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Effect of basalt rock powder associated with different substrates on the initial development of aroeira seedlings (*Myracrodruon urundeuva*)

Efeito do pó de rocha basáltica associado a diferentes substratos no desenvolvimento inicial de mudas de aroeira (*Myracrodruon urundeuva*)

Efecto del polvo de roca basáltica asociado con diferentes sustratos en el desarrollo inicial de plántulas de aroeira *(Myracrodruon urundeuva)*

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Abstract

This study aimed to evaluate the initial growth of aroeira in Oxisol soil with the addition of different organic (humus and vermicompost) and organic/mineral substrates (commercial substrate) and rock powder. Seeds were collected and, after germination, transplanted to different types of substrate. The treatments assembled, with different proportions of compounds, were: T1 (50% humus + 50% Oxisol); T2 (50% commercial substrate + 50% Oxisol); T3 (50% vermicompost + 50% Oxisol); T4 (40% humus + 40% Oxisol + 20% rock powder); T5 (40% commercial substrate + 40% Oxisol + 20% rock powder); T6 (40% vermicompost + 40% Oxisol + 20% rock powder); T7 (30% humus + 30% Oxisol + 40% rock powder); T8 (30% commercial substrate + 30% Oxisol + 40% rock powder); and T9 (30% vermicompost + 30% Oxisol + 40% rock powder). Initial plant development was influenced by the treatments; 20% powder and 40% nitrogen from humus (T4) produced seedlings with the greatest root, aerial part and total weight, in addition to greatest height and collar diameter. The data obtained indicate that aroeira develops better when in argillaceous substrates, with the addition of 40% humus and 20% rock powder, indicating the adequacy of this composition for its initial growth.

Keywords: Anacardiaceae; Organic substrates; Rock powder; Plant initial development.

Resumo

Este estudo teve o objetivo de avaliar o crescimento inicial de aroeira em solo Latossolo Vermelho Distrófico com adição de diferentes substratos orgânicos (húmus e vermicomposto) e orgânico/mineral (substrato comercial) e, pó de rocha. Sementes foram coletadas e após sua germinação, transplantadas para diferentes tipos de substratos, sendo os tratamentos montados, com diferentes proporções de compostos, foram: T1 (50% húmus + 50% Latossolo); T2 (substrato comercial de 50% + 50% Latossolo); T3 (50% vermicompost + 50% Latossolo); T4 (40% húmus + 40% Latossolo + 20% pó de rocha); T5 (substrato comercial de 40% + 40% Latossolo + 20% pó de rocha); T6 (40% vermicompost + 40% Latossolo + 20% pó de rocha); T7 (30% húmus + 30% Latossolo + 40% pó de rocha); T8 (substrato comercial de 30% + 30% Latossolo + 40% pó de rocha); e T9 (30% vermicompost + 30% Latossolo +

40% pó de rocha). O delineamento experimental foi inteiramente casualizado, com quatro repetições, uma planta por saco de plantio, a pleno sol. A adição de pó não alterou significativamente as concentrações de fósforo, potássio e cálcio e apenas o valor do magnésio se destacou em T4 (20% de pó), que também apresentou valores significativos de soma das bases e capacidade de troca catiônica. Os dados obtidos indicam que a aroeira se desenvolve melhor, quando em substratos argilosos, com adição de 40% de húmus e 20% de pó de rocha, indicando a adequação desta composição para seu crescimento inicial.

Palavras-chave: Anacardiaceae; Rochagem; Substrato orgânico; Vermicomposto; Análise de crescimento de plantas.

Resumen

Este estudio tuvo como objetivo evaluar el crecimiento inicial de la aroeira en suelos distróficos de Red Latosol con la adición de diferentes sustratos orgánicos (humus y vermicompost) y orgánicos/minerales (sustrato comercial) y polvo de roca. Se recogieron semillas y después de la germinación, trasplantadas a diferentes tipos de sustratos. Los tratamientos ensamblados, con diferentes proporciones de compuestos, fueron: T1 (50% humus + 50% Latosol); T2 (sustrato comercial de 50% + 50% Latosol); T3 (50% vermicompost + 50% Latosol); T4 (40% humus + 40% Latosol + 20% polvo de roca); T5 (sustrato comercial de 40% + 40% Latosol + 20% polvo de roca); T6 (40% vermicompost + 40% Latosol + 20% polvo de roca); T7 (30% humus + 30% latosol + 40% polvo de roca); T8 (sustrato comercial de 30% + 30% Latosol + 40% polvo de roca); y T9 (30% vermicompost + 30% Latosol + 40% polvo de roca). El diseño experimental fue completamente aleatorizado, con cuatro replicaciones, una planta por bolsa de plantación, a pleno sol. La adición de polvo no alteró significativamente las concentraciones de fósforo, potasio y calcio y sólo el valor de magnesio se destacó en T4 (20% de polvo), que también presentaba valores significativos de suma de las bases y capacidad de intercambio catiónico. Los datos obtenidos indican que la aroeira se desarrolla mejor, cuando está en sustratos de arcilla, con la adición de 40% de humus y 20% polvo de roca, lo que indica la adecuación de esta composición para su crecimiento inicial.

Palabras clave: Anacardiaceae; Mecedoras; Sustrato orgánico; Vermicompost; Análisis de crecimiento de plantas.

1. Introduction

An increase in overall consumption of agricultural inputs, together with growing concern with the environmental impacts caused by the indiscriminate use of fertilizers, has stimulated the search for alternative sources that allow full or partial replacement of conventional fertilizers (Silva et al. 2012). One possibility is the use of residues from other activities such as mining. However, their use requires planning so that the application is economically viable and environmentally sustainable. Mineral extraction of basalt rock produces as residue rock powder, which contains macro and micronutrients, contributing to soil fertility as a function of the predominance of minerals which are easily weatherable and rich in cations, allowing their gradual release (Silva et al. 2017). In addition, there are other advantages, such as pH correction, the absence of soil salinization and excess potassium absorption, benefiting the absorption of calcium and magnesium, and a reduction of soluble phosphorus fixation by the presence of silica. This occurs because the powder is not readily soluble in water and not immediately leached by rainwater or intense irrigation. Thus, this residue is considered a type of 'remineralizer' for exhausted soil (Martins et al. 2014). Marek and Richardson (2020), studying the influence of glacial geologic materials on soil properties, tree nutrient acquisition and tree growth rates in New England (USA), confirmed the hypothesis that geologic materials can affect tree growth. Thus, rock powder can improve establishment and growth of trees species; another possible less evident use is its addition to the substrate for production of seedlings of commercial interest. Adequate seedling growth is related to the substrate used, because initial development is associated with aeration, drainage and water retention ability and nutrient availability, factors closely linked to quality (Larramendy and Soloneski 2016). Due to the reduced volume of seedling containers and the nutrient leaching in nursery irrigation, cover fertilization is frequently necessary. Such nutrient demand increases the cost of seedling production, but stimulates new research into alternative materials for fertilization and for substrate composition. The mixture of mineral, organic and/or organic/mineral material in the substrate can improve its chemical, physical and biological characteristics, creating a more suitable environment for the development of changes (Silva et al. 2012). The use of rocks to obtain nutritional gains can be done in different ways. For example, Mwangi et al. (2020) concluded that the dissolution of phosphate rock with lemon juice and its combined application (immediately after dissolution) with compost at planting improves nutrient uptake, phosphorus use efficiency and crop yields of *Daucus carota* L. On the other hand, Boroumand et al. (2020), working with *Nasturtium* *officinale* R. Br. and phosphate solubilizing bacteria from rhizospheres, enhanced the soil nitrogen and phosphorus content and the vegetative growth of land cress plants. In this way, the presence of rock powder can improve biological activity and favour types of microorganisms, as mentioned, in the absorption of water and nutrients by the plant. The plant itself can release some acids into the rhizosphere, which can solubilize nutrients from rock powder. The biofertilizers and rocks could satisfy the nutrient needs of the plants by making them potential for sustainable agriculture (Silva et al. 2015). In Brazil, many forest species are intensively exploited, in particular the Anacardiaceae and, among these, aroeira (*Myracrodruon urundeuva* Allem.). This species is medium-sized to large (15 to 30 m in height and 80 to 100 cm in diameter) and was originally widely distributed in the Northeast, Southeast and Central-West Brazilian regions. It has multiple uses and quite dense wood which is considered valuable and used to produce luxury furniture and in civil construction, for example, with great durability in natural conditions. As a result of the selective exploitation of aroeira for use in the timber industry, which virtually extinguished large individuals, the species was inserted in the official list of Brazilian flora species threatened with extinction, in the vulnerable class (Brasil 1992). Given its importance, it is necessary to make efforts to produce seedlings, aiming to plant them on a large scale. The work is based on the hypothesis of the use of basaltic rock residue as an alternative in the mixture of substrates of organic origin for the production of seedlings forest species of better quality and more sustainable inputs. Thus, this study aimed to evaluate seedling growth of *Myracrodruon urundeuva* cultivated under the effect of rock powder associated with different substrates, organic and organomineral, in clayey soil, classified as Oxisol.

2. Methodology

The experiment was conducted between November 2017 and February 2018, at the Agricultural Unit of Anhanguera-Uniderp University, Campo Grande, Mato Grosso do Sul. The experimental area is located at an altitude of 665 m and a climate, according to Köppen–Geiger classification, in the range of transition between the Cfa mesothermal humid subtype, without drought or little drought, and the Aw tropical humid subtype, with a rainy season and hot in the summer and dry in the winter.

2.1 Characteristic of soil

The soil used as a basis for all substrates was collected in an area of Cerrado and classified as an Oxisol, taken at a depth of 0–20 cm, dried in the shade, loosened and passed through a sieve (2 mm). Characterization of the pH in H_2O; P and K extracted by the Mehlich-1 method; Ca, Mg and Al extraction by the KCl method (1 N); H + Al by the calcium acetate method; and organic matter by the colorimetric method was carried out as described by Donagema et al. (2011). The results indicated pH = 5.8 ± 0.12 in water, P = 16 ± 1.5 mg dm^{-3}, K = 85 ± 3.78 mg dm^{-3}, Ca = 3.2 ± 0.19 $cmol_+$ dm^{-3}, Mg = 2.2 ± 0.35 $cmol_+$ dm^{-3}, H = 3.8 ± 0.26 $cmol_+$ dm^{-3}, organic matter (OM) = 29.6 ± 1.75 g dm^{-3}, clay = 520 ± 15.6 g kg^{-1}, sand = 360 ± 10.6 g kg^{-1} and silt = 120 ± 5.7 g kg^{-1}.

The experiment was conducted in a completely randomized experimental design (nine treatments). The characteristics of the materials used were determined as detailed below.

2.2 Origen and characteristic basalt rock powder

Basalt rock powder was obtained through a commercial quarry, located in the municipality of Dourados, in the state of Mato Grosso do Sul, Brazil, from basaltic rock. To qualify it as powder, the rock was fragmented and passed through a ball mill, capped on a vibrating sieve separator to obtain diameters of 0.10 and 0.05 mm. The material was analysed and characterized for oxide content by the fusion method with lithium tetraborate and quantified by X-ray fluorescence spectrometry (XRF - XRF79C): SiO_2 (52.97 ± 0.36%), Al_2O_3 (13.98 ± 0.15%), Fe_2O_3 (13.12 ± 0.13%), CaO (7.22 ± 0.07%), MgO (2.99 ± 0.06%), TiO_2 (2.2 ± 0.04%), P_2O_5 (0.7 ± 0.05%), Na_2O (3.09 ± 0.06%) and K_2O (1.85 ± 0.09%), characterizing the material as a possible supplier of Ca and Mg to soil. For mineralogical characterization, the X-ray diffraction technique was used (Brasil 2014). The main elements contained in the basalt rock powder are shown in Table 1.

Table 1. Mean values of the main mineral elements and smaller elements in the basalt rock powder used, for which detection levels were reached. Method: Manual of Official Methods for Mineral, Organic and Corrective Fertilizers (Brasil 2014).

Minerals	(%)	Smaller elements	(mg kg^{-1})	Smaller elements	(mg kg^{-1})
Orthoclase	13.1±0.2	Scandium	20.0±0.8	Strontium	485.0±12.8
Magnetite	1.7±0.0	Vanadium	165.0±5.4	Yttrium	43.0±5.3
Apatite	1.6±0.0	Cobalt	15.0±0.2	Zirconium	310.0±11.4
Quartz	4.3±0.4	Nickel	14.0±0.8	Niobium	24.0±3.2
Ilmenite	1.5±0.1	Copper	251.0±6.3	Molybdenum	6.0±0.2
Hematite	1.2±0.0	Zinc	143.0±4.8	Caesium	19.0±0.3
Plagioclase	55.8±1.9	Gallium	27.0±2.5	Barium	600.0±16.4
Clinopyroxene	19.9±1.2	Rubidium	39.0±3.2	Lanthanum	34.0±1.3

Source: Authors.

2.3 Substrates organic

The substrates used were cattle manure-based humus (HU; pH = 6 ± 0.13; C/N ratio = 14 ± 1.24; cation exchange capacity (CEC) = 8.0 ± 1.07 cmol$_c$ kg^{-1}; total organic carbon (TOC) = 10 ± 1.32%; humidity = 50 ± 4.75%), vermicompost (Vc) prepared with residues from the rumen of cattle under action of earthworms *Eisenia foetida* (pH = 7.0 ± 0.19; electrical conductivity = 1.23 ± 0.11 mS dm^{-1}; P = 260 ± 7.29 mg kg^{-1}; K = 600 ± 15.64 mg kg^{-1}; Ca = 2.5 ± 0.24 cmol$_+$ dm^{-3}; H = 6.54 ± 0.11 cmol$_+$ dm^{-3}; density = 0.39 ± 0.03 g cm^{-3}; organic matter = 12.94 ± 1.27%) and commercial substrate (Sc) prepared with powder from *Pinus* and vermiculite (pH = 5.5 ± 0.69; density = 0.45 ± 0.07 g cm^{-3}; water retention capacity = 165 ± 6.24%; electrical conductivity = 1.5 ± 0.05 mS dm^{-1}; moisture = 25 ± 1.28%; raw material = ash, organic compounds).

2.4 Treatments

The treatments assembled, with different proportions of compounds, were: T1 (50% humus + 50% Oxisol); T2 (50% commercial substrate + 50% Oxisol); T3 (50% vermicompost + 50% Oxisol); T4 (40% humus + 40% Oxisol + 20% rock powder); T5 (40% commercial substrate + 40% Oxisol + 20% rock powder); T6 (40% vermicompost + 40% Oxisol + 20% rock powder); T7 (30% humus + 30% Oxisol + 40% rock powder); T8 (30%

commercial substrate + 30% Oxisol + 40% rock powder); and T9 (30% vermicompost + 30% Oxisol + 40% rock powder).

After homogenization, the substrates were packed in plastic planting bags (20 cm width × 30 cm height) with a volumetric capacity of 3 L, one seedling per bag. The seeds used were obtained from 13 matrices in areas of forest in the municipality of Campo Grande and placed in a stainless steel tray with vermiculite, moistened substrate, for germination. After germinating and the seedlings having reached approximately 4 cm in height, they were transplanted to the planting bags. After 2 days of acclimatization in the shade, the bags were carried to the field (full sun). In Brazil, special authorizations for studying the reproductive and growth processes of threatened plant species are not necessary.

2.5 Evaluated of characteristic plant

At 105 days, the plants were collected and waste was cleaned from the root system, then the aerial part was measured with a graduated ruler (cm) and the collar diameter (mm) was assessed with a digital caliper. Afterward, the structures were separated into underground and aerial parts and the material wrapped in paper bags, identified and placed in a forced ventilation oven at 60 °C until a constant weight was obtained; then the dry mass (g) and Dickson quality index (DQI) were evaluated (Dickson et al. 1960):

$$DQI = \frac{MSTT}{\frac{MSPA}{MSR} + \frac{CPA}{DC}}$$

Where:

MSTT = total dry mass;

MSPA = dry mass of aerial part;

MSR = dry mass of roots;

CPA = length of aerial part;

DC = collar diameter.

2.6 Statistical analysis

The results were submitted to multivariate analysis (principal components) and variance, using SAS software (Statistical Analysis System), with significance tested at α <

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5%; averages were subjected to the Waller–Duncan test.

3. Results

The treatments without the addition of rock powder showed significantly higher levels of organic matter (OM) (Table 1), particularly treatment T3 (50% Vc). The addition of 20% and 40% powder led to a drop in the OM content, which would be expected, because with an increase in powder percentage, regardless of which organic substrate was used, there would be a reduction of OM. The commercial substrate, which contains vermiculite, would also provide a lower OM content, which is what occurred.

The sum of the bases and the CEC were not affected positively by adding the powder, as there was a drop in their values. The exception was treatment T4 (40% Hu + 40% Lt + 20% Rp), for which values were statistically equal to those for treatments without the addition of powder, T1 (50% Hu + 50% Lt + 0% Rp) and T2 (50% Cs + 50% Lt + 0% Rp) (Table 1). The greatest value of CEC indicates sites occupied by essential cations such as Ca, Mg and K^+. Therefore, it is possible to say that the substrates are appropriate, in this sense, for the plants' nutrition. The addition of rock powder (20% and 40%) did not significantly change the number of ions of phosphorus, potassium and calcium, when compared to the treatments without this substrate. Treatment T1 (50% Hu + 50% Lt + 0% Rp) stood out, with higher values for these nutrients. Only magnesium had a greater concentration when 20% powder was added, in treatment T4 (40% Hu + 40% Lt + 20% Rp) (Table 2).

Table 2. Chemical parameters and quantity of organic matter found in the different substrates used (Rp = rock powder, Hu = humus, Vc = vermicompost, Cs = commercial substrate, Lt = Oxisol, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, H + Al = potential acidity, OM = organic matter, SB = sum of bases, CEC = cation exchange capacity).

Treatment and substrate	Lt (%)	pH H_2O	P	K	Ca	Mg	H+Al	OM	SB	CEC
			mg dm^{-3}		cmol$_+$ dm^{-3}			g dm^{-3}	cmol$_+$ dm^{-3}	
		0% rock powder								
T1 – 50% Hu	50	7.0 a (±0.1)	77.4 a (±0.6)	198 a (±6.1)	12.3 a (±1.4)	4.2 cd (±1.0)	1.0 d (±0.0)	45.3 b (±1.9)	17.0 a (±1.2)	18.0 a (±1.3)
T2 – 50% Cs	50	6.9 ab (±0.2)	35.4 d (±2.3)	192 a (±11)	11.2 ab (±1.0)	4.4 c (±0.4)	1.2 c (±0.0)	42.9 c (±1.4)	16.1 a (±1.0)	17.3 a (±0.8)
T3 – 50% Vc	50	6.6 c (±0.1)	27.3 f (±1.7)	110 e (±8,9)	8.7 de (±0.9)	4.3 cd (±0.7)	2.0 a (±0.0)	59.5 a (±2.5)	13.2 bc (±1.1)	15.2 b (±1.2)
		20% rock powder								
T4 – 40% Hu	40	7.1 a (±0.1)	53.3 b (±1.8)	179 b (±9.5)	10.6 bc (±1.0)	6.3 a (±0.7)	1.0 d (±0.0)	33.9 d (±1.2)	17.3 a (±1.1)	18.3 a (±1.0)
T5 – 40% Cs	40	7.0 a (±0.1)	31.4 e (±1.4)	144 c (±5.4)	9.6 cd (±1.1)	4.0 d (±0.6)	1.2 c (±0.0)	34.2 d (±1.1)	13.9 b (±0.9)	15.2 b (±0.8)
T6 – 40% Vc	40	6.8 bc (±0.2)	24.8 f (±1.3)	60 f (±3.3)	7.8 e (±1.0)	4.2 cd (±1.0)	1.7 b (±0.0)	41.1 c (±1.3)	12.1 c (±0.9)	13.8bc (±1.0)
		40% rock powder								
T7 – 30% Hu	30	6.9 ab (±0.1)	46.5 c (±1.5)	152 c (±5.6)	8.2 e (±1.3)	5.2 b (±0.9)	0.9 d (±0.0)	25.5 f (±2.0)	13.8 b (±1.3)	14.7 bc (±1.4)
T8 – 30% Cs	30	6.9 ab (±0.1)	30.6 e (±1.2)	122 d (±3.5)	8.9 cd (±1.1)	3.4 e (±0.7)	1.0 d (±0.0)	28.6 e (±1.3)	12.6 bc (±1.1)	13.6 c (±1.3)
T9 – 30% Vc	30	7.1 a (±0.2)	21.1 g (±1.6)	46.0 g (±3.7)	6.4 f (±0.9)	3.3 e (±0.4)	1.6 c (±0.0)	28.1 e (±1.0)	9.7 d (±0.9)	10.9 d (±0.9)
CV		1.9	6.3	6.0	9.2	15.0	5.5	4.2	7.7	7.2
DMS		0.2	3.2	10.4	1.2	0.9	0.1	2.1	1.5	1.5

Values followed by the same letter in a column do not differ statistically for Waller–Duncan test ($\alpha \leq$ 5%).
Source: Authors.

Although the addition of rock powder affected some chemical parameters in a negative way, the results for aroeira seedling growth were influenced by the different treatments, indicating that the addition of powder, at a concentration of 20%, with the addition of humus (40%) to the Oxisol (40%) (T4), produced the best plants, with greater root, shoot and total weight, in addition to greater height and collar diameter, the single parameter similar in all treatments with the addition of humus. The second-best treatment was also due to the addition of humus (T1), again indicating the preference of the species for this type of OM (Table 3).

Table 3. Growth of aroeira plants (AP – aerial part, DQI – Dickson quality index) in Oxisol (Lt) containing different percentages of rock powder and organic and organic/mineral substrates.

Organic substrate	Lt (%)	Root (g)	AP (g)	Total (g)	Height (cm)	Collar (mm)	DQI
		0% rock powder					
T1 – 50% humus	50	2.0 b (±0.3)	14.2 b (±1.2)	16.2 b (±1.4)	43.3 bc (±3.5)	9.0 abc (±0.9)	1.34 b
T2 – 50% commercial substrate	50	1.3 cd (±0.3)	3.8 f (±0.4)	5.1 f (±0.3)	26.8 e (±1.4)	7.9 cd (±0.8)	0.79 e
T3 – 50% vermicompost	50	1.2 d (±0.2)	9.9 cd (±0.8)	11.1 d (±0.8)	37.3 d (±4.5)	8.9 bc (±1.1)	0.89 d
		20% rock powder					
T4 – 40% humus	40	2.5 a (±0.2)	16.1 a (±0.8)	18.6 a (±0.7)	52.8 a (±5.9)	10.6 a (±0,8)	1.63 a
T5 – 40% commercial substrate	40	0.4 e (±0.1)	2.5 g (±0.6)	2.9 g (±0.7)	22.1 ef (±2.5)	6.4 de (±1.0)	0.30 f
T6 – 40% vermicompost	40	1.7 bc (±0.6)	8.8 cd (±2.2)	10 cd (±2.8)	45.4 b (±9.0)	8.6 bc (±2.5)	0.99 c
		40% rock powder					
T7 – 30% humus	30	2.1 b (±0.6)	10.6 c (±0.9)	13.3 c (±1.4)	43.1 bc (±3.5)	10 ab (±0.7)	1.61 a
T8 – 30% commercial substrate	30	0.4 e (±0.2)	1.5 g (±0.3)	1.9 g (±0.4)	19.3 f (±2.8)	5.0 e (±0.4)	0.27 f
T9 – 30% vermicompost	30	1.4 cd (±0.3)	7.9 e (±1.4)	9.3 e (±1.5)	38.2 cd (±1.7)	8.8 bc (±0.9)	0.94 c
CV		22.92	10.65	11.42	11.73	10.42	
DNS		0.458	1.16	1.47	5.68	1.69	

Values followed by the same letter in a column do not differ statistically for Waller–Duncan test ($\alpha \leq$ 5%).
Source: Authors.

4. Discussion

4.1 Availability of nutrients in the substrates

The organic substrates directly influenced the contents of OM, P, SB and CPB indicating their ability to improve fertility, without altering the pH and may have influenced biological activity. Rock powder did not influence the fertility attributes studied. The time elapsed from 105 days, from application to substrate analysis, may not have been sufficient to solubilize some nutrient from rock dust, to the appearance of electrical charges on the surface of rock particles. The concentration of Al_2O_3 rock powder and Fe_2O_3, there was no increase in these elements in the exchange complex, possibly because they are still precipitation in amorphous forms in the soil. It is interesting to note that, in treatments without the addition of OM, the values for these elements were higher.

After adding 20% rock powder, the values fell significantly and became even smaller when 40% dust was added, showing a smaller reduction for substrates with the addition of humus and the largest for addition of vermicompost. That is, an increase of rock powder led to a reduction in the availability of these nutrients. As it is expected that the best plant growth occurs in substrates with greater availability of nutrients, it would be plausible to assume that, under the conditions tested, this would occur in the treatments that did not use the powder. This situation did not occur, indicating that other edaphic factors interfered in plant growth, in addition to the concentration of P, K and Ca. Sandhya et al. (2018), working with diatomaceous earth, observed increased nutrient and Si uptake which was explained by the combination of the physical and chemical properties of diatomaceous earth and was not only due to the contribution of amorphous silica. Diatomaceous earth might be useful for improving crop yield, but soil composition and water regimes play a key role that influences the availability of nutrients in soils. Ramos et al. (2019) showed accumulated amounts of Ca, K, Mg and P, indicating that they were enough to supply the nutritional needs of maize, with the use of dacite rock by-product. Improvements in soil properties, such as high levels of Ca, K and P and low levels of exchangeable Al and Al saturation, were observed. The results of the study suggest that the by-product can be used as a soil remineralizer. OM affects the availability of phosphorus due to organic acids released during its oxidation, because they occupy places where P could be fixed, thereby increasing its availability. Potassium, an important element for plant growth, is also associated with a higher amount of OM (Larramendy and Soloneski 2016). For the substrates evaluated, the largest concentration of these elements was not related to a higher OM content, with the addition of powder changing the elements mobility. It is interesting to note that the lowest values for P, K and Ca were found for all treatments with the addition of vermicompost.

The dacite rock by-product studied here has the potential to be an environmental solution to soil fertilization problems because it does not require chemical processing and can be used as it is mined. Ramos et al. (2017) used volcanic rock waste from southern Brazil and verified that several important nutrients were transferred into acidic solutions, indicating the

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significant potential and feasibility of this waste to be effectively used as a natural fertilizer. This study is of great relevance to the mining sector and to agriculture in the region because it can create an alternative disposal treatment for tailings and improve the environmental sustainability of local farms, thereby avoiding excessive consumption of chemical fertilizer. According to Marek and Richardson (2020), tree species can acquire similar nutrient concentrations, even with lower available nutrient concentrations, a factor associated with the peculiarities of the type of substrate, which affect nutrient release and the absorption process. It should be emphasized that all treatments showed a slightly acidic, slightly basic or neutral pH, demonstrating that the addition of rock powder or its absence interfered only a little with this parameter. However, the potential acidity was significantly higher for the T3 treatment (50% Vc + 50% Lt + 0% Rp), which made this substrate more acidic (6.6) (Table 1).

According to Larramendy and Soloneski (2016), OM is important for reducing soil acidity and aluminium toxicity, allowing better development of plants. As all treatments included OM, at different proportions, its action benefited all the substrates. Silva et al. (2012), testing powder of crushed basalt, explained that the soil pH increased (less acidic) as a function of applying the powder.

4.2 Microbiological activity on substrates

This deserves special attention, because elevation of pH favours microbiological activity, these microorganisms being responsible for the solubilization of inorganic P through the process called biological weathering. Thus, one must highlight the biological activity when using rock powder, who applied powder to an area with the objective of soil remineralization and verified that better microbiological restocking occurred in the site when organic waste was applied. Yang et al. (2020) confirmed the positive effects on soil quality traits and purslane growth and nutritive quality with addition of organic-mineral fertilizer, produced by a combination of OM, potassium (K)-feldspar powder and microbial fermentation. The authors suggested that the treatment might be a promising approach for sustainable crop production and soil remediation in soil oversupplied with chemical fertilizer.

This compost is produced by the action of earthworms, resulting in a fertilizer that has been extensively studied for containing microorganisms. The result of this reaction is earthworm droppings rich in nutrients, especially N, P, Ca, Mg and K, presenting optimum CEC and a high OM content. It is known that soil OM has the power to positively influence physical characteristics, such as density and porosity; chemical characteristics, acting on the release and adsorption of nutrients and pH regulation; and biological characteristics, as a source of food and substrate for the development of microorganisms (Larramendy and Soloneski, 2016). The highest values found for treatments without the addition of rock powder (T1, T2 and T3) did not provide a significant increase in seedling growth (Table 3), indicating that OM alone is not sufficient for better development, other components in the substrate being necessary. Substrate fertility may be affected by the addition of rock powder; papers by different researchers have reported results partially similar to those of the present study. Silva et al. (2012), assessing soil fertility through the addition of crushed basalt, reported a reduction in pH, maintenance of the levels of K and Ca, and an increase of Mg, indicated that the addition of crushed basalt, at the highest concentrations assessed, provided the maximum reduction of active acidity, raising the pH and promoting an increase in the concentrations of Ca, Mg, Zn, Fe and Cu in the soil. Prates et al. (2012), studying the growth of *Jatropha curcas* L. in response to fertilization with ordinary superphosphate and rock powder after 60 days, also did not find an influence on seedlings' morphological characteristics, citing the reason for this as insufficient time for the release of nutrients and the action of soluble fertilizer to meet the plants' needs. The organic compound used in this substrate, humus, is the result of alteration of the partial decomposition of organic waste (cattle manure) and does not have a differentiated concentration of nutrients, as does the vermicompost. Authors such as Gomes et al. (2002), comparing humus resulting from cattle manure with other types of humus, indicated that treatment consisting only of manure showed the highest levels of OM and lower values of P, K, Ca and Mg. The authors concluded that just adding humus is not enough to produce a differential growth in plants, due to nutrient immobilization in soil OM.

Li et al. (2019) observed that vermicompost mixed into soil slightly increased soil nutrient availability compared to unamended soil but had little effect when placed on the soil surface. Vermicompost mixed into soil with inorganic N and P could be used to minimize the loss of N and P after the addition of inorganic fertilizer and thereby provide a longer-lasting nutrient supply for plants.

4.3 The growth of the seedlings (*Myracrodruon urundeuva*)

Although vermicompost, individually, may be considered more appropriate for the plants, the mixture of 40% humus with 20% rock powder produced better results in terms of growth. The addition of only vermicompost, in a greater quantity (50%), did not produce distinctive growth, demonstrating that the composition of the substrate interferes with growth. According to Brandão et al. (2014), high concentrations of vermicompost induce a lower dry mass of the aerial part of plants, as a result of the greater availability of nutrients, discouraging expansion of the root system and hampering plant development, which was observed in treatment T3 (50% Vc + 50% Lt + 0% Rp). The addition of rock powder improved seedling growth, which was also observed by Ehlers and Arruda (2014), evaluating the growth of *Eucalyptus grandis* W. Hill ex Maiden. The authors concluded that the powder, at doses of 10% to 20%, in addition to substrates such as vermiculite and compost to the peat base, resulted in development of the aerial part and collar diameter, a result similar to that found in this study. According to Marek and Richardson (2020), some species are more adapted to growing in certain types of soil and mineral–biological interactions, improving long-term nutrient acquisition. On the other hand, application of the commercial substrate produced less growth in the plants in the present study, demonstrating that it is not suitable for the production of seedlings of the species evaluated.

Delarmelina et al. (2014), evaluating the growth in height, collar diameter, and aerial part, root and total dry mass in seedlings of *Sesbania virgata* (Cav.) Pers., 150 days after sowing, also found the lowest rates using a commercial substrate, when compared to sewage sludge, coconut fibre, vermiculite or carbonized rice *in natura*. Despite the addition of 40% rock powder leading to a process of substrate compaction, hindering the processes of gaseous exchange and absorption of nutrients (T7, T8 and T9), this situation affected the seedlings more strongly only in treatment T8 (30% commercial substrate) (Table 3). The other treatments with commercial substrate, T2 and T5, also did not have adequate growth, indicating inadequacy of the substrate for the species. On the other hand, T7, with 30% humus, can be considered the third-best treatment, demonstrating that despite the greater concentration of powder, humus is suitable for the development of aroeira plants (Table 3). Regarding collar diameter, with equal growth in the treatments with the addition of humus, this is one of the most important variables to be evaluated in the seedlings, since it is directly related to the survival index and initial plant growth in the field (Campos and Uchida 2002).

Taiz et al. (2015) emphasized that plants with a larger collar diameter exhibit a greater tendency to survive, mainly due to greater capacity for the formation and growth of new roots. A thick collar indicates the presence of substance reserves, indicating that the seedling is nutritionally suitable for planting in the field, because the energy to form new roots comes from the stem. But this parameter alone is not adequate for indicating the best growth when plants are still in the nursery phase. The results also showed that all substrates produced seedlings with the ability to survive in the field, considering only the collar diameter. A good-quality seedling presents a stem height ranging from 20 to 35 cm and a collar diameter of between 5 and 10 mm, and all plants reached this standard. This information is in accordance with Larramendy and Soloneski (2016), who mentioned that forest seedlings are deemed suitable for transplanting after passing through a period of hardening, which starts in the period from 70 to 90 days after planting, and ends at approximately 150 days, a phase that tends to thicken the stem and expand the roots. Gomes et al. (2002) affirmed that the period from 90 to 100 days is ideal for assessment of the quality of forest seedlings. Confirming this statement, DQI is pointed out as a good indicator of seedling quality and is used for the calculation of robustness (height/DC ratio) and the balance of biomass distribution (MSPA/MSR ratio). The greater the DQI, the better the quality of the seedlings produced; 0.20 represents the minimum value (Gomes and Paiva 2011). Evaluation of this index showed that it was significantly higher for treatments T4 (20% powder + 40% humus + 40% Oxisol) and T7 (40% powder + 30% humus + 30% Oxisol) than for the others. This demonstrates that the seedlings subjected to the addition of rock powder with humus were of better quality, presenting a greater probability of survival after planting. Gomes and Paiva (2011) considered collar diameter, easily measurable, one of the most important characteristics for estimating seedling survival, as it is an important morphological variable to ensure good development after final planting in the field. Thus, two parameters (root weight and collar diameter) considered important for seedling survival when in the field had better results in T4.

The use of different organic substrates (mainly humus), with the addition of rock powder, evaluated in the present study, was shown to be more appropriate as it produced larger individuals. Fisher (1995), evaluating the growth of species using sewage sludge and silicate fertilization, found maximum growth of 54.2 cm stem height and 19.9 mm collar diameter after 265 days, values lower than those found in this study, with 150 days of evaluation. The success in using humus, vermicompost and commercial substrate for the production of forest seedlings is dependent on the species tested, as reported by Silva et al. (2017), evaluating the growth of *Eucalyptus grandis* Hill ex. Maiden and *Pinus elliottii* var. *elliottii* Engelm. In that case, the addition of vermicompost to the commercial substrate provided greater development of the eucalyptus, in relation to the pure commercial substrate. On the other hand, *Pinus* seedlings were not favoured by the addition of vermicompost, developing better in pure commercial substrate. This situation occurs because plants have specific requirements for their better growth and each type of substrate provides different nutrition conditions, in addition to physical characteristics.

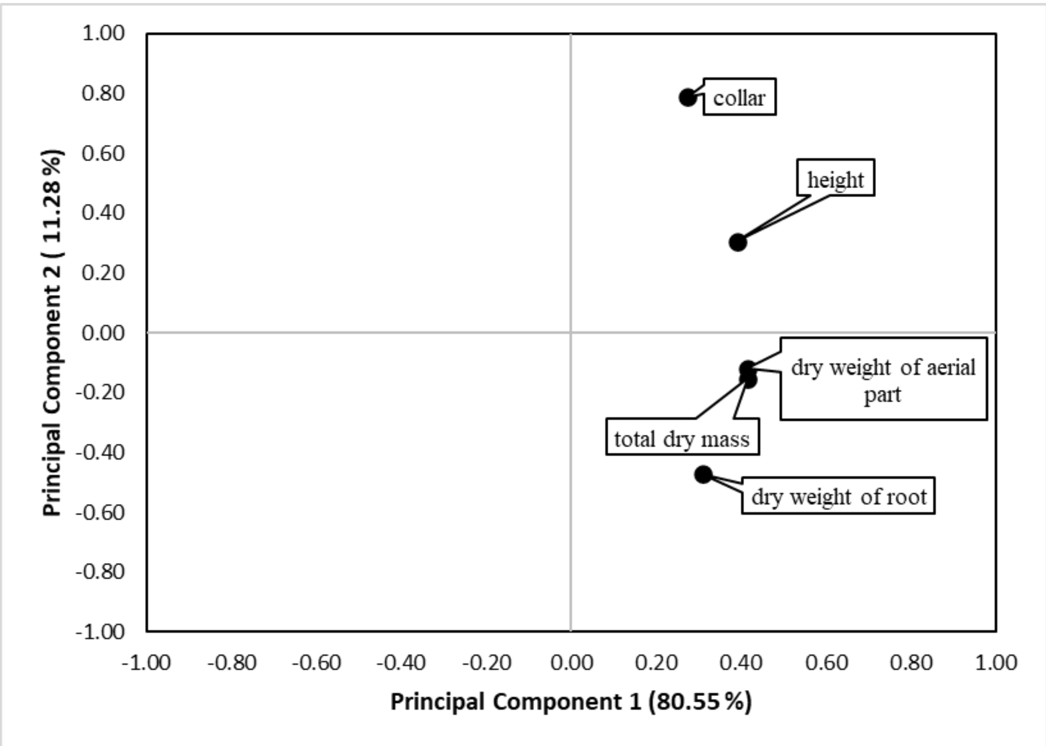
Dalmora et al. (2020), working with eucalyptus and geological materials of andesite rock, verified gains in eucalyptus diameter. Increased availability in soil phosphorous and potassium and the use of these geological materials are presented as an alternative to increase agricultural productivity and reduce the environmental impacts caused by excessive use of highly soluble fertilizers.

4.4 Multivariate analysis

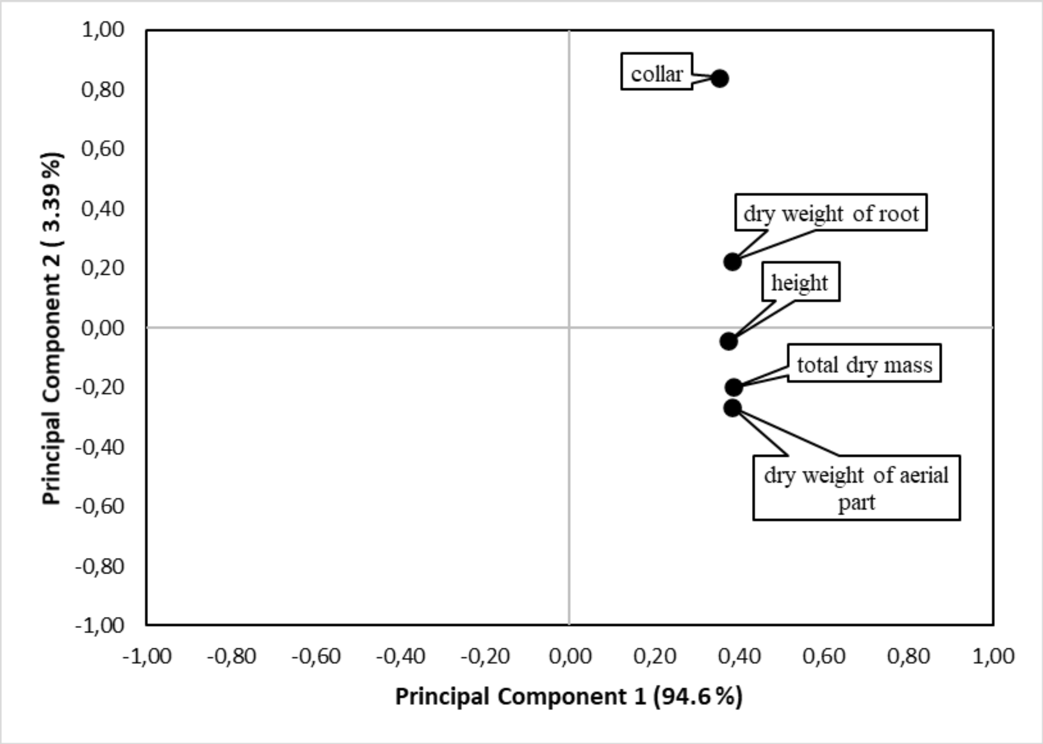
The multivariate analysis (Figure 1) indicates that the addition of 20% rock powder provides greater clustering of growth parameters in relation to the other proportions, demonstrating that the powder induced a more uniform growth. Collar diameter is the parameter that showed differential growth in all treatments, while root and total dry mass showed more homogeneous growth. The addition of 40% powder produced a more unequal growth, indicating that the structures evaluated grew differently, a factor perhaps related to a more compact substrate.

Figure 1. Principal component analysis for the variables root, aerial part and total dry weight, height and collar diameter of aroeira seedlings, grown in different substrates.

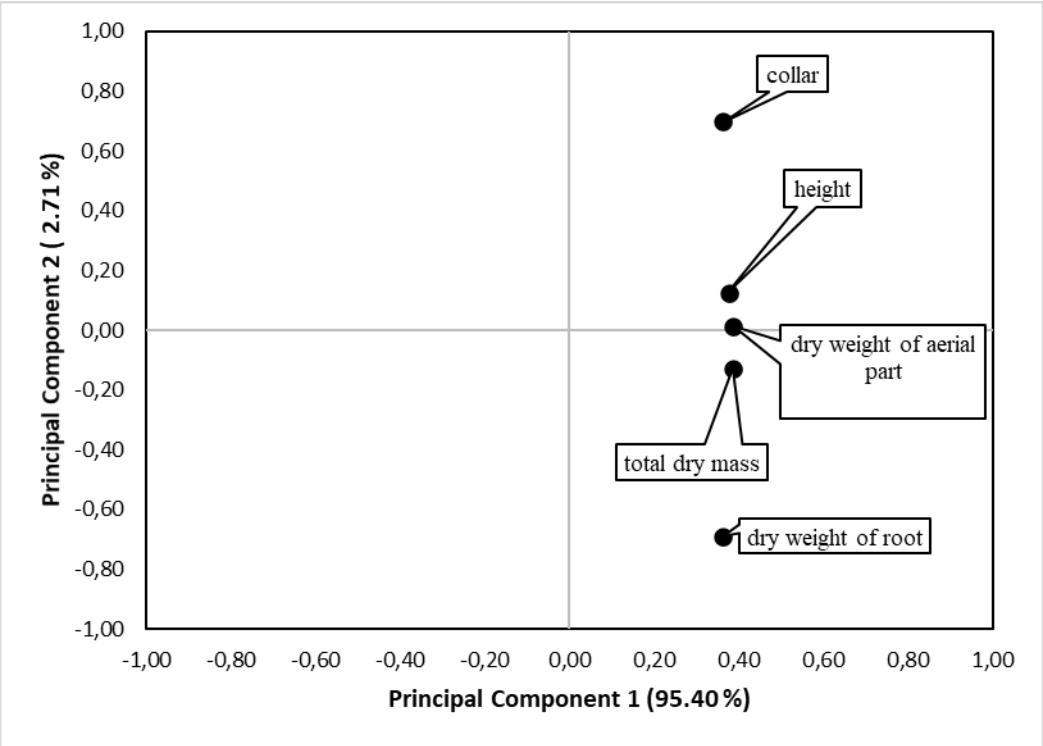
0% rock powder



20% rock powder



40% rock powder



Source: Authors.

On the other hand, in treatments without the addition of powder or with 40% powder, root weight stands out (Figure 1), isolated, indicating that it grew differently, likely the result of greater compression generated by adding the rock powder or less nutrition to the soil. In addition, with 40% powder, the parameters are more dispersed, indicating that at this proportion the plant should spend more energy on the root system, at the expense of the aerial part, possibly due to the fact that the proportion of powder creates a more compressed environment for the seedlings. Martinez et al. (2018) showed stronger root development in plants grown with application of compost and inoculant, along with increased activity of enzymes, particularly β-glucosidase, acid phosphatase and alkaline phosphatase.

The application of humic extract produced a larger increment in water-soluble carbon per carbon unit applied compared to compost, meaning that the former would be more efficient than the latter for providing C for soil microorganisms. This study showed that the joint application of compost, mineral fertilizer and microbial inoculant should be considered to improve root development in *Vitis vinifera* L., and soil quality under Integrated Nutrient Management Programmes. The largest difference among the substrates without addition of powder or with 20% powder relates to the positioning of the root system. When root weight is positioned closer to collar diameter and height, it indicates more vigorous plants, in terms of growth.

These data accord with those of Prates et al. (2010), who recorded increased growth of passion fruit seedlings on increasing the dose of simple superphosphate and a reduction of the effect of phosphate fertilization on addition of rock powder to the substrate, possibly related to adsorption phenomena by amorphous iron and/or carbonates, considering that rock powder comes from the disintegration of slates, marble and granite. The processes releasing nutrients from rock dust to the soil solution can be slow; however, some groups of microorganisms, such as bacteria, fungi and actinomycetes, have the ability to solubilize silicate minerals through their decomposition, so when adding manure to rock dust a synergy occurs and thus the release of nutrients is more efficient. Brandão et al. (2014) worked with the association between A. *niger with rock powder* was able to produce organic acids that solubilized ions, indicating the potential of this bacteria to alter minerals contained in rock powders and interact in different ways with nutrients.

5. Conclusions

From the results obtained and for the experimental conditions it is possible to conclude that the addition of 20% of rock powder to Oxisol, associated with 40% humus in the substrate, resulted in greater initial development of the aroeira seedlings.

The doses with percentage of rock powder above 40% did not impact the growth of aroeira seedlings

Conflict of Interest

The authors declare no conflict of interest of a financial, personal or institutional order associated with the results and discussion in the manuscript.

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