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Physico-chemical and hydrological properties of soilless substrates

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Abstract

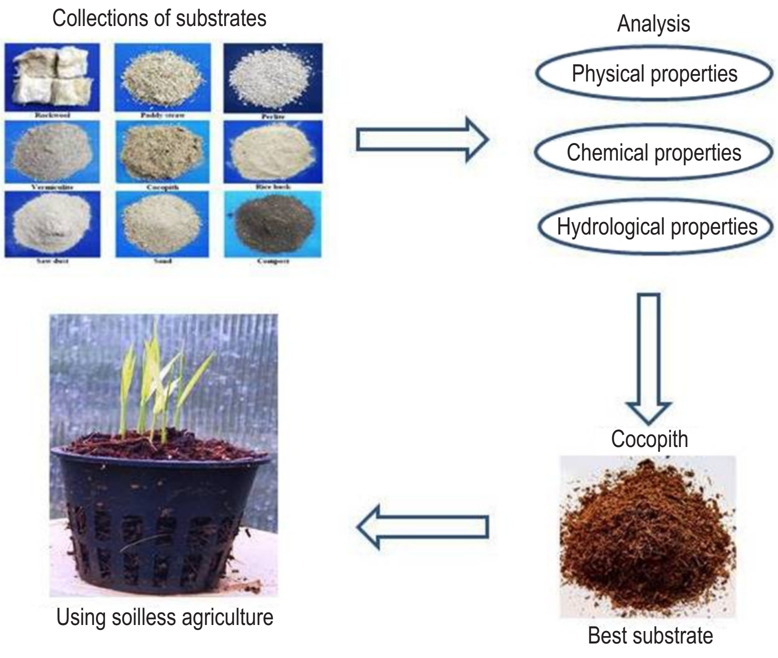
Aim: To evaluate the physico-chemical and hydrological characteristics of cocopith, perlite, vermicullite, vermicompost, sand, rice husk, paddy straw, saw dust and rock wool for using them as substrates for soilless agriculture.

Methodology: The soilless substrates were initially evaluated for pH and EC, and then estimated for total organic carbon by dry combustion method, total nitrogen by Kjeldahl digestion method, potassium by atomic absorption and phosphorus by colorimetric method. The hydrological properties of substrates were estimated by Keen - Rackzowski box method.

Results: The desirable level of physical properties of bulk density (0.47 gm cm^{-3}), particle density (0.63 gm cm^{-3}), total porosity (75.81%) and chemical properties of pH (6.23), EC (5.02 dS m^{-1}), total organic carbon (36.39 %), and other properties were noticed under cocopith. The maximum level of water holding capacity (769.30 %) and volume of expansion (185.78 %) was registered by cocopith.

Interpretation: Cocopith has favourable hydrological properties with desirable level of physical and chemical properties, which makes it the best medium for soilless agriculture. Coconut fiber is a characteristic natural fiber from the external husk of coconut and its extraction process also without polluting nature.

Key words: Cocopith, Perlite, Rockwool, Soilless agriculture, Vermiculite



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Introduction

Any potting media comprise parts that can give air, water, and supplements to help the plant development (Pual, 2000). Distribution of air, water and solid in a container medium depends on several factors including pore space, bulk density, particle size distribution of the substrates used and container height and media settling quality. Various substrates, both inorganic and organic, can be used as growth medium and inorganic substrates include expanded clay, glass wool, gravel, perlite, pumice, rock wool, sand, sepiolite, vermiculite, volcanic tuff and zeolite or synthetic, foam mats, hydrogel and plastic foam. The organic substrates include bark, coconut coir, coco soil, fleece, marc, peat, ruffia bark, rice husk, saw dust and wood chips. The growing media should fulfil different criteria like physical, chemical, hydrological and biological properties in order to meet the growth requirements of plant (Nelson, 2012). Regardless, there is no ideal substrate or mixture that can fulfil all the requirements of plant species in all conditions (Di Lorenzo *et al.,* 2013; Gruda, 2012).

However, the use of coir as growing media has highly increased since 2004, not only in Europe but also in the Western United States (Carlile *et al.,* 2015). Barrett *et al.* (2016a) and Savvas and Gruda (2018 a) demonstrated the performance of growing media wherein they included not only substrate properties but also the ability to perform well in natural growing conditions. The material used for production as well as growing media should be sustainable and environmental eco-friendly (Singh and Singh, 2012). In order to guarantee a continued growth and sustainable development of soilless cultivation, it is important to identify effective and environmentally sustainable materials for growing media (Barrett *et al.,* 2016 b). Therefore, selecting a growing medium is not an easy task because of environmental issues, technical and financial implications which need to be considered (Gruda *et al.,* 2016; QUANTIS, 2012).

Efforts have been made to investigate and develop growing media from locally available sources such as, bark or other wood-based materials, co-products from a forest harvest, or wood processing industries (Gruda and Schnitzler, 2000 a; Gruda and Schnitzler, 2000 b; Gruda and Schnitzler, 2004; Jackson *et al.,* 2009). Factors like geographical location, selection of plant cultivation and production types, substrate cost and performance, as well as other societal concerns govern the selection of growing media. At this juncture, it is vital to understand the importance of selected substrate's physical, chemical and hydrological properties which will aid in designing a growing substrate that is consistent of good quality and matches soilless agricultural production practices. Keeping in view the above, the present study evaluated few physical, chemical and hydrological properties of soilless substrates and their constituents through laboratory experimentation for better understanding of the dynamic nature of substrates and their suitability for soilless agriculture.

Materials and Methods

A laboratory experiment was carried out to evaluate the physico-chemical and hydrological properties of soilless substrates at the Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India. The substrates (cocopith, vermicompost, sand, rice husk, paddy straw, saw dust, Perlite, rock wool, vermiculite) were assembled from various parts of India such as Karnataka, Mumbai, Dharmapuri and Madurai. About 5.0 kg all the substrates were collected, except for rock wool (500 g). The results for each characterization data were obtained from the mean procedure of three replicate and statistical analysis was performed in complete randomized design. The pH of the substrates were analysed using pH meter (Model ORION 230A – Range -2 – 19.99 ± 0.01, USA), and electrical conductivity in EC meter (Model ORION 105 – Range 0 – 199.99 dS m-1 ± 0.01, USA). The total organic carbon content in substrates were determined by dry combustion method at 540◦C for 4 hr (Rather, 1917) and total nitrogen content by Kjeldahl method (Bremmer and Mulvaney, 1982). The potassium content in the substrate was determined by atomic absorption and phosphorus by colorimetric method (Murphy and Riley, 1962). The physical properties of substrates like bulk density, particle density, total porosity, water holding capacity, water in air dry substrate, volume expansion were estimated by Keen - Rackzowski box method (Piper, 1966).

Determination of substrate properties by Keen - Rackzowski box: Keen box was measured for its dimensions, cleaned, dried and weighed. Filter papers (Whatman No.1 and 44) were placed at the bottom of keen box, air-dried, sieved (2mm) soilless substrates were filled in the box till top of the box for complete and uniform packing. The total weight of keen box with substrates was weighed. Later, the box was placed in soaking tray and gradually filled with water up to 1.0 cm above the base of the box. The tray was covered and kept for 12 hrs or more for equilibrium. A continuous and shining film of water at the surface of soilless media confirmed this. Finally, the box was carefully removed from the water, wiped and weighed quickly. The expanded soilless substrate was cut off and transformed to pre-weighed watch glass, and the watch glass was weighed again with expanded soilless medium. The soilless substrates of watch glass and keen box were oven dried at 105°C till constant weight was recorded. A blank test (only with keen box and filter paper) was also run simultaneously to estimate the weight of water absorbed by filter paper alone. Following this method, the physical properties of soilless substrate was determined.

Statistical analysis: The data on various parameters studied during the course of investigation were statistically analysed by Analysis of variance, suggested by Gomez and Gomez (1984). Wherever the treatment differences were found significant (completely randomization design) critical difference was worked out at one per cent probability level. The treatment differences that were not significant were denoted as "NS".

Results and Discussion

The pH and EC are two important properties of any growing media as these parameters directly influence the availability as well as indicate inherent nutrient status in the media, besides affecting the plant growth. A lot of variations were observed in pH values of both organic and inorganic media and it varied from acidic (5.35) in rice husk to alkali (9.04) in vermiculite. (Table 1) The pH of sand and paddy straw was 7.11 and 7.93, respectively. The availability of total organic carbon, total nitrogen, total phosphorus and total potassium is a major factor that influences the plant growth. The highest total organic carbon content of 43.41% was recorded in organic substrate (saw dust) followed by cocopith (36.39 %) and rice husk (35.16 %), while inorganic substrates registered the lowest total organic carbon contents in Perlite (0.30 %) and sand (0.33 %).

The highest total nitrogen was recorded in both vermicompost (1.90) and rice husk (1.88), while total potassium content was maximum in paddy straw (2.57) followed by cocopith (1.84) and rice husk (1.8) . However, the total phosphorus content was non-significant in all soilless substrates evaluated. The density and pore space of soilless substrates are the most important factors which indicate the substrate ability to function for anchorage, structural support, water, solute movement and aeration. Also, the pore space of substrates is the portion occupied by air and water. The amount of pore space highly depends on the texture, compaction and aggregation of soilless substrates. Analysis of variance showed that bulk density, particle density and total porosity of soilless media differed significantly (Table 2). Among the soilless substrates, sand registered significantly the highest bulk density (4.57 gm cm^{-3}), followed by vermiculite (4.29 gm cm^{-3}). The lowest bulk density was registered in both rock wool (0.44 gm cm^{-3}) and cocopith (0.47 gm cm^{-3}). For particle density, the highest value was recorded in vermiculite (4.67 gm cm^{-3}) and the lowest in rock wool (0.23 gm cm^{-3}). Saw dust recorded maximum total porosity (216.05 %) while the lowest was observed in paddy straw (76.26 %). The results of the investigation carried out for the assessment of water relation characteristics of soilless substrates are presented in Table 2.

Table 1: Chemical properties of soilless substrates

Soilless substrates	pH	EC (dS m^{-1})	TOC (%)	Total N (100 g)	Total P_2O_5 (100 g)	Total K_2O (100 g)
Cocopith	6.23	5.02	36.39	0.84	0.02	1.84
Perlite	8.53	0.08	0.30	0.06	0.00	0.21
Vermiculite	9.04	0.07	3.43	0.03	0.45	0.20
Vermicompost	6.28	6.65	14.51	1.90	0.35	0.54
Sand	7.93	0.15	0.33	0.06	0.16	0.21
Rice husk	5.35	2.54	35.16	1.88	0.01	1.81
Paddy straw	7.11	2.06	30.78	1.12	0.08	2.57
Saw dust	5.45	1.05	43.41	0.50	0.01	1.53
Rockwool	8.47	0.04	0.49	1.40	0.30	0.22
SEd	0.131	0.060	0.692	0.029	NS	0.032
CD (0.01)	0.328	0.152	1.732	0.074	NS	0.081

(ANOVA, $p < 0.01$)

Table 2: Water relation characteristics of soilless substrates

Soilless substrates	Bulk density (gm cm^{-3})	Particle density (gm cm^{-3})	Total porosity (%)	Maximum water holding capacity (%)	Water in air dry substrate (%)	Volume of expansion (%)
Cocopith	0.47	0.63	75.81	769.30	19.85	185.78
Perlite	1.58	1.27	124.78	133.63	4.86	12.92
Vermiculite	4.29	4.67	92.90	47.18	7.92	10.58
Vermicompost	2.15	1.74	124.91	134.21	24.10	64.98
Sand	4.57	3.32	138.89	51.80	22.48	0.92
Rice husk	1.10	0.75	146.91	221.76	27.87	1.78
Paddy straw	0.41	0.55	76.26	496.23	15.23	29.54
Saw dust	0.79	0.37	216.05	369.03	22.42	23.26
Rockwool	0.44	0.23	190.35	650.63	27.62	1.60
SEd	0.058	0.144	2.600	7.412	0.586	0.546
CD (0.01)	0.145	0.361	6.502	18.530	1.466	1.367

(ANOVA, $p < 0.01$)

The maximum water holding capacity and expansion of volume was registered in cocopith (769.30 % and 185.78 %) whereas the minimum water holding capacity was noted in vermiculite (47.18 %) and volume of expansion in sand (0.92 %). Water in air dry substrate was highest both in rice husk (27.87 %) and rock wool (27.62 %) and lowest in vermiculite (7.92 %). From the study, it was evident that among the soilless substrates cocopith showed maximum values for parameters like water holding capacity (769.30 %), water in air dry substrate (19.85 %) and volume of expansion (185.78 %) as compared to remaining soilless substrates. Cocopith was able to absorb more water, as evidenced in this study, and holds it against the pull of gravity referable to more number of microspores present in the substrates compared to remaining substrates (Johnson, 1968). Organic substrates like compost, coco¬nut coir, peat moss, bark, rice hulls and sawdust contain more nutrients due to the presence of carbon, oxygen, hydrogen in them.

This was supported by Winsor and Schwarz (1990), who stated that the plant based materials have more available nutrients compared to inorganic soilless substrates. As observed in this study, the inorganic substrates had high EC values and low nutrient contents. As water holding capacity varies with types and sizes of the growing medium ingredients, the present study proved that cocopith held more water than other substrates. For instance, peat moss particle holds more water than a similarly sized piece of pumice. Further, the degree of compaction is also extremely important (Evans *et al.,* 1996). Although different plant species have different pH range for optimal growth, overall the optimum pH of soilless media for good availability of essential elements was approximately 6.0 -7.0. The EC values of media differed between the substrates, with vermicompost showing the highest EC value (6.65 dS m^{-1}) whereas both vermiculite and Perlite showed the lowest EC values (0.07 and 0.08 dS m^{-1}), respectively. The EC values reflect the total inorganic ion concentration in the media extracts. Low EC value indicates that the media did not contain excessive salt that could cause salinity injury to plants, but at the same time contains insufficient amount of nutrients to support healthy plant growth (Yahya *et al.,* 1999).

A growing medium primarily composed of large particles will have more aeration and less water-holding capac¬ity than a medium with smaller particles will have less aeration and more water-holding capacity (Gordon, 2004). Mugnozza *et al.* (2007) determined, using LCA, that soilless cultivation reduced the environmental impact by more than double, due to lower levels of fertilizers and pesticides discharged in the environment, compared to soil cultivation. High pH value in the inorganic media is a common phenomenon as it is mainly associated by fixed negative electrical charges that attract and hold positively charged nutrient ions with a high buffering capacity of soilless substrates, while organic substrates had low pH with poor buffering capacity (Argo and Fisher, 2008). The bulk density and pore space are interrelated and any change or increase in one of these parameters affects the other. Decrease in total pore space affects plant growth because of reduced free pore space which would often decrease oxygen transport and root penetration. However, decrease in total pore space may also increase water retention as pore diameters decrease. It is inferred that loss of physical structure of the substrate often results in increased water retention of the remaining material. Hence, the influence of bulk density on growth may be improved by focussing on the individual effects of pore space rather than the broader concept of bulk density (Michael and Lieth, 2008), as porosity and bulk density are negatively correlated. The results indicate that the porosity of soilless media is decreased for good water holding capacity (Pardossi *et al.,* 2011). Total porosity of a growing medium is the sum of both macropores and micropores. Coir is used in mixtures for potting industry as it is a lightweight material and contains more lignin and less cellulose than peat, it is more resistant to microbial breakdown and usually shrinks less; further it is also more hydrophilic and easier to re-wet after drying and tends to retain its basic structure when wet or dry (Robbins and Evans, 2011; Gruda *et al.,* 2013; Nichols, 2007).

The present study showed that certain physical, chemical and hydrological properties of soilless substrates need to be improved for soilless agriculture. At present, life cycle analysis is used for the classification of growing media constituents, based on their environmental impact and sustainability, environmental protection, and application of “green technologies” for their production (Savvas and Gruda, 2018 b; Gruda *et al.,* 2019). The coconut coir offers an ideal rooting medium to the plants and also provides protection against root diseases and fungus (Jemima Macwan *et al.,* 2020). Among all the soilless substrates evaluated in the study, cocopith has favourable hydrological properties with desirable level of physical and chemical properties and, hence, it can be used as substrate for soilless agriculture. Cocopith or coir fiber pith is derived as a byproduct in the process of fiber extraction from the husk of the coconut. The eco-friendly material cocopeat is a 100% natural growing medium, ecologically stable and reusable.

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Add-on Information

Author' contribution: Anbarasu Mariyappillai: Research conceptualization, Methodology, formal analysis, data curation, writing original draft preparation, visualization, review, editing, project administration; **Gurusamy Arumugam:** Supervision, validation, formal analysis, data correction, review, editing.

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References

Argo, W.R. and P.R. Fisher: Understanding plant nutrition: An introduction. *Greenhouse Grower,* **1**, 34 - 42 (2008).

Barrett, G.E. P.D. Alexander, J.S. Robinson and N.C. Bragg: Achieving environmentally sustainable growing media for soilless plant cultivation systems–A review. *Scientia Horticul.,* **212**, 220–234 (2016).

Bremmer, J.M. and C.S. Mulvaney: Nitrogen-total. In: Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties (Eds.: A.L. Page, R.H. Miller and D.R.Keeney). 2nd Edn., Agronomy series No. 9 ASA, SSSA, Madison, WI, pp. 595–624 (1982).

Carlile, W.R., C. Cattivello and P. Zaccheo: Organic growing media: Constituents and properties. *Vadose Zone J.,* **14**, 14-24 (2015).

Di Lorenzo, R. Pisciotta, A. Santamaria and P. Scariot: From soil to soil-less in horticulture: Quality and typicity. *Ital. J. Agron.,* **8**, 30–37 (2013).

Evans, M.R., S. Konduru and R.H. Stamps: Source variation in physical and chemical properties of coconut coir dust. *Hort. Sci.,* **31**, 965–967 (1996).

Gomez, K. A. and A.A. Gomez: Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley Sons, New York, 680 pages (1984).

Gordon, I.: Potting media constituents. International Plant Propagators' Society, Combined Proceedings, pp. 78–84 (2004).

Gruda, N. and W.H. Schnitzler: Suitability of wood fiber substrates for production of vegetable transplants. I. Physical properties of wood fiber substrates. *Scientia Horticul.,* **100**, 309-322 (2004).

Gruda, N. and W.H. Schnitzler: The effect of water supply of seedlings, cultivated in different substrates and raising systems on the bio-morphological and plant-physiological parameters of lettuce. *J. Appl. Bot. Food Qual.,* **74**, 240-247 (2000 a).

Gruda, N. and W.H. Schnitzler: The effect of water supply on bio-morphological and plant-physiological parameters of tomato transplants cultivated in wood fiber substrate. *J. Appl. Bot. Food Qual.,* **74**, 233-239 (2000 b).

Gruda, N., J. Caron, M. Prasad and M.J. Maher: Growing media. In: Encyclopedia of Soil Sciences (Ed.: R. Lal). 3rd Edn., CRC Press Taylor & Francis Group: Boca Raton, FL, USA, pp. 1053–1058 (2016).

Gruda, N., M.B. Bisbis and J. Tanny: Impacts of protected vegetable cultivation on climate change and adaptation strategies for cleaner production-A review. *J. Clean. Prod.,* **225**, 324-339 (2019).

Gruda, N., M.M. Qaryouti and C. Leonardi: Growing media. In: Good Agricultural Practices for Greenhouse Vegetable Crops– Principles for Mediterranean Climate Areas. Plant Production and Protection Paper FAO: Rome, Italy, **217**, 271-302 (2013).

Gruda, N.: Current and future perspective of growing media in Europe. *Acta Hortic.*, **960**, 37-43 (2012).

Jackson, B.E., R.D. Wright and N. Gruda: Container medium pH in a pine tree substrate amended with peat moss and dolomitic limestone affects plant growth. *Hort Sci.,* **44**, 1983-1987 (2009).

Jemima, M., P. Dhruv and H. Pandya: Review on soilless method of cultivation: hydroponics. *Int. J. Rec. Sci. Res.,* **11**, 37122-37127 (2020).

Johnson, P: Horticultural and agricultural uses of sawdust and soil amendments. National City, CA: Paul Johnson, p. 46 (1968).

Michael, R. and J. H. Lieth: Soilless Culture: Theory and Practice. 1st Edn., Elsevier., **1**, 209-244 (2008).

Mugnozza, G.S., G. Russo and B. De Lucia Zeller: LCA methodology application in flower protected cultivation. *Acta Hortic.,* **761**, 625-632 (2007).

Murphy, J. and J.P. Riley: A modified single solution method for determination of phosphate in natural waters. *Anal. Chem. Acta.,* **27**, 31–36 (1962).

Nelson, P.V.: Root Substrates. In: Greenhouse Operation and Management. 7th Edn., Prentice Hall, Upper Saddle River, NJ., pp. 161-194 (2012).

Nichols, M.A.: Coir-A XXIst Century sustainable growing medium. *Acta Hortic.*,**747**, 91-95 (2007).

Pardossi, A., G. Carmassi, C. Diara, L. Incrocci, R. Maggini and D. Massa: Fertigation and Substrate Management in Closed Soilless Culture. Dipartimento Department di Biologiadelle Piante Agrarie, University of Pisa, Italy (2011).

Piper, C.S.: Soil and Plant Analysis. University of Adelaide. Australia.Interscience Publishers., XIV, p.368 (1966).

Pual, C.: Heath and Hydroponic. Practical Hydroponic & Greenhouse, 53, 28-30 (2000).

QUANTIS:ComparativeLifeCycleAssessmentofHorticulturalGrowing Media Based on Peat and Other Growing Media Constituents. Bibliothèquecantonaleetuniversitaire-Lausanne, 1 brochure électronique. P.156 (2012).

Rather, J.B.: An accurate loss on ignition method for determination of organic matter in soils. Arkansas Agric. Expt. Stn. Bull. No. 140 (1917).

Robbins, J.A., M.R. Evans: Growing media for container production in a greenhouse or nursery. Part I (Components and Mixes). Greenhouse and Nursery Series.Published by Arkansas State Library. (2011). Available online: https://www.uaex.edu/publications/PDF/FSA-6097.pdf

Savvas, D. and N. Gruda: Application of soilless culture technologies in the modern greenhouse industry-A review. *Eur. J. Hortic. Sci.,* **83**, 280-293 (2018 a).

Savvas, D. and N. Gruda: Application of soilless culture technologies in the modern greenhouse industry - A review. *Eur. J. Hortic. Sci.,* **83**, 280-293 (2018 b).

Singh, S. and B.S. Singh: Hydroponics - A technique for cultivation of vegetables and medicinal plants. In. Proceedings of 4th Global conference on Horticulture for Food, Nutrition and Livelihood Options Bhubaneshwar, Odisha, India, p.220 (2012).

Winsor, G. W. and M. Schwarz: Soilless culture for horticulture crop production. FAO Plant Production and Protection Paper, Publication No. 101, Rome, Italy (1990).

Yahya, A., H. Safie and M.S. Mohklas: Growth and flowering responses of potted chrysanthemum in a coir dust-based medium to different rates of slow released-fertilizer. *J. Trop. Agric. Food Sci.,* **27**, 39-46 (1999).