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Physical properties of AGROMENAS - G and NEREA fertilizers produced at the Empresa Geominera del Centro

Propiedades físicas de los fertilizantes AGROMENAS-G y NEREA producidos en la Empresa Geominera del Centro

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ABSTRACT: The performance of fertilizer spreaders during mechanized fertilizer application depends on their physical properties. Therefore, it is essential to understand the properties of any new fertilizer. This study aimed to determine the physical properties of AGROMENAS - G and NEREA fertilizers, which influence their mechanized application. The methodology used included determining the particle size distribution, bulk density, moisture content, and angle of repose of the material using well-known methods available in the scientific literature. The results showed that the NEREA zeolite-based fertilizer has a particle size distribution in which 72.61% of the material has particle sizes between 2 and 4 mm, that the bulk density of the material is 1120 kg m^{-3}, the moisture content is 6.03%, and the angle of repose is 31.12°. AGROMENAS - G, on the other hand, has a particle size distribution where 56.6% of the material has particle sizes less than 1 mm, the bulk density is 1350 kg m^{-3}, the moisture content is 6.06%, and the angle of repose is 29.34°.
Keywords: particle size distribution, bulk density, angle of repose.

RESUMEN: El desempeño de las fertilizadoras durante la aplicación mecanizada de fertilizantes depende de las propiedades físicas de estos. Por lo tanto se hace necesario conocer estas propiedades de cualquier fertilizante nuevo. El presente trabajo se realizó con el objetivo de determinar propiedades físicas de los fertilizantes AGROMENAS - G y NEREA, que influyen en su aplicación mecanizada. La metodología empleada incluyó la determinación de la granulometría, densidad aparente, humedad y ángulo de reposo del material, a partir de la utilización de métodos conocidos y disponibles en la literatura científica. Los resultados mostraron que el fertilizante en base a zeolita NEREA, tiene una granulometría donde el 72.61% del material tiene tamaños de partícula entre 2 y 4 mm, que la densidad aparente del material es de 1120 kg m^{-3}, la humedad es de 6.03% y el ángulo de reposo de 31.12°. Por otra parte, la AGROMENAS - G, tiene una granulometría donde el 56.6% del material tiene tamaños de partícula inferiores a 1 mm, la densidad aparente del material es de 1350 kg m^{-3}, la humedad es de 6.06% y el ángulo de reposo de 29.34°.
Palabras clave: granulometría, densidad aparente, ángulo de reposo.

INTRODUCTION

Zeolites are natural rocks with exceptional physical properties, thanks to their crystalline structure, which is crisscrossed by countless channels that make it an effective sieve. This three-dimensional grid largely determines their most important properties: high levels of cation exchange and ion selectivity, high absorption capacity, reversible hydration-dehydration, high thermal stability, and resistance to aggressive agents (Rodríguez *et al.*, 2011; Díaz *et al.*, 2019).

Zeolite is made up of silicate tetrahedra SiO_4 (four oxygen ions surrounding a central silica or aluminum ion) linked by oxygen atoms, such that part of the silicon atoms are replaced by aluminum atoms, forming AlO_4. This generates a typical spatial structure, with a considerable number of cavities linked by small channels where metal cations or water molecules are placed. They are crystalline and porous aluminosilicates, allowing ion exchange without changing their atomic structure (Paredes *et al.*, 2013; Ferrán & Núñez, 2023).

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The application of zeolites to soil improves its physical and chemical properties, especially those related to the cation exchange capacity (CEC) in the root zone or rhizosphere (Osuna *et al.*, 2012; Días & Núñez, 2016; Soca & Daza, 2016). Due to its high ion exchange capacity, zeolite increases the soil's ability to retain essential nutrients (Ca^{2+}, K^{+}, Mg^{2+}, $NH4^{+}$), gradually releasing them to the roots and reducing losses through leaching. It allows the soil to retain moisture, gradually releasing it to plants. This improves water availability and reduces irrigation frequency, especially valuable in sandy soils or in areas with frequent droughts. When incorporated into the soil, zeolite improves porosity and aeration, prevents compaction, and facilitates drainage, which promotes root development and prevents disease. By retaining and slowly releasing nutrients, it reduces the need for and frequency of chemical fertilization, improving fertilizer efficiency and reducing environmental pollution (Paredes *et al.*, 2013; Ferrán & Núñez, 2023; Muñiz *et al.*, 2024).

The limited availability of chemical fertilizers in Cuba, due to their high international market prices, leads to low yields, among other associated causes. In the case of sugarcane, only 32.8 t ha^{-1} were obtained in the seasons 2022 (ONEI, 2024).

The Universidad Central "Marta Abreu" de Las Villas is coordinating a research project within the National Program for the Development of the Sugarcane Agroindustry, funded by the Ministry of Science, Technology and Environment. It is entitled "Increasing sugarcane (*Saccharum* spp.) production through the use of organomineral fertilizers and a domestically produced biostimulant." The fertilizers referred to in the project are AGROMENAS - G and NEREA (both zeolite-based), which could be used to compensate for the nutrient deficiency in sugarcane soils.

The application of fertilizers to sugarcane, due to the large number of hectares of soil that must be fertilized in short periods of time, makes the use of agricultural mechanization essential. However, the physical properties (granulometry, apparent density, angle of repose) of these fertilizers differ from those traditionally applied to sugarcane. Therefore, it is necessary to know the physical properties of AGROMENAS - G and NEREA fertilizers that influence the mechanized application of these products. Based on these elements, this research is carried out with the objective of determining the physical properties of AGROMENAS - G and NEREA fertilizers that influence their mechanized application.

MATERIALS AND METHODS

The trials were carried out at the Soil and Biofertilizers Laboratory of the Agricultural Research Center, which belongs to the Faculty of Agricultural Sciences of the Central University "Marta Abreu"de las Villas, in the period between September 2023 and September 2024. The samples used were from AGROMENAS - G and NEREA from a production batch of the Empresa Geominera del Centro.

Methodology used to determine particle size distribution

The procedure described in NC ISO 5690-1 (2004), (Rutland, 1986) and IFDC (2016). was used as a reference.

Materials used

- Sieves of the following sizes: > 4 mm; > 2 mm < 4 mm; > 1 mm < 2 mm; > 0.5 mm < 1 mm; > 0.25 mm < 0.5 mm; > 63 microns < 0.25 mm; < 63 microns.
- AERN brand digital scale with a precision of 0.001 g.
- KARL KOLB brand sieve shaker (Figure 1).

Figure 1. Sieve vibrator used for determining particle size distribution.

To conduct the test, 500 g of the product was weighed on a digital scale. It was then placed on the 4 mm sieve in the sieve shaker. The other sieves were placed in decreasing order of sieve opening size, with the largest sieve at the top. After the material was placed on the top sieve, the shaker was operated for five minutes. After the material had passed through the sieves, the product present in each sieve was collected and taken to the scale, where the contents of each sieve were weighed, and the percentage of each particle size was obtained.

The fertilizer size guide number was also determined as the particle size in mm at which 50% of the particles are retained (median), multiplied by 100 and rounded to the nearest multiple of five (IFDC, 2016).

Methodology used to determine bulk density

Bulk density (kg m^{-3}) was determined as the ratio of the sample weight to the volume occupied by the sample. The fertilizer sample was placed in the test tube, and the product was leveled within the test tube until a uniform surface was obtained. The test tube with the material was then weighed, and the weight of the test tube was subtracted to obtain the net weight of the sample. This procedure was repeated three times, and the average bulk density was finally obtained.

Methodology for determining fertilizer moisture

Fertilizer moisture was determined using the gravimetric method. Three fertilizer samples were taken and weighed on a precision balance (wet fertilizer weight) to 1 g. They were then dried in an oven at 105°C. Once their weight remained constant, they were weighed, and the dry weight was obtained. Moisture was obtained as the percentage of water (liquid fraction) divided by the soil (solid fraction).

Methodology for determining the angle of repose of the material

To determine the angle of repose, the material to be used was placed in the sun to dry. A 25 mm diameter funnel was placed on a stand, and the fertilizer sample was poured from it onto a flat surface. The height of the cone (H) was measured, the diameter of the cone base was marked, and its inclined length was measured. The angle of repose was obtained as the arctangent of the cone height divided by the radius (r) of the cone base (Figure 2). This test was repeated three times, and the average angle of repose was obtained.

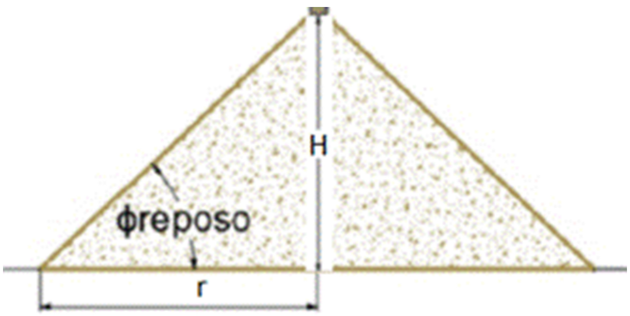

Figure 2. Scheme for determining the angle of repose.

RESULTS AND DISCUSSION

Particle size distribution

Figure 3 shows the particle size distribution of NEREA fertilizer. Most of the grains, exactly 72.61%, are between 2 and 4 mm in size. NEREA is not an ordinary chemical fertilizer; it consists of zeolite with a 1.4 to 10% complete NPK fertilizer formula.

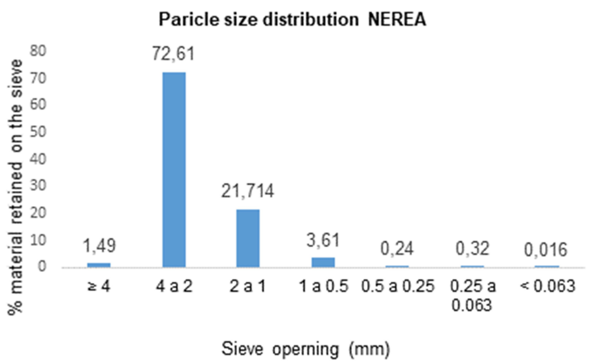

Figure 3. Particle size distribution of NEREA fertilizer

Rodríguez & Caisés (2023) report that the particle size distribution of NEREA was between 1 and 4 mm, coinciding with the results found here given that 94.32% of the product's granulometry is within this range. These authors suggest that this fertilizer is not water-soluble, since it is mainly made up of zeolite, a non-soluble material. Its use by the plant is fundamentally based on the properties of zeolite to retain water and nutrients that are subsequently slowly delivered to the plants. Díaz et al. (2019) refer to the fact that zeolite grain dimensions of three millimeters together with urea or another chemical fertilizer are the most effective to optimize its efficiency and crop yield.

Figure 4 presents the results of the particle size distribution of AGROMENAS - G. As can be seen, 56.6% of the grains are smaller than 1 mm, which is why they are considered to have a fine particle size. The effect of grain size on the level of use made by plants depends on factors such as the crop species, soil properties, physical properties of the fertilizer or manure, and the technology used for its application (Guerrero, 2004).

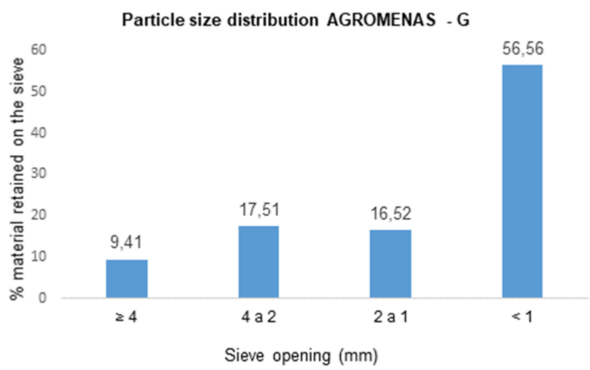

Figure 4. Particle size distribution of fertilizer AGROMENAS - G.

This distribution of grain dimensions could influence the broadcast application of AGROMENAS - G, since grain sizes less than one millimeter increase the unevenness of application and decrease the working width when the product is broadcast applied (Carciochi & Tourn, 2017).

Carciochi & Tourn (2021) consider the main factor affecting the distribution of solid fertilizers and amendments to be the grain size or particle size distribution of the product. Larger fertilizer particles are propelled by the distribution body to a greater distance than smaller particles. The centrifugal force on the particles is proportional to their mass.

The size guide number (SGN) for NEREA is 200, and for AGROMENAS - G it is 100. The SGN is required to determine the physical blendability of fertilizers. A large difference in SGN (greater than 20%), such as that obtained between NEREA and AGROMENAS - G, which is 50%, makes the fertilizers incompatible for physical blending. A difference greater than 20% in SGN causes fertilizers to respond differently to the forces acting on them during storage, handling, transportation, and application.

The vibrations and forces acting on the different particle sizes present in a physical mixture will cause material segregation. This occurs inside the fertilizer spreader hoppers during fertilization (Figure 5). The smaller grains tend to accumulate in the center and top of the pile, while the larger ones will accumulate at the base and on the outside. The greater the uniformity of the product's particle size, the lower the segregation at the time of application, and therefore a more uniform distribution of the fertilizer will be achieved (Carciochi & Tourn, 2021).

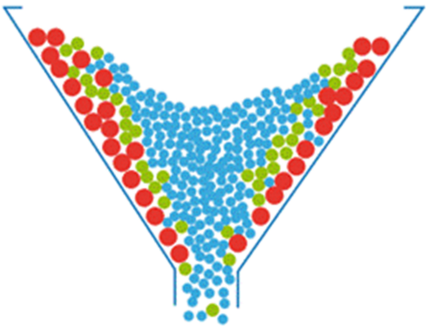

Figura 5. Fertilizer segregation inside the fertilizer spreader hopper. Coarser particles (red) remain on the hopper walls, and smaller particles (blue) remain in the center (Carciochi & Tourn, 2017).

Blended granular fertilizers are commonly applied using rotating disc spreaders. Distribution uniformity is critical; site-specific application machines utilize global navigation satellite-based guidance systems that allow equipment to follow the same field paths over time. However, variations in the physical properties of fertilizer components make uniform dispersion difficult, leading to segregation, which negatively impacts precision application (Thaper *et al*., 2021).

Bulk Density

Bulk density is defined as the weight of the product per unit volume in bulk, generally expressed in kg m^{-3}. Bulk density is a measure of the density, porosity, and voids between the material's particles (IFDC, 2016).

The bulk density of NEREA was 1120 kg m^{-3}, and that of AGROMENAS - G was 1350 kg m^{-3}. NEREA's bulk density is higher than the average bulk density of granular fertilizers. Guerrero (2004) presents the bulk densities of ten granular fertilizers. NEREA has a higher value than most of them, such as ammonium nitrate "prill" (720 kg m^{-3}), urea "prill" (740 kg m^{-3}), ammonium sulfate (1060 kg m^{-3}), among others. This means that for the same fertilizer machine distribution mechanism setting, the weight of the NEREA material delivered is greater than the weight of the aforementioned fertilizers delivered by the machine. Therefore, appropriate adjustments will need to be made to the machine's setting to ensure the established dosage (kg ha^{-1}). This consideration applies to any fertilizer machine.

The bulk density of AGROMENAS - G is higher than that obtained by González-Cueto et al. (2023) in another batch of AGROMENAS - G from the same producer. The bulk density in that study was obtained from samples that had 49.91% of the grains with particle sizes less than 1 mm. The bulk density of fertilizers and other granulated products depends largely on the particle size distribution of the material, since bulk density is a measure of the porosity of the material and the voids between the pores of the material (IFDC, 2016). The smaller the volume of voids and the greater the number of contacts between particles, as is the case with materials with smaller particle size distribution, the higher the apparent density.

Bulk density is important during broadcast fertilizer application, since fertilizers with lower apparent density are projected a shorter distance than those with higher density. For the same particle size, those with higher density are projected the greatest distance. Variations in the bulk density of the fertilizer influence the quantity (weight in kg) delivered by mechanical or pneumatic distributors. Therefore, appropriate adjustments must be made to the fertilizer spreader's settings to obtain the required application rate (kg ha^{-1}). Bulk density is usually fairly stable across different types of fertilizers; for nitrogen fertilizers, it ranges between 850 and 950 kg m^{-3}, and for compound NPK, NP, and PK fertilizers, it ranges between 900 and 1200 kg m^{-3} (Márquez, 2011).

The media of moisture content of NEREA was 6.03%, and for AGROMENAS - G was 6.06%, similar to that of domestically produced fertilizers such as NPK 11-5-14-3, NPK 20-0-0, NPK 5-5-24-3, NPK 7-14-7, NPK 9-13-17, and NPK 9-13-16, produced by EQUIFA in Cienfuegos. These fertilizers have a moisture content of 6%, which meets the standard for this type of product (GEIQ, 2024).

During transportation, handling, and application of NEREA and AGROMENAS - G, no lumps or compaction of the product were observed. The presence of low moisture content and zeolite, a material with a high concentration in the fertilizer, prevent the material from compacting.

Repose angle

Angle of repose is the steepest slope of the unconfined material, measured from the horizontal plane on which the material can be heaped without collapsing (Beakawi Al-Hashemi & Baghabra Al-Amoudi, 2018).The average of angle of repose for NEREA was 31.12°, and for AGROMENAS - G it was 29.34°. These angle of repose values are within the range for this physical property shown by IFDC (2016), where the angles of repose of eight types of fertilizers appear. According to this publication, the angle of repose values are between 27 and 41 degrees. The angle of repose of granular materials is used in the design of equipment for the processing and transport of granular particles. In the maritime transport of granular products, it is related to the displacement of the cargo, which affects the transverse stability of the vessel. In the case of fertilizer hoppers, material with a lower angle of repose will flow more easily towards the distribution mechanisms located at the bottom of the hoppers.

The angle of repose is used as an indicator of the flowability of bulk solids, such as powders or granules. Different values for this angle can be obtained depending on the methodology used to determine the angle of repose (Beakawi Al-Hashemi & Baghabra Al-Amoudi, 2018). The most common method is to allow the material to pour freely through a funnel, forming a mound.

Angle of repose is an important property when designing bins, silos, and other seeds, bulk foods or powder storage vessels, as it will dictate the effective fill, and thus storage capacity. Also, the angle of repose determines whether the grain will flow of its own accord or whether external force is necessary to move it (Rosentrater & Bucklin, 2022). The angle of repose shows how easily a powder or granulated product flows when dropped onto a pile; it is a measure of the material's fluidity. The smaller the angle of repose, the greater the material's flowability. When analyzing the material's fluidity, according to the table showing the expected fluidity based on the angle of repose of different granular materials (POWDERPROCESS, 2024), it can be seen that AGROMENAS - G has excellent fluidity, that is, it flows very freely when discharged into a pile. The fluidity of AGROMENAS - G is greater than that of NEREA.

CONCLUSIONS

The physical properties of the NEREA zeolite-based fertilizer were determined. It was found that 72.61% of the material had particle sizes between 2 and 4 mm, that the apparent density was 1120 kg m^{-3}, that the moisture content was 6.03%, and that the angle of repose was 31.12°.

The physical properties of the AGROMENAS - G organomineral fertilizer were determined. It was found that 56.6% of the material had particle sizes less than 1 mm, that the apparent density was 1350 kg m^{-3}, that the moisture content was 6.06%, and that the angle of repose was 29.34°.

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