrica. Los materiales geológicos que se emplean en los ensayos experimentales son tobas vítreas, tobas zeolitizadas cargadas con residuo amoniacal, calcilutitas y el suelo laterítico. Los resultados muestran que las calcilutitas, con su estructura poco porosa, presentan baja capacidad de absorción, mientras que las tobas, ricas en minerales absorbentes, exhiben mayor capacidad de retención de agua.

Palabras claves: agricultura urbana, minerales naturales, productividad agrícola

Introduction

The search for sustainable solutions to improve agricultural productivity and soil quality is a global priority today**.** Sustainable agriculture is key to guaranteeing food security and natural resources protection for future generations. In this sense, agrominerals are presented as an innovative and promising option to address these challenges (Domingo Santos, 2006; Jiménez Ramírez, 2018).

Agrominerals are natural mineral materials that can significantly improve the physical, chemical, and biological characteristics of soil (Beltrán *et al.,* 2019; Trigo Zapotoski & Ferreira, 2023). This sustainable approach is particularly relevant in modern agriculture, where proper soil management is vital to maintain crop productivity and agricultural ecosystems' long-term health. Orozco Melgar & Cuza Fernández (2022) highlight their importance for the improvement of lateritic soils of Moa, in Holguin province.

Soil is an essential and non-renewable natural resource, whose formation and recovery are slow processes. It plays a critical role in agriculture by providing nutrients, water, and support to crops, as well as by participating in water, nitrogen, carbon, and phosphorus cycles. However, inadequate management in agricultural systems can disrupt soil chemical properties, affecting its fertility and reducing crop yield (Ferreras *et al.,* 2015).

Moa's lateritic soils insufficient water storage directly impacts plants growth and agricultural productivity. This difficulty in water retention can compromise the success of food programs and negatively affect the local economy development (Cuza Fernández, 2023). Therefore, it is imperative to find effective solutions to improve these soils water retention capacity.

Zeolites are used to improve soil quality for agriculture (Sobus *et al.*, 2020; Torri *et al*, 2021; Thatikayala, Noori & Min, 2023; Affendi *et al.*, 2023; Umejuru *et al.*, 2023; Turki, Hamdouni & Enesca, 2023; Maubert, Rojas & Castañeda, 2024).These minerals structure is crossed by countless channels that make them a true sieve, which largely determines their most important properties such as cationic exchange, adsorption (as a physical process), and their hydration-dehydration capacity (Díaz, Liriano & Abreu, 2019).

Application of fertilizers produced from carbonated rocks, vitreous and zeolitized tuffs constituent minerals, with the addition of an ammonia residue from CARON technological process, has been proposed as a local solution to sustainably improve soil quality. This approach, proposed by Orozco & Cuza (2022), provides essential chemical elements to the lateritic soil such as nitrogen, magnesium, and calcium to improve its water retention capacity and provide plants with the necessary nutrients for their optimal growth.

Soil moisture retention capacity is a crucial aspect that influences plant growth, soil health, and proper water management in various environmental systems. Weil and Brady (2017) emphasize the importance of this physical parameter which describes the amount of water the soil can retain against the force of gravity.

The aim of this paper is to evaluate the influence of water absorption and retention capacity of lateritic soil, with the addition of an agromineral, on the agricultural productivity of the University of Moa's organoponic garden by using the gravimetric moisture method.

Materials and methods

As expressed by Riverón, Rodríguez & Linares (2009), moisture is a parameter that varies over time and increases with depth. The lowest values are found in the upper part of the cut, called ferralite or ferricrete. This zone has the largest granulometric particle size and is exposed to drying processes due to evaporation and wind.

To better understand this phenomenon in the soils of the university's organoponic garden, the chemical and mineralogical characteristics of a lateritic profile upper layer (*in situ*) were analyzed (Riverón, Rodríguez & Linares,2009).

Upper limonitic zone (ferralite or ferricrete): The layer thickness varies between 0.2-15 m. Sand fraction can reach up to 5%. Pores water pH is slightly acid (5.1-6.5). The predominant mineralogy is iron oxide and hydroxide (hematite and goethite) (Table 1).

Table 1. Predominant chemical elements in the upper limonitic zone (Riverón, Rodríguez & Linares, 2009).

Ni	Fe	Mg	Cr	Al	Mn	Co
< 0,7 %	35-50 %	1-5 %	1-3 %	5-10 %	> 1 %	0,01-0,07%

The raw materials used to produce the agromineral were mineralogically composed mostly by minerals from the zeolite group in its clinoptilolite-heulandite and mordenite phases in zeolitized tuffs, volcanic glass and montmorillonite clays in vitreous tuffs, carbonate material in the calcilutites, and the ammonia residue resulting from nickel processing. These materials chemical composition is shown in tables 2, 3, 4, and 5.

Table 2. Chemical analysis results. Zeolitized tuffs from San Andrés (Almenares Reyes, 2011)

Oxide	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
%	65,55	0,276	11,75	1,43	2,824	0,947	1,376	1,677

Table 3. Chemical analysis results. Volcanic Glass from Sagua de Tánamo (Almenares Reyes, 2011)

Oxide	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
%	60,86	0,49	13,63	4,58	5,34	2,64	1,87	2,27

Table 4. Chemical analysis results. Calcilutites from Yaguaneque (Cuza-Fernández, 2023)

Oxide	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MnO_2	K_2O
%	3,02	ND	1,77	1,34	52,22	0,04	2,27

Table 5. Chemical composition of ammonia residue from Che Guevara Company (Aguirre, 1999)

NH_3 (mg/L)	Ni (mg/L)	Co (mg/L)	Fe (mg/L)	Mg (mg/L)
1,500 a 2000	30-40	0,25–0,3	0,1–0,15	0,6–0,7

Materials and methods

The research was developed into three stages: 1) Fieldwork; 2) Laboratory tests; 3) Desk work.

Fieldwork

The fieldwork involved the recognition, location, and extraction of raw materials for the production of an agromineral. This soil improver is made of zeolitized tuffs from San Andrés deposit in Holguín province, vitroclastic tuffs from El Picao deposit in Sagua de Tánamo municipality, carbonated rocks from Yaguaneque deposit in Moa municipality, and ammonia residue from Ernesto Che Guevara nickel processing plant.

Zeolitized tuffs' granulometry was reduced from 1 to 3 mm, according to Soca & Daza-Torres (2016) recommendation for its use in agriculture; the vitroclastic tuffs were reduced from 0.1 to 0.8 mm, as recommended by Cuza-Fernández (2023); while the calcilutites and the lateritic soil were used in their natural granulometry. Twelve samples were prepared for laboratory tests by mixing lateritic soil with the agromineral at a 20 cm depth.

Sample preparation and laboratory tests

The samples were analyzed in the University of Moa's Hydrogeology laboratory. Two experiments were carried out: the first under natural conditions, using eight samples consisting of different lateritic soil combinations: laterites plus calcilutites, laterites plus vitreous tuffs, laterites plus zeolitized tuffs; and the second under water-saturation conditions in the laboratory, using four simple samples from these materials.

The first experiment involved adding 20% of water above of the-samples-obtained-in-the-field volume. Afterwards, they were weighed on a 120-grams-maximum-capacity analytical scale to obtain their initial wet weight. Then, they were placed in a muffle furnace at 105°C for 6 hours and were weighed again to obtain their final dry weight. Next day, this same procedure was repeated to determine their weight variation and, therefore, their moisture loss/day.

The second experiment consisted of drying the samples in an oven until they lost their total natural moisture. Then, they were added 20 ml of water and the first weighing was carried out to obtain their initial wet weight. Over the next four days, the samples were weighed on a scale to determine these materials moisture retention at room temperature. Muffle furnace, analytical scale, and beaker were the materials used in the sample weighing and drying processes.

Desk work

In this stage, the data obtained in the laboratory tests were processed to determine water absorption and retention capacity by using the Gravimetric Moisture analytical method (%). This method involves measuring the soil water content by weight, expressing the results as a percentage of moisture relative to the dry soil mass or in grams of water per gram of dry soil, which is a way of expressing the soil water content by measuring its total weight. The equation used to calculate gravimetric moisture is:

$$Wp = \frac{qh - qs}{qh} \times 100$$

Where

Wp: weight's moisture, (%)

qh: wet sample weight, (g)

qs: dry sample weight after drying in the muffle furnace, (g)

Results and discussion

Based on the study conducted at the University of Moa, the lateritic soil water absorption and retention capacity was evaluated after applying agrominerals, in order to improve agricultural productivity and soil fertility.

Figure 1 reveals that vitreous tuffs show a lower weight loss compared to other materials during the drying process at 105 degrees. This phenomenon may be related to vitreous tuffs water retention capacity, which may be due to the presence of pores in their structure or the high content of montmorillonite clay.

It is advisable to perform additional analyses such as these materials water absorption, porosity, and density tests. The data obtained contribute to a better understanding of the relationship between the vitreous tuffs structure and their water retention capacity.

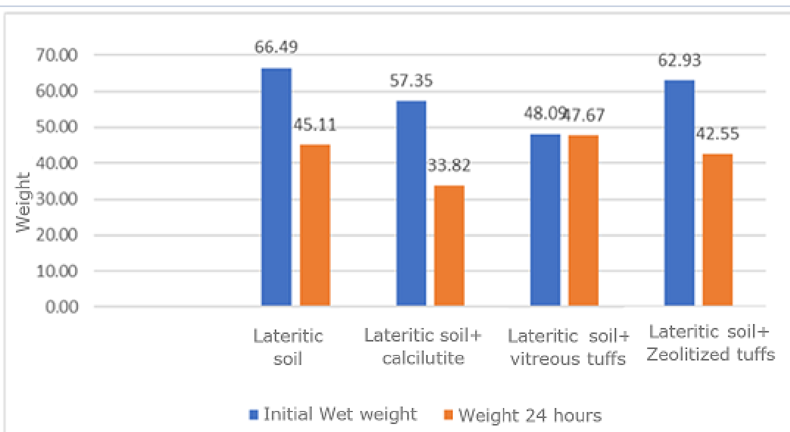

Figure 1. Water loss.

The analysis of the graph in Figure 2, which shows the normalized gravimetric water loss versus the dry weight at 105 degrees, reinforces the conclusion previously established in relation to vitreous tuffs and their water retention capacity. In this case, it is observed all materials show a marked tendency to lose water, but the lowest values correspond once again to vitreous tuffs, suggesting that the presence of pores in their structure is a determining factor in their behavior during the drying process.

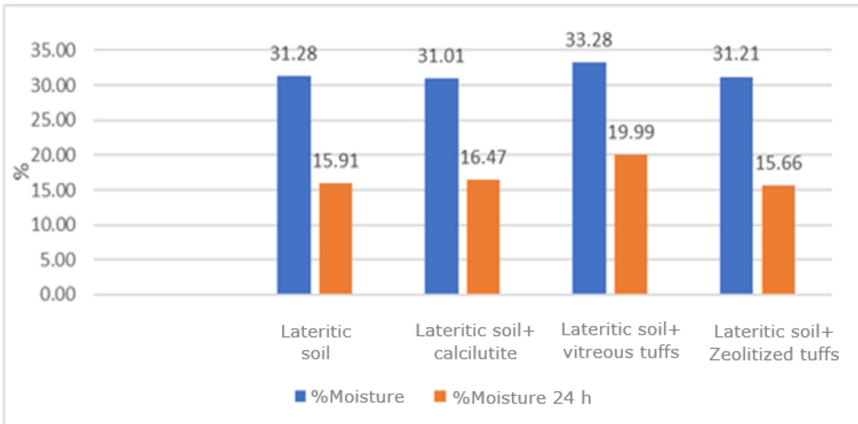

Figure 2. Gravimetric water retention.

The analysis of the graph in Figure 3, showing the correlation between weight loss in grams during drying at 105°C and the normalized gravimetric water retention measurement at that same temperature, provides additional information on the relationship between these two factors and how they relate to water retention properties of the materials, especially in the case of vitreous tuffs. This suggests that the amount of water a material can retain is directly related to the amount of liquid it loses during the drying process.

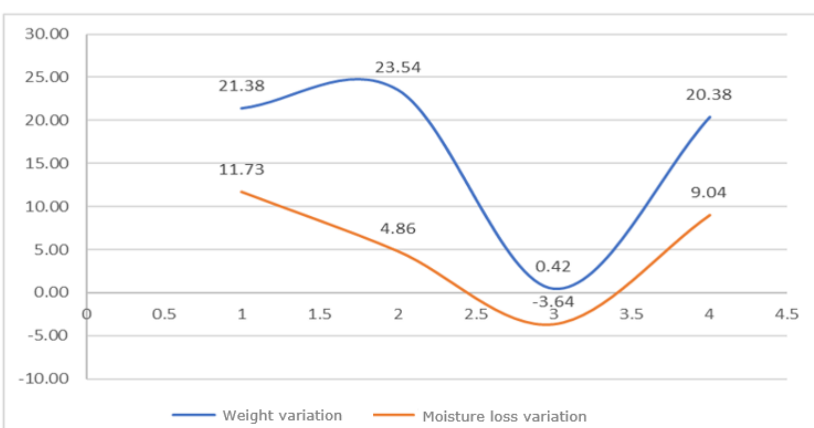

Figure 3. Correlation between weight loss and gravimetric water retention.

Up to this point, the four materials' capacity to retain water under natural conditions has been evaluated, attaining contact of the materials in the field with water, but not saturating the samples. The different materials' water saturation under artificial (or laboratory) conditions may offer different results.

Graph in Figure 4 shows the tendency to lose water over a 4-days period in water-saturated materials. First, it is observed both vitreous tuffs and zeolitized tuffs evidence the greatest tendency to retain water. This reinforces what was discussed earlier about vitreous tuffs' water retention capacity based on their porosity. However, it is pointed out that zeolitized tuffs present a better tendency to retain water compared to vitreous tuffs in this specific situation.

The zeolitized tuffs' superior water retention capacity under saturation conditions is attributed mainly to the presence of absorbent minerals in their composition, such as montmorillonite clays and minerals from the zeolite group, which contribute to improving water absorption and retention phenomena in this type of material.

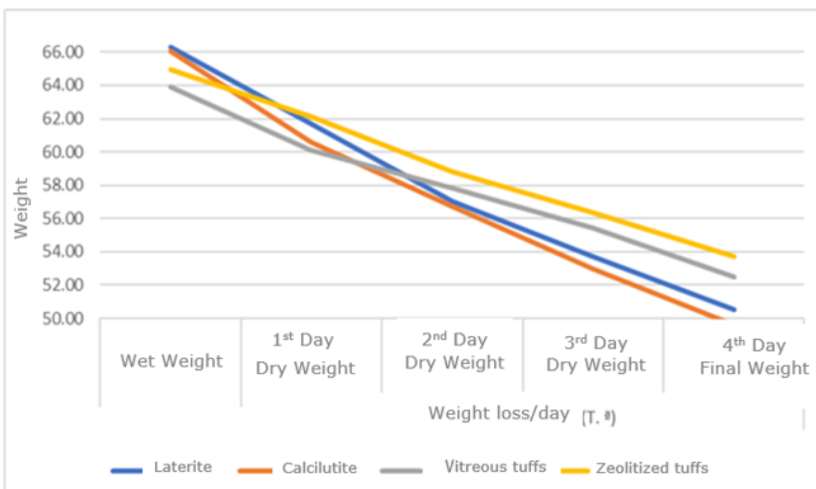

Figure 4. Weight loss tendency.

The analysis of graph in Figure 5 illustrates the amount of water (by weight) absorbed by the different materials after saturation in the laboratory. From the comparison between the materials initial dry weight and their weight after saturation with water, it can be established that all materials are capable of absorbing water, but calcilutites are the ones presenting the greatest limitations in this aspect.

In line with the previous findings, it can be concluded calcilutites generally exhibit the worst water absorption and retention values compared to the other materials under study. This result is mainly due to the lack of effective porosity in their structure, which does not allow liquid absorption. This is also related to their mineralogical composition, as calcilutites do not present absorbent clay minerals that allow moisture retention.

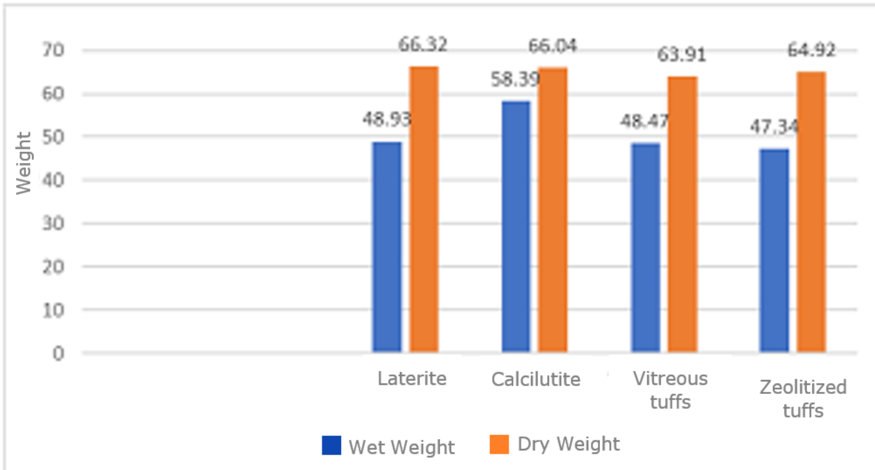

Figure 5. Water absorption capacity.

The analysis of the graph in Figure 6 presents the gravimetric water retention normalized to the dry weight of the experiment. Once again, it can be observed that tuffs, especially zeolitized tuffs, are the materials retaining the largest amount of water; which is related to the presence of zeolitic minerals in their composition. Besides, their porous structure favors liquid absorption and retention.

In contrast, calcilutites exhibit negative values regarding gravimetric water retention, indicating they can easily lose the water they are able to absorb. It is interesting to note that, from the second day of the experiment on, calcilutites weights are lower than the dry weight obtained on the first day, which suggests these materials are capable of completely naturally dehydrating, possibly due to their poor water retention capacity.

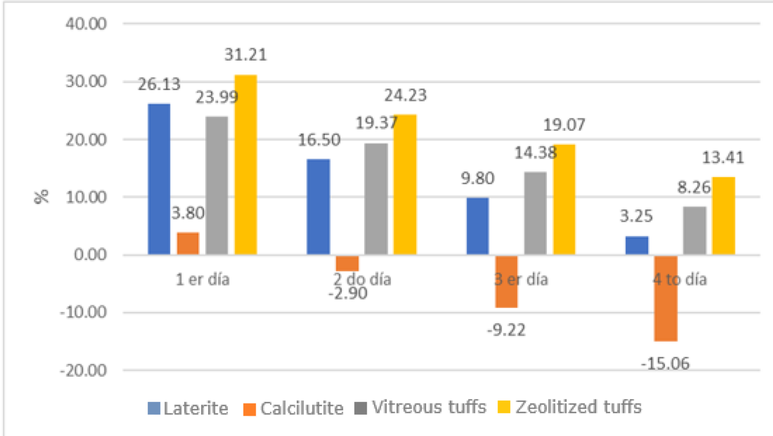

Figure 6. Gravimetric water retention.

Up to this point, various geological materials water absorption and retention properties detailed analysis, including calcilutites, vitreous tuffs, zeolitized tuffs, and laterites has been carried out. The analysis of the gravimetric water retention normalized to the dry weight of the experiment confirms tuffs are the materials retaining the largest amount of water, while calcilutites show a greater tendency to lose moisture.

The experiments results show that calcilutites present the worst water absorption and retention capacities among the materials studied, probably due to their mineralogical composition and low-porosity structure. In contrast, vitreous and zeolitized tuffs exhibit a greater capacity to retain water due to the presence of absorbent minerals such as montmorillonite clays and zeolites, in addition to their favorable porous structure.

Tables 6 and 7 reflect the statistical results of the tested samples, both under natural conditions and water saturation. They show the wet sample initial weight and the dry sample final weight, their weight variation over time, the materials water absorption capacity, and retained moisture percentage.

Table 6. First experiment's statistical results

Mixure	Initial weight	Weight 24 hours	Weight variation	Final dry weight	Final dry weight 24h	Moisture loss variation	Moisture percentage	Moisture percentage 24 h
Lateritic soil	66,49	45,11	21,38	50,65	38,92	11,73	31,28	15,91
Lateritic soil + calcilutite	57,35	33,82	23,54	43,78	29,04	4,86	31,01	16,47
Lateritic soil + vitreous tuffs	48,09	47,67	0,42	36,08	39,73	-3,64	33,28	19,99
Lateritic soil + vitreous tuffs	62,93	42,55	20,38	47,96	36,79	9,04	31,21	15,66

Table 7. Second experiment's statistical results

Materials	Dry weight	Wet weight	Weight loss/day			
			Dry weight 1er day	Dry weight 2do day	Dry weight 3er day	Final weight 4to day
Laterite	48,93	66,32	61,72	57,00	53,72	50,52
Calcilutite	58,39	66,04	60,61	56,69	53,01	49,60
Vitreous tuffs	48,47	63,91	60,10	57,86	55,44	52,47
Zeolitized tuffs	47,34	64,92	62,12	58,81	56,37	53,69

Conclusions

Based on the chemical and mineralogical analyses carried out by previous studies, it was recognized that the lateritic soil of the University of Moa's organoponic garden holds high contents of iron oxides and hydroxides (35-50 %) represented by hematite and goethite. Vitreous tuffs have high values of silica (60.86 %) and a predominance of clay group minerals, mainly montmorillonite. Zeolitized tuffs have a high silica content (65.55 %) and are represented by minerals from the zeolite group in their clinoptilolite-heulandite and mordenite phases. In the case of calcilutite, it contains high values of calcium (52.22 %) and is mineralogically represented by minerals from the actinolite-tremolite group.

It was determined that the materials with the best water retention and absorption capacity are vitreous tuffs, with a 19.99 % after 24 hours under natural conditions, and zeolitized tuffs, with a 13.41 % after four days under water saturation conditions in the laboratory. This is due to the presence of a porous structure and the content of clay and zeolitic minerals, unlike calcilutites which do not present physical and mineralogical properties that allow moisture retention and water storage.

The conducted experiment contributed positively to achieving a greater increase in agricultural productivity in University of Moa's organoponic garden. The moisture retention capacity in these materials allowed for a higher yield in crops, which gained the necessary water for their growth and development. In addition, they benefited from the absorption of nutrients rich in nitrogen, magnesium, and calcium content, which also helps to decrease soil acidity and increase land fertility.

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