



1 Article

2 Valorization of Spent Coffee Grounds, Biochar and 3 other residues to Produce Lightweight Clay Ceramic 4 Aggregates Suitable for Nursery Grapevine 5 Production

6 Domenico Ronga ^{1,4*}, Mario Parisi ², Luisa Barbieri ³, Isabella Lancellotti ³, Fernanda Andreola ³
7 and Cristina Bignami ⁴

8 ¹ Centro Ricerche Produzioni Animali—CRPA S.p.A, Viale Timavo, n. 43/2, 42121 Reggio Emilia, Italy;
9 d.ronga@crpa.it (D.R.)

10 ² CREA Research Centre for Vegetable and Ornamental Crops, Via Cavallegeri, 25, 84098 Pontecagnano
11 Faiano, Italy; mario.parisi@crea.gov.it (M.P.)

12 ³ Department of Engineering ‘Enzo Ferrari’, University of Modena and Reggio Emilia, Via Vivarelli 10, 41125
13 Modena, Italy; luisa.barbieri@unimore.it (L.B.), isabella.lancellotti@unimore.it (I.L.),
14 andreola.fernanda@unimore.it (F.A.)

15 ⁴ Department of Life Science, Centre BIOGEST-SITEIA, University of Modena and Reggio Emilia, Via
16 Amendola, n. 2, 42122 Reggio Emilia (RE), Italy; cristina.bignami@unimore.it (C.B.)

17 * Correspondence: domenico.ronga@unimore.it; Tel.: +39 3396805848 (D.R.)

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19 **Abstract:** The valorization of the agro-industrial by-products is one of the key strategies to improve
20 agricultural sustainability. In the present study, spent coffee grounds (T2) and T2 + biochar (T3)
21 were used as a pore forming agents in the realization of lightweight clay ceramic aggregates that
22 were used as sustainable fertilizers for nursery grapevine production. The properties of lightweight
23 aggregates were improved using a specifically tailored fertilizer glass. The obtained fertilizers were
24 assessed in a pot experiment for the fertilization of bare-rooted vines. Unfertilized (T0) and
25 fertilized plants (T1, using commercial fertilizer) were used as controls. T2- and T3 fertilized plants
26 recorded higher values of plant height, shoot diameter, leaf and node number. Moreover, T2
27 treatment induced highest chlorophyll content, shoot and root dry weight. The present study
28 shows that lightweight clay ceramic aggregates containing spent coffee grounds, can be used for
29 nursery grapevine production, in turn improving the agricultural sustainability.

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

31

32 1. Introduction

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

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

43 Currently, several works have mainly focused the attention on management of vineyard
44 starting from planting, while little attention was paid to the previous stage, that is, nursery
45 production. The production process of planting materials plays an important role both for the
46 establishing of new vineyards and for the replacement of lost or very weak vines or plants infected
47 with trunk disease pathogens [3–5]. Greenhouses production of potted vines might be a successful
48 alternative to open-field propagation, allowing also the transplanting of high-quality plant material
49 throughout all seasons [2].

50 Soil and vineyard canopy management plays a key role in viticulture, impacting vegetative and
51 reproductive development of the vines [6,7]. Fertilization provides essential nutrients to young
52 plants, which reach a well-established root system and the full size of canopy. In reproductive phase,
53 a balanced supply of nutrients ensures optimal yield, berry composition and wine quality.
54 Furthermore, biological and physical-chemical soil characteristics are improved by properly
55 fertilization programs [8]. A shortage of nutrient availability due to unbalanced fertilization can lead
56 to a reduction of plant efficiency and biomass production and allocation. On the other hand, an
57 over-fertilization causes improper biomass partitioning, imbalances between vegetative and
58 productive activity and increasing in production costs and in environmental impact of vine
59 cultivation [9]. Nitrogen, phosphorus, potassium and magnesium are key elements of vineyard
60 nutrition, with a fundamental role on the modulation of vegetative growth and production activity
61 [10]. Among these elements, Phosphorus is critical from an agronomic point of view due to the direct
62 or indirect actions on radical activity, yielding potential and mitigation of soil Cu excess toxicity
63 symptoms [11,12]. From an environmental point of view, since P fertilization is mainly based on use
64 of non-renewable phosphate rocks, alternative strategies are required [13].

65 Organic fertilizers, characterized by a gradual release of the nutrients into soil, represent a
66 valuable source for the fertilization of important crops, especially in fruit tree crops showing longer
67 vegetative and reproductive phases than horticultural one. Manure, green manure, digestate and
68 compost are the most adopted organic fertilizers [14–17]. However, several biodegradable wastes can
69 be exploited and recycled to produce eco-friendly fertilizing matrix thus contributing to reuse of
70 organic matter in the waste management processes in accordance with the concept of circular
71 economy. An innovative process to produce controlled release fertilizers was proposed by Andreola
72 et al. [18,19], who suggested the valorization of agro-industrial and post-consumer residues as raw
73 materials for clay ceramic materials, in particular lightweight aggregates (LWAs). LWA is the
74 generic name for a group of aggregates characterized by a lower density than common aggregates
75 such as natural sand, gravel, and crushed stones. For example, expanded clay is one of the several
76 granular lightweight aggregate available in commerce. Expanded clay is produced by subjecting
77 special natural clays to a thermal expansion and vitrification process at temperatures higher than
78 1200 °C [20]. For this material, porosity has an important role, in fact, is fundamental to give
79 lightness, and when used as fertilizer can impact on important agronomic performance like ability to
80 release nutrients over time, draining as well as retaining water [18].

81 In order to give porosity to the ceramic material, residues based on great high organic fraction
82 can be considered, such as spent coffee grounds and biochar. One of the most widely consumed hot
83 beverages worldwide is brewed coffee. According to European Coffee Report 2017–2018 [21] Europe
84 is the second worldwide green coffee importer. According to ISTAT data [22], Italy exports roasted
85 coffee of about 4 million equivalent green bags (60 kg bag⁻¹), and spent coffee grounds (SCGs) are
86 generated as post-consumer products. SCGs are commonly treated as organic waste sent to
87 composting plants or in the unsorted garbage that it is fired into incinerator power plants [23]. In the
88 context of circular economy, in the ceramic sector, the great availability of organic matter could be
89 exploited for lightening an aggregate material, while the high calorific power could contribute to
90 lower the firing temperature and the fuel consumption. Biochar is a fine-grained vegetable carbon
91 extracted from the bottom of the gasifier. When it is added to the soil it improves its
92 chemical-physical properties, increasing soil fertility [24] and crop yield [25], due to the strongly
93 stable nature of organic carbon, which is not subject to degradation and mineralization. A further
94 advantage of the storage of biochar in the ground is the reduction of CO₂ emissions in the

95 atmosphere [26]. Indeed, the carbon sink process occurring in the soils rescues carbon dioxide from
96 the cycle of carbon. In the last 15 years the use of biochar as soils or substrates improver has been
97 studied, while its application in building materials is starting to gain more attention recently. The
98 use of biochar contributes to reducing the raw material consumption and the energy saving of the
99 LAWS firing process due to the residual carbon content present [27]. Therefore, the aim of the
100 present study was the assessment of spent coffee grounds and biochar in the production of
101 innovative LWAs fertilizers and their use in the sustainable production of potted grapevine planting
102 materials.
103

104 2. Materials and Methods

105 2.1. Lightweight aggregates Productions and Characterization

106 Lightweight aggregates were obtained by powder sintering of a local ferruginous red clay (85
107 wt%) with the addition of spent coffee grounds (SCGs) or spent coffee grounds and biochar (B) (15
108 wt%) as poring agents to reduce both density and sintering temperature. The raw materials were
109 dried in an oven at 105 °C for 24 hours and subjected to grinding and sieving process in order to
110 reach a particle size < 100 µm for clay and < 250 µm for B and SCGs. 30 wt% of a powdered glass (100
111 µm) containing the nutrients phosphorus and potassium, previously developed by the authors [18],
112 based on cattle-bone flour ash (CBA), packaging glass cullet and K₂CO₃ and obtained by melting the
113 mixture at 1400°C in an electric furnace and quenching in water, was added to the clayey body in
114 order to confer fertilizing effect to the materials. Spherical shape samples of 1.5–2.0 g of weight and a
115 medium diameter of 1-1.5 cm were hand pelletized by the addition of water to obtain the adequate
116 plasticity required for shaping. Samples were dried at 105 °C for 24 hours to reduce their moisture
117 content and then subjected to a firing process in laboratory electrical kiln (Lenton AWF13/12) that
118 caused sintering of the grains and changes in their density and porosity. In order to imitate the
119 thermal shock produced in the rotary furnace, the samples were introduced and kept in the furnace
120 at 1000 °C for 1 hour and finally allowed to cool through natural convection. The samples were
121 codified as reported: red clay (C) + pore forming agent (spent coffee ground (SCG) or biochar (B)
122 followed by a number indicating the percentage introduced 15%) + fertilizer glass (FG) followed by a
123 number indicating the percentage of fertilizer glass added 30%).

124 The specimens after firing were subjected to different physical-chemical tests in order to
125 determine their possible use in agriculture or green roofs. In particular, weight loss (WL%) at
126 1000°C, 1 h, static water absorption (WA%) in cool distilled water after 24 h following UNI EN
127 772-21 (2011); apparent density (AD) by Envelope density analyzer Geo Pyc 1360 equipment
128 (Micromeritics, , USA); absolute or real density (RD) by Gas Helium-pycnometer Accupyc TM II
129 1340 (Micromeritics, USA); total porosity percentage (TP), calculated from the densities values by
130 the equation: $TP\% = [(RD-AD)/RD] * 100$; pH according to UNI-EN 13037 (2012) standard, using a
131 pH-meter (XS Instruments, pH 6); - USA); electrical specific conductivity (SC), according to UNI-EN
132 13038 (2012) standard, using an Oakton conductimeter CON6/TDS6 (OAKTON Instruments P.O.
133 Vernon Hills, IL, USA).

134 Specific tests of release were performed according to both Italian and European regulations [28]
135 to evaluate the release capacity of P and K nutrients as well as of elements that for their quantity and
136 type could be harmful for the environment. As reaction environment distilled water and citric acid
137 solution 2 vol.% were used; the values were monitored in a period from 7 to 90 days to verify
138 controlled release. The aggregates were tested in whole size, to simulate the conditions occurring in
139 the soil. The liquid solutions derived were analyzed by inductively coupled plasma mass
140 spectrometry (ICP-MS Agilent 7500a, 5301 Stevens Creek Blvd, Santa Clara, CA95051, USA).

141 142 2.2. Nursery Greenhouse Experiments 143

144 Potting experiment was performed in a nursery greenhouse, located at Reggio Emilia (Italy)
145 with controlled temperature ranging from 19 to 25 °C (day/night) and relative humidity varying
146 from 60% to 70%. Plants were grown under long-day conditions (15 h light, 9 h dark; light intensity
147 280 $\mu\text{mol m}^{-2} \text{s}^{-1}$).

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

156 Fertilization was performed only at planting, administering, in total, 6 g of N, 1.4 g of P_2O_5 and
157 1.6 g of K_2O *per* pot. Experimental thesis were: unfertilized treatment (TO); synthetic fertilization
158 with Osmocote Topdress [22 (N) - 5 (P_2O_5) - 6 (K_2O) + 2 (MgO)] (T1); LWA based on spent coffee
159 grounds (T2); LWA based on spent coffee grounds and biochar (T3).

160 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) -
161 5.4 (K_2O) + 1.9 (MgO), respectively.

162 In order to supply the expected nitrogen rate (6 g *per* pot) ammonium nitrite and urea (2.9 and
163 3.1 g of N, respectively) were applied in combination with LWAs.

164

165 2.2. Recorded parameters

166

167 During the experiment, the main phenological growth stages were recorded following the
168 BBCH-scale (BBCH = Biologische Bundesantalt, Bundessortenamt and CHemische Industrie,
169 Germany) [29].

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

185 In order to compare N use across the treatments, the nitrogen efficiency index was calculated
186 from the measured plant total dry matter (g pot^{-1}) and the amount of N applied (g pot^{-1}) and was
187 expressed as g dry biomass g^{-1} N [31].

188

189

190 2.3. Data Analysis

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

194 3. Results and Discussion

To produce grapevines planting materials for new vineyard or to replace diseased plants, high standard quality attributes (such as good vigour, 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 [32]. Nowadays the environmental sustainability of orchard or vineyard 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. In the present study, considering some previous evidences of the positive effects of spent coffee grounds and biochar on growth of horticultural and woody species [2, 8, 9, 17, 33, 37], these organic matrices were valorized to obtain new LWAs which were for the first time tested for the fertilization of bare-rooted vines in 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 have a darker colour but after firing it disappears obtaining aggregates with a classic red colour. 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 pore forming 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 E.C 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). In Table 1 are reported the results of the physical and chemical characterization.

Table 1. Physical and chemical parameters of the LWAs

Physical properties	CSCG15FG30	CBSCG15FG30
Weight Loss (%)	16.73	17.82
Water Absorption (%)	14.29	13.48
App. Density (kg/m ³)	1,490	1,400
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 to classify the specimens functionalized with 30wt% of fertilizing glass as LWAs, because their apparent density values are lower than 2,000 Kg/m³ (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 guideline above reported while the pH of CBSCG15FG30 is slightly higher.

By the citric acid test, the release of main nutrients P and K was monitored until 90 days. LWAs prepared with only SCG as pore forming showed an increase of P% release from 30 to 90% while those prepared using the mix (SCG+B) as pore forming highlighted a P% release from 30 to 60%. The K% release observed is lower than P% for the two compositions analyzed. For CSCG15FG30 the values increase from 5% (7days) to 17% in 90 days while a higher release is observed for CBSCG15FG30 from 10% (7days) to 26% in 90 days. The tests conducted in distilled water gave results that were not significant for the purposes of the analysis. Very low releases were observed for P% between 0-0.30% and for K% between 0.02-1.60% for the two compositions. The very marked

236 effect of the citric acid on the aggregates compared to the same test in water, is probably due to the
 237 pH which facilitates the solubilization of the elements regardless of the compositions.
 238

239 3.2. Bare-rooted vines production

240 The main parameters recorded for the growing media are reported in Table 2. Peat fertilized with
 241 LWA containing spent coffee grounds and biochar (T3) showed the highest values of soil humidity, soil
 242 temperature and soil electrical conductivity (on average, +33%, +1% and +9). These three soil parameters
 243 are strictly correlated with the plant growth and its development. Indeed, is well documented that a
 244 higher soil humidity promotes plant growth and an increased peat water retention capacity leads to a
 245 reduction of irrigation volume throughout the growing season [33], as also confirmed in the present
 246 study by the values of soil humidity. Furthermore, soil temperature is positively correlated with root
 247 growth and development [34]. Regarding soil electrical conductivity, as effect of fertilization [35]. Abad
 248 et al. [36] reported 0.5 dS m⁻¹ as threshold to achieve the highest plant growth. In our experiment lower
 249 EC was found for T1 and T2 treatments than T0; moreover, the values detected for the overall thesis
 250 never reached the threshold indicated by Abad et al. [36].
 251

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

Treatment	Soil Humidity		Soil temperature		Soil EC	
	(m ³ m ⁻³)		(°C)		(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

254 T0 = unfertilized pot; T1 = fertilized pot with commercial fertilizer (Osmocote Topdress); T2 = fertilized pot with
 255 LWA based on spent coffee ground; T3 = fertilized pot with LWA based on spent coffee grounds + biochar; EC =
 256 electrical conductivity. Means followed by the same letter do not significantly differ at p ≤ 0.05.
 257

258 Morpho-physiological parameters of bare-rooted vines were affected by LWAs applications
 259 which induced, on means, a better performance than that the plants fertilized with commercial
 260 fertilizer (Table 4). At 314 DOY, corresponding to the “Principal growth stage 8: Senescence” of the
 261 BBCH-scale, T2- and T3 fertilized plants displayed higher values of plant height, node number and
 262 shoot diameter than T1-fertilized or T0 unfertilized ones (+9%, +21% and +22% of T2 and T3 respect
 263 to T0). Within stage 8, the degree of phylloptosis ranged from 93 “beginning of leaf-fall” for the
 264 fertilized theses to 97 “end of leaf-fall” for the unfertilized one, indicating a longer growth duration
 265 and a slower entry into rest of fertilized plants. Moreover, the highest value of leaf number (16 *per*
 266 plant) was detected in plants fertilized with LWAs containing spent coffee grounds (T2). Regarding
 267 the physiological parameters, T2- and T3-fertilized plants reported the highest values of leaf
 268 chlorophyll and flavonoid contents, NBI, leaf temperature. Moreover, for the same treatments the
 269 lowest of leaf anthocyanins content were measured (on average, +19%, +3%, +16%, +0.4% and -24%,
 270 respectively).

271 Our results are in agreement with those of previous research reporting, for different species,
 272 improving in plants development under low supplies of spent coffee ground or biochar [37-40]. The
 273 increased Chl and NBI values for T2 and T3 treatments suggested a highest rate of leaf
 274 photosynthetic activity, assimilation and use (protein synthesis) of mineral nitrogen from the
 275 substrate. These results are in agreement with what reported by Ronga et al. [2,37] and Bozzolo et
 276 al. [8]. Leaf chlorophyll, flavonoid, and anthocyanin contents are adopted as indices of plant
 277 physiological status and are associated with the N uptake and leaf photosynthetic activity [30].
 278 Chalker-Scott, 1999 [41], suggested that high leaf Anth levels are correlated to improving in abiotic
 279 and biotic stresses tolerance. Interestingly, T3-fertilized plants showed the highest values of Anth.

Hence, our results suggest that LWA based on spent coffee ground and biochar may be used to improve plant physiological performances (increasing in stress resistance), while supplying of LWA based on biochar represents a valuable agronomic solution to increase leaf photosynthetic activities in grapevine nursery management.

Table 4. Morphological (A) and Physiological (B) parameters recorded on bare-rooted vines measured at 301 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	15.33	a	4.65	a

(B) Treatment	Chl (-)	Flav (-)	Anth (-)	NBI (-)	Leaf temperature (°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 fertilizer (Osmocote Topdress); T2 = fertilized pot with LWA based on spent coffee ground; T3 = fertilized pot with LWA based on spent coffee grounds + biochar; 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 $p \leq 0.05$.

The results regarding the main agronomic parameters are shown in Table 5. Among the investigated treatments, bare-rooted vines fertilized with T3 showed the highest values of root, shoot and total fresh weights (on average, +15%, +24% and +11%), while the highest value of RSFW (on average, +16%) was measured for T1-fertilized plants. (Table 5A). 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 (on average, +23%, +19% and +10%), while T1-fertilized plants showed the highest value of RSDW (on average, +12%). Anyhow, this value did not significantly differ by T2 treatments, as well as total dry weight of T3 and T2 treatments were statistically comparable among them (46.3 g plant⁻¹ 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. [42], Raviv et al. [43] and Ronga et al. [2,37], 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 increasing in grapevine root biomass under different soil amendments like biochar, compost and digestate [2,8,44,45]. 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 which used the same fertilizers based on agro-industrial by-products [2,46,47]. Finally, vines showing high total dry weight can better overcome transplanting stresses [48] and this improved plant physiological state represents a very important goal for nursery growers.

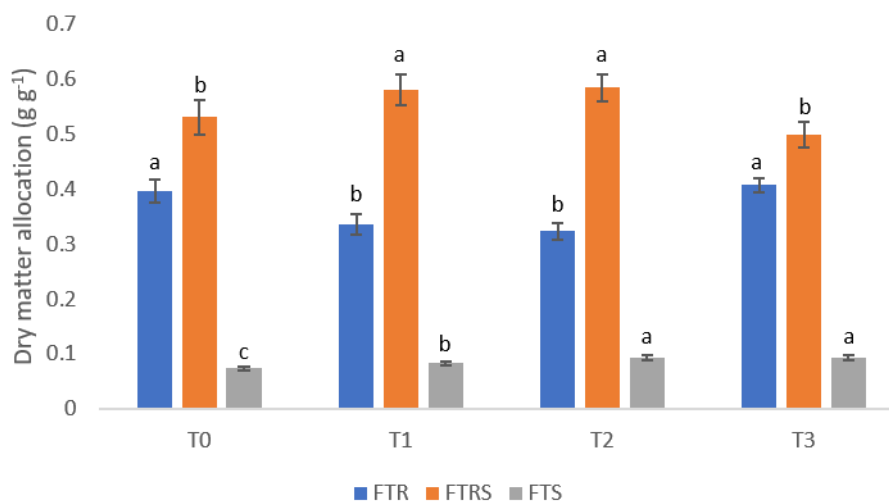
313
314

315
316**Table 5.** 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

317 T0 = unfertilized pot; T1 = fertilized pot with commercial fertilizer (Osmocote Topdress); T2 = fertilized pot with
 318 LWA based on spent coffee ground; T3 = fertilized pot with LWA based on spent coffee grounds + biochar; (A) =
 319 biomass fresh weight; (B) = biomass fresh weight; Means followed by the same letter do not significantly differ
 320 at $p \leq 0.05$.
 321

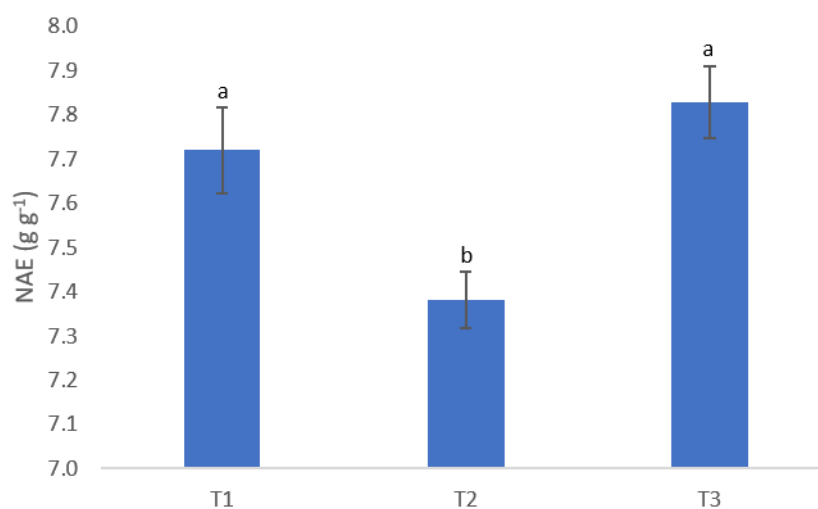
322 Figure 1 shows the biomass allocation to the different organs: root, above-ground part of the
 323 rootstock and shoot. T3-fertilized plants displayed the highest values of FTR (on average, +11% and
 324 +4%), while the highest values of biomass allocated to rootstock (FTRS) were observed in T1- and
 325 T2-fertilized plants (on average, +5%). As suggested by Ericsson et al. [49] changes in the source-sink
 326 organ relationship can impact on the growth of the fruit-tree. Indeed, the same authors
 327 demonstrated that a higher shoot development can negatively impact on the root growth. Anyway
 328 this behavior was also partially highlighted in our work in T2 treatment; instead enhanced
 329 percentages of biomass allocation to shoot did not result in reduction of partitioning to the roots.
 330 This physiological behavior is much appreciated by vine-growers since they can dispose of planting
 331 material with a good development of both root and shoot ensuring early and faster plant
 332 establishment after transplanting, due to the good availability of accumulated reserves.
 333



334

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

341
 342 Figure 2 reports nitrogen efficiency, representing an important parameter to assess the effect of
 343 the nitrogen fertilization on the plant growth. T3-treated plants, as well as plant fertilized with
 344 Osmocote Dropress, showed similar nitrogen efficiency values (7.8 g of biomass produced *per* each g
 345 of N applied). The performance of LWAS based on spent coffee grounds is improved with addition
 346 of biochar. Our results confirm that this kind of substrates act synergistically on plant growth,
 347 similarly to what has been observed in grapevine [2,8] and tomato [17].



348 **Figure 2. Comparison of nitrogen efficiency in the three fertilized thesis.**

349 T0 = unfertilized pot; T1 = fertilized pot with commercial fertilizer (Osmocote Topdress); T2 = fertilized pot with
 350 LWA based on spent coffee ground; T3 = fertilized pot with LWA based on spent coffee grounds + biochar;
 351 fraction to root (FTR); NAE = nitrogen efficiency; Bars indicate standard deviations. Means followed by the
 352 same letter do not significantly differ at $p < 0.05$.

353
 354
 355 Finally, results are broadly in accordance with those of several previous studies, which reported
 356 increasing in plant biomass production as effect of the use of agro-industrial by-products, such as
 357 compost, digestate, and biochar as fertilizers [2,8,15]. Increasing in plant biomass is obtained
 358 fertilizing with agro-industrial by-products as effect of humic substances and some compounds able
 359 to enhance the plant growth [50]. Furthermore, plant biochemical activity is improved by plant
 360 hormone-like promoters [51].

361 4. Conclusions

362 Results obtained in the present study suggest that spent coffee grounds and biochar represent
 363 useful ingredient in LWAs production. To our knowledge, this is the first study investigating the
 364 suitability of spent coffee grounds and biochar in innovative slow-release fertilizers (LWAs)
 365 production. These recycled matrices well fit in sustainable agriculture managements and in circular
 366 economy contest. LWAs based on spent coffee grounds and biochar showed good agronomic
 367 performances comparable to those of synthetic fertilizer in the production of grapevine planting
 368 materials. LWAs here studied also proved to be able to reduce the needs to use phosphate and
 369 potassium rocks in nursery management phase. The positive effects on the physical characteristics of
 370 the substrate, especially on its water retention capacity, provide an interesting opportunity to save
 371 irrigation water. Finally, bare-rooted vines grown using LWAs resulted in better agronomic
 372 performances and in improved plant physiological status. However, further research is needed to

373 assess the effect of LWAs in nursery greenhouse production of other fruit planting materials as well
374 as in open field vine nursery production.
375

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378 D.R.; writing—review and editing, D.R., M.P., F.A., L.B., I.L. and C.B.; supervision, C.B.; project administration,
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386

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