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Physical And Chemical Characterization Of Substrates Formed By Different Source Material

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Abstract:
Background*: The search for the ideal substrate that does not burden the production system is the key to discovering different components that, together, may have all the physical and chemical characteristics suitable for full plants development. Therefore, it is essential to find cheap, local alternatives and, at the same time, dispose of materials with high pollutant potential, such as agro-industrial waste. The present study aimed to characterize the physical and chemical characteristics of substrates formed by different materials of different origin and quantities.*
Materials and Methods*: The experiment was developed at the Experimental Farm Laboratory of the Federal University of Grande Dourados, in a completely randomized design, with four substrates (treatments) and five replicates. All substrates were formed by the same quantities of sugarcane ash (20%), coarse sand (10%) and swine biological sludge (10%). Substrate A was formed by 30% sugarcane bagasse, 10% vermiculite, 10% sugarcane filter cake and 10% chicken litter; substrate B was formed by 20% sugarcane bagasse, 20% sugarcane filter cake and 20% chicken litter; substrate C was formed by 10% vermiculite, 10% sugarcane filter cake, 10% chicken litter and 30% sugarcane straw; finally, substrate D was formed by 20% sugarcane filter cake, 20% chicken litter and 20% sugarcane straw. The characteristics evaluated were: current moisture content, wet density, dry density, water retention capacity at 10 cm, total porosity, aeration space, available water, particle size, percentage of moisture loss, pH and electrical conductivity.*
Results*: Substrates A and B may be indicated for use in pots measuring 20 to 30 cm in height, depending on the dry density, while substrates C and D may be used in pots larger than 30 cm. Total porosity and available water of all substrates presented values considered ideal.*
Conclusion: *The values indicated in the theoretical reference of the literature indicate the substrates as non-adequate due to the high pH value, however, this indication may be reassessed depending on the species of plant that will be cultivated, while the electrical conductivity is in the range considered ideal for cultivation.*
Key Word: *Substrate components, agro-industrial waste, alternative materials.*

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I. Introduction

Substrate may be defined as a cultivation medium in which the roots of cultivated plants develop (ex situ cultivation) in the absence of soil (in situ cultivation)[1], in addition to serving to fix them and provide air, water and nutrients[2].

Substrates are widely used throughout the world precisely due to promoting physical, chemical and biological conditions suitable for plants[1] and because these characteristics may be easily adapted according to the species to be cultivated, types of containers, materials available for formulation, among others.

In relation to the materials that form a substrate, it is very difficult for just one material in isolation to present all the physical and chemical characteristics at ideal levels, making it necessary to mix components to achieve them.

Substrate components may be formed from different raw materials, classified according to their source material: plant origin (sphagnum, peat, tree fern fiber, coal, coconut fiber, processing residues such as shells, bagasse, cakes); mineral origin (sand, vermiculite, perlite) and synthetic origin (phenolic foam, rock wool, Styrofoam)[3].

A major obstacle to the formulation of substrates with different components is the availability in the necessary quantities, as well as the difficulty in obtaining some materials, since they are prohibited because they fall under extractivism, such as peat and xaxim.

Due to the continental size of the country, even if components are available, substrate producers may be far from these sources, which would characterize an increase in production costs, making the entire production chain of cultivated plants more expensive.

In this way, agro-industrial waste may be an alternative to reduce substrate production costs, in addition to helping to dispose of this waste in a sustainable way.

Among these materials from the agroindustry, sugarcane bagasse may be cited as one of the most used, both due to the high availability of the material and the maintenance of its physical characteristics in a stable way for a relatively long time[4,5], which is ideal as, in some cases, the seedling needs more time in the nursery.

Another alternative component is biosolids, the solid, sanitized and stabilized part of sewage sludge[6], which may come from different sources, mainly from animal farming. In addition to conditioning the physical and chemical characteristics of the substrate by adding organic matter and nutrients[7], there is better destination for this residue that would otherwise be deposited in landfills or incinerated[8].

Once the raw materials that will form the substrate have been chosen, the physical and chemical characterization of the mixtures is essential to adapt the quantities of each component[3,9] to meet the minimum quality requirements for good plant development.

For Verdonck et al.[10], physical characteristics are the most important because the relationship between air and water may not change throughout the cultivation. Among them, Kämpf[1] cites substrate density, porosity, macroporosity (aeration space) and microporosity (available water) as some of the most important. Regarding chemical characteristics, the author cites pH and electrical conductivity as the most limiting, as they are directly linked to the availability of nutrients in the substrate solution.

Thus, the present work aims to evaluate the physical and chemical characteristics of substrates formed with different source materials in different quantities.

II. Material And Methods

The experiment was developed at the Research, Teaching and Extension Support Laboratory (LAPEX) of the Experimental Farm (FAECA) of Grand Dourados Federal University (UFGD) located at latitude 22° 13' 52.4495'' W, longitude 54° 59' 10.5372'' S, altitude 411.75 m; in the municipality of Dourados-MS, Brazil.

The experimental design used was completely randomized, with four treatments (substrates) and five replicates. The substrates evaluated had in common in their composition 20% sugarcane bagasse ash, 10% coarse sand and 10% swine biological sludge; the other components are described in Table 1.

Table 1. Composition of the substrates evaluated.

Substrate	Composition
Substrate A	30% sugarcane bagasse; 10% vermiculite; 10% sugarcane filter cake; 10% chicken litter.
Substrate B	20% sugarcane bagasse; 20% sugarcane filter cake; 20% chicken litter.
Substrate C	30% sugarcane straw; 10% vermiculite, 10% sugarcane filter cake; 10% chicken litter.
Substrate D	20% sugarcane straw; 20% sugarcane filter cake; 20% chicken litter.

To improve the standardization of substrate samples, as they are not commercial, before the start of the evaluations all materials were moistened with tap water in a 4:1 ratio (V/V: substrate/water) aiming to make them as close as possible to the ideal for use as substrate.

Following the sample preparation, the amount of hydrated material was passed through a 19 mm x 19 mm mesh sieve (ASTM ¾"). If an amount less than or equal to 10% was retained, the particles were physically reduced in equal parts and as many times as necessary so that all the material passed through the sieve. If an amount greater than 10% was retained, the physical and chemical analyses could not be performed, as stated in Normative Instruction No. 17 of May 21, 2007 of the Ministry of Agriculture, Livestock and Food Supply[11].

In addition to this Normative, the physical and chemical characteristics were evaluated in accordance with Normative Instruction No. 17 of May 21, 2007, of the Ministry of Agriculture, Livestock and Food Supply, which deals with the Official Analytical Methods for Analysis of Substrates and Soil Conditioners[11], such as current moisture, wet density, dry density, water retention capacity at 10 cm, pH and electrical conductivity and according to the methodology adapted from the Soil Analysis Methods Manual of Embrapa Solos[12] for total porosity, macroporosity and microporosity.

To determine the current moisture content (%), 100 g samples of substrate were weighed and placed in a drying and sterilization oven at 65ºC ± 5.0ºC until reaching a constant mass (approximately 48 hours). After this period, the samples were weighed again and the moisture content was calculated using formula 1:

$$CM\ (\%) = [(M1 - M2)/ M1] \times 100 \quad [1]$$

Where CM (%) is the current moisture, M1 is the wet mass (g) and M2 is the dry mass (g).

Regarding the wet density of the substrate, the self-compaction method was used: A 500 mL plastic test tube was filled to the 300 mL mark with the substrate at the current moisture. This test tube was dropped, under the action of its own mass, from a height of 10 cm, ten consecutive times.

Using a spatula, the surface was slightly leveled and the volume obtained (mL) was read. The material was weighed (g), discounting the mass of the test tube. With these results, it was possible to calculate the wet density using formula 2.

$$WD\ (kg\ m^{-3}) = [M1/V1] \times 1000 \quad [2]$$

Where, WD (kg m^{-3}) is the wet density, M1 is the wet mass of the substrate after compaction (g) and V1 is the volume occupied by the substrate in the test tube after compaction (cm^3).

With the results of current moisture and wet density it was possible to calculate the dry density using formula 3.

$$DD\ (kg\ m^{-3}) = WD \times [100 - CM/ 100] \quad [3]$$

Where, DD (kg m^{-3}) is the dry density, WD is the wet density (kg m-^{3}) and CM is the current moisture (%).

To determine the water retention capacity at 10 cm (WRC10), total porosity, available water and aeration space, the tension table methodology was used.

The sample preparation was the same for the four characteristics: the bottom of the volumetric rings was sealed with a screen secured by a rubber tie. As this is a deformed sample, it was necessary to fill the rings with the substrates and the substrate mass was calculated using formula 4.

$$M\ (g) = (IV \times WD)/1000 \quad [4]$$

Where M (g) is the mass of substrate required to fill the volumetric ring (g), IV is the internal volume of the ring (m^3) and WD is the wet density calculated using formula 2.

Once the rings were prepared, they were placed for saturation for 24 hours with a layer of distilled water located 0.5 cm below the edge of the cylinders. After saturation, the rings were weighed (M1) and distributed on the tension table adjusted to a tension of 10 cm of water column (1 kPa or 10 hPa).

The samples remained on the table until reaching equilibrium when they were removed, weighed (M2), and returned to the tension table adjusted to 60 cm of water column (6 kPa or 60 hPa).

After reaching equilibrium again, the rings were removed, weighed (M3) and placed to dry in a drying and sterilization oven at 65ºC ± 5.0ºC until reaching constant mass, weighing again (M4).

Formula 5 was used to calculate the water retention capacity at 10 cm.

$$WCR10\ (\%\ v/v) = [(M2 - M4) \times 100]/RV \quad [5]$$

Where, WRC10 (% v/v) is the water retention capacity at 10 cm, M2 is the mass of the sample after equilibrium at a tension of 10 cm (g), M4 is the dry mass of the sample (g) and RV is the volume of the ring (cm^3).

Regarding the calculations of total porosity (TP), available water (AW) and aeration space (AS), formulas 6, 7 and 8 were used.

$$PT\ (\%) = [(M1 - M4)/RV] \times 100 \quad [6]$$

$$AD\ (\%) = [(M3 - M4)/RV] \times 100 \quad [7]$$

$$EA\ (\%) = TP - AW \quad [8]$$

Where, TP (%) is the total porosity, AW (%) is the available water, AS (%) is the aeration space, M1 is the mass of the saturated sample (g), M3 is the mass of the sample after equilibrium at a tension of 60 cm (g), M4 is the mass of the oven-dried sample (g) and RV is the volume of the ring (cm^3).

The particle size distribution of the substrate (%) was determined in an orbital sieve shaker, according to methodology adapted from Yoder[13]. Each set in the shaker consisted of six sieves, whose mesh sizes had the following openings: 2.36; 2.00; 1.18; 0.600; 0.300 and 0.075 mm; approximately 60 g of sample was added to the upper sieve and shaken for one minute. After shaking, the mass retained in each sieve was weighed and the result was converted into a percentage.

The percentage of moisture loss was measured by simulating the storage of the substrates. Five samples of approximately 100 g were placed in a black polyethylene bag and stored in an environment with an average temperature of 25°C. During this period, the samples were weighed nine times (0, 1, 2, 5, 6, 7, 9, 12 and 19 days) and the masses were transformed into % moisture loss, always comparing with the initial mass (0 days).

To determine the pH, a sample equivalent to 60 mL of substrate was separated and transferred to a container and 300 mL of distilled water was added, and this sample was stirred for one hour in a Wagner shaker with a rotation of 40 rpm.

After agitation, the samples were sieved, placed in identified containers and the pH was read using the Digimed pHmeter device, after stabilization, when the reading did not vary by more than 0.1 pH unit for 15 seconds.

The determination of electrical conductivity (mS cm^{-1}) occurred by filtering the suspension used to determine the pH, discarding the first 10 mL and measuring the solution after one hour of extraction of the filtrate with the aid of Digimed electrical conductivity meter.

The results were subjected to analysis of variance and, when significant, the treatment means were compared using the Tukey test at 5% probability and the mass loss percentage data were subjected to regression analysis.

III. Result And Discussion

Table 2 shows the averages of current moisture (CM - %), wet density (WD - kg m^{-3}), dry density (DD - kg m^{-3}) and water retention capacity at 10 cm of water column (WRC10 - %) of evaluated substrates.

Table 2. Current moisture content (CM - %), wet density (WD - kg m^{-3}), dry density (DD - kg m^{-3}) and water retention capacity at 10 cm water column (WRC10 - %) of substrates formed by different source materials.

Substrate	CM	WD	DD	WRC10
	%	kg m^{-3}	kg m^{-3}	%
A	37.59 a	739.20 c	461.37 c	40.09 b
B	31.29 b	664.16 d	456.29 c	40.42 b
C	27.27 c	842.09 a	612.44 a	46.44 a
D	27.90 c	785.06 b	566.00 b	45.20 a
CV(%)	1.80	1.64	1.64	8.19

Means followed by the same letter in the column do not differ from each other at the 5% level by the Tukey test.

Regarding the current moisture, it was observed that there was statistical difference between the treatments, with substrate A (30% sugarcane bagasse, 20% sugarcane bagasse ash; 10% coarse sand; 10% vermiculite, 10% sugarcane filter cake; 10% swine biological sludge; 10% chicken litter) having the highest humidity (37.59%), differing statistically from the others, followed by substrate B (20% sugarcane bagasse, 20% sugarcane bagasse ash, 10% coarse sand, 20% sugarcane filter cake, 10% swine biological sludge, 20% chicken litter) with 31.29%, substrate D (20% straw sugarcane, 20% sugarcane bagasse ash, 10% coarse sand, 20% sugarcane filter cake, 10% swine biological sludge, 20% chicken litter) with 27.90% and substrate C (30% sugarcane straw, 20% sugarcane bagasse ash, 10% coarse sand, 10% vermiculite, 10% sugarcane filter cake, 10% swine biological sludge, 10% chicken litter) with 27.27%.

Substrate moisture is a fundamental characteristic at the moment of use, as water availability may interfere in the early stages of sowing or planting seedlings.

In this case, the substrates arrived at the laboratory dry, since they were packaged in raffia bags that facilitate water loss. For the physical and chemical evaluations, it was necessary to hydrate them and, for all, the same proportion of 4:1 (v:v) was used, with four parts of substrates and one part of water, thus substrate A was the one that obtained the greatest hydration in relation to the others, possibly due to the greater amount of sugarcane bagasse in its composition (30% - Table 1).

Sugarcane bagasse is an agro-industrial residue obtained after the plant is milled. It is a fibrous material that, when it leaves the mill, has around 30% of the sugarcane mass and 50% moisture[14], that is, when incorporated into the substrate, even after decomposition, the spaces that previously contained water are filled again after hydration.

Regarding wet density (WD) and dry density (DD), there was also statistical difference between the treatments (Table 2), with substrate C presenting the highest average for the WD (842.09 kg m^{-3}), followed by substrate D (785.06 kg m^{-3}), substrate A (739.20 kg m^{-3}) and substrate B (664.16 kg m^{-3}).

For the second (DD), the order remained the same with substrate C presenting 612.44 kg m^{-3}, substrate D with 566.00 kg m^{-3} and substrates A and B not differing from each other (461.37 and 456.29 kg m^{-3}, respectively).

Wet density will always vary depending on the time of assessment and also the source material used, therefore, dry density is the best characteristic to be assessed, as it disregards any water content present.

The ideal dry density of substrate will depend on the container to be used. According to Kämpf[1], the density for use in multi-cell trays should be between 100 and 300 kg m^{-3}; for pots smaller than 15 cm in height, the dry density should be between 200 and 400 kg m^{-3}; for pots between 20 and 30 cm in height, substrates with

300 to 500 kg m^{-3} are used, and for pots over 30 cm in height, the ideal substrates are between 500 and 800 kg m^{-3}. Therefore, the substrates evaluated could be recommended for use in pots 20 cm or more in height.

The water retention capacity at 10 cm of water column (WRC10) showed a significant difference between group AB and group BC, with no statistical difference within the groups. This separation was made because, according to Table 1, substrates A and B have the same components, differing only in their quantities, the same occurring with substrates C and D.

In this case, WRC10 was higher in substrates with the presence of sugarcane straw (substrate C with 46.44% and substrate D with 45.20%), values presented in Table 2.

The capacity to retain water will depend, among other factors, on the particle size of each substrate. Souza et al.[15], working with the physical properties of organic substrates, reported that the smaller the particles, for example, of sugarcane bagasse, the greater the water absorption by the substrate.

Thus, when analyzing the results of the particle size evaluation (Figure 1), it is observed that substrates A and B present larger parts of their composition with particles greater than or equal to 2.36 mm (A - 37.70%; B - 35.73%); in contrast, substrates C and D presented higher percentages of particles between 0.60-0.30 mm (C - 40.45%; D - 34.33%).

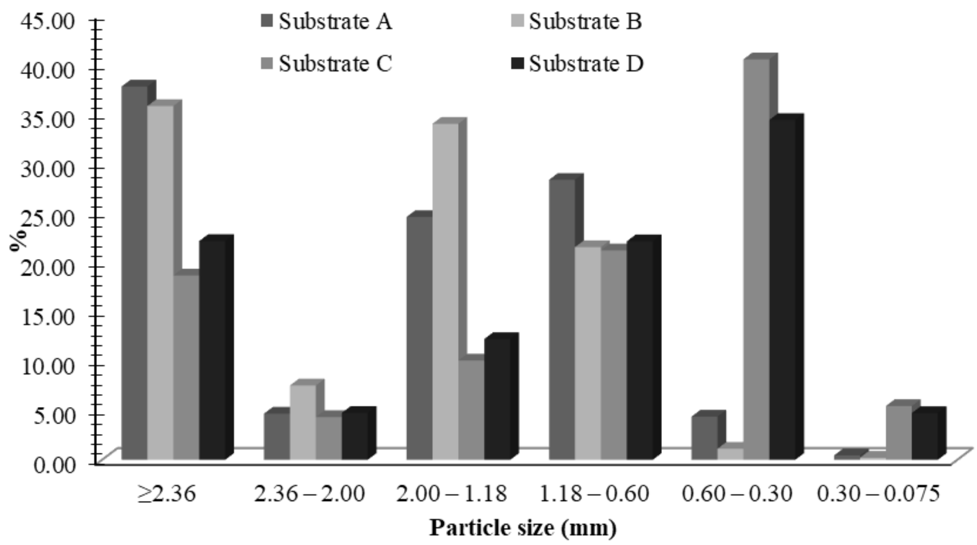

Figure 1. Particle size of substrates formed by different source materials.

With these particle size means, there was also interference in dry density as already observed in Table 2, larger particles produced substrates with lower density (Substrates A and B), the opposite is true (Substrates C and D).

Smaller particle sizes generate denser substrates with greater water retention capacity, proven by the percentage of available water that was higher in substrates C (38.75%) and D (37.44%) compared to substrates A (32.32%) and B (31.62%) (Table 3).

Table 3. Total porosity (TP - %), aeration space (AS - %) and available water (AW - %) of substrates formed by different source materials.

Substrate	TP	AS	AW
	%		
A	83.66 a	51.34 a	32.32 b
B	80.67 ab	49.06 a	31.62 b
C	77.14 b	38.39 b	38.75 a
D	76.77 b	39.33 b	37.44 a
CV(%)	4.07	5.52	5.25

Means followed by the same letter in the column do not differ from each other at the 5% level by the Tukey test.

Available water is also mentioned as microporosity and according to Abad et al.[16] an ideal substrate should have available water between 24 and 40%, in this case, all the substrates evaluated are within this range.

The aeration space or macroporosity corresponds to the spaces filled with air. Substrates A (51.34%) and B (49.06%) did not differ from each other, as well as substrates C (38.39%) and D (39.33%); however, group CD presented lower averages than group AB, differing statistically (Table 3).

According to De Boodt and Verdonck[17] and Cattivello[18], the ideal range of aeration space for a substrate is between 20 and 30%. For the substrates evaluated, this range is below that found; however, substrates C and D were the ones that came closest to this ideal.

The total porosity (Table 3) which includes the sum of the aeration space and available water showed a similar standard in which the AB and CD substrate groups did not differ statistically from each other, but differed between the groups. For De Boodt and Verdonck[17] and Cattivello[18] an ideal substrate should have up to 85% of total porosity, thus, including all the substrates evaluated in the present work.

Regarding the percentage of moisture loss (Figure 2), it is observed that the substrate trend was linear with gradual moisture loss and followed the same behavior as the other physical characteristics.

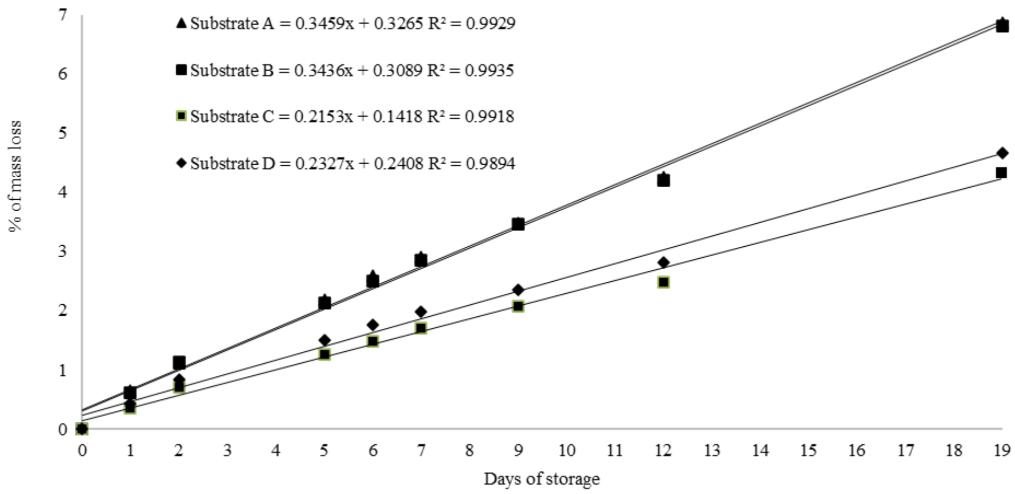

Figure 2. Percentage of mass loss of substrates formed by different source materials simulating storage.

Substrates A and B lost more moisture as time passed in the storage range of 6.86% and 6.81%, respectively, while the loss of substrates C and D was only 4.32% and 4.67%, respectively, at 19 days of storage.

Projecting for 30 and 60 days using the regression equation presented, substrate A would lose 10.70% and 21.08% of moisture, respectively, followed by substrate B with 10.62% and 20.92%, substrate C with 6.60% and 13.06% and substrate D with 7.22% and 14.20%.

Knowing the possibility of mass loss is very important to establish the forms to storage the substrates, with this, storage and transportation strategies may be implemented, if commercial, the recipient receives a quality product, with characteristics as close as possible to those that were purchased and that the producer stated it would have. Therefore, more tests need to be carried out to simulate adverse storage and transportation conditions, among others.

All of these physical characteristics are important as they will determine the plants growth potential in which they will be cultivated. For Ludwig et al.[19], irrigation scheduling will take these attributes into account, as the amount of water that will be available to plants will depend on the substrate's ability to retain this water. The authors also state that there must be a balance between all of the characteristics, as too much water available may reduce the aeration space, reducing the amount of oxygen for the roots, in opposite, little water available and very large aeration spaces may cause stress due to lack of water.

Some chemical analyses are essential for substrate characterization, such as pH and electrical conductivity, mainly because they are intrinsic to each formulation.

For pH in water, there was statistical difference between the substrates, with A presenting the highest value (8.06) and B and C presenting the lowest values (7.49 and 7.62, respectively) (Table 4).

Table 4. pH and electrical conductivity (EC - mS cm-1) values of substrates formed by different source materials.

Substrate	pH	CE
	in water	**mS cm^{-1}**
A	8,06 a	1,38 b
B	7,49 c	1,22 c
C	7,62 bc	1,48 b
D	7,77 b	1,80 a
CV(%)	1,75	5,92

As substrate A was the one that differed from the others and observing the composition of each one (Table 1), the component that has the most in this substrate is sugarcane bagasse. In relation to substrate B, the first has 10% more of this material in its composition, while in C and D there is no percentage.

Scarassatti et al. [20] when using malt and sugarcane bagasse as a source of substrates observed that sugarcane bagasse presented the highest pH values in rainwater leached, understanding that this material, naturally, has a basic nature and thus stands out in the formulations in which it is present.

The pH is one of the most important chemical characteristics to evaluate in substrates as its value is directly linked to the availability or not of the main nutrients required by plants, in addition to interfering in some physiological processes[1].

According to the author, substrates with values lower than 5.0 may make nutrients such as N, K, Ca, Mg and B unavailable; while pH above 6.5 may cause deficiencies of P, Fe, Mn, Zn and Cu. Furthermore, in general, the optimal pH range for plant production would be between 5.2 and 5.5. In this case, no substrate meets the optimal range.

On the other hand, Bailey et al.[21] states that very low pH values in forest species may cause phytotoxicity for some species. According to Waldemar[22] the ideal pH range for the production of forest seedlings varies between 5.0 and 7.0.

These differences are important to be highlighted to understand that the ideal pH range may vary according to the species being worked with, thus requiring specific studies considering different types of packaging to be used and species, noting that these ideals found in the literature are theoretical references.

Salinity, which is measured by electrical conductivity (EC), evaluates the amount of salts contained in the substrate solution and showed statistical difference between the substrates evaluated, as shown in Table 4.

The substrate that presented the highest EC was A with 1.80 mS cm^{-1}, followed by substrates C (1.48 mS cm^{-1}), A (1.38 mS cm^{-1}) and B (1.22 mS cm^{-1}) (Table 4). Although substrates A and C did not differ statistically from each other, when analyzing groups AB and CD, which have the same components but in different quantities, the substrates with sugarcane straw (C and D) presented a higher CE compared to substrates A and B that contain sugarcane bagasse.

According to Kämpf[1], the ideal EC value for substrates, in general, is 1.00 to 2.00 mS cm^{-1}, thus, all substrates are in this range. In contrast, Calvins et al.[23] report that ideal EC values are in the range of 0.36 to 0.65 mS cm^{-1}. Considering this new range, no substrate would be suitable for use in plant cultivation.

This difference in understanding is important to highlight, as is the case with pH, which, depending on the type of crop and the species used, the EC will change and thus, these materials may be used without presenting risks to plants.

The salinity of the substrate solution needs to be carefully assessed, as at some point in the plant's cycle, fertilization will be necessary, with the application of fertilizers by soil or fertigation. This fertilization, using soluble products, may increase the EC of the substrate, which was already high, thus becoming toxic to the species.

High EC may be easily resolved by leaching the salinity (washing), however, care must be taken with this practice for not wasting fertilizers.

It is important to emphasize that the physical and chemical characterization of substrates are of great importance, to have a general view of the behavior of the components that each one has, however, when dealing with mixtures that are not yet commercial, it is essential that tests with different species are performed, as well as types of containers, in addition to use in different phases of development, germination, temporary conduction or definitive conduction.

IV. Conclusion

Regarding physical attributes, substrates A and B may be indicated for use in pots measuring 20 to 30 cm in height depending on dry density, while substrates C and D may be used in pots larger than 30 cm.
Regarding total porosity and available water, all substrates presented values considered ideal.

For pH, the values indicated in the theoretical reference of literature indicate that the substrates are not suitable due to the high value, however, this indication may be reassessed depending on the species of plant that will be cultivated.

The salinity of the substrate, measured by means of electrical conductivity, demonstrated that the substrates are within the range considered ideal for cultivation.

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