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# HYDRO-PHYSICAL CHARACTERISTICS OF SUBSTRATES FOR LETTUCE PRODUCTION IN FLOATING GROWTH SYSTEM

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## 1 ABSTRACT

The objective was to evaluate the hydro-physical properties of different substrates and their effects on the development of lettuce seedlings in a floating system. The study was carried out in a greenhouse during the months of January and February of 2017. The design was randomized blocks with 16 treatments, represented by 13 proportions of substrates based on organic fertilizer, carbonized rice husk and vermiculite, and three other commercial substrates. The hydro-physical characteristics (granulometric fraction, dry bulk density, total porosity, aeration space, easily available water, available water, remaining water and water retention capacity), pH, and electrical conductivity of the substrates were evaluated. Number of leaves, plant height, root system length, fresh mass of root and shoot and dry mass of root and shoot were evaluated at 25 days after emergence. Aeration space and remaining water are the priority hydro-physical variables that should be evaluated in substrates that will be used in floating systems. The formulations with 33.33% organic fertilizer, 43.33 to 53.33% of carbonized rice husk, and 23.33 to 13.33% vermiculite presented the best performance among the substrates studied for the production of seedlings lettuce in floating systems.

**Keywords:** *Lactuca sativa L.*, carbonized rice husk, organic compost.

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## 2 RESUMO

O objetivo foi avaliar as propriedades físico-hídricas de diferentes substratos e seus efeitos no desenvolvimento de mudas de alface em sistema floating. O estudo foi realizado em casa de vegetação durante os meses de janeiro e fevereiro de 2017. O delineamento foi de blocos casualizados, com 16 tratamentos, representandos por 13 proporções de substratos à base de composto orgânico, casca de arroz carbonizada e vermiculita e três substratos comerciais. Foram avaliadas as características físico-hídricas (fração granulométrica, densidade seca, porosidade total, espaço de aeração, água facilmente disponível, água disponível, água remanescente e capacidade de retenção de água), pH e condutividade elétrica dos substratos. O número de folhas, altura das plantas, comprimento do sistema radicular, massa fresca de raiz e parte aérea e massa seca de raiz e parte aérea foram avaliados aos 25 dias após a emergência. O espaço de aeração e a água remanescente são as variáveis físico-hídricas aprioritárias que devem ser avaliadas em substratos que serão utilizados em sistema floating. As formulações com 33,33% de composto orgânico, 43,33 a 53,33% de casca de arroz carbonizada, e 23,33 a 13,33% de vermiculita apresentaram os melhores desempenhos entre os substratos estudados para a produção de mudas de alface em sistema *floating*.


**Palavras-chave:** *Lactuca sativa* L., casca de arroz carbonizada, composto orgânico.

## 3 INTRODUCTION

Rio Grande do Sul (RS) is the state with the largest rice production in Brazil, with a harvest of 7,866.9 thousand tons produced in 2019/2020 (ARROZ/CONAB, 2020). Being the southern region of the state of RS one of the main productive poles (MIRANDA el al., 2016). The rice processing generates 21 solid residues, including the husk (SAIDELLES et al., 2012).

Rice husk, in its carbonized form, has been used as a structural element in formulations of substrates, conferring high macroporosity, being necessary to combine it with higher microporosity materials to balance the solid-pore ratios of the substrate (KRATZ; WENDLING, 2016). Several studies have indicated the use of rice husk as a component of substrates for plants growth (COSTA et al., 2017; WATTHIER et al., 2017; MENEZES JÚNIOR; VIEIRA NETO; RESENDE, 2018; TERRA et al., 2018), making up most of the commercial substrates available in the market of southern Brazil.

In general, the substrates are formulated and marketed for the production of a forest, horticultural, and ornamental seedlings in protected environments. However, there are few studies are indicating the best combination between the substrate type and the seedling production system. Each production system has specific requirements, especially about in relation to the species to be cultivated, the type of irrigation, and the hydro-physical characteristics of the substrate, which can be widely different. Vermiculite is another well-known and widely used material, which is easy to obtain and has a low density as the main advantages (MARTINS; BOVI; SPIERING, 2009).

The floating system is common for vegetables, such as lettuce seedlings, as it provides uniformity in water availability and allows nutritional complementation when necessary (RODRIGUES et al., 2010). However, it should be performed using substrates with adequate air/water ratios, avoiding water stress.

To our knowledge, very few, if any studies have evaluated the most suitable physical conditions for substrates developed with raw materials of regional occurrence and worldwide used. Locally sourced substrates can reduce production costs compared to commercial ones, as well as being more socio-economic and environmentally sustainable with the use of local waste such as rice husk. In this context, the present work was developed with the objective to evaluate the hydro-physical properties of different substrates and their effects on the development of lettuce seedlings in a floating growth system.

## 4 MATERIAL AND METHODS

Substrates hydro-physical mixing and characterization was conducted in the Laboratory of Soil Physics, while lettuce seedlings were grown in a greenhouse with automated controlled temperature (15-30 ºC), located at Embrapa Clima Temperado - Terras Baixas Experimental Station, Capão do Leão, Rio Grande do Sul State, Brazil, (31° 49’ 13” S; 52° 27’ 50” W and elevation 14.0 meters).

The experiment was carried out in a randomized blocks design with 16 treatments and four replications, represented by 13 proportions of substrates based on organic fertilizer class B (OC) (constitution: wood bark, tree pruning and trimmings, leftover food, pulp, bagasse and citrus juice, hatchery residues, sludge from effluent treatment plants in the beverage, dairy, cellulose and refrigerator industries, among others components to a lesser extent seeking physical-chemical balance), carbonized rice husk (CRH) and fine vermiculite (<3 mm) (VER), and three other commercial substrates (controls) having the following compositions: organic waste from Class A agribusiness (grape seed, bagasse and stalk), ashes, peat and charcoal (carbonized rice husk) (commercial 1); pine bark, vermiculite, acidity concealer and macronutrients (commercial 2); and sphagnum peat, expanded vermiculite, charred rice husk, dolomitic limestone, agricultural gypsum, NPK fertilizer and micronutrients (commercial 3).

The three substrates (OC, CRH and VER) were formulated in the following proportions (m:m): S1: 53.33% OC + 33.33% CRH + 13.33% VER; S2: 43.33% OC + 33.33% CRH + 23.33% VER; S3: 13.33% OC + 33.33% CRH + 53.33% VER; S4: 23.33% OC + 33.33% CRH + 43.33% VER; S5: 43.33% OC + 23.33% CRH + 33.33% VER; S6: 53.33% OC + 13.33% CRH + 33.33% VER; S7: 23.33% OC + 43.33% CRH + 33.33% VER; S8: 13.33% OC + 53.33% CRH + 33.33% VER; S9: 33.33% OC + 43.33% CRH + 23.33% VER; S10: 33.33% OC + 53.33% CRH + 13.33% VER; S11: 33.33% OC + 23.33% CRH + 43.33% VER; S12: 33.33% OC + 13.33% CRH + 53.33% VER; S13: 33.33% OC + 33.33% CRH + 33.33% VER. The commercial substrates S14 (commercial 1), S15 (commercial 2) and S16 (commercial 3) were used without mixtures.

The substrates were homogenized and distributed in 110 $cm^3$ cells (styrofoam trays containing 78 cells). In the trays with the substrates were sown commercial seeds of lettuce cv. ‘Simpson’ (germination power of 74%), on January, 2017. Each plot had six cells with one seedling per cell. The trays were kept in a floating system during the experimental time.

The plants were evaluated at 25 days after emergence, when the ideal crop stage for transplantation was reached. The variables evaluated were: number of leaves (NL), plant height (PH, in cm), root system length (RSL, in cm), shoot fresh mass (SFM, in g) and root fresh mass (RFM, in g), shoot dry mass (SDM, in g) and root dry mass (RDM, in g). The NL was obtained by counting, while PH and RSL were measured with a graduated ruler. The SFM and RFM were determined by weighting in precision balance (0.001 g) after harvest, then packed in paper bags and dried out at 65 ºC until reaching constant mass to determine SDM and RDM. All variables were determined individually in six plants of each plot.

The following hydro-physical and chemical attributes were determined in the substrate samples prior to the experiment: granulometric fraction, dry bulk density (DD), total porosity (TP), aeration space (AS), easily available water (EAW), available water (AW), water retained (WR), water retention capacity (WRC), hydrogenionic potential (pH) and electrical conductivity (EC).

The DD of the substrates were determined by the self-compacting method described by Brasil (2007). The granulometric fraction was performed with 100 g of air-dried substrate, with a set of sieves (4.76, 2.00, 1.00 and 0.50 mm) coupled to a mechanical stirrer, working for three minutes. The variables TP, AS, EAW, WA, WR and WRC were determined according to De Boodt and Verdonck (1972), Brasil (2007) and Fermino (2014). The pH and EC values of the substrates were determined in 1:5 (substrate:water ratio) according to Brasil (2007).

The data sets obtained in experiment and in the characterization of the substrates were evaluated in relation to the normality of their distributions and about the presence of discrepant values then, each response variable was submitted to analysis of variance and, for those variables with significant treatment effect, the Scott-Knott means comparison test was applied at a 0.05 probability level. Pearson correlation coefficients were also performed from the hydro-physical characteristics of the substrates and the growth and productivity variables of lettuce seedlings. Statistical analyzes were performed with SISVAR software (FERREIRA, 2008).

## 5 RESULTS AND DISCUSSION

The hydro-physical and chemical characteristics were significantly influenced by the composition of the substrates (Table 1). A great heterogeneity among the evaluated treatments can be observed on the DD values, being that substrates S3, S4, S9, S10 and S16 showed DD values close to the reference values (100 to 300 kg $m^{-3}$) for the growing seedlings in cell trays (KÄMPF, 2005), while the other substrates presented values outside the range (Table 1).

**Table 1.** Dry bulk density (DD), total porosity (TP), aeration space (AS), available water (AW), water remaining (WR), hydrogenionic potential (pH) and electrical conductivity (EC) of different substrates.

| Substrates | Hydro-physical characteristics | | | | | Chemical Characteristics | |
|---|---|---|---|---|---|---|---|
| | DD | TP | AS | AW | WR | pH | CE |
| | kg m$^{-3}$ | ------------------- | % | ------------------ | | | mS cm$^{-1}$ |
| S1 | 411.02 | 59.33 | 29.01 | 12.41 | 18.55 | 7.48 | 0.71 |
| S2 | 363.55 | 62.33 | 33.29 | 10.07 | 19.66 | 7.29 | 0.66 |
| S3 | 301.39 | 59.72 | 33.15 | 8.24 | 18.98 | 7.36 | 0.28 |
| S4 | 307.52 | 59.08 | 35.51 | 7.58 | 16.70 | 7.58 | 0.39 |
| S5 | 356.32 | 63.02 | 32.39 | 9.43 | 21.86 | 7.21 | 0.71 |
| S6 | 441.29 | 62.13 | 24.33 | 11.28 | 27.22 | 7.16 | 0.91 |
| S7 | 327.93 | 61.66 | 33.85 | 9.54 | 18.93 | 7.61 | 0.30 |
| S8 | 339.67 | 63.89 | 32.73 | 12.08 | 19.73 | 7.72 | 0.18 |
| S9 | 307.09 | 63.63 | 39.18 | 8.48 | 16.64 | 7.56 | 0.44 |
| S10 | 279.73 | 60.28 | 39.91 | 8.13 | 12.90 | 7.56 | 0.36 |
| S11 | 327.55 | 66.84 | 33.38 | 8.35 | 25.79 | 7.29 | 0.58 |
| S12 | 356.96 | 68.87 | 29.90 | 9.00 | 30.67 | 7.26 | 0.62 |
| S13 | 348.46 | 66.50 | 37.20 | 9.44 | 20.54 | 7.47 | 0.58 |
| S14 | 418.79 | 55.33 | 13.62 | 13.22 | 29.11 | 5.24 | 0.81 |
| S15 | 426.82 | 54.48 | 6.36 | 11.30 | 37.44 | 5.26 | 0.31 |
| S16 | 287.07 | 71.35 | 27.12 | 13.06 | 31.88 | 6.70 | 0.62 |
| CV(%) | 2.68 | 2.69 | 5.24 | 3.22 | 2.56 | 1.30 | 7.89 |

The low dry densities presented by substrates S3, S4, S9 and S10 can be explained by the fact that the high proportion of CRH and VER in relation to OC. Given that CRH and VER provide low density and good drainage to substrates formulated with these raw materials (CASTOLDI et al., 2014). However, pure CRH used as substrate can cause production problems seedlings from seeds, for presenting low nutrient content, water retention capacity and electrical conductivity, as well as high aeration space and pH (STEFFEN et al., 2010).

Total porosity (TP) presented the highest values in substrates S12 and S16 (Table 1). The lowest values of TP were found in substrates with the commercial S14 and S15, respectively. In general, the substrates tested did not reach the minimum level of porosity recommended by De Boodt and Verdonck (1972), which is 85%. However, Waller e Wilson (1984) reported that TP is a slightly informative physical-hydraulic parameter, since it expresses the relationship between pore volume and total volume, not considering the pore size distribution present in the substrate, since TP can be occupied by different proportions of air and water.

In relation to the aeration space (AS), the highest values were found in substrates S9 and S10, 39.18 and 39.91%, respectively (Table 1). The lowest AS value was obtained on substrate S15 (6.36%) followed by S14 (13.62%). According to De Boodt and Verdonck (1972), ideal AS is expected to be between 20 to 30%. Thus, only substrates S14 and S15 did not reach this range considered ideal. All other formulations reached or exceeded the reference range.

It is pertinent to emphasize that the irrigation of seedlings in a floating system is due to capillary ascension. In this case, the air circulation inside the pore network plays an important role in crop development, since the proximity of roots to the water blade allows high moisture conditions. In this production form, if the AS is low, it is probable that much of pores can be filled by water, and stress occurs due to lack of oxygenation of the root system.

Substrates S14 (commercial 1) and S16 (commercial 3) presented the highest percentages of available water (AW), of the order of 13.22 and 13.06%, respectively, followed by S1 (12.41%). Even so, all 13 substrates (S1 to S13), as well as the three controls (S14 to S16) presented values of AW below the interval of 20 to 30%, considered as a reference by De Boodt and Verdonck (1972). The lowest percentage of AW was observed in the substrate S4 (7.58%), with a close relationship with the highest proportion of structuring materials: vermiculite - VER (43%) followed by carbonized rice husk - CRH (33%).

In relation to the remaining water in the substrate (WR) one can observe a variability between the tested substrates (Table 1). The highest percentage observed on S15 (37.33%) differed statistically from the others, followed by S12 (30.67%) and S16 (31.88%).

These values were above of those considered ideal for De Boodt and Verdonck (1972), who recommend values of WR between 20 and 30%. The lowest $WR_{10}$ was observed on S10 (12.90%), possibly related to the highest CRH (53%) content. Since CRH presents low water retention capacity, fast and efficient drainage, it promotes aeration space to the substrates and consequently a good oxygenation to the root system.

The values of pH and electrical conductivity (EC) were significantly influenced by the amount of raw materials (Table 1). While higher pH values were found in substrates S4, S7, S8, S9 and S10, between 7.72 and 7.56, the lowest pH values were found in substrates S14 (5.24) and S15 (5.26), followed by S16 (6.70). In general, the substrates with organic compost (OC), CRH and VER presented values of pH above 7.0. This fact is directly related to the natural pH of each component of these substrates, whose individual characterization resulted in values above 7.0 for all the three raw materials.

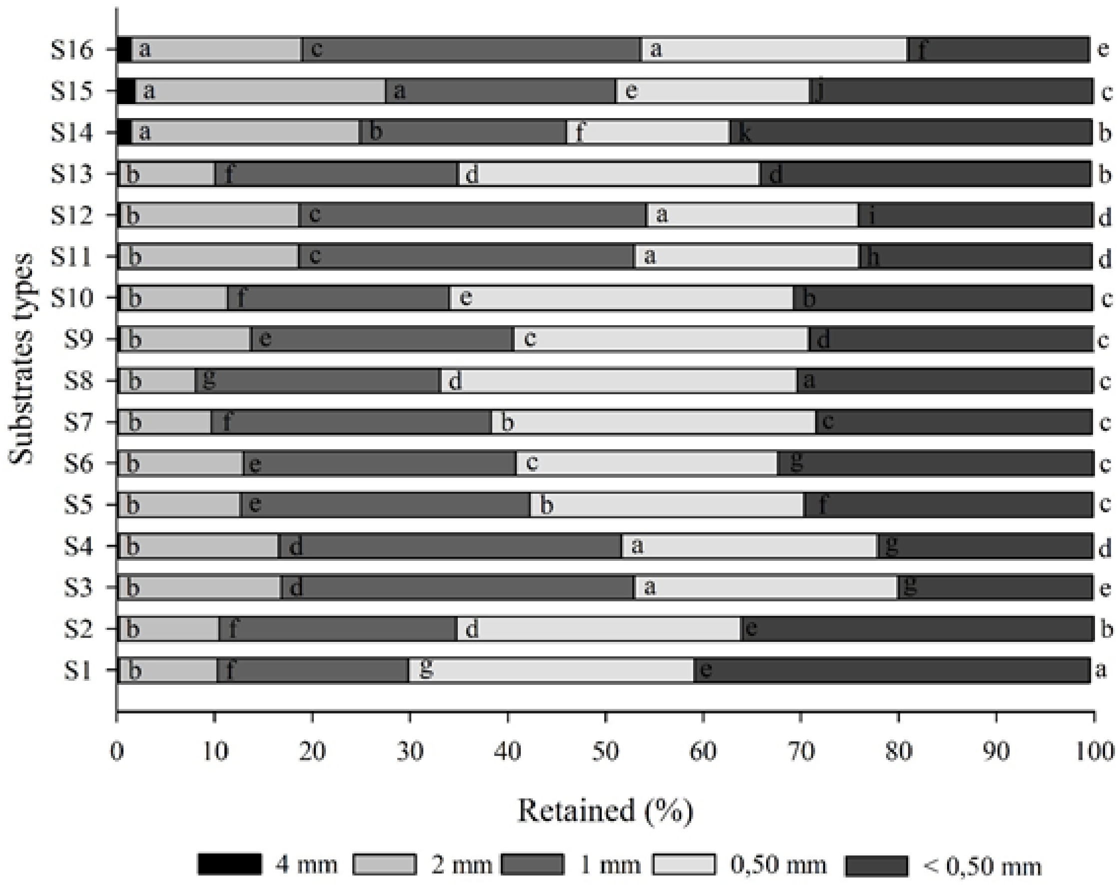
Substrates that have pH below 5.0 may result in important nutrient deficiencies such as for nitrogen, potassium, calcium, magnesium and boron; on the other hand, in those with pH values above 6.5, the deficiencies may be seen for phosphorus, iron, manganese, zinc and copper (VALERI; CORRADINI, 2000). Although these deficiencies were not evident in lettuce seedlings during the experiment, the introduction of more acidic raw material could result in a substrate with a pH closer to 6.0, considered ideal for most crops.

EC values range from 0.18 mS $cm^{-1}$ (S8) to 0.91 mS $cm^{-1}$ (S6) (1:5 - v:v) (Table 1). According to Cavins et al. (2000) substrates with EC between 0.36 to 0.65 mS $cm^{-1}$ (1:5 - v:v) can be considered normal. Thus, only substrates S4, S9, S10, S11, S12, S13 and S16 presented EC values within the range considered normal by the authors. Substrates S3, S7, S8 and S15 showed EC values below 0.36 mS $cm^{-1}$ (1:5 - v:v) being classified as low by Cavins et al. (2000) and thus, the authors recommend the use of these substrates for seedling production and for plants that are sensitive to salt.

Already the substrates S1, S2, S5 and S14 presented high EC (0.66 to 0.89 mS $cm^{-1}$ - method 1:5 – v:v) according to the classification of Cavins et al. (2000) may cause reduction in growth and reduction of plant beams, especially in warm periods. The highest EC value was found on S6 (0.91 mS $cm^{-1}$ – 1:5) corresponding to 53% OC + 13% CRH + 33% VER (Table 1), which is considered too high and may cause deficiency by salt concentrations, reduction in growth and leaf burns (CAVINS et al., 2000). However, no symptoms of excess salt stress were observed in lettuce seedlings, possibly related to the floating system that maintains the seedlings with optimal water availability.

In general, the substrates had a low percentage of particles larger than 4 mm (Figure 1). The commercial substrates (S14, S15 and S16) showed the highest percentage of particles retained in the 4 mm sieve, not differing statistically from each other, however, they differed from all our formulated substrates. With respect to the particles between 4 and 2 mm, S15 presented the highest percentage among all substrates.

**Figure 1.** Particle size distribution of different growth substrates.




Means followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability level.

In the formulated substrates, those with the higher amount of VER, S3 and S11, and also S4 and S12 with 43 and 53%, respectively, also presented higher percentage of particles between 2 and 1 mm, while between 1.0 and 0.5 mm, S8 (13.33% of OC + 53.33% of CRH + 33.33% of VER) had the highest percentage (Figure 1). The original granulometric composition of the used raw materials in our formulations impacted AS, as long as they presented insufficient amount of large particles (greater than 4 mm). The use of larger particles (easily obtained by sieving) from the same raw materials or even from other sources could probably solve this deficiency.

On the other hand, the greatest differences were observed in the class of particles less than 0.5 mm. The highest proportions of OC and CRH on S1 (53.33% of OC + 33.33% of CRH + 13.33% of VER) resulted in higher proportions of these particles (~ 40%) (Figure 1), and probably have also influenced the higher AW observed in this substrate in relation to the others (Table 1).

Analyzing the variables related to the volume and pore size distribution, as well as water retention and their availability bands, a proportional relationship between the amount of structural materials, carbonized rice husk and vermiculite, and the amount of macropores can be observed, with benefits to root aeration and drainage, avoiding losses of seedlings by overirrigation. The finer particles, are rather abundant in the organic compost, promoting higher water retention and water available to the plants, desired for seedlings that tolerate a higher level of humidity, as well as those that support longer intervals between irrigations.

Except for RDM, the parameters of growth (NL, PH and RSL) and yield (PFM, RFM and PDM) of lettuce were significantly influenced by the different substrate types (Table 2). Was possible to observe the formation of two different groups of results, one group with higher values of NL, PH, RLS and RFM was formed by the 13 substrates composed of OC, CRH and VER, and the commercial 1 and commercial 3 substrates, while the other group with the lowest values were observed for commercial 2 substrate.

**Table 2.** Number of leaves (NL), plant height (PH), root system length (RSL), shoot fresh mass (SFM), root fresh mass (RFM), shoot dry mass (SDM) and root dry mass (RDM) of lettuce seedlings grown on different substrates.

| Treatment | NL | PH | RSL | RFM | RDM | SFM | SDM |
|---|---|---|---|---|---|---|---|
| S1 | 3.500 a | 18.700 a | 13.831 a | 2.737 a | 0.202$^{ns}$ | 15.941 a | 0.602 a |
| S2 | 3.688 a | 18.819 a | 13.438 a | 2.668 a | 0.179 | 16.820 a | 0.564 a |
| S3 | 3.750 a | 16.888 a | 14.731 a | 2.551 a | 0.011 | 14.223 a | 0.493 a |
| S4 | 3.625 a | 17.238 a | 13.656 a | 2.001 a | 0.147 | 12.633 b | 0.373 b |
| S5 | 3.253 a | 17.800 a | 14.519 a | 2.936 a | 0.302 | 14.981 a | 0.347 b |
| S6 | 4.188 a | 18.844 a | 13.713 a | 3.227 a | 0.231 | 17.194 a | 0.493 a |
| S7 | 3.563 a | 17.031 a | 13.725 a | 2.159 a | 0.200 | 11.948 b | 0.464 a |
| S8 | 3.563 a | 17.838 a | 14.163 a | 2.219 a | 0.001 | 12.791 b | 0.408 b |
| S9 | 3.813 a | 17.669 a | 13.106 a | 2.322 a | 0.285 | 17.670 a | 0.637 a |
| S10 | 3.563 a | 18.194 a | 14.619 a | 2.270 a | 0.003 | 17.371 a | 0.582 a |
| S11 | 3.688 a | 17.731 a | 11.888 a | 2.044 a | 0.071 | 16.989 a | 0.595 a |
| S12 | 3.813 a | 18.081 a | 11.013 a | 2.345 a | 0.029 | 16.548 a | 0.369 b |
| S13 | 3.625 a | 18.163 a | 14.063 a | 2.384 a | 0.016 | 13.218 b | 0.410 b |
| S14 | 3.750 a | 16.869 a | 12.981 a | 1.820 a | 0.004 | 10.493 b | 0.364 b |
| S15 | 2.875 b | 12.444 b | 6.494 b | 0.626 b | 0.002 | 4.766 c | 0.084 c |
| S16 | 3.750 a | 16.838 a | 15.150 a | 2.285 a | 0.027 | 12.843 b | 0.358 b |
| CV (%) | 8.29 | 7.51 | 13.92 | 25.49 | 213.26 | 17.15 | 36.52 |

Means followed by the same letter in the column do not differ by the Scott-Knott test at 0.05 probability level.

The worst performance for these four variables was observed in commercial 2 (S15). For the RDM, there was no significant difference between the evaluated substrates (Table 2). Differently from the other variables, RDM presented a high coefficient of variation (213.26%), disabling the identification of any significant difference between treatments. The hydro-physical conditions may have influenced RDM drastically, being the water excess and poor root aeration the key factors to cause such effects.

For PFM, the group with the higher values were with the substrates S1, S2, S3, S5, S6, S9, S10, S11 and S12, that is, generally those that employed higher amounts of OC and CRH (Table 2). The second response group was composed by substrates S4, S7, S8, S13, S14 and S16, whereas the worst crop performance was observed with S15. As expected, PDM results were similar to those observed for PFM. The substrates S1, S2, S3, S6, S7, S9, S10 and S11 stood out positively favoring the plants, while again the worst performance was observed with S15 (Table 2).

Analyzing the formulations with OC, CRH and VER, with reference to the responses of the lettuce crop, it is observed that in general, these substrates were similar to commercial substrates 1 and 3.

The correlation analysis (Table 3), turns in evidence the hydro-physical variables that best explain the RSL results of the seedlings, namely EAW, AW, WR and WRC, presenting inversely proportional behavior to RSL, that is, higher mean values of these four variables negatively influenced root system length.

**Table 3.** Pearson correlation coefficients from the hydro-physical characteristics of the substrates and the variables of growth and yield of lettuce seedlings.

| Variables | NL | Plant height | RSL | PFM | PDM | RFM | RDM |
|---|---|---|---|---|---|---|---|
| TP | 0.240 | -0.026 | -0.266 | 0.026 | -0.159 | -0.213 | 0.107 |
| AS | 0.084 | -0.087 | 0.222 | -0.280 | -0.175 | -0.041 | 0.039 |
| EAW | 0.239 | 0.185 | -0.400** | 0.380** | 0.055 | 0.076 | 0.033 |
| BW | -0.226 | 0.154 | -0.004 | -0.069 | -0.101 | -0.080 | 0.043 |
| AW | 0.044 | 0.269 | -0.346* | 0.278 | -0.025 | 0.009 | 0.059 |
| WR | 0.044 | 0.023 | -0.389** | 0.315* | 0.129 | -0.098 | 0.006 |
| DD (kg $m^{-3}$) | -0.104 | 0.173 | 0.023 | 0.183 | 0.209 | 0.166 | 0.168 |
| WRC (%v/v) | 0.049 | 0.084 | -0.416** | 0.337* | 0.105 | -0.081 | 0.020 |

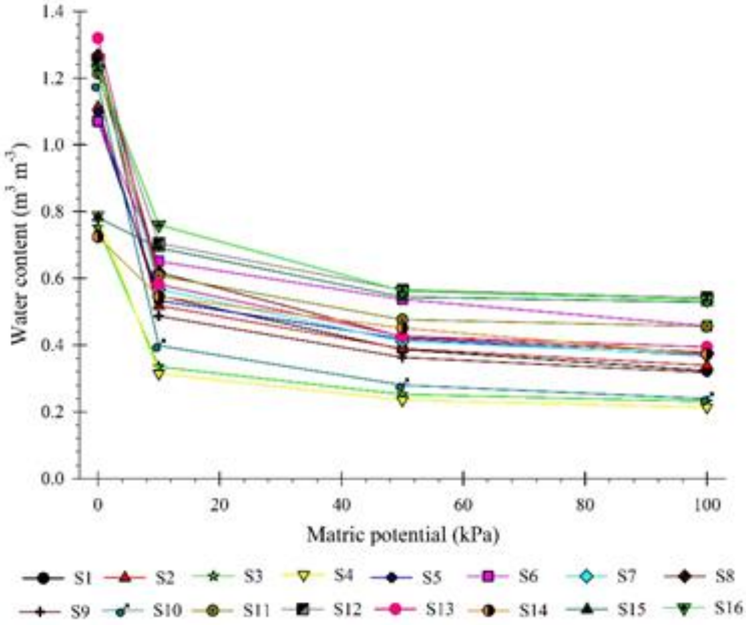
[1] TP - Total Porosity; AS - Aeration Space; EAW - Easily Available Water; BW - Buffering Water; AW - Available Water; WR - Water Remaining; DD - Dry Bulk Density; WRC - Water Retention Capacity; NL - Number of leaves; RSL - Root system length; PFM - Plant fresh mass; PDM - Plant dry mass; RFM - Root fresh mass; RDM - Root dry mass. [ns] - Not significant at $p < 0.05$; * - Significant at $p < 0.05$; ** - Significant at $p < 0.01$.

On the other hand, the water retention had a relevant role in the yield of PFM, since EAW, WR and WRC were positively correlated to this variable, with EAW ($r = 0.38$, $p < 0.01$) being the variable that best correlated with PFM (Table 3).

These results demonstrate how the hydro-physical characteristics of substrates play a crucial role in the production of seedlings in a floating system. The high sensitivity of lettuce cultivation to both water shortage and waterlogging conditions demonstrates the importance of developing specific formulations for this crop in a floating system, which only develops well where water and nutrients are readily available.

The worst performance presented by lettuce occurred when cultivated with the substrate S15 (Table 2). In addition to the higher WRC (Figure 2), S15 also presented the highest WR (Table 1), indicating that this formulation results in a significant volume of water retained at high potentials, making it unavailable. Such conditions lead to lack of oxygen in the root zone, which certainly contributed to the worse development of lettuce seedlings, especially because plants are found in the early stages of life.

**Figure 2.** Water retention curve of different growth substrates.




The low amplitude in WRC (Figure 2) ranging from 0.78 $m^3$ $m^{-3}$ (tension of 0 kPa) to 0.53 $m^3$ $m^{-3}$ (tension of 10 kPa), with an amplitude of only 0.25 $m^3$ $m^{-3}$, also influenced negatively the development of lettuce seedlings. This high WRC has to be avoided in floating systems, because most of the pores will be filled with water. This low WRC amplitude is possibly related to the low WRC presented by the carbonized rice husk and vermiculite, since these materials confer higher AS.

In general, in floating systems we suggest that WD values shouldn't stand higher than 750 kg $m^{-3}$, total porosity lower than 55%, AS lower than 13% and WR higher than 31%. Additionally, it can be said that the main aspects that negatively influenced the growth of lettuce seedlings were the low AS and the high WR. It has also been found to be fundamental for floating seedling production systems that AS is relatively high (> 30%) and WR is low (> 20%).

## 6 CONCLUSIONS

Aeration space and water remaining are the priority hydro-physical variables that should be evaluated in substrates that will be used in floating systems.

As formulações com 33,33% de composto orgânico, 43,33 a 53,33% de casca de arroz carbonizada, e 23,33 a 13,33% de vermiculita apresentaram os melhores desempenhos entre os substratos estudados para a produção de mudas de alface em sistema *floating*.

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