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Effect of Agrominerals on the Growth of *Casuarina* and *Ocuje* for Mine Rehabilitation in Area 5 of the Punta Gorda Deposit, Moa, Cuba

Efecto de agrominerales en el crecimiento de casuarina y ocuje para rehabilitación minera del área 5 del Yacimiento Punta Gorda, Moa, Cuba

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Abstract: The objective of this research was to determine the effect of agrominerals added to lateritic soil in order to evaluate the growth of *casuarina* (*Callophyllum antiullanum*) and *ocuje* (*Casuarina equisetifolia*) crops for mine-site rehabilitation in Area 5 of Punta Gorda deposit, in Moa. Three treatments were applied (control, organic matter, and agrominerals) in two cultivation media (bags and lateritic soil), assessing plant height and diameter over a 45-day period. The results showed that seedlings treated with agrominerals exhibited greater growth, with *ocuje* in soil standing out due to its increase in height and diameter compared to the control. It is concluded that the application of agrominerals significantly improves the development of these species in soils degraded by mining, representing a viable alternative for mining areas rehabilitation.

Keywords: erosion, soil fertility, forest management, phytochemicals, forest resources

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Resumen: El objetivo de la investigación fue determinar el efecto de agrominerales agregados al suelo laterítico para evaluar el crecimiento de los cultivos de casuarina (*Callophyllum antiullanum)* y ocuje (*Casuarina equisetifolia)*, para la rehabilitación minera en el área 5 del yacimiento Punta Gorda, Moa. Se emplearon tres tratamientos (testigo, con materia orgánica y con agromineral) en dos medios de cultivo (bolsas y suelo laterítico), evaluándose la altura y el diámetro de las plantas durante 45 días. Los resultados mostraron que las posturas tratadas con agromineral presentaron un mayor crecimiento, destacando el ocuje en tierra con un incremento en altura y en diámetro respecto al testigo. Se concluye que la aplicación de agrominerales mejora significativamente el desarrollo de estas especies en suelos degradados por la minería, representando una alternativa viable para la rehabilitación de áreas mineras.

Palabras claves: erosión, fertilidad del suelo, gestión forestal, producto fitoquímico, recursos forestales

1. Introduction

Open-pit mining operations in nickel, iron, and cobalt ore deposits formed in the weathering crust cause a strong impact on areas where they are carried out and its surrounding environment. To extract mineral raw material, it is mandatory to remove the entire crust where animal and plant life is established, thus getting severely affected (Torres *et al.,* 2021; Perdomo-Millán, 2023). This is the reason why rehabilitation process in areas degraded by mining exploitation must be conceived in parallel with the mining deposit exploitation project (Torres *et al*., 2019).

Authors such as Suntasig-Negrete *et al.* (2024) point out the use of native or exotic forest species as a strategy to restore soils degraded by mining activities, especially when combined with other revegetation and management techniques. Valois-Cuesta *et al*. (2022), Márquez-Huitzil *et al*. (2022), Couic *et al*. (2022), Abella-Sanclemente *et al*. (2023), and Cuza Fernández *et al*. (2024) have validated ecological restoration to revegetate soils degraded by mining.

Rocks resources and industrial minerals have a wide use in several industrial branches. They also have an extensive distribution on the earth's surface, being an essential factor in soil development and fertility (Martínez-Bring *et al*., 2025).

According to Zhang *et al.* (2017), agrominerals can provide essential nutrients for plants. Some of them are produced naturally or can be processed to be used as alternative fertilizers or soil improvers. Orozco Melgar & Cuza Fernández (2022) define agrominerals as an enhancer added to the soil to positively influence its structure, its physical-chemical characteristics, and its fertility, as they contain properties that aid in moisture retention, nutrient loss reduction, pH regulation in acidic soils, and compact and hard soils loosening.

Punta Gorda deposit is exploited by Ernesto Che Guevara Nickel Producing Company, which uses the carbonate-ammonia technology to obtain nickel oxide (Rojas-Purón *et al*., 2025). Its exploited zones generate negative impacts on the environment, which have been documented by Aguilera Fernández *et al.* (2016) who propose, among other impact mitigation measures, the use of natural screens, especially vegetation.

The poor development of plants is among the most notorious problem within mine-site rehabilitation process at Punta Gorda deposit, which results from the lateritic substrate acidity, as well as nutrients and organic matter loss produced by mining activity. In this scenario, the use of agrominerals is conceived as a promising strategy for the rehabilitation process in areas degraded by mining activity.

The plants proposed for the research's experimental phase are *casuarina* and *ocuje* due to their demonstrated resistance (Villaseñor Araiza & Rutiaga Quiñones, 2000; Álvarez de Zayas, 2023). *Casuarina* is a valuable species for degraded lands rehabilitation due to its nitrogen-fixing capacity and high leaf litter production rates, which facilitates the early development of microflora, microfauna, and insect communities; besides, it increases nutrient availability (Geigel 1977; Parrotta, 1993). Herrero *et al.* (2009), Torres *et al*. (2021), and Torres & Rodríguez (2022) have reported promising results when using *casuarina* for the rehabilitation of areas damaged by mining activity.

Manzanares *et al.* (2005) classify *ocuje* as a tree suitable for reforestation because it possesses positive attributes within its evaluation. Ortiz-Alba *et al.* (2024) point it out as one of the species with the highest ecological importance index in the region. Other studies refer to its effectiveness for damaged areas rehabilitation (Begué-Quiala *et al.,* 2019).

The aim of this research is to determine the effect of agrominerals, incorporated into the lateritic soil found in Area 5 of Punta Gorda deposit, on the growth of *casuarina* and *ocuje* crops, in order to use these species for mine-site rehabilitation.

1.1. Deposit's geographic location

Punta Gorda deposit is bordered to the north by the Atlantic Ocean and the lower course of Moa River, to the south by the conventional line separating it from Camarioca Norte and Camarioca deposits, to the west by Los Lirios River and Moa River's canyon and, to the east, it is separated from Yagrumaje Norte deposit by Yagrumaje River.

2. Materials and methods

2.1 Experimental design

An experimental design of divided plots in randomized blocks was implemented with two factors under study: type of treatment and growing medium. The treatments evaluated were:

T1: Control (only lateritic substrate)
T2: Organic matter application
T3: Agromineral application

The cultivation media considered were:
- Bags
- Direct soil (nursery)

The agromineral obtention process was developed according to the methodology proposed by Cuza Fernández (2023).

The results were tabulated and analyzed using the descriptive method. To analyze the results among the different measured aspects, Tukey's method was used, allowing for comparisons on the base of the established parameters: height and diameter.

2.2. Collection and preparation of substrate samples from Punta Gorda deposit's Area 5

50 samples were taken from the degraded area, approximately 3 m apart from each other. The zigzag method was used for sampling, and excavation was carried out to a depth of 30 cm. The samples were quartered and homogenized, forming 3 equal parts.

2.2.1. Agromineral obtention process

To obtain the agromineral, an ion exchange process of zeolitized tuff with residual ammonia was applied. The zeolitized tuffs were mixed with the residual liquor for two hours at room temperature to promote cation exchange. The zeolitized tuffs had a particle size of 1-3 mm, as recommended by Soca & Daza-Torres (2016) for agricultural use. The residual liquor was added to a tank filled with zeolitized tuffs so that the liquid was 1-2 cm above the tuffs. For each kilogram of zeolitized tuff, 1.1 liters of ammonia residual liquor are required. After two hours, the liquor was drained, and a sample was taken from the residual liquid.

Once air-dried, the zeolitized tuffs were mixed at a 1:1 mass ratio, with vitroclastic tuffs obtained in El Picao area, located 10-15 km from Sagua de Tánamo city, on topographic sheet 5177-I, at a scale of 1:50,000, within the limits determined by Lambert coordinates of the Cuban Sur system.

2.3. Materials used

Vitreous tuffs, zeolitized tuffs, ammonia residual from CARON process, calcilutites, and substrate from Area 5 of Punta Gorda deposit were used.

As ammonium source, the ammonia residual resulting from nickel production process at Ernesto Che Guevara factory was used. Its chemical analysis was performed at Nickel Research Center of Moa, employing the methodology proposed by Cuza-Fernández (2023).

Table 1 shows the composition of the residual used in the research, and Table 2 shows the nickel, cobalt, and ammonium content.

Table 1. Chemical composition of ammonia residual from Che Guevara

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

Table 2. Analysis of Ni, Co, and ammonium content in ammonia residual from Che Guevara Factory

mg/L	Ni	Incert	mg/L	Co	Incert	mg/L	NH_3	Incert
5,00	±	0,69	1,00	±	0,340	1951,6	±	111

Zeolitized tuffs used in this research come from San Andrés deposit; their chemical composition can be seen in Table 3 (Almenares, 2011).

Table 3. Chemical composition of a zeolitized tuff sample from San Andrés deposit

Óxide	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	Cao	MgO	Na_2O	K_2O	PPI
%	65,55	0,276	11,75	1,43	2,824	0,947	1,376	1,677	14,15

Vitreous tuffs contain chemical elements of great application in the agricultural sector. Their magnesium, iron, potassium, and calcium content validate the effect they have on the improvement of soils to enhance crop development (Table 4). A granulometry ranging from 0.1 to 0.8 mm was used (Almenares, 2011).

Table 4. Chemical composition of a vitroclastic tuff sample from El Picao

Óxide	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	Cao	MgO	Na_2O	K_2O	PPI
%	60,86	0,49	13,63	4,58	5,34	2,64	1,87	2,27	8,83

Table 5 shows the characteristics of calcilutites used in the research.

Table 5. Geological characterization of calcilutites from Yaguaneque region

Fe_2O_3	MnO_2	Cr_2O_3	TiO_2	SiO_2	Al_2O_3	CaO	K_2O	Fe_2O_3
1,34	0,04	ND	ND	3,02	1,77	52,22	0,15	1,34

2.4. Methodology followed for the agromineral experiment

1. 6 kg-mass bags were used, where 4 kg of spoil were mixed with 1 kg of calcilutites to regulate substrate acidity.

2. The agromineral was made from charged zeolitized tuffs plus vitroclastic tuffs in a one-to-one ratio.

3. 4 kg of lateritic substrate mixed with the calcareous material were added to the base of each bag, followed by 1 kg of agromineral.

4. Seedlings were planted on the agromineral, then bags were added more the mixture of spoil plus calcilutites to complete them.

5. Two *casuarina* and *ocuje* seedlings were planted as controls in lateritic soils to compare behavior and development. In addition, two other seedlings were planted in soils amended with organic matter to serve the same purpose.

6. The procedure was repeated following the direct soil planting method under the same characteristics and conditions.

The sample size for bags and direct soil planting was six for each method, specifically two for each experiment (two with agromineral, two with organic matter, and two with untreated substrate).

2.5. Characteristics of the plants

Ocuje (*Calophyllum antillanum*) and *casuarina* (*Casuarina equisetifolia*) species were chosen on the characteristics stated by Urbino Rodríguez *et al.* (2019).

Ocuje
- Tolerates acidic, nutrient-lacking soils with high metal toxicity (such as post-mining lateritic soils).
- High resistance to drought and water stress conditions.
- Moderate fast growth under favorable conditions, but slow in degraded soils.

Casuarina
- Grows in poor, sandy, saline, and acidic soils, even in high contaminated areas.
- Extremely tolerant to drought, strong winds, and low fertility soils.
- Very fast growth under adverse conditions, making it ideal for early mine-site rehabilitation.

3. Research results

3.1. Results of the substrate chemical analyses

Table 6 shows the liquor chemical composition laboratory results before and after its treatment with zeolite.

Table 6. Chemical composition of the initial liquor and the liquor treated with zeolite. Contents are expressed in mg/l

Liquor	S	Ca	Ni//Incert	Co/Incert	NH_3/Incer
Initial liquor	1.06	----	7.46±1.0	1.48±0.50	2346±134
Liquor treated with zeolite	1.05	9.64	0.52±0.071	0.110±0.037	537±31

Analysis methods:
UPL-PT-G-09 Determination of total sulfur. Gravimetric method.
UPL-PT-A-25 Determination of Cd, Ca, K, Na, Mo, Sn, Se, Be in water samples.

AAS Method:
UPL-PT-A-11 Determination of Ni, Co, Fe, Cu, Zn, Mg, Al, Cr, Si, V, Pb. Atomic absorption spectrophotometry method.
UPL-PT-V-15 Determination of distilled ammonia. Volumetric method.

The zeolitized tuffs managed to remove NH3 concentration from 2346 mg/l to 537 mg/l through cation exchange, confirming their efficiency as an adsorbent material and their capacity to capture ammonium cations. Zeolite contributes to purifying industrial residuals, transforming it into a useful resource for the rehabilitation of areas degraded by mining.

Table 7 shows nickel and iron contents present in the spoil removed from the deposit. The spoil is predominantly characterized by low nickel concentrations in off-balance iron (FF, abreviation in Spanish), balanced iron (FB, abreviation in Spanish), and off-balance laterite (LF, abreviation in Spanish). On the other hand, high iron concentrations, above 20 % and up to 35 %, are evident.

Table 7. Classification by ore type for lateritic horizons

Horizon	Ore type	Symbol	% Ni Limit	% Fe Limit
spoil	Off-balance iron	FF	Ni < 0.7	20 ≤ Fe < 30
	Balanced iron	FB	Ni < 0.7	Fe ≥ 30
	Off-balance laterite	LF	Ni < 0.7 ≤ 0.9	Fe ≥ 35

The spoil horizon in Punta Gorda deposit presents a chemical composition dominated by iron oxides, reflecting thus its lateritic origin. It also contains high alumina contents along with minor amounts of titanium oxide, magnesium, and calcium. Nickel and cobalt are present in variable proportions depending on the ore type. Additionally, traces of chromium and sulfur were detected. This composition evidences a typical iron-and-aluminum-rich laterites profile, with an heterogenous metal distribution.

3.2. *Ocuje* and *casuarina* seedlings growth evaluations regarding diameter and height

Initial measurements of the plants height and diameter were recorded after planting to use them as baseline for comparison with the data collected during the time intervals set within a 45 days period (Table 8).

Table 8. Initial diagnosis of the plants

Seedlings	Species	In bag		In soil	
		Height (cm	Diameter (mm)	Height (cm)	Diameter (mm)
Control	Ocuje	23	5	17.5	4
	Casuarina	20	2.5	18	2
With organic matter	Ocuje	24	4	25	4
	Casuarina	22	2	16	2
With agromineral	Ocuje	24	4.5	22	4
	Casuarina	16.5	2.5	17	2

Table 9 shows the plants development sown following the three variants (control, organic matter, and agrominerals) after 15 days. The most significant changes were evidenced in the plants cultivated with agromineral, which achieved greater height and stem diameter. Additionally, a greater foliage and a high green color concentration in the leaves could be observed in *ocuje* plants.

Table 9. Diagnosis of the plants 15 days after sowing

Seedlings	Species	In bag		In soil	
		Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)
Control	Ocuje	24.6	6	19.5	4
	Casuarina	28.2	3	23.5	3
With organic matter	Ocuje	24.5	5	27.5	5
	Casuarina	35	3	20	2
With agromineral	Ocuje	26.5	5	28	7
	Casuarina	26	3	21.5	2

After 30 days, the plants treated with agromineral showed sustained growth in height, especially *ocuje* planted in soil. Improvements in stem diameter were also observed, particularly for *ocuje* seedlings planted in lateritic soil amended with agrominerals. *Casuarinas* sown in bags with organic matter registered the highest growth in height but lower diameter development (Table 10).

Table 10. Diagnosis of the plants 30 days after sowing

Seedlings	Species	In bag		In soil	
		Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)
Control	Ocuje	25.8	6	22.3	5
	Casuarina	38.5	4	26.7	4
With organic matter	Ocuje	29.4	5	29.4	6
	Casuarina	49.1	3.5	22.1	3
With agromineral	Ocuje	28.2	5.1	31.2	7.5
	Casuarina	33.5	3.3	26.6	2.5

After 45 days, *ocuje* with agromineral in soil reached the greatest height and the most prominent diameter, confirming the effectiveness of the treatment. *Casuarina* with organic matter in bag increased in height, but its diameter was smaller. Controls showed moderate development, evidencing the need for amendments to optimize growth in degraded soils (Table 11).

Table 11. Diagnosis of the plants 45 days after sowing

Seedlings	Species	In bag		In soil	
		Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)
Controls	Ocuje	34.6	6.5	22.8	5.8
	Casuarina	48.5	5	31.9	5
With organic matter	Ocuje	30.3	6	31.4	6.3
	Casuarina	65.4	5	31.7	3.2
With agromineral	Ocuje	31.5	6	33.6	8
	Casuarina	42.5	4	37.9	4

Tables 12 and 13 evidence that agrominerals significantly improve plant growth in degraded soils, although its effect is more noticeable on height than on diameter.

Table 12. Summary of diameter and height behavior of *ocuje* and *casuarina* sown in bags across four measurements

Seedlings	Species	1st h	2nd h	3rd h	4th h	1est diameter	2nd diameter	3er diameter	4to diameter
Controls	Ocuje	23	24.6	25.8	34.6	5	6	6	6.5
	Casuarina	20	28.2	38.5	48.5	2.5	3	4	5
With organic matter	Ocuje	24	24.5	29.4	30.3	4	5	5	6
	Casuarina	22	35	49.1	65.4	2	3	3.5	5
With agromineral	Ocuje	24	26.5	28.2	31.5	4.5	5	5.1	6
	Casuarina	16.5	26	33.5	42.5	2.5	3	3.3	4

Table 13. Summary of diameter and height behavior of *ocuje* and *casuarin*a sown in soil across four measurements

Seedlings	Species	1st h	2nd h	3rd h	4th h	1st diamete	2nd diameter	3rd diameter	4th diameter
Controls	Ocuje	17.5	19.5	22.3	22.8	4	4	5	5.8
	Casuarina	18.0	23.5	26.7	31.9	2	3	4	5
With organic matter	Ocuje	25.0	27.5	29.4	31.4	4	5	6	6.3
	Casuarina	16.0	20	22.1	31.7	2	2	3	3.2
With agromineral	Ocuje	22.0	28	31.2	33.6	4	7	7.5	8
	Casuarina	17.0	21.5	26.6	37.9	2	2	2.5	4

The graphs in Figures 1 and 2 show the growth of *casuarina* and *ocuje* seedlings planted in bags and in soil.

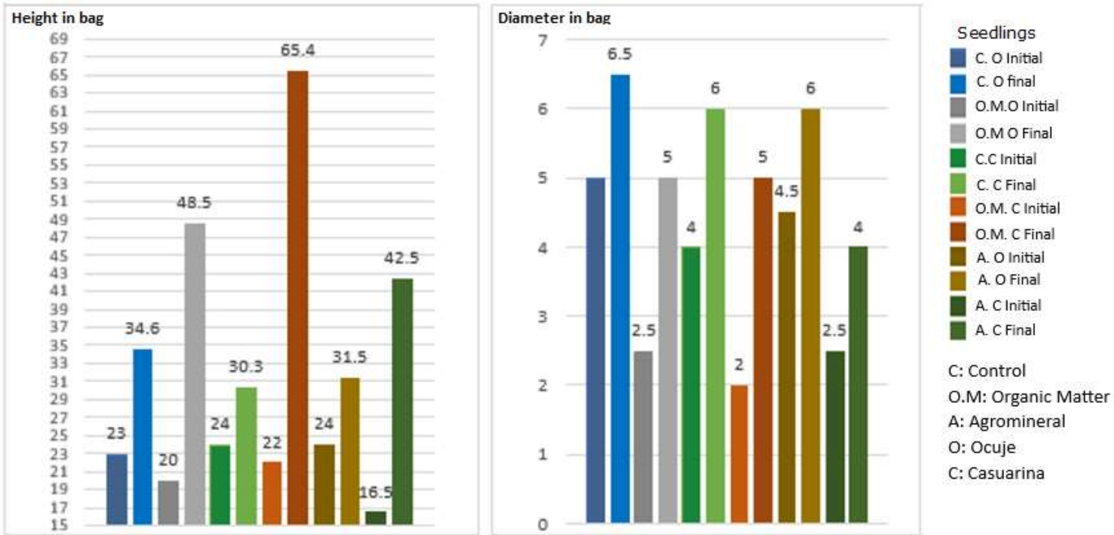

Figure 1. Growth graphs of seedlings in bags. a) Height. b) Diameter.

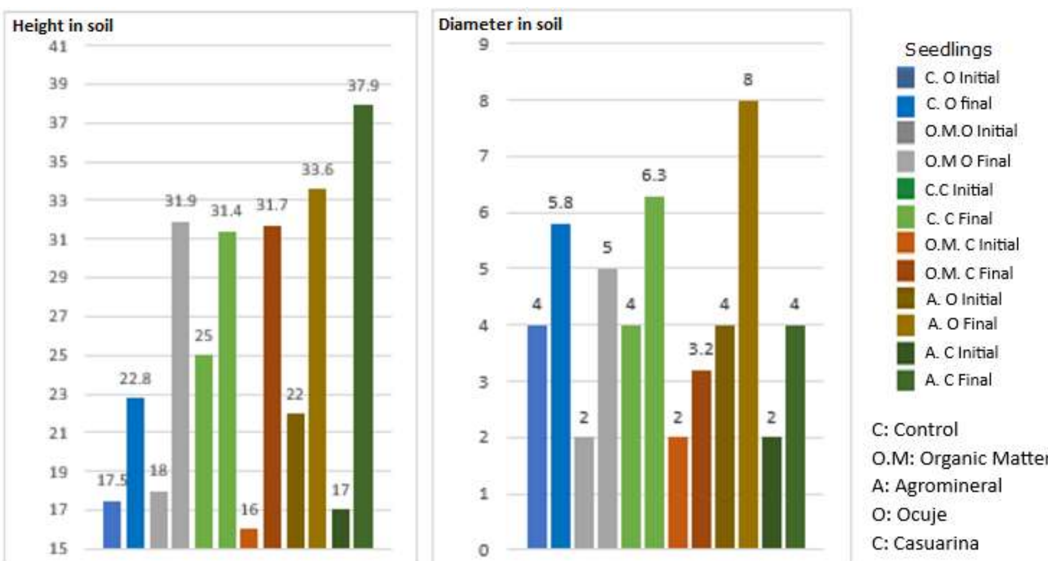

Figure 2. Growth graphs of seedlings in soil. a) Height. b) Diameter.

It is shown that *ocuje* and *casuarina* seedlings, both in bags and in soil, whith agrominerals applied, have a marked growth in height. As for diameter, there is no marked difference in any of the three experiments in bags, but for ocuje sown in soil with agromineral application, there is a notable development of 4 mm compared to the other experiments.

4. Conclusions

The lateritic substrate in Area 5 of Punta Gorda Deposit was physically and chemically characterized. It was determined that the substrate presents chemical (acidity, low fertility) and physical (compaction) limitations that justify the use of agrominerals for its rehabilitation.

The effect of an agromineral on the growth of *casuarina* and *ocuje* plants was evaluated, demonstrating that it favors their development compared to the controls. The height of *ocuje* sown in a bag with agromineral showed a growth of 7.5 mm and, in soil, 11.6 mm. Its diameter sown in a bag showed an increase of 1.5 mm and, in soil, 4 mm. *Casuarina* planted in a bag with agromineral increased by 26 mm and sown in soil by 20.9 mm. The diameter of *casuarina* planted in a bag increased by 1.5 mm and sown in soil by 2 mm. These data suggest an improvement induced by the agromineral under experimental conditions; however, a greater number of trials is required to generalize.

It is discerned that the use of agromineral favors the height more than the diameter in *ocuje* and *casuarina* plants.

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Author's Contribution according to CRediT Taxonomy

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