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Growing Substrates Alternative to Peat for Ornamental Plants

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1. Introduction

Nowadays, the search for alternative high-quality and low-cost materials as growing media in horticulture is a necessity due to the increasing demand and rising costs for peat, the most widely used substrates component during the last decades, as well as for its uncertain availability in the near future owed to environmental constraints. The recent and rising interest in waste recycling has resulted in a greater use of organic materials and composts as potting media representing, at the same time, a smart solution for waste disposal problems. In the present chapter, after describing main characteristics and limitations of peats, some alternative organic wastes as substrate components are outlined, comparing their physical and chemical properties to those from peat. Benefits obtained from their use, from an environmental and economic point of view, are briefly discussed. Moreover, three case-studies on peat sustainable substitutes for ornamental plants are reported.

1.1. Peat use in horticulture, characteristics and limits

Among the numerous organic materials used as substrates for soilless cultivation of horticultural crops, peat is currently a major component of containerized mixtures for commercial plant production [1]. Its long-time success is certainly due to the physical properties (slow degradation rate, low bulk density, high porosity, high water holding capacity [WHC]) and the chemical characteristics (relatively high cation exchange capacity, CEC) that makes peat particularly suitable as growing media for a large number of vegetables and ornamentals [2]. Peat is formed as a result of the partial decomposition of plants (*Sphagnum*, *Carex*) typical of poorly drained areas (peat bogs), with low nutrients and pH, under low temperatures and anaerobic conditions [3]. Plant species, climatic conditions, harvest and processing methods influence the specific characteristics of peat and its value so different types can be obtained

varying on color, texture and degree of decomposition [4]. In particular, some physical properties as water retention and air capacity generally decrease with the increasing of the degree of decomposition. Recently, Prasad and Maher [5] tried to test if determinations of peat colour could be used to predict lignin content and peat stability and they observed a strong correlation between colour parameters and shrinkage as well as with lignin content.

Among different peat typologies, sphagnum moss is maybe the most used for the preparation of soilless substrates because of the light bulk density and the low degree of decomposition [6]. It is obtained from acid bog-plants of the genus *Sphagnum* and is produced, with high extraction rhythms, in northern regions as Baltic Republics, Finland, Germany and Ireland. Sphagnum peat is usually included in growing mixtures to increase WHC or to decrease the weight of the substrates. It contains 75% fibre at least, consisting of dehydrated remains of leaves and stems of *Sphagnum* plants; this fibrous structure is characterized by a high surface charge density, with consequent high CEC which helps to reduce leaching of nutrients [7]. Other relevant properties are the high easily available water (EAW) under conditions of container capacity, i.e. after the end of free drainage and the high oxygen diffusion rate. On the other hand, as negative aspect peat can be a conducive substrate for numerous soil-borne diseases and its sterilization does not solve the problem as it leaves a biological vacuum that can be easily filled by pathogenic fungi.

Peat use in horticulture increased during the last decades, resulting in rising costs [8] and generating doubts about availability of this material in the near future due to environmental constraints. In fact, peat mining has been recently questioned because it is harvested from peat lands, highly fragile wetlands ecosystems with a great ecological and archaeological value, included in the list of natural habitats with a potential degradation [9]. Peat also plays an important role in improving groundwater quality, and peat bogs also serve as a special habitat for wild plants and animals. Moreover, these ecosystems represent important carbon dioxide (CO₂) sinks [10]. Thus, the increasing use of peat in horticulture has resulted in a rapid depletion of wetlands, determining the loss of a non-renewable resource and creating a source of greenhouse gases through copious CO₂ release due to the aerobic peat decomposition. For this reason, a global movement has been originated to achieve a sustainable peat use and a smart exploitation of wetlands. Many individual countries (Austria, Switzerland, Germany, Great Britain) have begun to limit the extent of peat mining. Government and commercial peat policies support and encourage the use of sustainable peat substitutes which have to satisfy the specific technical requirements and be readily available in sufficient quantities at reasonable costs.

The increasing demand for soilless substrates for horticultural crop production and the rising environmental concerns about the use of non-renewable resources such as peat as medium has led to the search for alternative materials as constituents of growing mixtures for containerized plants, such as solid organic waste by-products coming from industrial and agricultural activities.

1.2. Growing media alternative to peat

1.2.1. Compost

Compost is a general term describing all organic matter that has undergone a long, thermophilic, aerobic decomposition process calling composting [11]. Composts may vary with raw materials used, and duration and nature of the composting process. The combination of these factors results in a wide range of characteristics (physical, chemical and biological) and qualities of end-product as biological oxygen demand, organic matter and nutrients content, degree of disease suppressiveness [12].

Composts used as growing media are produced from different organic wastes such as sewage sludge, municipal solid waste, animal manure and food-industry waste (sugar cane fibre, olive and grape marc, rice and peanut hulls, cotton gin waste). The latter typology of waste is particularly convenient for composting since it is uniform, rich in organic matter and easily available. Differently from other treatment methods for organic waste (land-filling, incineration) which may cause severe air and/or water pollution (leachates), composting is considered a safer process. It is a method that turns waste in a resource which, if obtained properly, represents a beneficial product for agriculture as able to restore the depleted soil/substrate organic matter [13].

Nowadays composts are widely used as ingredient of growing media for containerized plants for the following reasons: 1) need to find a safe outlet for compost (nonedible plants as ornamentals, forest species) that may be considered not desirable for food crops production; 2) characteristics and performances in containers are similar to peat but with a considerably lower cost; 3) high suppressiveness for many soil borne disease.

Composts used as potted substrates must be stable. Mature compost are more stable than young ones still containing readily biodegradable compounds which can undergo secondary degradation leading to oxygen and N deficiencies in the root zone. As compost stability is not identical to compost maturity, which is a prerequisite for suppressiveness of many root pathogens, mature composts are preferable for growing media preparation.

As regards the physical properties of composts for potted substrates, hydraulic conductivity, as well as air filled porosity (AFP) and EAW should be high. Fast and slow-release of nutrients should be strongly considered as excessive vegetative growth and/or salinity effects may occur, even though high concentrations of phytotoxic ions can be reduced by leaching. It must be reiterated that unless all these requirements are met simultaneously, the compost may fail to serve successfully as a container medium.

Different authors have suggested that some organic materials such as tree bark, sawdust, sludge, and different kind of wastes could be used, after composting, as partial peat substitute [14, 15] as composts may have physical and chemical properties superior or similar to peat because of their higher nutrients availability, not excessive water content, and optimum porosity [16, 17].

The combination of peat and compost in growing media is synergistic: peat often enhances aeration and water retention while compost improves the fertilizing capacity of the substrate.

In addition, organic by-products and composts tend to have porosity and aeration properties comparable to those of peat and, as such are ideal substitutes in propagating media [18]. Because the physical and chemical properties of waste and compost-based media may shift with time and source, these substrates should always be tested for local conditions. Waste-recycling end-products used as composts greatly vary on pH, electrical conductivity (EC), and/or nutrients contents and this variability also depends on the type of collection as well as on the composting process. For this reason, it is important to know the physical, chemical and biological characteristics of each material and to compare them with those required for its use as a growing medium.

On the other hand, though the use of mixtures of compost with peat can minimize the potential poor properties of single materials (heterogeneity, presence of contaminants, immaturity, alkaline pH), the percentage of compost used for potting substrates must be carefully determined to avoid negative effects on plant growth (high soluble salt contents, presence of heavy metals, etc.) [19, 20]. Moreover, disposal of sewage sludge and urban compost may pose an environmental hazard if their heavy metals content is high: in these cases they must be sent to landfills.

1.2.2. *Coir dust*

Coir dust is produced from the mesocarp tissue, or husk, of the coconut fruit and originates primarily from several tropical countries as Sri Lanka, India, Philippines, Indonesia, Mexico, Costa Rica and Guyana. The Philippines is one of the largest producers of coconuts with >400 million trees, Sri Lanka annually produces from 350,000 to 500,000 tons of new husk [21]. With this level of production, large volumes of coir dust are potentially available to horticultural markets.

The husk contains approximately from 60 to 70% pith tissue with the remainder being fibre of varying lengths. Husks may be soaked in water to soften them and facilitate grinding. After grinding of the husk, the long fibers are removed and used for various industrial purposes such as rope and mat making. The remaining material, composed of short and medium length fibers as well as pith tissue, is commonly referred to as waste-grade coir. The waste-grade coir may be screened to remove part of the fiber, and the remaining product is referred to as coir dust which is more stable while fibers tend to undergo secondary decomposition in the growth medium [22]. During composting, hemicellulose, cellulose and partially lignine components are decomposed, causing an increase of C/N ratio, CEC and humic acid content, as well as of some physical properties like total porosity, EAW and water buffer capacity, but a decrease of AFP. After composting, coir dust is allowed to dry to a specific moisture level and is then compressed into bales, wrapped, and shipped. The source, the moisture level and the compression pressures often differ among producers so coir is not a uniform material resulting in a large variability of end-product. With the addition of water, coir dust expands to 5 to 9 times its compressed volume [23].

Coconut coir dust (CD) is widely used, alone or mixed with other materials, as an alternative growing medium for soilless cultivation of vegetables, cut flowers and potted plants as it evidenced growth performances similar to that of peat. Coir can also be used as rooting

medium for cuttings under mist because of the presence of root-promoting substances. Evans et al. [24] examined the chemical and physical properties of CD from numerous sources and reported that properties were generally within acceptable ranges except for EC and chloride, which often exceeded recommended levels. Coir physical properties usually varied in according to the quantity of fibrous particles included, so increasing fibre is generally associated with increased porosity and decreased bulk density and WHC.

Coir dust characteristics were also investigated by other authors who reported this material of plant origin as suitable for use in substrates and an effective substitute for sphagnum peat moss for many container crops [25, 26, 23]. In fact, it may present some chemical and hydrological features (organic matter content, CEC, water retention) similar to peat, but with a higher pH and durability. Shrinkage was found to be lower compared to sphagnum moss and higher than in Irish peat moss.

Nevertheless, literature on main physical and chemical characteristics of coir dust is sometimes contradictory: discordances among references can be linked to the heterogeneity of the material which presents different features related to the source and fibre size. pH (in water) ranged between 5 and 7, so higher than peat and suitable for neutrophil crops, without need to use adequate adjustments (CaCO_3). CEC ranged from 30 and 100 meq/100g, values similar to that of brown peat, so with a high buffer capacity. Sometimes a high salinity occur due to a high content of K, Na and Cl as coconut palms live near seashores. EC measured on fresh coir fibre ranged between 0.3 and 2.9 dS m^{-1} , according Sonneveld method (1:1.5 v/v), whereas an EC lower than 0.5 dS m^{-1} is optimal for a substrate component. Soluble salts level affect the quality of coir dust: high salinity and, in particular, excessive content of Na and Cl may cause severe problems according to plant species and growth stage. Evans and Stamps [25] reported that coir dust with a Cl content of 600-700 mg L^{-1} may provide high-yield results if a leaching was applied to plants.

Air content at pF1 is similar to that of blonde peat [27], but extremely different values (from 9 to 92% of total volume) have been recorded from other authors. Water retention capacity seems to be higher than sphagnum peat: according Evans et al. [24], coir dust retention is about 750-900% of its weight, while that of peat is about 400-800%. Contrasting information are however present in literature: Prasad [28] refers about a higher water retention in peat than in coir. Changes of physical characteristics of coir dust are slower than those of sphagnum peat, indicating a higher bio-stability during use (cultivation).

1.2.3. Biochar

Biochar (biologically derived charcoal) is a fine-grained and porous substance produced by pyrolysis, a 300-500°C thermo-chemical process where waste biomass is heated in the absence of oxygen [29]. As results, bio-oil, synthesis gas and black carbon (biochar) are obtained. It can be obtained from different feedstocks (tree wood, grape wine marc, olive cake, chicken manure). Also known as Amazonian Dark Earth or Terra Preta de Indio, biochar is a stable solid material originally obtained from the carbonization of biomass which endured in soil for hundreds of years. It is characterized by the presence of low-temperature charcoal in high

concentrations, high quantities of organic matter (plant residues, manures, bones), and nutrients. It also shows high levels of microorganism activities.

Soil application of biochar can be used to overcome some of the limitations faced during land farming, thereby providing a supplementary management option in addition to other organic materials and having many environmental and sustainability advantages over manures and composts. In fact, it is a porous material with a high inner surface area which helps to retain more water and increase saturated hydraulic conductivity of top soils [30]. Biochar may improve the physical structure of the soil and can also modify soil hydraulic properties: as its pore size is relatively fixed, biochar increases available moisture in sandy soils while has a neutral effect in medium textured ones and decreases moisture availability in clay soils. Glaser et al. [31] observed that biochar-enriched Terra Preta had a WHC 18% higher than the adjacent soils. Biochar seems able to decrease nutrient leaching thus enhancing nutrient availability. Moreover, its CEC is consistently higher than that of the whole soil: the concentration of negative charges on biochar surfaces increases with age as well as the adsorption of charged organic matter. Field experiments on biochar application in different soils and crops have been conducted, and describing positive yield responses [32, 29] and attributing them to the effects of biochar on nutrients availability (i.e. nutrient savings in terms of improved fertilizer use efficiency). Therefore, biochar can enhance soil fertility, increase agricultural productivity and provide protection against some foliar and soil-borne diseases.

Recently, Lehmann et al. [32] and Steiner et al. [33] introduced the concept of converting residues to biochar as an alternative agricultural method to reduce CO₂ emissions. In fact, soil application of biochar may have the greatest potential for the long-term sequestration of carbon (C) as it can remain in the soils for many hundreds of years, due to its stable structure and complex aromatic polycyclic form, thus enhancing the resistance of C to microbial decay and replenishing the scarce carbon stocks. For these reasons, incorporating biochar into soil is currently considered as an interesting option to reach mitigation targets like agricultural management able to reduce greenhouse gases (atmospheric CO₂ concentrations) [34, 35]. Increased soil C sequestration, through biochar addition, can improve soil quality because of the vital role that this element plays in chemical, biological, and physical processes.

Aside from the lack of commercial biochar available to farmers and legislative barriers that prevent it being applied to land (e.g. in Europe) due to the main uncertainty about its long-term performance, widespread adoption of biochar application from a large variety of feedstocks is partially hampered by the unpredictability of plant growth response across different systems. As with many agricultural practices, biochar is reported to result in positive, negative and neutral effects on productivity. Direct comparison of plant growth outcomes is often difficult due to the high variation in numerous experimental parameters including the particular biochar used (feedstock and pyrolysis conditions), the studied plant system (annual/perennial, vegetable, ornamental, etc.) and the growth resources provided (soil type, nutrient availability, moisture, etc).

Until now, numerous studies on biochar agricultural use have been conducted on its application on soil but few researches on the utilization as growing medium for potted plants have

been carried out [36, 37, 38, 39]. The positive characteristics of biochar as soil ameliorant (enhancing CEC, reducing nutrient run-off, improving water retention capacity, providing suitable conditions for micro-organisms) could be exploited for using it as a substrate component, together or as alternative to peat, for containerized plants.

2. Case-studies on peat substitutes for ornamental plants

2.1. Sphagnum peat and coir dust as growing substrates for *Euphorbia × lomi* hybrids in soilless culture

2.1.1. Aim of the study

In order to evaluate the performances of sphagnum peat and coir dust as growing media for ornamentals, a study of soilless cultivation of *Euphorbia × lomi* Rauh (an interspecific hybrid recently introduced to the Mediterranean countries as a new floral crop) using two organic substrates was carried out, collecting data on growth and production and considering possible technical problems for plant management. In fact, the possibility to grow Spurge family plants in soilless culture with organic substrates could be interesting to maintain mother-plants of these genotypes in optimal health conditions during a mass propagation process, evaluating their vegetative and productive behavior. In fact, it is well-known that one of the numerous advantages of this innovative technique is to limit problems associated with the soil as soil-borne diseases.

2.1.2. Materials and methods

The study was carried out in a double-span polyethylene -covered 540 m² greenhouse (28°C day/14°C night). Mother plants of the Thai cultivars 'Nam Chok' and 'Sabckaeron Suk' were grown in polypropylene benches (720 L) filled with two growing media composed of sphagnum peat/perlite (1:1, v/v) and coconut coir dust/perlite (1:1, v/v) in an open-loop system with no recirculating solution. The physical and chemical characteristics of the organic substrates were determined according De Boodt et al. [40] and Sonneveld et al. [41], respectively.

A split-plot experimental design with two substrates as the main plot and two cultivars as subplots with three replications and 20 plants per replication was used. Plants were transplanted in double rows (row spacing of 0.4 m) with a final density of 6.2 plants m⁻². Water and nutrients were supplied by a drip system controlled by a computer. Irrigation scheduling was performed using electronic low-tension tensiometers that control irrigation on the basis of substrate matric potential [42]. Plants were daily fertigated at 2 L h⁻¹ one to five times during the growing cycle. The duration of each fertigation was adjusted when the drainage exceeded the range of 10 to 20%. The composition (mg L⁻¹) of the supplied nutrient solution was as follows: 150 N total (NO₃+NH₄), 50 P, 200 K, 120 Ca, 30 Mg, 1.2 Fe, 0.2 Cu, 0.2 Zn, 0.3 Mn, 0.2 B, and 0.03 Mo. The pH and the EC were maintained at 6.0 and 2.0 dS m⁻¹, respectively.

Plant height, stem diameter, total number (basal and lateral) of shoots per plant, and number of cuttings suitable for rooting (with average length of 8-12 cm) harvested per plant, were recorded for a 12-month period. Water absorption was calculated from the difference between the volume of nutrient solution applied and the volume of collected drainage. Nutrients content in the root zone (uptaken by roots and retained by substrate) was determined by photometric test as the difference between the concentration of each element in the given solution and in the collected drainage.

Collected data were subjected to two-way analysis of variance and means were separated according to Duncan's multiple range test at $p \leq 0.05$.

2.1.3. Results and discussion

As regards physical and chemical characteristics of the two organic substrates, similar values were recorded on bulk density and total porosity, whereas air content was higher in coir dust/perlite than in sphagnum peat/perlite (48.1 and 34.5%, respectively) (Table 1). Peat-based substrate showed higher WHC (58.6 and 47.2%, respectively) and EAW (20.1 and 13.4%) than those measured in coir dust, which was also characterized by a higher pH. EC was similar in both media, while CEC was higher in peat/perlite than in the coir dust-based substrate (55.2 and 36.1 meq/100 g, respectively) (Table 1).

Plants grown in sphagnum peat/perlite showed a similar height than those cultured in coir dust/perlite (51.7 and 48.2 cm, respectively) as well as a similar basal stem diameter (Table 2). No significant differences between substrates were recorded as regards shoots production: an average amount of 18.3 shoots plant⁻¹ was obtained regardless of the growing medium (Table 2). A higher number (10.4) of cuttings suitable for rooting was produced from plants cultivated in peat-based substrate compared with that (5.6) from hybrids grown in coir dust (Table 2). Higher water absorption was recorded from plants grown in peat/perlite (265.2 mL plant⁻¹ day⁻¹) than those cultivated in coir dust mixture (153.4 mL plant⁻¹ day⁻¹) (Table 3). Plants in sphagnum peat/perlite evidenced higher macro- and micronutrients content in the root zone compared to that recorded in coir dust (Figure 1).

The influence of the two organic mixtures on plant growth, water and nutrients absorption are most likely correlated to their physical and chemical properties, which were previously described by other authors [24, 43, 44] who referred that the sphagnum peat and coir dust, though showing some similarities, significantly differ on important chemical and hydrological characteristics: coir dust evidenced higher porosity and air content and lower total and EAW capacity than peat [45].

In our case-study, the similar growth performances (absence of differences recorded on plant height, stem diameter, and shoot total production) recorded in plants cultivated in peat/perlite and coir dust/perlite, seem to suggest that *Euphorbia × lomi* hybrids can be grown in both substrates, corroborating the thesis according with coir dust is considered one of the most important peat substitute as organic medium for soilless cultivation of ornamental plants.

Substrate characteristics	Sphagnum peat/Perlite	Coir dust/Perlite
Bulk density (g cm ⁻³)	0.12 a ^z	0.11 a
Total porosity (% v/v)	93.1 a	95.3 a
Air content (% v/v)	34.5 b	48.1 a
Water holding capacity (% v/v)	58.6 a	47.2 b
Easy available water (% v/v)	20.1 a	13.4 b
pH (on water extract 1:1.5 v/v)	5.3 b	6.0 a
Electrical conductivity (dS m ⁻¹)	0.5 a	0.6 a
Cation exchange capacity (meq/100g)	55.2 a	36.1 b

^zIn any row, means followed by different letters are significant at $p \leq 0.05$ (DMRT)

Table 1. Physical and chemical characteristics of the sphagnum peat and coir dust-based growing media of *Euphorbia × lomi* soilless plants

Substrate mixture	Plant height (cm)	Stem diameter (cm)	Shoots (n. plant ⁻¹)	Cuttings (n. plant ⁻¹)	Water absorption (mL plant ⁻¹ d ⁻¹)
Sphagnum peat/Perlite	51.7 a ^z	3.2 a	21.0 a	10.4 a	265.2 a
Coir dust/Perlite	48.2 a	3.0 a	15.5 a	5.6 b	153.4 b
Significance	ns	ns	ns	*	**

^zWithin a column, means followed by different letters are significant at $p \leq 0.05$ (DMRT)

ns, *, ** = nonsignificant or significant at $p \leq 0.05$ and ≤ 0.01 , respectively.

Table 2. Effects of organic soilless substrates on *Euphorbia × lomi* plant height, stem diameter, shoots and cuttings production, and water absorption

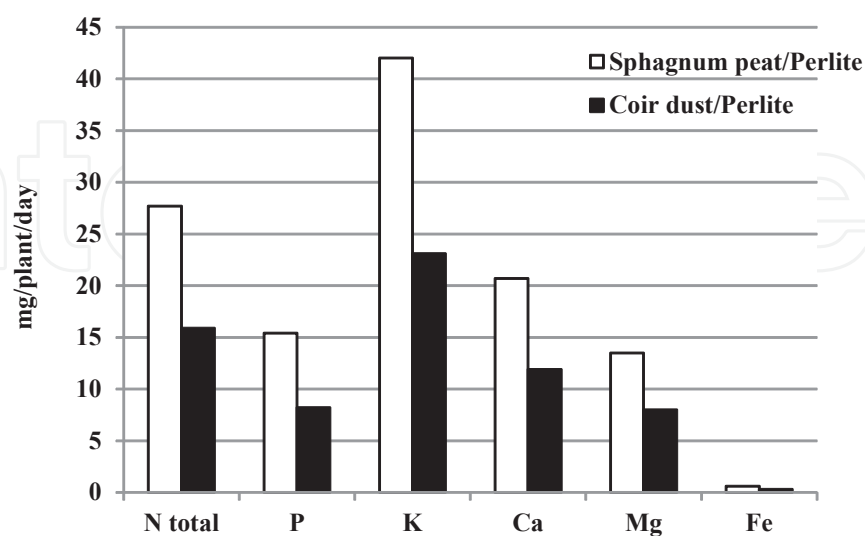


Figure 1. Nutrients content (mg plant⁻¹ day⁻¹) in the root zone of *Euphorbia × lomi* plants as affected by organic soilless substrates

2.2. Changes in physico-chemical characteristics and growth performances of a coir dust-based substrate during a long-term cultivation of cut rose plants

2.2.1. Aim of the study

Coconut coir dust is frequently used as organic medium, singularly or mixed with inert materials (perlite), in soilless systems for vegetable crops but is rarely employed for pluriannual culture of ornamental species. The possibility of finding affordable growing substrates suitable for long-term cultivation of cut flowers could allow for a reduction of prime costs for growers and avoid a short turn-over of plants and substrates. Few reports on the reuse of growing materials (pluriannual cycles on the same substrates) for ornamental species are available in literature and less on a prolonged period of culture of hydroponically grown roses.

Most physical characteristics described for coir dust have been recorded at the beginning of a crop or shortly thereafter, but it is highly probable that these properties would change over time as coir resulted in NO_3 depletion during plants cultivation due to microbial decomposition. Therefore, it is important to determine the physical characteristics of a substrate over a crop period rather than just prior to production.

The aim of this study was to test the changes in the physical and chemical properties of a coir-based growing medium during a three year-soilless cultivation cycle of cut roses, collecting data regarding the evolution of substrate characteristics as well as rose yield and quality response.

2.2.2. Materials and methods

The study was conducted in an unheated (28 °C day/14 °C night) single-span EW oriented greenhouse (25 × 8 m) with steel structure and polyethylene cover (thickness 0.15 mm). Plants of *R. hybrida* cultivars 'Dallas' and 'Red France', grafted on *R. indica major* rootstock, were grown in 80 L polyethylene bags filled with a mixture of coconut coir dust and perlite (3-5 mm diameter) (1:1, v/v) in a semi-closed hydroponic system. Each bag (100 × 50 cm) supported 10 plants of the same cultivar with a final density of 4.5 plants m⁻².

A completely randomized blocks experimental design was used; each treatment (the two cultivars) was replicated 3 times; each replicate was a group of 30 plants (3 bags) leading to a total of 180 plants (30 plants × 3 replications × 2 cultivars). All the plants were cultivated following the 'arching' technique according which weaker and unmarketable stems were bent horizontally in order to promote basal shoot formation and to increase plant canopy and light interception [46, 47].

Water, macro and micronutrients were supplied to plants via a drip-system (1 dripper plant⁻¹, 2 L h⁻¹) which was automatically controlled by a fertigation computer. The nutrient solution had the following composition (mg L⁻¹): 180 N total ($\text{NO}_3 + \text{NH}_4$), 50 P, 200 K, 120 Ca, 30 Mg, 1.3 Fe, 0.2 Cu, 0.2 Zn, 0.3 Mn, 0.2 B and 0.03 Mo. The pH and the EC were maintained at 5.8 and 1.8 dS m⁻¹, respectively.

Irrigation scheduling was performed using electronic low-tension tensiometers that control irrigation on the basis of substrate matric potential. The number of daily irrigations varied from 3 to 6 (corresponding to 0.4 and 1.5 L plant⁻¹ day⁻¹, respectively). The duration of each

delivery was adjusted when the leachate fraction exceeded, for each growing material, the range of 15-25%. This fraction was calculated by collecting the drainage solutions.

The main physical properties (bulk density, total pore space, air content, WHC and EAW) and the chemical characteristics (pH, EC and CEC) of the coir dust-based substrate were determined according to De Boodt et al. [40] and Sonneveld et al. [41], respectively, at the beginning and at the end of the trial. Four bags were randomly selected and analyzed before planting and another four were selected and analyzed after 36 months and removal of the 40 plants.

Nutrient content in the root zone was determined by a photometric test and calculated, at the end of the first year of cultivation and at the end of the third one, as the difference between the concentration of each element in the supplied solution and in the collected leachate.

Rose stems were harvested by cutting to the second 5-leaflet leaf from their origin. Parameters as number of stems plant⁻¹, stem length, basal stem thickness and flower bud height and width were recorded throughout the trial.

Data collected over the 36 month-period were subjected to one-way analysis of variance and means were separated at $p \leq 0.05$ using Duncan's multiple range test.

2.2.3. Results and discussion

Numerous changes in physical and chemical properties of the coir dust-based substrate were recorded during the 36 month-growing period: bulk density significantly increased after 3 years of cultivation, whereas total pore space (TPS) moderately decreased (-6.2%) and air content significantly decreased (-18.3%) (Table 3). In the same period, WHC of the organic mixture increased (+15.6%) and EAW moderately improved (+6.2%) (Table 3). During the growing period, the pH of the substrate did not vary considerably, whereas the EC significantly increased (Table 3); no difference in the CEC was evidenced from the beginning to the end of the experiment. A general decrease in the content of macro and micronutrients in the root zone of the growing medium was also shown from the 1st to the 3rd year of rose cultivation (Table 4).

With regard to the influence of the length of the growing period on flower yield, prolonged cultivation was characterized by an increase in yield (+61%) during the 2nd year and by a decrease (-29%) in the 3rd one (Figure 2). Rose plants averagely produced 15.5 cut stems during the 1st year of culture, 25.3 in the 2nd one and 18.0 in the 3rd, respectively. Significant differences were also observed between cultivars as 'Dallas' evidenced a higher flower production than 'Red France' (21.5 and 17.8 stems plant⁻¹, respectively) (Figure 2). Triennial rose yield response of our case-study agrees with the outcomes recorded in a 2.5 year-trial with gerbera cultured on different growing media [48].

As regards the annual variations of quality traits of cut flowers, stem length showed constant values (average 65.4 cm) during the first two years of cultivation, but slightly decreased in the third one (60.0 cm) (Table 5). A progressive decrease of stem thickness was observed from the beginning (8.6 mm) to the end (6.8 mm) of the experiment. Flower bud height increased from the 1st to the 2nd year (from 5.1 to 5.6 cm) of cultivation but reduced in the 3rd one (4.8 cm) (Table 5). A progressive increase of bud width (from 4.6 to 6.1 cm) was yearly recorded all over the study.

Different yields and quality performances of soilless roses grown in coir dust-based medium during the three-year case-study are most likely linked to the physical and chemical properties of coir dust and to their evolution throughout the cultivation period. Actually, numerous changes in main physical and hydrological characteristics of the tested mixture occurred during the 36-month culture: bulk density increased whereas TPS and air content decreased, WHC and EAW increased. These outcomes agree with those reported by Nowak and Strojny [49] during a 1.5 year-cultivation of gerbera in different growing media.

As conclusive remarks, this case-study indicates that coir dust is highly suitable as organic growing medium for cut rose production during a three-year soilless culture in a south Mediterranean region. This material of plant origin, mixed with perlite, resulted in high yield and quality with an adequate physical and chemical stability over time (high WHC, CEC and nutrients content in the root zone, essential factors for successful plants performances in the extreme [summer] greenhouse conditions), sufficient to ensure a relatively long turn-over of crops and substrates.

Substrate characteristics	1 st year	3 rd year
Bulk density (g cm ⁻³)	0.13 b ^z	0.24 a
Total pore space (% vol.)	95.2 a	89.0 b
Air content (% vol.)	58.5 a	40.2 b
Water holding capacity (% v/v)	33.2 b	48.8 a
Easy available water (% v/v)	11.2 b	17.4 a
pH	6.4 a	5.3 b
Electrical conductivity (dS m ⁻¹)	0.6 b	2.2 a
Cation exchange capacity (meq/100 g)	45.2 a	36.1 a

^zIn any row, means followed by different letters are significant at p≤0.05 (DMRT)

Table 3. Physical and chemical characteristics of coir dust/perlite recorded at the beginning and at the end of the three years of soilless rose culture.

Nutrients	1 st year	3 rd year
N	118.4 a ^z	90.5 b
P	58.0 a	41.6 b
K	130.2 a	107.1 b
Ca	72.9 a	64.0 a
Mg	33.2 a	22.3 b
Fe	1.2 a	0.6 b

^zIn any row, means followed by different letters are significant at p≤0.05 (DMRT)

Table 4. Nutrient content (mg L⁻¹) in the root zone recorded at the end of the 1st and of the 3rd year of cultivation in the coir dust-based substrate.

Growing years	Stem length (cm)	Stem thickness (mm)	Bud height (cm)	Bud width (cm)
1 st year	65.2 a ^z	8.6 a	5.1 ab	4.6 b
2 nd year	65.6 a	7.3 ab	5.6 a	5.8 a
3 rd year	60.0 a	6.8 b	4.8 b	6.1 a
Significance	ns	*	*	*

^zWithin a column, means followed by different letters are significant at $p \leq 0.05$ (DMRT). ns, *, = not significant, significant at $P \leq 0.05$.

Table 5. Annual variations of cut roses qualitative characteristics during the three-year growing cycle in coir dust-based substrate.

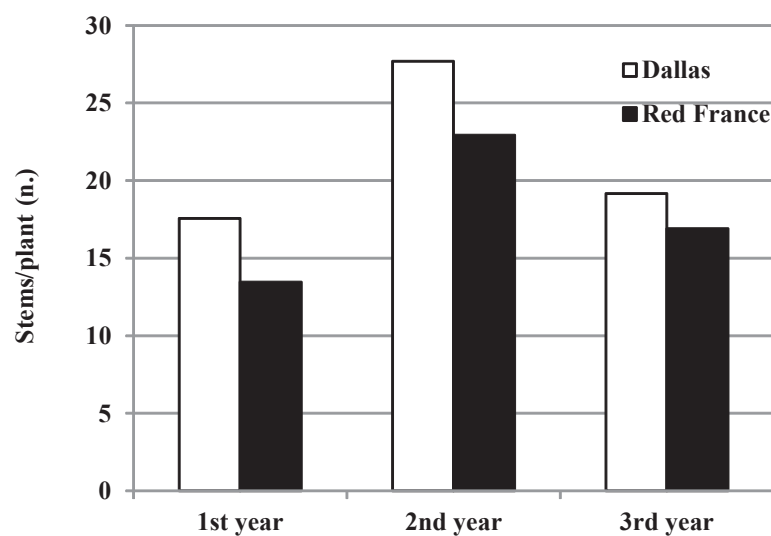


Figure 2. Annual variations of cut roses production of two cultivars during the three year growing cycle in coir dust-based substrate.

2.3. Conifers wood biochar as peat reduced-growing substrate for containerized ornamental plants

2.3.1. Aim of the study

The present study deals with the use of biochar made from conifers wood as a growing medium for containerized *Euphorbia × lomi* in order to reduce peat use in horticulture. The scopes of this work were to evaluate the main physical and chemical properties of potting substrates composted with decreasing content of sphagnum peat and increasing percentages of biochar, and to observe the influence of these materials on the growth and ornamental characteristics of flowering potted plants.

2.3.2. Materials and methods

The study was conducted in an unheated single-span EW oriented greenhouse (25 × 8 m) with steel structure and polyethylene cover (thickness 0.15 mm). Plants of *Euphorbia × lomi* Rauh cv. 'Serena' were grown in plastic pots of 13 cm diameter (vol. 1 L) filled with different mixtures (v/v) of sphagnum peat and conifers wood biochar (100% peat – 0% biochar, 85% peat - 15% biochar, 70% peat - 30% biochar, 55% peat - 45% biochar, 40% peat - 60% biochar, respectively). Used biochar derived from pyrolysed (at 450 °C for 48h) trunks and branches of silver fir, larch, spruce, black pine, and Scots pine trees.

Water, macro and micronutrients were supplied to plants through a drip fertigation system (1 dripper plant⁻¹, 2 L h⁻¹) controlled by a computer. All plants were fed with the same nutrient solution which had the following composition (mg L⁻¹): 180 N total (NO₃+NH₄), 50 P, 200 K, 120 Ca, 30 Mg, 1.2 Fe, 0.2 Cu, 0.2 Zn, 0.3 Mn, 0.2 B. The pH and the EC of the nutrient solution were maintained at 6.0 and 2.0 dS m⁻¹, respectively.

Main chemical (pH and EC) and physical characteristics (bulk density, TPS, air and water content) of the tested substrates were analyzed according Sonneveld et al. [40] and De Boodt et al. [41], respectively. Plant growth (plant height, stem diameter, leaf area, root length, dry biomass and its allocation) and ornamental traits (number of leaves, flowers, and shoots, number of marketable plants) were monitored during the trial. Dry weight of the biomass was determined after 72h in a 100°C air-forced oven when harvested tissues reached a constant value. Leaf area (LA) was measured using a digital area meter. Leaf chlorophyll content of three randomly selected leaves of all plants in each experimental unit was measured with a chlorophyll meter and expressed as SPAD unit. Percentage of marketable plants was determined as the amount of potted plants with a high ornamental value (compact habit, presence of three open inflorescences at least, absence of leaf chlorosis, etc.) at the end of the trial (3 month-cultivation).

A completely randomized blocks design with 3 replications per treatment was used; each replication consisted of 20 plants. Collected data were subjected to one-way analysis of variance and means were compared using Duncan's Multiple Range Test at 5% of probability by using a statistical software package.

2.3.3. Results and discussion

Addition of conifers wood biochar significantly affected chemical characteristics of the growing substrates as pH increased (from 5.7 to 7.9) with the increase of biochar content, while higher value of EC was recorded in the substrate with 100% peat (Table 6). Biochar addition also influenced physical characteristics of the growing media as bulk density increased together with the increase of biochar content (from 310 to 525 g L⁻¹), while TPS moderately increased (from 77.5 to 90.4%) (Table 6). Air content did not significantly varied among treatments whereas water content moderately decreased (from 58.7 to 48.3%) as biochar content in the substrates increased. Vaughn et al. [50], during an experiment with wheat straw and wood biochar for peat moss replacement in soilless substrates, referred that both biochars (at rates of 5, 10, and 15%, v/v) had significantly higher pH, EC and bulk density than peat

moss. Our results partially differed with those obtained from Dumroese et al. [37] who reported that pelletized wood-derived biochar used in soilless substrate performed well when substituted for peat at a rate of 25% (v/v) only, but at higher levels (50, 75 and 100% pellets) proved unsatisfactory, possibly due to high C/N ratios and bulk densities, and swelling of the substrates after the addition of water.

As regards *Euphorbia × lomi* growth, biochar content did not affect plant height, leaves and shoots production averaging 16.6 cm, 90.9 leaves plant⁻¹ and 13.1 shoots plant⁻¹, respectively, across all treatments (Table 7). Stem diameter was higher (18.5 mm) in plants grown with 60% biochar as well as for leaf area (1505.0 cm²). No significant differences among substrates were recorded on leaf chlorophyll content (SPAD values). Flower production and root length were influenced by biochar content of the growing media as higher values (2.6 inflorescences plant⁻¹ and 18.1 cm, respectively) were observed in plants grown with 45% and 60% biochar (Table 7).

Biochar content of the growing substrates significantly affected biomass production and its allocation as higher dry weight of plants (26.0 g) were recorded in *Euphorbia* grown with lower peat percentage (Figure 3). Biochar also influenced the number of marketable potted plants obtained at the end of the trial as an increase was observed (from 24.3% to 56.7%) by increasing biochar content in the growing media (Figure 4). Results from our case-study are more encouraging than those recorded by Vaughn et al. [50] who reported that straw and wood biochar addition to peat in potted tomatoes and marigolds significantly increased plant heights in all treatments but had only a minor or even no effect on dry weights.

Biochar content ^z	pH	EC (dS m ⁻¹)	Bulk density (g L ⁻¹)	Total pore space (% v/v)	Air content (% v/v)	Water content (% v/v)
0%	5.7 b ^y	46 a	310 e	77.5 b	32.3 a	58.7 a
15%	6.4 ab	16 b	350 d	80.1 b	29.2 a	57.6 a
30%	6.7 ab	15 b	420 c	82.2 ab	27.3 a	53.4 a
45%	7.3 a	24 b	485 b	85.7 ab	34.0 a	46.1 b
60%	7.9 a	25 b	525 a	90.4 a	32.1 a	43.3 b

^zSubstrate mixture contain 100% peat – 0% biochar, 85% peat - 15% biochar, 70% peat - 30% biochar, 55% peat - 45% biochar, and 40% peat - 60% biochar.

^yWithin a column, means followed by different letters are significant at p≤0.05 (DMRT)

Table 6. Effect of biochar content in the growing substrates on main chemical and physical characteristics

As final remarks, results of this study seem to indicate a high suitability of conifers wood biochar as an alternative to peat for growing media component of *Euphorbia × lomi* containerized plants. In fact, using a substrate composed with 60% biochar and 40% sphagnum peat is possible to obtain marketable plants with high ornamental value after a 3 month-cultivation period. Obviously, other researches are needed in order to evaluate and/or to confirm the

performances of biochar obtained from other biomass feedstocks and with other ornamental species.

Biochar content ^z	Plant height (cm)	Stem diameter (cm)	Leaves (n. plant ⁻¹)	Leaf area (cm ²)	SPAD	Flowers (n. plant ⁻¹)	Shoots (n. plant ⁻¹)	Root length (cm)
0%	16.4 a ^y	12.3 b	92.3 a	1114.0 b	49.5 a	1.2 b	13.8 a	12.7 b
15%	15.8 a	13.5 b	97.8 a	1035.0 b	42.6 b	1.2 b	14.7 a	13.8 b
30%	17.5 a	13.8 b	93.0 a	1245.2 ab	45.3 ab	1.8 b	11.7 a	17.5 a
45%	15.9 a	13.8 b	85.5 a	1377.0 ab	44.1 ab	2.7 a	12.2 a	18.3 a
60%	17.3 a	18.5 a	86.0 a	1505.0 a	46.8 a	2.5 a	13.2 a	18.0 a

^zSubstrate mixture contain 100% peat – 0% biochar, 85% peat - 15% biochar, 70% peat - 30% biochar, 55% peat - 45% biochar, and 40% peat - 60% biochar.

^yIn any column, means followed by different letters are significant at p≤0.05 (DMRT)

Table 7. Growth and ornamental characteristics of *Euphorbia × lomi* containerized plants as affected by biochar content in the growing substrates

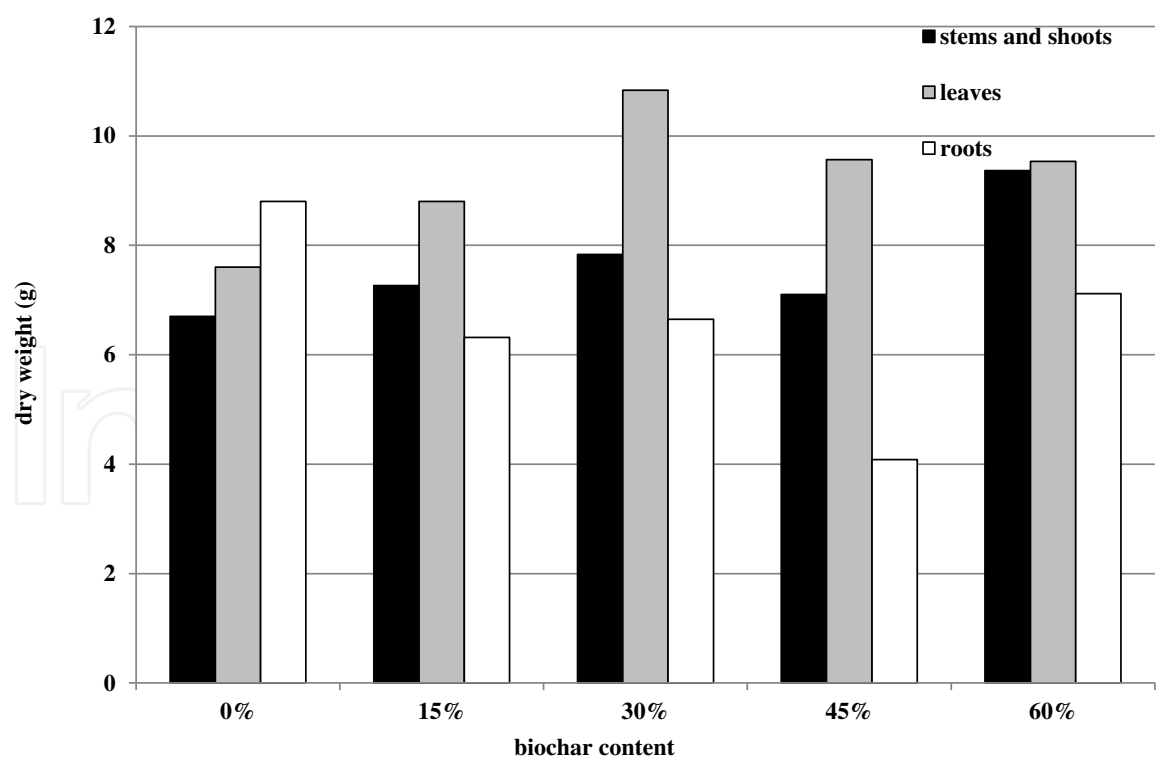


Figure 3. Influence of biochar content in the growing substrates on dry matter allocation of *Euphorbia × lomi* containerized plants. Substrate mixture contain 100% peat – 0% biochar, 85% peat - 15% biochar, 70% peat - 30% biochar, 55% peat - 45% biochar, and 40% peat - 60% biochar.

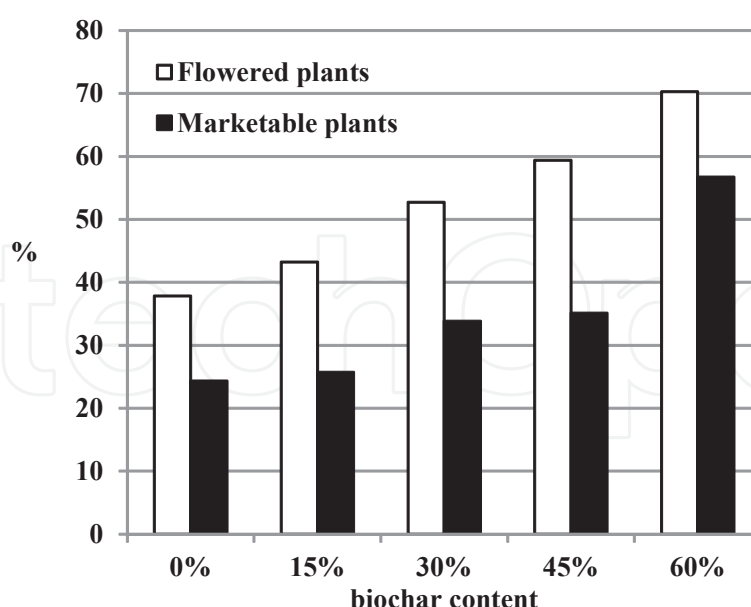


Figure 4. Influence of biochar content in the growing substrates on flowered and marketable potted plants (%) of *Euphorbia × lomi* after 3 months of cultivation. Substrate mixture contain 100% peat – 0% biochar, 85% peat - 15% biochar, 70% peat - 30% biochar, 55% peat - 45% biochar, and 40% peat - 60% biochar.

3. Conclusion

Results reported in the numerous studies previously conducted on peat substitutes, as well as outcomes from the three case-studies above described, confirm that many organic materials, after proper composting, may be used as soilless substrates components for ornamental crops. Some by-products obtained from waste recycling of human activities, agricultural and food industry, and/or energy production processes represent valid alternative to peat, partially or totally, as constituents of growing media for cut flowers and flowering potted plants because having adequate physical and chemical properties and high contents of nutrients. However, their use as substrates depends on the species to be cultivated, as the EC and potentially toxic element accumulation are the main limiting factors. Therefore, the percentage of these waste components in the final substrate is extremely important, with the aim to minimize potential hazards, especially salinity. The evaluation of the beneficial (root zone improvement, nutrients input) and non-beneficial effects (salinity, heavy metals) of organic residues–peat mixtures on growth and yield of ornamentals have to be considered, in order to optimize their wide application. Balanced proportions of many of these materials combined with other compounds (inert or organic), instead of using singularly, could allow to avoid possible negative effects on plant growth and production. As described before and as reported by many authors, coconut coir dust provided higher performances on ornamental plants when combined with inert materials like perlite at 40-60% ratios of substrate final volume depending on plant species, irrigation and nutrient managements; conifers wood biochar may be used as growing

medium even with no previous composting and showed best yield and quality results when mixed with specific amounts of sphagnum peat.

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