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Valorization of Spent Coffee Grounds, Biochar and other residues to Produce Lightweight Clay Ceramic Aggregates Suitable for Nursery Grapevine Production

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Abstract: The valorization of agro-industrial by-products is one of the key strategies to improve agricultural sustainability. In the present study, spent coffee grounds and biochar were used as pore forming agents in the realization of lightweight clay ceramic aggregates that were used as sustainable fertilizers, in addition to tailored glass fertilizer containing phosphorous (P) and potassium (K) and nitrogen (N) synthetic fertilizer, for nursery grapevine production. The obtained fertilizers were assessed in a pot experiment for the fertilization of bare-rooted vines. Unfertilized (T0) and fertilized plants (T1, using NPK-containing commercial fertilizer) were used as controls. Plants fertilized by spent coffee grounds and spent coffee grounds + biochar-containing lightweight aggregates and added with 30 wt% of the above-mentioned glass and N fertilizers (T2 and T3, respectively) recorded higher values of plant height, shoot diameter, leaf and node numbers. Moreover, T2 treatment induced the highest chlorophyll content, shoot and root dry weights. The present study shows that lightweight clay ceramic aggregates containing spent coffee grounds and glass and N fertilizers can be used for nursery grapevine production, in turn improving the agricultural sustainability.

Keywords: by-products; recycle; smart agriculture; sustainability; nitrogen efficiency

1. Introduction

The increasing request of grapevine (*Vitis vinifera* L.) planting materials, due to the expansion of global viticulture and vineyard renewal, is encouraging research studies to increase sustainability of this crop already starting from the nursery phase [1].

Nowadays, different grapevine planting materials are available in commerce. For the planting of a new vineyard, the 1-year-old dormant bare-rooted vines are the most adopted material [2]. It is produced by bench grafting at the end of winter-early spring the dormant one-bud cuttings of the scion onto hardwood cuttings of the rootstock collected during plant dormancy phase, subsequently growing the grafted vines in a greenhouse to achieve the callusing and thereafter transferring them in the open field for the growth and development of roots and shoot. Finally, after excavation and roots and shoot pruning, bare-rooted plants are commercialized.

Currently, several works have mainly focused attention on management of the vineyard in the different stages of its commercial life starting from planting [1,3–7], while little attention was paid to the previous stage, that is, nursery production. The production of planting materials plays an important role both for the establishing of new vineyards and for the replacement of lost or very weak vines or plants infected with trunk disease pathogens [8–10]. Greenhouse production of potted vines might be a successful alternative to open-field propagation, allowing also the transplanting of high-quality plant material throughout all seasons [2].

Soil and vineyard canopy management plays a key role in viticulture, impacting vegetative and reproductive development of the vines [3,11]. Fertilization provides essential nutrients to young plants, which reach a well-established root system and the full size of canopy. In the reproductive phase, a balanced supply of nutrients ensures optimal yield, berry composition and wine quality. Furthermore, biological and physical-chemical soil characteristics are improved by properly fertilization programs [12]. A shortage of nutrient availability due to unbalanced fertilization can lead to a reduction of plant efficiency and biomass production and allocation. On the other hand, an over-fertilization causes improper biomass partitioning, imbalances between vegetative and productive activity and increasing in production costs and in environmental impact of vine cultivation [13]. Nitrogen, phosphorus, potassium and magnesium are key elements of vineyard nutrition, with a fundamental role in the modulation of vegetative growth and development activities [4]. Among these elements, phosphorus is critical from an agronomic point of view due to the direct or indirect actions on radical activity, yielding potential and mitigation of soil copper excess toxicity symptoms [14,15]. Regarding the environmental aspect since phosphorus fertilization is mainly based on use of non-renewable phosphate rocks, alternative strategies are required [16].

Organic fertilizers, characterized by a gradual release of the nutrients into soil, represent a valuable source for the fertilization of important crops, especially in fruit trees showing longer vegetative and reproductive phases than herbaceous crops. Manure, green manure, digestate and compost are the most adopted organic fertilizers [17–20]. However, several biodegradable wastes can be exploited and recycled to produce eco-friendly fertilizing matrix, thus contributing to reuse of organic matter in the waste management processes in accordance with the concept of circular economy. An innovative process to produce controlled-release fertilizers was proposed by Andreola et al. [21,22], who suggested the valorization of agro-industrial and post-consumer residues as raw materials for clay ceramic materials, in particular lightweight aggregates (LWAs). LWA is the generic name for a group of aggregates characterized by a lower density than common aggregates such as natural sand, gravel, and crushed stones. For example, expanded clay, one of the several granular lightweight aggregates available in commerce, is produced by subjecting special natural clays to a thermal expansion and vitrification process at temperatures higher than 1200 °C [23]. For this material, porosity has an important role, in fact, it is fundamental to give lightness, and when used as fertilizer can impact on important agronomic performance like ability to release nutrients over time, draining, as well as retaining water [21].

In order to give porosity to the ceramic material, residues based on great high organic fraction can be considered, such as spent coffee grounds and biochar. One of the most widely consumed hot beverages worldwide is brewed coffee. According to European Coffee Report 2017–2018 [24], Europe is the second worldwide green coffee importer. According to ISTAT data [25], Italy exports roasted coffee of about 4 million equivalent green bags (60 kg bag⁻¹), and spent coffee grounds (SCGs) are generated as post-consumer products. SCGs are commonly treated as organic waste sent to composting plants or in the unsorted garbage that it is fired into incinerator power plants [26]. In the context of a circular economy, in the ceramic sector, the great availability of organic matter could be exploited for lightening an aggregate material, while the high calorific power could contribute to lower the firing temperature and the fuel consumption. Biochar is a fine-grained vegetable carbon extracted from the bottom of the gasifier. When it is added to the soil it improves its chemical-physical properties, increasing soil fertility [27] and crop yield [28], due to the strongly stable nature of organic carbon, which is not subject

to degradation and mineralization. A further advantage of the storage of biochar in the ground is the reduction of CO₂ emissions in the atmosphere [29]. Indeed, the carbon sink process occurring in the soil rescues carbon dioxide from the cycle of carbon. In the last 15 years the use of biochar as a soil or substrate improver has been studied, while its application in building materials is starting to gain more attention recently. The use of biochar contributes to reducing the raw material consumption and the energy saving of the LAW firing process due to the residual carbon content present [30]. Therefore, the aim of the present study was the assessment of spent coffee grounds and biochar in the production of innovative LWAs in combination with a tailored glass-fertilizer based on cattle bone flour ash, K₂CO₃ and packaging glassy sand and their use in the sustainable production of potted grapevine planting materials.

2. Materials and Methods

2.1. Lightweight Aggregates Production and Characterization

Lightweight aggregates were obtained by powder sintering of a local (Modena, Italy) ferruginous red clay (85 wt%) with the addition of spent coffee grounds (SCGs) or spent coffee grounds (Modena, Italy) + biochar (B) (15 wt%) (Emilia Romagna Region, Italy) as poring agents to reduce both density and sintering temperature. Biochar was derived from gasification of woody biomass from river maintenance. The raw materials were dried in an oven at 105 °C for 24 h and subjected to a grinding and sieving process in order to reach a particle size <100 µm for clay and <250 µm for B and SCGs. A 30 wt% of a powdered glass (100 µm) containing the nutrients phosphorus and potassium, previously developed by the authors [21], based on cattle-bone flour ash (CBA), packaging glass cullet and K₂CO₃ and obtained by melting the mixture at 1400 °C in an electric furnace and quenching in water, was added to the clayey body in order to confer fertilizing effect to the materials. Spherical shape samples of 1.5–2.0 g of weight and a medium diameter of 1–1.5 cm were hand-pelletized by the addition of water to obtain the adequate plasticity required for shaping. Samples were dried at 105 °C for 24 h to reduce their moisture content and then subjected to a firing process in a laboratory electrical kiln (Lenton mod. AWF13/12, Hope Valley, United Kingdom) that caused sintering of the grains and changes in their density and porosity. In order to imitate the thermal shock produced in the rotary furnace, the samples were introduced and kept in the furnace at 1000 °C for 1 h and finally allowed to cool through natural convection. The samples were codified as reported: red clay (C) + pore forming agent [spent coffee ground (SCG) or biochar (B) followed by a number indicating the percentage introduced 15% + fertilizer glass (FG) followed by a number indicating the percentage of fertilizer glass added 30%].

The specimens after firing were subjected to different physical-chemical tests in order to determine their possible use in agriculture or green roofs. In particular, weight loss (WL%) at 1000 °C, 1 h, static water absorption (WA%) in cool distilled water after 24 h following UNI EN 772-21 (2011); apparent density (AD) by Envelope density analyzer Geo Pyc 1360 equipment (Micromeritics, Norcross, GA, USA); absolute or real density (RD) by Gas Helium-pycnometer Accupyc TM II 1340 (Micromeritics, USA); total porosity percentage (TP), calculated from the densities values by the equation: $TP\% = [(RD-AD)/RD]*100$; pH according to UNI-EN 13037 (2012) standard, using a pH-meter (XS Instruments, pH 6);-USA); electrical specific conductivity (EC), according to UNI-EN 13038 (2012) standard, using an Oakton conductimeter CON6/TDS6 (OAKTON Instruments P.O. Vernon Hills, IL, USA).

Specific tests of release were performed according to both Italian and European regulations [31] to evaluate the release capacity of P and K nutrients as well as other elements that could be harmful for the environment. Distilled water and citric acid solution 2 vol.% were used as reaction media; the values were monitored in a period from 7 to 90 days to verify controlled release. The aggregates were tested in whole size, to simulate the conditions occurring in the soil. The liquid solutions derived

were analyzed by inductively coupled plasma mass spectrometry (ICP-MS Agilent 7500a, 5301 Stevens Creek Blvd, Santa Clara, CA 95051, USA).

2.2. Nursery Greenhouse Experiments

The potting experiment was performed in a nursery greenhouse, located at Reggio Emilia (Italy) under controlled temperature ranging from 19 to 25 °C (day/night) and relative humidity varying from 60% to 70%. Plants were grown under long-day conditions (15 h light, 9 h dark; light intensity 280 $\mu\text{mol m}^{-2} \text{s}^{-1}$).

The scion/rootstock combination was ‘Lambrusco Salamino’ cultivar grafted onto ‘Kober 5BB’ as rootstock. Bare-rooted vines were manually transplanted (one plant *per* pot) in plastic pots of 4.5 L capacity and filled with commercial neutralized peat (Fondolinfia Universale, Linfa Spa, RE, Italy), containing 70% organic matter, 35% organic carbon, 0.6% nitrogen (N) and having pH 6.0. Pots were arranged in a completely randomized design with five replicates and manually irrigated every two days in order to ensure the water holding capacity of the substrate. Pests were controlled according to the integrated production rules of the Emilia-Romagna Region (Italy). Plants were pruned according to one-stem training system.

Fertilization was performed only at planting, administering, in total, 6 g of N, 1.4 g of P_2O_5 and 1.6 g of K_2O *per* pot. Experimental theses were: unfertilized treatment (T0); synthetic fertilization with Osmocote Topdress [22 (N)–5 (P_2O_5)–6 (K_2O) + 2 (MgO)] (T1); LWA based on spent coffee grounds in combination with glass and N fertilizers (T2); LWA based on spent coffee grounds and biochar in combination with glass and N fertilizers (T3).

T2 and T3 showed the following composition: 7.0 (P_2O_5)–5.9 (K_2O) + 1.7 (MgO) and 5.3 (P_2O_5)–5.4 (K_2O) + 1.9 (MgO), respectively.

In order to supply the expected nitrogen rate (6 g *per* pot) ammonium nitrite and urea (2.9 and 3.1 g of N, respectively) were applied in combination with LWAs.

2.3. Recorded Parameters

During the experiment, the main phenological growth stages were recorded following the BBCH-scale (BBCH = Biologische Bundesantalt, Bundessortenamt and CHemische Industrie, Germany) [32].

Growing media (GM) were weekly monitored for the different parameters: GM water content, temperature and electrical conductivity (using a sensor Teros 11/12, Meter Group, Washington, USA). At day 314 of the year (DOY) the following traits were measured: leaf chlorophyll (Chl) and flavonoid (Flav) contents, nitrogen balance index (NBI) as ratio between Chl and Flav [30], leaf anthocyanin content (Anth), basal shoot diameter, shoot height, number of leaves and nodes. Chl, Flav, NBI, and Anth were measured on the youngest fully expanded leaf by Dualex 4 Scientific (Dx4, FORCE-A, Orsay, France), an optical leaf-clip meter for non-destructive assessment of the physiological status of the plants [33]. Leaf temperature was recorded on the fully expanded leaf using an infra-red thermometer (Everest Instruments, Chino Hills, CA, USA). Moreover, parameters characterizing plant growth were recorded: shoot fresh weight of the scion (SFW), above-ground rootstock fresh weight (RSFW), root fresh weight (RTFW), total fresh weight (TFW), shoot dry weight (SDW), above ground rootstock dry weight (RSDW), root dry weight (RTDW), total dry weight (TDW). Using these parameters, the following indexes were calculated: fraction of total dry weight allocated to shoot (FTS) $((\text{SDW}/\text{TDW}) * 100)$, fraction of total dry weight allocated to above-ground rootstock (FTRS) $((\text{RSDW}/\text{TDW}) * 100)$, and fraction of total dry weight allocated to root (FTR) $((\text{RTDW}/\text{TDW}) * 100)$.

In order to compare N use across the treatments, the nitrogen efficiency index was calculated from the measured plant total dry matter (g pot^{-1}) and the amount of N applied (g pot^{-1}) and was expressed as $\text{g dry biomass g}^{-1} \text{N}$ [34].

2.4. Data Analysis

All recorded data were analyzed using GenStat 17th software (VSN International, Hemel Hempstead, UK) for analysis of variance (ANOVA). Significant means were separated by Duncan's test at $p \leq 0.05$.

3. Results and Discussion

To produce grapevine planting materials for new vineyards or to replace diseased plants, high-standard quality attributes (such as good vigor, absence of defects, well healed graft union, in addition to the guarantees of satisfactory phytosanitary status and genetic identity of rootstock and scion), can be obtained under greenhouse conditions [35]. Nowadays the environmental sustainability of orchards or vineyards must necessarily consider the pre-planting phases, i.e., the propagation phases of the plant material (i.e., proper recycling of any plastic residues or use of biodegradable pots, low impacting irrigation, disease control and fertilization methods). For the latter agronomic practice, researchers are called to find alternative fertilizers for nursery phase ensuring good plant development and low environmental impact. Considering some previous evidences of the positive effects of spent coffee grounds and biochar on growth of horticultural and woody species [2,12,13,20,36], in the present study SCGs and B were valorized to obtain new LWAs which were for the first time tested for the fertilization of bare-rooted vines in a nursery greenhouse.

3.1. Lightweight Aggregates Characteristics

All specimens prepared using red clay together with spent coffee ground (CSCG) and mixed with biochar (CBSCG) showed good workability and a good final aggregation. Unfired samples containing biochar had a darker color but after firing it disappeared obtaining aggregates with a classic red color. The idea of mixing biochar and spent coffee ground as poring agent derives from the natural alkaline pH of the biochar (11.8) and acid pH of SCGs (5.5). Aggregates prepared with only biochar as a pore-forming agent had an alkaline pH (9.3) out of the limit. The aggregates to be used in the soil must have a pH value within the optimal range of plant comfort (6–8) and EC less than 2 mS/cm. Considering these premises, it is important to evaluate the properties of LWAs functionalized with 30 wt% of fertilizing glass (FG). Table 1 shows the results of the physical and chemical characterization.

Table 1. Physical and chemical parameters of the lightweight aggregates (LWAs).

Physical Properties	CSCG15FG30	CBSCG15FG30
Weight Loss (%)	16.73	17.82
Water Absorption (%)	14.29	13.48
App. Density (kg/m ³)	1490	1400
Calculated Total Porosity (%)	42.21	45.35
Chemical Properties	CSCG15FG30	CBSCG15FG30
pH	7.24	8.31
Electrical Conductivity (dS m ⁻¹)	0.24	0.36

The physical characterization permitted us to classify the specimens functionalized with 30 wt% of fertilizing glass as LWAs, because their apparent density values are lower than 2000 kg m⁻³ (UNI-EN 13055–1:2003) and their porosity higher than 40%.

pH and electrical conductivity are the most important parameters to check for an agronomic application. As can be seen in Table 1, the CSCG15FG30 shows results in line with the soil guidelines above reported values while the pH of CBSCG15FG30 is slightly higher.

By the citric acid test, the release of the main nutrients P and K was monitored until 90 days. LWAs prepared with only SCG as a pore-forming agent showed an increase of P% release from 30 to 90% while those prepared using the mix (SCG + B) as a pore-forming agent highlighted a P% release

from 30 to 82%. The K% release observed was lower than P% for the two compositions analyzed. For CSCG15FG30, the values increased from 5% (7 days) to 17% in 90 days while a higher release was observed for CBSCG15FG30 from 8% (7 days) to 24% in 90 days.

These differences are putatively due to the capacity of biochar to adsorb nutrients like P and K as already suggested by Carrey et al. in 2005 [37]. However, further studies are needed to corroborate this hypothesis. In addition, regarding the use of the proposed innovative fertilizers and their possible implication for soil-plant relationship, it is well known that nutrient availability of P and K depends on soil pH and on the interaction between soil microbiota and rhizosphere [38].

3.2. Bare-Rooted Vines Production

The main parameters recorded for the growing media were reported in Table 2. Peat fertilized with LWA containing spent coffee grounds and biochar (T3) showed the highest values of growing media water content, temperature and electrical conductivity (+33%, +1% and +9%, on average). These three parameters are strictly related with the plant growth and its development. In fact, soil/growing media temperature and water availability play a key role in the growth and development of roots and the vegetative growth of the vineyard canopy. During the productive phase of the vineyard, to obtain high-quality grapes, an optimal soil water deficit pattern is required [36]. On the other hand, young vines in the nursery and after planting need a high water availability, allowing maximum growth to hasten the development of the vineyard canopy [39]. Furthermore, soil temperature is positively related with root growth and development. Indeed, root growth starts above a threshold of 6–7 °C and increases with temperature with an optimum occurring at around 30 °C [40]. In bare-rooted vines after planting the availability of carbohydrate reserves is presumably quite low, and roots, shoots and leaves may face competition for photoassimilates. Warmer soil increases the mobilization of root reserves and the shoot biomass and may enhance root growth through a higher rate of carbohydrate reserve catabolism and a consequent greater availability of energy and carbon, according to Clarke et al. [41]. Together with the good water availability, a warmer soil also enhances the uptake of nitrogen, phosphorus, potassium and other nutrients [42]. These considerations are consistent with the best growth observed in T3-treated vines and with higher values of root and shoot weights, plant height, number of nodes and shoot diameter of T2-treatment than the control (T0) (Tables 3 and 4).

Table 2. Mean physical parameters of the growing media recorded in the compared thesis during the trial.

Treatment	Growing Media Water Content ($\text{m}^3 \text{m}^{-3}$)		Growing Media Temperature ($^{\circ}\text{C}$)		Growing Media EC (dS m^{-1})	
T0	0.18	b	23.48	b	0.24	a
T1	0.15	c	23.46	b	0.15	c
T2	0.18	b	24.08	a	0.22	b
T3	0.21	a	24.12	a	0.24	a

T0 = unfertilized pot; T1 = fertilized pot with commercial NPK fertilizer (Osmocote Topdress); T2 = fertilized pot with LWA based on spent coffee ground, glass and N fertilizers; T3 = fertilized pot with LWA based on spent coffee grounds + biochar, glass and N fertilizers; EC = electrical conductivity. Means followed by the same letter do not significantly differ at $p \leq 0.05$.

Regarding soil electrical conductivity, by the effect of fertilization [43], Abad et al. [44] reported 0.5 dS m^{-1} as the threshold to achieve the highest plant growth. In our experiment a lower EC was found for T1 and T2 treatments than T0; moreover, the values detected for the overall thesis never reached the threshold indicated by Abad et al. [44].

Morpho-physiological parameters of bare-rooted vines were affected by LWA applications which, induced for the overall measured traits a better performance respect to commercial fertilizer applications (Table 3). At 314 DOY, corresponding to the “Principal growth stage 9: Senescence” of the BBCH-scale, T2- and T3-fertilized plants displayed higher values of plant height, node number and shoot diameter than T1-fertilized or T0-unfertilized ones (+9%, +21% and +22% of T2 and T3 respect to T0). Within stage 9, the degree of leaf fall ranged from 93 “beginning of leaf-fall” for the

fertilized these to 97 “end of leaf-fall” for the unfertilized one, indicating a longer growth duration for fertilized plants. Moreover, the highest value of leaf number (16 *per* plant) was detected in plants fertilized with LWAs containing spent coffee grounds (T2). Regarding the physiological parameters, T2- and T3-fertilized plants reported the highest values of leaf chlorophyll and flavonoid contents, NBI and leaf temperature. Moreover, for the same treatments the lowest value of leaf anthocyanins content was measured (on average, +19%, +3%, +16%, +0.4% and -24%, respectively).

Table 3. Morphological (A) and Physiological (B) parameters recorded on bare-rooted vines measured at 314 day of the year (DOY).

(A)										
Treatment	Plant Height (cm)		Leaf Number (No.)		Node Number (No.)		Shoot Diameter (mm)			
T0	80.00	d	3.00	d	13.00	c	3.71	c		
T1	83.50	c	10.00	c	14.00	b	3.85	b		
T2	86.00	b	14.00	a	16.00	a	4.38	a		
T3	89.00	a	11.67	b	5.33	a	4.65	a		
(B)										
Treatment	Chl ($\mu\text{g cm}^{-2}$)		Flav ($\mu\text{g cm}^{-2}$)		Anth ($\mu\text{g cm}^{-2}$)		NBI (-)		Leaf Temperature ($^{\circ}\text{C}$)	
T0	35.80	c	0.89	b	0.24	b	40.18	b	24.18	a
T1	38.95	b	0.88	bc	0.24	b	44.06	a	23.77	b
T2	22.10	d	0.84	c	0.34	a	26.25	c	24.78	a
T3	41.20	a	0.91	a	0.19	c	45.22	a	24.37	a

T0 = unfertilized pot; T1 = fertilized pot with commercial NPK fertilizer (Osmocote Topdress); T2 = fertilized pot with LWA based on spent coffee ground, glass and N fertilizers; T3 = fertilized pot with LWA based on spent coffee grounds + biochar, glass and N fertilizers; leaf chlorophyll content (Chl); leaf flavonoid content (Flav); leaf anthocyanins (Anth); nitrogen balance index (NBI). Parameter without unit of measure (-). Means followed by the same letter do not significantly differ at $p \leq 0.05$.

Table 4. Agronomic parameters recorded on bare-rooted vines.

(A)								
Treatment	Root Fresh Weight (g plant^{-1})		Rootstock Fresh Weight (g plant^{-1})		Shoot Fresh Weight (g plant^{-1})		Total Fresh Weight (g plant^{-1})	
T0	38.42	c	29.90	c	7.17	c	75.48	c
T1	31.67	d	43.17	a	10.00	b	84.83	b
T2	39.83	b	37.00	b	11.50	b	88.33	b
T3	44.17	a	38.50	b	12.83	a	95.50	a
(B)								
Treatment	Root Dry Weight (g plant^{-1})		Rootstock Dry Weight (g plant^{-1})		Shoot Dry Weight (g plant^{-1})		Total Dry Weight (g plant^{-1})	
T0	13.28	c	17.81	c	2.46	d	33.55	c
T1	15.57	b	26.90	a	3.85	c	46.32	a
T2	14.33	b	25.88	a	4.08	b	44.29	b
T3	19.13	a	23.45	b	4.40	a	46.97	a

T0 = unfertilized pot; T1 = fertilized pot with commercial NPK fertilizer (Osmocote Topdress); T2 = fertilized pot with LWA based on spent coffee ground, glass and N fertilizers; T3 = fertilized pot with LWA based on spent coffee grounds + biochar, glass and N fertilizers; (A) = biomass fresh weight; (B) = biomass dry weight; means followed by the same letter do not significantly differ at $p \leq 0.05$.

Our results were in agreement with those of previous research reporting, for different species, improvement in plant development under low supplies of spent coffee ground or biochar [45–48]. The increased Chl and NBI values for T3 treatment suggested a higher rate of leaf photosynthetic activity, assimilation and use (protein synthesis) of mineral nitrogen from the substrate. These results were in agreement with those reported by Ronga et al. [2,45] and Bozzolo et al. [12]. Leaf chlorophyll, flavonoid, and anthocyanin content are suggested as indices of plant physiological status and are associated with the N uptake and leaf photosynthetic activity [33]. Furthermore, Chalker-Scott [49] suggested that high leaf Anth levels are related with an improvement of tolerance to abiotic and biotic stresses. Interestingly, T2-fertilized plants showed the highest values of Anth. T2 treatment showed lower values of Chl and higher of Flav than T0, due to higher values of all the measured morphological parameters. In fact, in the investigated treatments, the same amount of nutrients was used, hence plants with a higher development can result in a dilution of the macro- and micronutrients that are involved

in the physiological activities and related parameters like Chl content [33]. On the other hand, biochar application can allow a slow and constant release of the nutrients in the soil/growing media for plant nutrition as previously reported by Zhao et al. [50] and Gwenzi et al. [51]. In addition, this slowing release can allow a higher plant physiological activity as observed in the present study in T3-fertilized plants. Hence, our results suggested that LWA based on spent coffee ground and biochar may be used to improve plant physiological performance (increasing in stress resistances), since supplying of LWA based on biochar increased leaf photosynthetic activity in grapevine nursery management.

The results regarding the main agronomic parameters were shown in Table 4. Among the investigated treatments, bare-rooted vines fertilized with T3 showed the highest values of root, shoot and total fresh weights (+15%, +24% and +11%, on average), while the highest value of RSFW (+16%, on average) was measured for T1-fertilized plants (Table 4A). A similar trend was also noticed for the biomass dry weight. Indeed, plants fertilized with LWA based on spent coffee ground and biochar (T3) showed the highest values of root, shoot and total dry weights (+23%, +19% and +10%, on average), while T1-fertilized plants showed the highest value of RSDW (+12%, on average). In any case, this value did not significantly differ from T2 treatments, as well as total dry weight of T3 and T2 treatments was statistically comparable among them (46.3 and 27.0 g plant⁻¹, respectively).

Results regarding the improved biomass production using LWA based on spent coffee ground and biochar were in accordance with those reported by Setti et al. [52], Raviv et al. [53] and Ronga et al. [2,45], who suggested that composts derived from several by-products like spent coffee grounds and biochar positively affected the growth of potted plants grown in greenhouses. Moreover, different works reported increases in grapevine root biomass under different soil amendments like biochar, compost and digestate [2,12,54,55]. The increased biomass was putatively due to the availability of some growth-promoting compounds in the LWAs both based on spent coffee grounds and biochar as suggested by different researchers who used the same fertilizers based on agro-industrial by-products [2,56,57]. Finally, vines showing high total dry weight can better overcome transplanting stresses [58] and this improved plant physiological state represents a very important goal for nursery growers.

Figure 1 shows the biomass allocation to the different organs: root, above-ground part of the rootstock and shoot. T3-fertilized plants displayed the highest values of FTR (+11% and +4%, on average), while the highest values of biomass allocated to rootstock (FTRS) were observed in T1- and T2-fertilized plants (+5%, on average). As suggested by Ericsson et al. [59], changes in the source-sink organ relationship can impact on the growth of the fruit-tree. Indeed, the same authors demonstrated that a high shoot development can negatively impact on the root growth. Anyway, this behavior was also partially highlighted in T2 treatment; instead, in our work, enhanced percentages of biomass allocation to shoot did not result in reduction of partitioning to the roots. The differences reported between our results and ones reported by Ericsson et al. [59] were probably ascribed to the use of SCGs and biochar in the present study. In fact, SCGs and biochar can stimulate the growth of the different plant organs as already reported in other studies [20,60]. This physiological behavior is much appreciated by vine-growers since they can dispose of planting material with a good development of both root and shoot ensuring early and faster plant establishment after transplanting, due to the good availability of accumulated reserves.

Figure 2 reports nitrogen efficiency, representing an important parameter to assess the effect of the nitrogen fertilization on the plant growth [61,62]. T3-treated plants, as well as plant fertilized with Osmocote Dropress, showed similar nitrogen efficiency values (7.8 g of biomass produced *per* each g of N applied). The performance of LWAs based on spent coffee grounds was improved with addition of biochar. Our results confirmed that this kind of substrate acts synergistically on plant growth, similarly to the results of previous studies on the same fruit tree [2,12] and on tomato [20]. In fact, in the fertilization, the use of SCGs and biochar can allow a higher plant nutrient uptake as observed in the present study and in the already published study [2,12,20].

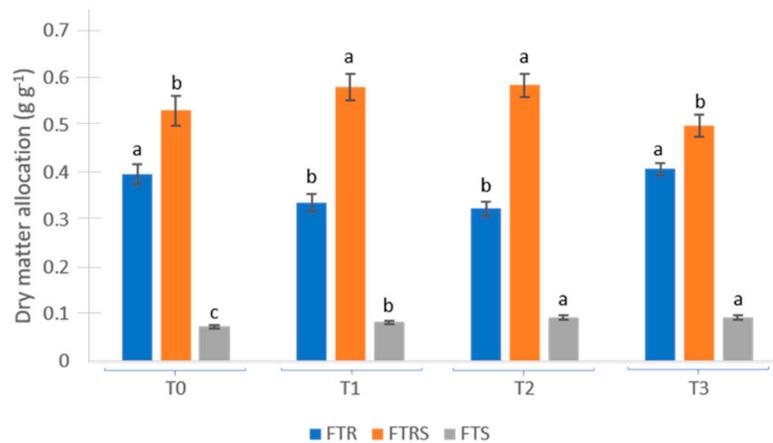


Figure 1. Dry matter allocation to different part of the bare-rooted vines in the compared thesis. T0 = unfertilized pot; T1 = fertilized pot with commercial NPK fertilizer (Osmocote Topdress); T2 = fertilized pot with LWA based on spent coffee ground, glass and N fertilizers; T3 = fertilized pot with LWA based on spent coffee grounds + biochar, glass and N fertilizers; FTS = fraction of total dry weight allocated to shoot; FTRS = fraction of total dry weight allocated to above-ground rootstock; FTR= fraction of total dry weight allocated to root Bars indicate standard deviations. Means followed by the same letter do not significantly differ at $p \leq 0.05$.

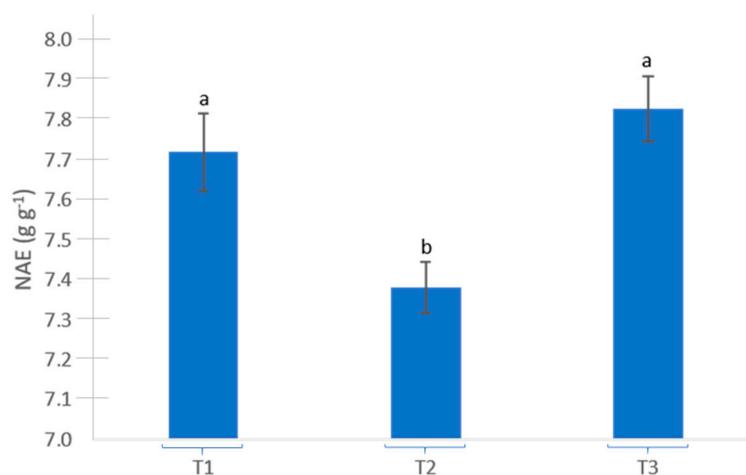


Figure 2. Comparison of nitrogen efficiency in the three fertilized theses. T1 = fertilized pot with commercial NPK fertilizer (Osmocote Topdress); T2 = fertilized pot with LWA based on spent coffee ground, glass and N fertilizer; T3 = fertilized pot with LWA based on spent coffee grounds + biochar, glass and N fertilizers; NAE = nitrogen efficiency; bars indicate standard deviations. Means followed by the same letter do not significantly differ at $p < 0.05$.

Finally, the obtained results were broadly in accordance with those of several previous studies, which reported increases in plant biomass production as effect of agro-industrial by-products, such as compost, digestate, and biochar adopted as fertilizers [2,12,18]. Increases in plant biomass were obtained by fertilizing with agro-industrial by-products and were related to the content of humic substances and some compounds able to enhance the plant growth [63]. Finally, Jindo et al. [64] reported that plant biochemical activity is improved by plant hormone-like promoters.

4. Conclusions

Results obtained in the present study suggested that spent coffee grounds and biochar represent useful components, due to their pore-forming role, for producing the matrix of lightweight aggregates.

To our knowledge, this was the first study investigating the suitability of spent coffee grounds, biochar and other residues in the form of glass in innovative slow-release fertilizer production. These recycled matrices fit well in with sustainable agriculture management and in circular economy contests. LWAs based on spent coffee grounds and biochar, when functionalized by the addition of 30 wt% of glass fertilizer, showed good agronomic performances comparable to those of synthetic fertilizer in the production of grapevine planting materials. LWAs here studied also proved to be able to reduce the needs to use phosphate and potassium rocks in nursery management phase. The positive effects on the physical characteristics of the substrate, especially on its water retention capacity, provided an interesting opportunity to save irrigation water. Finally, bare-rooted vines grown using LWAs resulted in better agronomic performances and in improved plant physiological status. However, further research is needed to assess the effect of LWAs in nursery greenhouse production of other fruit planting materials as well as in open field vine nursery production.

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References

1. Reynolds, A.G. *Managing Wine Quality: Viticulture and Wine Quality*; Woodhead Publishing: Cambridge, UK, 2010.
2. Ronga, D.; Francia, E.; Allesina, G.; Pedrazzi, S.; Zaccardelli, M.; Pane, C.; Tava, A.; Bignami, C. Valorization of vineyard by-products to obtain composted digestate and biochar suitable for nursery grapevine (*Vitis vinifera* L.) production. *Agronomy* **2019**, *9*, 420. [[CrossRef](#)]
3. Tesic, D.; Keller, M.; Hutton, R.J. Influence of vineyard floor management practices on grapevine vegetative growth, yield, and fruit composition. *Am. J. Enol. Vitic.* **2007**, *58*, 1–11.
4. Arrobas, M.; Ferreira, I.Q.; Freitas, S.; Verdial, J.; Rodrigues, M.Â. Guidelines for fertilizer use in vineyards based on nutrient content of grapevine parts. *Sci. Hortic.* **2014**, *172*, 191–198. [[CrossRef](#)]
5. Palliotti, A.; Tombesi, S.; Silvestroni, O.; Lanari, V.; Gatti, M.; Poni, S. Changes in vineyard establishment and canopy management urged by earlier climate-related grape ripening: A review. *Sci. Hortic.* **2014**, *178*, 43–54. [[CrossRef](#)]
6. Eldon, J.; Gershenson, A. Effects of Cultivation and Alternative Vineyard Management Practices on Soil Carbon Storage in Diverse Mediterranean Landscapes: A Review of the Literature. *Agroecol. Sustain. Food Syst.* **2015**, *39*, 516–550. [[CrossRef](#)]
7. Medrano, H.; Tomás, M.; Martorell, S.; Bota, J. Improving water use efficiency of vineyards in semi-arid regions. A review. *Agron. Sustain. Dev.* **2015**, *35*, 499–517. [[CrossRef](#)]
8. Borsellino, V.; Galati, A.; Schimmenti, E. Survey on the innovation in the Sicilian grapevine nurseries. *J. Wine Res.* **2012**, *23*, 1–13. [[CrossRef](#)]
9. Waite, H.; May, P.; Bossinger, G. Variations in phytosanitary and other management practices in Australian grapevine nurseries. *Phytopathol. Mediterr.* **2013**, *52*, 369–379.
10. Whitelaw-Weckert, M.A.; Rahman, L.; Appleby, L.M.; Hall, A.; Clark, A.C.; Waite, H.; Hardie, W.J. Co-infection by *B otryosphaeriaceae* and *I lyonectria* spp. fungi during propagation causes decline of young grafted grapevines. *Plant Pathol.* **2013**, *62*, 1226–1237. [[CrossRef](#)]
11. Salomé, C.; Coll, P.; Lardo, E.; Metay, A.; Villenave, C.; Marsden, C.; Blanchart, E.; Hinsinger, P.; Le Cadre, E. The soil quality concept as a framework to assess management practices in vulnerable agroecosystems: A case study in Mediterranean vineyards. *Ecol. Indic.* **2016**, *61*, 456–465. [[CrossRef](#)]

12. Bozzolo, A.; Pizzeghello, D.; Cardinali, A.; Francioso, O.; Nardi, S. Effects of moderate and high rates of biochar and compost on grapevine growth in a greenhouse experiment. *AIMS Agric. Food* **2017**, *2*, 113–128. [[CrossRef](#)]
13. Ciesielczuk, T.; Rosik-Dulewska, C.; Wiśniewska, E. Possibilities of coffee spent ground use as a slow action organo-mineral fertilizer. *Rocz. Ochr. Srodowiska* **2015**, *17*, 422–437.
14. Stanley, G.; Matthews, M.A. The influence of Phosphorus availability, scion, and rootstock on grapevine shoot growth, leaf area, and petiole Phosphorus concentration. *Am. J. Enol. Vitic.* **1996**, *47*, 217–224.
15. Baldi, E.; Miotto, A.; Ceretta, C.A.; Brunetto, G.; Muzzi, E.; Sorrenti, G.; Quartieri, M. Soil application of P can mitigate the copper toxicity in grapevine: Physiological implications. *Sci. Hortic.* **2018**, *238*, 400–407. [[CrossRef](#)]
16. Gautier, A.; Cookson, S.J.; Hevin, C.; Vivin, P.; Lauvergeat, V.; Mollier, A. Phosphorus acquisition efficiency and phosphorus remobilization mediate genotype-specific differences in shoot phosphorus content in grapevine. *Tree Physiol.* **2018**, *38*, 1742–1751. [[CrossRef](#)]
17. Ronga, D.; Mantovi, P.; Pacchioli, M.T.; Pulvirenti, A.; Bigi, F.; Allesina, G.; Pedrazzi, S.; Dal Prà, A. Combined Effects of Dewatering, Composting and Pelleting to Valorize and Delocalize Livestock Manure, Improving Agricultural Sustainability. *Agronomy* **2020**, *10*, 661. [[CrossRef](#)]
18. Bortolini, S.; Macavei, L.L.; Saadoun, J.H.; Foca, G.; Ulrici, A.; Bernini, F.; Malferrari, D.; Setti, L.; Ronga, D.; Maistrello, L. *Hermetia illucens* (L.) larvae as chicken manure management tool for circular economy. *J. Clean. Prod.* **2020**, *262*, 121289. [[CrossRef](#)]
19. Ronga, D.; Pellati, F.; Brighenti, V.; Laudicella, K.; Laviano, L.; Fedailaine, M.; Benvenuti, S.; Pecchioni, N.; Francia, E. Testing the influence of digestate from biogas on growth and volatile compounds of basil (*Ocimum basilicum* L.) and peppermint (*Mentha x piperita* L.) in hydroponics. *J. Appl. Res. Med. Aromat. Plants* **2018**, *11*, 18–26. [[CrossRef](#)]
20. Ronga, D.; Caradonia, F.; Parisi, M.; Bezzi, G.; Parisi, B.; Allesina, G.; Pedrazzi, S.; Francia, E. Using digestate and biochar as fertilizers to improve processing tomato production sustainability. *Agronomy* **2020**, *10*, 138. [[CrossRef](#)]
21. Andreola, F.; Borghi, A.; Pedrazzi, S.; Allesina, G.; Tartarini, P.; Lancellotti, I.; Barbieri, L. Spent Coffee Grounds in the Production of Lightweight Clay Ceramic Aggregates in View of Urban and Agricultural Sustainable Development. *Materials* **2019**, *12*, 3581. [[CrossRef](#)]
22. Andreola, F.; Lancellotti, I.; Manfredini, T.; Barbieri, L. The circular economy of agro and post-consumer residues as raw materials for sustainable ceramics. *Int. J. Appl. Ceram. Technol.* **2020**, *17*, 22–31. [[CrossRef](#)]
23. Andreola, F.; Barbieri, L.; Lancellotti, I.; Pozzi, P.; Tartarini, P.; Vezzali, V.; Allesina, G.; Pedrazzi, S. *Patent Pending 102018000009844, Procedimento per Utilizzare Char da Gassificazione e/o Pirolisi con Altri Scarti Industriali per la Formulazione di Materiali Alleggeriti con Effetto Fertilizzante e di Materiali Polimerici per Isolamento Termico*; University of Modena and Reggio Emilia: Emilia, Italy, 2018.
24. European Coffee Federation. European Coffee Report 2017–2018. 2019. Available online: <https://www.ecf-coffee.org/publications/european-coffee-report> (accessed on 1 September 2020).
25. Comitato Italiano del Caffè. Esportazione Caffè 2017–2019. Available online: <http://comitcaf.it/index.php/esportazione-caffe/> (accessed on 30 July 2020).
26. Allesina, G.; Pedrazzi, S.; Lovato, F.; Allegretti, F.; Tartarini, P.; Siligardi, C. Discussion of possible coffee grounds disposal chains for energy production. In Proceedings of the 23rd EUBCE (European Biomass Conference and Exhibition), Wien, Austria, 1–4 June 2015.
27. Van Zwieten, L.; Kimber, S.; Sinclair, K.; Chan, K.Y.; Downie, A. Biochar: Potential for climate change mitigation, improved yield and soil health. In *Pastures at the Cutting Edge: Proceedings of the 23rd Annual Conference of the Grassland Society of NSW, Tamworth, Australia, 21–23 July 2008*; Boschma, S.P., Serafin, L.M., Ayres, J.F., Eds.; Grassland Society of NSW Inc: Orange, Australia, 2008; pp. 30–33152. 152p.
28. Yamato, M.; Okimori, Y.; Wibowo, I.F.; Anshori, S.; Ogawa, M. Effects of the application of charred bark of *Acacia mangium* on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. *Soil Sci. Plant Nutr.* **2006**, *52*, 489–495. [[CrossRef](#)]
29. Glaser, B.; Lehmann, J.; Zech, W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal—A review. *Biol. Fertil. Soils* **2002**, *35*, 219–230. [[CrossRef](#)]

30. Windeatt, J.H.; Ross, A.A.; Williams, P.T.; Forster, P.M.; Nahil, M.A.; Singh, S. Characteristics of biochars from crop residues: Potential for carbon sequestration and soil amendment. *J. Environ. Manag.* **2014**, *146*, 189–197. [[CrossRef](#)] [[PubMed](#)]
31. Decree, L. *Decreto Legislativo n. 75, 29 Aprile 2010: Riordino e Revisione Della Disciplina in Materia di Fertilizzanti, a Norma Dell'articolo 13 Della Legge 7 Luglio 2009 n. 88. Gazzetta Ufficiale della Repubblica Italiana 2010, 106*; European Parliament and European Council. Regulation (EC) No 2003/2003 of the European Parliament and of the Council Related to Fertilizers; European Union: Brussels, Belgium, 2003.
32. Lorenz, D.H.; Eichhorn, K.W.; Blei-Holder, H.; Klose, R.; Meier, U.; Weber, E. Phenological growth stages and BBCH—Identification keys of grapevine (*Vitis vinifera* L. ssp. *vinifera*). In *Growth Stages of Mono and Dicotyledonous Plants—BBCH Monograph*, 2nd ed.; Meier, U., Ed.; Federal Biological Research Centre for Agriculture and Forestry: Berlin, Germany, 2001; p. 158.
33. Cerovic, Z.G.; Masdoumier, G.; Ghozlen, N.B.; Latouche, G. A new optical leaf-clip meter for simultaneous non-destructive assessment of leaf chlorophyll and epidermal flavonoids. *Physiol. Plant* **2012**, *146*, 251–260. [[CrossRef](#)] [[PubMed](#)]
34. Ronga, D.; Pentangelo, A.; Parisi, M. Optimizing N Fertilization to Improve Yield, Technological and Nutritional Quality of Tomato Grown in High Fertility Soil Conditions. *Plants* **2020**, *9*, 575. [[CrossRef](#)]
35. Waite, H.; Whitelaw-Weckert, M.; Torley, P. Grapevine propagation: Principles and methods for the production of high-quality grapevine planting material. *N. Z. J. Crop Hort. Sci.* **2015**, *43*, 144–161. [[CrossRef](#)]
36. Valdés-Gómez, H.; Celette, F.; García de Cortázar-Atauri, I.; Jara-Rojas, F.; Ortega-Farías, S.; Gary, C. Modelling soil water content and grapevine growth and development with STICS crop-soil model under two different water management strategies. *J. Int. Sci. Vigne Vin* **2009**, *43*, 13–28. [[CrossRef](#)]
37. Carey, D.E.; McNamara, P.J.; Zitomer, D.H. Biochar from pyrolysis of biosolids for nutrient adsorption and turfgrass cultivation. *Water Environ. Res.* **2015**, *87*, 2098–2106. [[CrossRef](#)]
38. Caradonia, F.; Ronga, D.; Catellani, M.; Giaretta Azevedo, C.V.; Terrazas, R.A.; Robertson-Albertyn, S.; Francia, E.; Bulgarelli, D. Nitrogen fertilizers shape the composition and predicted functions of the microbiota of field-grown tomato plants. *Phytobiomes J.* **2019**, *3*, 315–325. [[CrossRef](#)]
39. Prichard, T. Vineyard Irrigation Systems. In *Raisin Production Manual University of California Agricultural and Natural Resources*; Apex: Oakland, CA, USA, 2000; Volume 3393, pp. 57–63.
40. Richards, D. The grape root system. *Hortic. Rev.* **1983**, *5*, 127–168.
41. Clarke, S.J.; Lamont, K.J.; Pan, H.Y.; Barry, L.A.; Hall, A.; Rogiers, S.Y. Spring root-zone temperature regulates root growth, nutrient uptake and shoot growth dynamics in grapevines. *Aust. J. Grape Wine Res.* **2015**, *21*, 479–489. [[CrossRef](#)]
42. Rogiers, S.Y.; Clarke, S.J.; Schmidtke, L.M. Elevated root-zone temperature hastens vegetative and reproductive development in Shiraz grapevines. *Aust. J. Grape Wine Res.* **2014**, *20*, 123–133. [[CrossRef](#)]
43. Jacobs, D.F.; Timmer, V.R. Fertilizer-induced changes in rhizosphere electrical conductivity: Relation to forest tree seedling root system growth and function. *New For.* **2005**, *30*, 147–166. [[CrossRef](#)]
44. Abad, M.; Noguera, P.; Bures, S. National inventory of organic wastes for use as growing media for ornamental potted plant production: Case study in Spain. *Bioresour. Technol.* **2001**, *77*, 197–200. [[CrossRef](#)]
45. Ronga, D.; Pane, C.; Zaccardelli, M.; Pecchioni, N. Use of spent coffee ground compost in peat-based growing media for the production of basil and tomato potting plants. *Commun. Soil Sci. Plant* **2016**, *47*, 356–368. [[CrossRef](#)]
46. Schmidt, H.P.; Kammann, C.; Niggli, C.; Evangelou, M.W.; Mackie, K.A.; Abiven, S. Biochar and biochar-compost as soil amendments to a vineyard soil: Influences on plant growth, nutrient uptake, plant health and grape quality. *Agric. Ecosyst. Environ.* **2014**, *191*, 117–123. [[CrossRef](#)]
47. Vaccari, F.P.; Maienza, A.; Miglietta, F.; Baronti, S.; Di Lonardo, S.; Guagnoni, L.; Lagomarsino, A.; Pozzi, A.; Pusceddu, E.; Ranieri, R.; et al. Biochar stimulates plant growth but not fruit yield of processing tomato in a fertile soil. *Agric. Ecosyst. Environ.* **2015**, *207*, 163–170. [[CrossRef](#)]
48. Sigua, G.C.; Novak, J.M.; Watts, D.W.; Johnson, M.G.; Spokas, K. Efficacies of designer biochars in improving biomass and nutrient uptake of winter wheat grown in a hard setting subsoil layer. *Chemosphere* **2016**, *142*, 176–183. [[CrossRef](#)]
49. Chalker-Scott, L. Environmental significance of anthocyanins in plant stress responses. *Photochem. Photobiol.* **1999**, *70*, 1–9. [[CrossRef](#)]

50. Zhao, L.; Cao, X.; Zheng, W.; Scott, J.W.; Sharma, B.K.; Chen, X. Coprolysis of biomass with phosphate fertilizers to improve biochar carbon retention, slow nutrient release, and stabilize heavy metals in soil. *ACS Sustain. Chem. Eng.* **2016**, *4*, 1630–1636. [[CrossRef](#)]
51. Gwenzi, W.; Nyambishi, T.J.; Chaukura, N.; Mapope, N. Synthesis and nutrient release patterns of a biochar-based N–P–K slow-release fertilizer. *Int. J. Environ. Sci. Technol.* **2018**, *15*, 405–414. [[CrossRef](#)]
52. Setti, L.; Francia, E.; Pulvirenti, A.; Gigliano, S.; Zaccardelli, M.; Pane, C.; Caradonia, F.; Bortolini, S.; Maistrello, L.; Ronga, D. Use of black soldier fly (*Hermetia illucens* (L.), Diptera: Stratiomyidae) larvae processing residue in peat-based growing media. *Waste Manag.* **2019**, *95*, 278–288. [[CrossRef](#)] [[PubMed](#)]
53. Raviv, M.; Oka, Y.; Katan, J.; Hadar, Y.; Yogev, A.; Medina, S.; Krasnovskya, A.; Ziadna, H. High-nitrogen compost as a medium for organic container-grown crops. *Bioresour. Technol.* **2005**, *96*, 419–427. [[CrossRef](#)] [[PubMed](#)]
54. Amendola, C.; Montagnoli, A.; Terzaghi, M.; Trupiano, D.; Oliva, F.; Baronti, S.; Miglietta, F.; Chiatante, D.; Scippa, G.S. Short-term effects of biochar on grapevine fine root dynamics and arbuscular mycorrhizae production. *Agric. Ecosyst. Environ.* **2017**, *239*, 236–245. [[CrossRef](#)]
55. Gaiotti, F.; Marcuzzo, P.; Belfiore, N.; Lovat, L.; Fornasier, F.; Tomasi, D. Influence of compost addition on soil properties, root growth and vine performances of *Vitis vinifera* cv Cabernet sauvignon. *Sci. Hortic.* **2017**, *225*, 88–95. [[CrossRef](#)]
56. Bernal-Vicente, A.; Ros, M.; Tittarelli, F.; Intrigliolo, F.; Pascual, J.A. Citrus compost and its water extract for cultivation of melon plants in greenhouse nurseries. Evaluation of nutriactive and biocontrol effects. *Bioresour. Technol.* **2008**, *99*, 8722–8728. [[CrossRef](#)]
57. Ronga, D.; Caradonia, F.; Setti, L.; Hagassou, D.; Giaretta Azevedo, C.V.; Milc, J.; Pedrazzi, S.; Allesina, G.; Arru, L.; Francia, E. Effects of innovative biofertilizers on yield of processing tomato cultivated in organic cropping systems in northern Italy. *Acta Hortic.* **2019**, *1233*, 129–136. [[CrossRef](#)]
58. Herrera, F.; Castillo, J.E.; Chica, A.F.; López Bellido, L. Use of municipal solid waste compost (MSWC) as a growing medium in the nursery production of tomato plants. *Bioresour. Technol.* **2008**, *99*, 287–296. [[CrossRef](#)]
59. Ericsson, T.; Rytter, L.; Vapaavuori, E. Physiology of carbon allocation in trees. *Biomass Bioenergy* **1996**, *11*, 115–127. [[CrossRef](#)]
60. Ronga, D.; Setti, L.; Salvarani, C.; De Leo, R.; Bedin, E.; Pulvirenti, A.; Mil, J.; Francia, E. Effects of solid and liquid digestate for hydroponic baby leaf lettuce (*Lactuca sativa* L.) cultivation. *Sci. Hortic.* **2019**, *244*, 172–181. [[CrossRef](#)]
61. Leghari, S.J.; Wahocho, N.A.; Laghari, G.M.; HafeezLaghari, A.; MustafaBhabhan, G.; HussainTalpur, K.; Lashari, A.A. Role of nitrogen for plant growth and development: A review. *Adv. Environ. Biol.* **2016**, *10*, 209–219.
62. Araujo, F.; Williams, L.E.; Matthews, M.A. A comparative study of young ‘Thompson Seedless’ grapevines (*Vitis vinifera* L) under drip and furrow irrigation. II. Growth, water use efficiency and nitrogen partitioning. *Sci. Hortic.* **1995**, *60*, 251–265. [[CrossRef](#)]
63. Graber, E.R.; Tschansky, L.; Mayzlish-Gati, E.; Shema, R.; Koltai, H. A humic substances product extracted from biochar reduces Arabidopsis root hair density and length under P-sufficient and P-starvation conditions. *Plant Soil* **2015**, *395*, 21–30. [[CrossRef](#)]
64. Jindo, K.; Martim, S.A.; Navarro, E.C.; Pérez-Alfocea, F.; Hernandez, T.; Garcia, C.; Aguiar, N.O.; Canellas, L.P. Root growth promotion by humic acids from composted and non-composted urban organic wastes. *Plant Soil* **2012**, *353*, 209–220. [[CrossRef](#)]

