



UNIVERSITÀ  
DEGLI STUDI  
FIRENZE

## FLORE

# Repository istituzionale dell'Università degli Studi di Firenze

### **Coconut coir as a sustainable nursery growing media for seedling production of the ecologically diverse quercus species**

Questa è la Versione finale referata (Post print/Accepted manuscript) della seguente pubblicazione:

*Original Citation:*

Coconut coir as a sustainable nursery growing media for seedling production of the ecologically diverse quercus species / Barbara Mariotti, Sofia Martini, Sabrina Raddi, Andrea Tani, Douglass F. Jacobs, Juan A. Oliet, Alberto Maltoni. - In: FORESTS. - ISSN 1999-4907. - ELETTRONICO. - 5:(2020), pp. 1-24. [10.3390/f11050522]

*Availability:*

This version is available at: 2158/1194908 since: 2022-05-18T09:14:24Z

*Published version:*

DOI: 10.3390/f11050522

*Terms of use:*

Open Access

La pubblicazione è resa disponibile sotto le norme e i termini della licenza di deposito, secondo quanto stabilito dalla Policy per l'accesso aperto dell'Università degli Studi di Firenze (<https://www.sba.unifi.it/upload/policy-oa-2016-1.pdf>)

*Publisher copyright claim:*

(Article begins on next page)

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46

Article

# Pure coconut coir as a sustainable nursery growing media for seedling production of ecologically diverse *Quercus* species

Barbara Mariotti<sup>\*1</sup>, Sofia Martini<sup>1</sup>, Sabrina Raddi<sup>1</sup>, Andrea Tani<sup>1</sup>, Douglass F. Jacobs<sup>2</sup>, Juan A. Olie<sup>3</sup>, Alberto Maltoni<sup>1</sup>

<sup>1</sup> Dipartimento di Scienze e Tecnologie Agrarie, Alimentari, Ambientali e Forestali – DAGRI. Università di Firenze. Via San Bonaventura 13. 50145 Firenze, Italy

<sup>2</sup> Department of Forestry and Natural Resources, Hardwood Tree Improvement and Regeneration Center, Purdue University, 715 West State Street, West Lafayette, IN 47907, USA

<sup>3</sup> Departamento de Sistemas y Recursos Naturales. Universidad Politécnica de Madrid, Ciudad Universitaria s/n, 28040 Madrid, Spain

\* Corresponding author: barbara.mariotti@unifi.it

Received: date; Accepted: date; Published: date

**Abstract:** Peat, a non-sustainable resource, is still predominately used in forest nurseries. Coconut coir may provide an alternative, renewable, and reliable growing media but few studies have evaluated this media type in forest nurseries. We assessed the influence of pure coir in combination with various fertilization regimes on the growth and physiology of three ecologically diverse *Quercus* species seedlings (*Q. robur*, *Q. pubescens*, *Q. ilex*) during nursery cultivation. Seedlings were grown using peat and pure coir in combination with 3 fertilization treatments (standard, K enriched, P enriched). Data were collected for: 1) growth and physiological traits; 2) detailed above- and below-ground morphological traits by destructive analysis; and, 3) NPK content in leaves, shoot and roots, and in growing media following cultivation.

Peat and coir in combination with the various fertilization treatments affected above- and below-ground morphology and, to a lesser extent, physiological traits of *Quercus* seedlings. Large effects of substrate occurred for most morphological variables, with peat more effective than coir in all studied species. Fertilization also produced significant differences. The effect of K-enriched fertilization on plant growth was clear across the three species and the two growing media. P-enriched fertilization in peat was the only combination that promoted a higher amount of this element in the tissues at the end of cultivation.

Despite the relatively smaller size, seedlings produced in coir were in compatible with standard *Quercus* forest stocktypes size, and showed a proportionally higher root system development and fibrosity. Our results suggest that coir can be used as an alternative substrate to grow *Quercus* species seedlings, and that fertilization can offset coir deficiencies in chemical properties. Because several functional traits drive planting performance under varying environmental conditions according to the Target Plant Concept, coir may thus serve as an acceptable material for seedling cultivation in some cases.

**Keywords:** forest nursery stock; coconut fiber; peat; seedling morphology; seedling physiology; growing media.

47

48 **1. Introduction**

49

50 Forest seedling field performance is related to target plant morphological and physiological  
51 characteristics [1–3]. Development of morpho-physiological traits, in turn, is strongly influenced by  
52 nursery practices [1,4–7]. In container plant production, the effectiveness of the growing medium is  
53 important to seedling quality [8,9]. An effective substrate should sustain a favourable balance  
54 between air porosity and water holding capacity, promoting root development and nutrient uptake  
55 [9,10]. Additionally, growing media must have a high cation exchange capacity and be economically  
56 viable [11].

57 Sphagnum peat moss (*Sphagnum* spp.), generally known as peat, is commonly and  
58 predominantly used in Europe and North America [9,12–15]. Peat production globally is about 28 Mt  
59 [15] and peatlands used for growing media cover about 2000 km<sup>2</sup> [16]. The effectiveness of peat is  
60 related both to material performance and economic aspects [17]. Despite a low re-wetting capacity  
61 [18], peat is a light, low bulk density material that contains low nutrient content but has a very high  
62 cation exchange capacity (CEC) [8]), and can adsorb fertilizer nutrients easily; thus, plant nutrition  
63 can be controlled during cultivation [19]. Moreover, peat requires relatively few post-harvest  
64 treatments and additives to be used effectively [9]. Nevertheless, concerns have been raised about  
65 environmental impacts of peat extraction [20–22] in relation to: a) the fragility of many peatland  
66 ecosystems [16,23–25]; b) their function as a C sink, whose drainage and exploitation increases C  
67 emissions [22,26]; and c) the non-sustainable length of the natural processes of peat production  
68 [24,25,27]. Environmental concerns in Europe promoted actions to preserve peatlands as ecosystem  
69 as well as to reduce C emissions [17,28]. The growing pressure on producers, retailers and growers,  
70 especially in the horticulture sector, has led to an increasing demand of alternative, renewable, and  
71 reliable growing media [29,30]. Coir (or coconut fiber) has been tested as an alternative to peat in  
72 horticulture [31], and is the most used alternative in this sector [14,32]. Coir is made of husk and short  
73 fibers from the nut mesocarp of *Cocos nucifera*, which are a waste product of the coconut industry,  
74 coming mainly from Philippines, Indonesia, Sri Lanka, Malaysia and Thailand. Coir is a renewable  
75 and largely available resource, and 25% of over 50 million tons of coconut produced annually are  
76 waste [33]. Coir provides a favourable balance between air and water, similar to peat [9], and a higher  
77 re-wetting capacity than peat [34]. However, coir has higher pH and lower cation exchange capacity  
78 (CEC) than peat [8]. In addition, to be effective as a soilless growing medium, coir needs to be further  
79 processed, which can lead to a low standardization of biological, chemical or physical properties of  
80 the material as compared to peat [9]. In particular, when it is produced in coastal marine areas, coir  
81 has to be treated to reduce toxic levels of sodium and potassium [35]. Such procedures increase coir  
82 production costs. According to Schmiliwski [32], coir is the third most common growing medium  
83 used by nurseries in horticulture after peat (which covers more than 2/3 of the market) and mineral  
84 substrates (such as vermiculite, perlite, rockwool, and others). According to recent reports [28,36], in  
85 Netherlands and in Italy, the use of coir is increasing.

86 Seedling physiological and morphological traits can also be strongly altered by fertilization  
87 during nursery cultivation, potentially interacting with substrate chemical properties. This may  
88 affect plenty of attributes, such as biomass accumulation and allocation to shoot- and root-system  
89 [37,38], leaf morphology and physiology [7,39], root-system architecture and functionality [7,40], and  
90 xylem conductance [41] with effects on survival and field performance [42–44]. Hence, by altering  
91 fertilization it may be possible to affect seedling quality [45,46] and the performance of transplanted  
92 seedlings [47]. Seedling nutrient availability can influence the amount of reserves available for  
93 remobilization after planting [44,48]. While many studies have investigated the effects of nitrogen  
94 fertilization on forest tree seedlings, less is known about phosphorous and potassium [43].  
95 Phosphorus is an immobile soil resource whose availability is linked to morpho-functional traits of  
96 the root system [49–53], and, consequently, it may have indirect effects on seedling post-planting  
97 survival, nutrient uptake and growth, drought resistance, and more in general, stress resistance

98 [40,54–56]. Less information is available for forest species about the effect of K, which is an element  
99 directly related to a plethora of physiological processes, including, among others, cellular turgor,  
100 stomatal conductance, and photosynthesis, which can influence drought resistance [57–60].

101 Although coir was introduced in horti-flori-fructiculture nursery production about two decades  
102 ago, and extensive literature covers its productive and economic aspects in these systems [9], far less  
103 information is available for the forest nursery sector [i.e., [11,61,62]. Moreover, coconut fiber is often  
104 tested as a component at different proportions of a soilless growing media mixture with other  
105 materials, complicating assessment of coir as single component [9], especially in relation to  
106 deficiencies in its chemical properties (i.e. CEC). In this sense, the use of controlled release fertilizer  
107 (CRF) with coconut fiber could help to offset mentioned low CEC. In this study, we focused on  
108 *Quercus* species widely used in the Mediterranean region for reforestation, afforestation and forest  
109 restoration projects [63–66]. The species were chosen according to different ecological adaptations,  
110 particularly in relation to Mediterranean and/or arid climates [67]: from the most well adapted to a  
111 Mediterranean climate with dry summers, *Q. ilex* (holm oak), to the intermediate *Q. pubescens*  
112 (pubescent or downy oak), to the less Mediterranean adapted, *Q. robur* (pedunculate oak), which  
113 prefers a temperate climate without a dry season, is widespread across Europe including the  
114 Mediterranean region, and is one of most common species for multi-purpose hardwood forest  
115 plantings in Europe [68,69]. We aimed to improve the knowledge of the influence of pure coir on the  
116 growth and physiology of these species during nursery cultivation. Coir was combined with three  
117 different fertilization treatments (nursery standard, enriched in K, enriched in P) to assess combined  
118 effects on seedlings in relation to: height, morphological traits, physiological traits and NPK content  
119 both in shoot- and root-system. Specifically, we addressed the following questions: (1) Is pure coir  
120 effective in growing forest seedlings to be used in forest plantation projects? (2) Which traits are  
121 mainly influenced by this renewable and more sustainable growing medium? (3) Is it possible to  
122 offset coir deficiencies in chemical properties by fertilization? (4) Did the studied species, which have  
123 different leaf habits despite genetic proximity, respond differently to fertilization and substrate  
124 treatments?

125

## 126 2. Materials and Methods

127

### 128 2.1 Nursery stock cultivation

129

130 The nursery stock was grown in 2017 in a central Italy nursery (43°55'31.4"N, 10°53'09.1"E, 85 m  
131 a.s.l.), using multi-pot containers (HerkuPlast QuickPot) with 12 cavities of 650 cm<sup>3</sup> each (frustum of  
132 pyramid shape; top width 76 mm, bottom width 17 mm, depth 180 mm).

133 Peat substrate (*Pe*), considered as control, was made of 70% coarse Baltic peat moss (0–40 mm  
134 particles size) and 30% pumice (5–8 mm), which was added to avoid excessive compaction of pure  
135 peat. Main traits of mixture were: pH 5.7, EC 0.43 dS/m; bulk density 298 kg/m<sup>3</sup>, and porosity 86.9%.  
136 Coir (*Co*) was composed of 30% fiber (fibrous material that constitutes the thick mesocarp of the nut)  
137 and 70% pith (fine residual material), with pH 5.2, EC 0.38 dS/m; bulk density 122 kg/m<sup>3</sup>, porosity  
138 92.5%. The week before sowing, the cavities were uniformly filled with growing media to 0.5 cm  
139 beneath the top.

140 Standard fertilization (*St*), a CRC fertilizer widely used in Italy to commercially grow oak  
141 seedling nursery stock, was considered as control, and it was compared to two alternative  
142 commercial fertilization formulas: enriched in potassium (*K*) or phosphorus (*P*). *St* formula was  
143 Osmocote Exact Standard 12-14 months NPK 15-9-11 plus micronutrients at 3 kg·m<sup>-3</sup>. P enriched  
144 substrate contained an addition of 19% P<sub>2</sub>O<sub>5</sub> fast release (single superphosphate, SSP, 2 kg·m<sup>-3</sup>) to  
145 control, while K enriched substrate was obtained by 4 kg·m<sup>-3</sup> of Osmocote Exact Standard High K 12-  
146 14 months NPK 11-11-18 plus micronutrients. N, P, and K amount per seedling is showed in Table  
147 S1.

148 A total of 6 treatments combinations per species (2 substrates x 3 fertilizations) were included in  
149 the experimental trial.

150 Seed was obtained from the National Center for Biodiversity (Italy); seed provenances were the  
151 following for *Q. robur*, *Q. pubescens*, and *Q. ilex*, respectively: Bosco Fontana (43°55'31.4"N,  
152 10°53'09.1"E), Ponte di Veja (45°36'27.4"N, 10°58'15.9"E), Torri del Benaco (45°36'59.1"N, 10°41'50.0"E).  
153 The 1,000-seed weight and germination of the three seed lots (according to ISTA procedures) were  
154 6.0 kg and 80% for *Q. robur*, 2.4 kg and 68% for *Q. pubescens*, 3.2 kg and 83% for *Q. ilex*, resp. From  
155 October 2016 to April 2017, the acorns were stored at  $3 \pm 0.5$  °C in moist sand to simulate normal  
156 overwintering and to prevent acorn germination before the experiment started. In March 2017, the  
157 seeds were moved outside to stimulate germination, and then the pre-germinated acorns (0.5 cm  
158 maximum radicle length) were sown in multi-pots placed under a tunnel protected by transparent  
159 plastic film that was removed at mid-May. Seedlings were irrigated daily by sprinklers following  
160 seedling evapotranspirative demands (i.e. spring: 5 l·m<sup>-2</sup> in 6 min; summer and autumn: 40 l/m<sup>2</sup> and  
161 20 l/m<sup>2</sup>, resp. in 24 min). Environmental conditions (air temperature and humidity) were monitored  
162 by a weather station (inside the tunnel) and substrate moisture was assessed once a week (6 pots per  
163 stocktype, Soil moisture meter PCESMM1, PCE Instr. Corp.).

164

## 165 2.2 Data collection

166

167 Emergence and height were measured weekly from the end of March until September. Here,  
168 final height data are presented. During the season, physiological traits, such as Chlorophyll content  
169 (SPAD-502, Konica-Minolta Sensing Europe B.V) and Chlorophyll fluorescence (ChlF, by Handy  
170 PEA, Hansatech, UK) were measured monthly on a sample of three fully expanded leaves on 9  
171 seedlings per stocktype in dark-adapted leaves (for at least 40 minutes) during the growing season  
172 (Jun, Jul, Aug). The PSII functionality was described by  $F_v/F_m$  (ratio of Variable to Maximum  
173 Fluorescence) to Strasser et al. [70]. Results related to physiological traits were only for August, the  
174 data closer to plant lifting.

175 Macro-element (N, P, K) were assessed in October (before leaf abscission) on 12 seedlings per  
176 stocktype ( $S \times F$ ) per species, merging 2 plants of the same multi-pot, by Nutrilab (Universidad Rey  
177 Juan Carlos, Madrid, Spain). Briefly, analysis of leaf, stem and root N and P concentration of these  
178 samples was done by the standard Kjeldahl method, while K concentration was determined using a  
179 perchloric acid extraction. Substrate analysis at the end of the nursery cultivation was performed by  
180 Denetra snc (Pescia, Italy) on 9 seedlings per stocktype ( $S \times F$ ) per species. Concurrently, seedling  
181 morphological traits were assessed, using 20 destructively sampled seedlings per treatment  
182 combination (360 in total). Height ( $H$ ), number and dry biomass of leaves ( $L_n$  and  $L_b$ ), root-collar  
183 diameter ( $R_cD$ ) and dry biomass of the shoot (stem) were measured. Root-system was assessed by  
184 main root (tap-root) dry biomass ( $MR_b$ ); first order lateral roots ( $FOLR$ ) dry biomass ( $FOLR_b$ ) for three  
185 diameter classes (<1 mm, 1-5 mm, >5 mm) measured at junction with the tap root, root-system volume  
186 (by immersion) and dry weight and density ( $R_v$ ,  $R_b$  and  $R_d$  resp.). Shoot to root ratio ( $S/R$ ),  $H/R_cD$ ,  
187 and Specific Leaf Area ( $SLA$ ) were also calculated.

188

## 189 2.3 Statistical analysis

190

191 A randomized complete block design (3 blocks) was used. Each block included the 6 randomized  
192  $S \times F$  combinations per species; each combination comprised 48 sowed cavities (over 4 multi-pots),  
193 for a total of 2592 sowed containers. In a preliminary multifactorial ANOVA (model,  $Y_{ijklm} = \mu + \text{Block}_i$   
194  $+ \text{Date}_j + \text{Substrate}(S)_k + \text{fertilization}(F)_l + S \times F \text{ interaction}_{kl} + \text{error}_{ijklm}$ ), the block effect was not  
195 significant for any morphological variables, highlighting homogeneous growing conditions.  
196 Multifactorial ANOVA was performed, separately for each species to avoid complex higher-level  
197 interactions, considering substrate ( $S$ ), fertilization ( $F$ ), and their interactions ( $S \times F$ ) as source of  
198 variation. In case of significant results ( $p \leq 0.05$ ), Tukey post hoc test was used for multiple  
199 comparisons ( $\alpha = 0.05$ ) to highlight homogenous groups within species. In this study, we present  
200 results related to substrate ( $S$ ), fertilization ( $F$ ), and their significant interactions ( $S \times F$ ). To provide  
201 information about the traits of the studied stocktypes (combinations  $S \times F$ ), Tukey test results among

202 combinations are shown in supplementary material. StatSoft Statistica 11 (Tulsa, Oklahoma, USA)  
 203 was used to process all data.

204

### 205 3. Results

206

#### 207 3.1 Emergence, growth and physiological traits during nursery cultivation

208

209 Final emergence was not affected by either factor in the three studied oaks. In *Q. ilex* seedlings  
 210 emergence started between 3 and 4 weeks later than in the two species (data not shown). In all species,  
 211 substrate affected height beginning relatively early, from June (from May in *Q. robur*, data not  
 212 shown), and seedlings in *Pe* where higher than in *Co* (Table 1); in all species, fertilization effect  
 213 occurred later (September in *Q. robur*, July in *Q. pubescens*, July in *Q. ilex*, data not shown), and K-  
 214 enriched fertilization promoted taller seedlings (Table 1). As a result, at the end of the growing  
 215 season, the tallest stocktype was grown in *Pe-K* in all species with different gaps with the stocktypes  
 216 in *coir*, and generally, seedlings grown in *Co-St* performed worse (Table S2). Interaction was not  
 217 significant in any case, excluding *Q. robur* in August and *Q. ilex* in August and September.

218

219 **Table 1.** Multifactorial ANOVA and Tukey post hoc test results ( $p \leq 0.05$  in bold) for seedling morphological traits  
 220 (mean  $\pm$  SD) at the end of the season ( $N_{\text{obs}} = 20$  seedlings per stocktype per species). Source of variation: substrate  
 221 (*S*), fertilization (*F*), and their interaction (*SxF*). Capital and lowercase letters indicate homogeneous groups for  
 222 *S* and *F*, resp. Variables: *H* (height); *RcD* (root collar diameter in mm); *H/RcD* (seedling taper); *Rv* (root-system  
 223 volume in  $\text{cm}^3$ ); *Rd* (root-system density= $\text{Rb/Rv}$  in  $\text{g cm}^{-3}$ ); *S/R* (shoot-root ratio); *SLA* (specific leaf area, in  $\text{cm}^2 \text{g}^{-1}$ );  
 224 *Ln* (number of leaves); *Lb* (leaf dry biomass in g).

<i>Q. robur</i>	<i>S</i>	<i>F</i>	<i>SxF</i>	<i>Pe</i>	<i>Co</i>	<i>St</i>	<i>P</i>	<i>K</i>
<i>H</i>	<0.0001	<b>0.0108</b>	0.8213	57.6 $\pm$ 10.8 <b>B</b>	45.8 $\pm$ 10.3 <b>A</b>	48.3 $\pm$ 11.4 <b>a</b>	51.5 $\pm$ 12.2 <b>ab</b>	55.4 $\pm$ 11.8 <b>b</b>
<i>RcD</i>	0.2265	<b>0.0006</b>	0.6354	11.2 $\pm$ 1.9	10.8 $\pm$ 1.7	10.1 $\pm$ 1.8 <b>a</b>	11.2 $\pm$ 1.8 <b>ab</b>	11.6 $\pm$ 1.6 <b>b</b>
<i>H/RcD</i>	<0.0001	0.4976	0.9521	52.6 $\pm$ 11.3 <b>B</b>	42.9 $\pm$ 9.1 <b>A</b>	48.4 $\pm$ 12.2	46.1 $\pm$ 9.8	48.6 $\pm$ 11.9
<i>Rv</i>	<b>0.0143</b>	<b>0.0001</b>	0.1355	28.0 $\pm$ 9.2 <b>B</b>	24.6 $\pm$ 7.8 <b>A</b>	21.0 $\pm$ 6.0 <b>a</b>	26.9 $\pm$ 8.0 <b>b</b>	31.0 $\pm$ 8.8 <b>b</b>
<i>Rd</i>	0.3264	<b>0.0040</b>	0.0711	0.43 $\pm$ 0.07	0.44 $\pm$ 0.09	0.47 $\pm$ 0.10 <b>b</b>	0.42 $\pm$ 0.06 <b>ab</b>	0.41 $\pm$ 0.06 <b>a</b>
<i>S/R</i>	<0.0001	<b>0.0419</b>	0.6985	0.65 $\pm$ 0.14 <b>B</b>	0.49 $\pm$ 0.15 <b>A</b>	0.53 $\pm$ 0.17 <b>a</b>	0.57 $\pm$ 0.14 <b>ab</b>	0.61 $\pm$ 0.18 <b>b</b>
<i>SLA</i>	<b>0.0016</b>	<b>0.0120</b>	0.5480	156.1 $\pm$ 29.2 <b>B</b>	142.1 $\pm$ 18.1 <b>A</b>	147.0 $\pm$ 20.2 <b>ab</b>	142.2 $\pm$ 32.0 <b>a</b>	157.9 $\pm$ 19.3 <b>b</b>
<i>Ln</i>	<b>0.0156</b>	<0.0001	0.7843	56.6 $\pm$ 26.0 <b>B</b>	47.2 $\pm$ 19.7 <b>A</b>	41.6 $\pm$ 13.2 <b>a</b>	48.0 $\pm$ 22.0 <b>ab</b>	66.1 $\pm$ 26.2 <b>b</b>
<i>Lb</i>	<0.0001	<0.0001	0.2137	4.5 $\pm$ 1.5 <b>B</b>	3.4 $\pm$ 1.3 <b>A</b>	3.2 $\pm$ 1.1 <b>a</b>	4.0 $\pm$ 1.3 <b>b</b>	4.7 $\pm$ 1.6 <b>b</b>
<i>Q. pubescens</i>	<i>S</i>	<i>F</i>	<i>SxF</i>	<i>Pe</i>	<i>Co</i>	<i>St</i>	<i>P</i>	<i>K</i>
<i>H</i>	<0.0001	<b>0.0028</b>	0.4337	36.8 $\pm$ 11.5 <b>B</b>	22.4 $\pm$ 8.2 <b>A</b>	27.9 $\pm$ 10.7 <b>ab</b>	27.0 $\pm$ 11.1 <b>a</b>	33.9 $\pm$ 14.0 <b>b</b>
<i>RcD</i>	<b>0.0003</b>	<b>0.0024</b>	0.4202	10.7 $\pm$ 1.9 <b>B</b>	9.4 $\pm$ 2.2 <b>A</b>	9.7 $\pm$ 1.9 <b>ab</b>	9.4 $\pm$ 2.3 <b>a</b>	10.9 $\pm$ 2.0 <b>b</b>
<i>H/RcD</i>	<0.0001	0.5218	0.5139	34.8 $\pm$ 10.3 <b>B</b>	24.2 $\pm$ 7.2 <b>A</b>	28.9 $\pm$ 10.6	28.9 $\pm$ 9.5	30.8 $\pm$ 11.1
<i>Rv</i>	<0.0001	0.3988	0.0951	25.8 $\pm$ 10.5 <b>B</b>	14.9 $\pm$ 6.1 <b>A</b>	20.9 $\pm$ 12.6	19.1 $\pm$ 8.6	21.3 $\pm$ 9.0
<i>Rd</i>	<b>0.0101</b>	0.2732	<b>0.0215</b>	0.41 $\pm$ 0.07 <b>A</b>	0.44 $\pm$ 0.06 <b>B</b>	0.42 $\pm$ 0.08	0.43 $\pm$ 0.06	0.42 $\pm$ 0.05
<i>S/R</i>	<0.0001	<b>0.0001</b>	0.0725	0.43 $\pm$ 0.13 <b>B</b>	0.27 $\pm$ 0.11 <b>A</b>	0.33 $\pm$ 0.11 <b>a</b>	0.31 $\pm$ 0.15 <b>a</b>	0.42 $\pm$ 0.16 <b>b</b>
<i>SLA</i>	0.0600	0.6396	0.7851	104.6 $\pm$ 13.4	100.6 $\pm$ 8.7	101.4 $\pm$ 9.0	103.8 $\pm$ 13.9	102.7 $\pm$ 11.2
<i>Ln</i>	<0.0001	<b>0.0232</b>	0.4068	60.5 $\pm$ 27.2 <b>B</b>	34.9 $\pm$ 15.1 <b>A</b>	46.5 $\pm$ 29.7 <b>ab</b>	41.7 $\pm$ 20.5 <b>a</b>	54.9 $\pm$ 24.0 <b>b</b>
<i>Lb</i>	<0.0001	<b>0.0192</b>	0.4390	4.3 $\pm$ 1.5 <b>B</b>	2.1 $\pm$ 1.1 <b>A</b>	3.1 $\pm$ 1.7 <b>ab</b>	2.9 $\pm$ 1.4 <b>a</b>	3.7 $\pm$ 1.9 <b>b</b>
<i>Q. ilex</i>	<i>S</i>	<i>F</i>	<i>SxF</i>	<i>Pe</i>	<i>Co</i>	<i>St</i>	<i>P</i>	<i>K</i>
<i>H</i>	<0.0001	<b>0.0032</b>	0.3332	52.7 $\pm$ 13.1 <b>B</b>	35.0 $\pm$ 10.3 <b>A</b>	40.9 $\pm$ 13.0 <b>a</b>	41.8 $\pm$ 13.3 <b>ab</b>	48.9 $\pm$ 16.7 <b>b</b>
<i>RcD</i>	<b>0.0114</b>	0.1610	0.5929	8.5 $\pm$ 1.1 <b>B</b>	7.8 $\pm$ 1.6 <b>A</b>	8.1 $\pm$ 1.3	7.9 $\pm$ 1.5	8.5 $\pm$ 1.3
<i>H/RcD</i>	<0.0001	<b>0.0386</b>	0.2352	62.7 $\pm$ 15.4 <b>B</b>	45.1 $\pm$ 12.3 <b>A</b>	50.1 $\pm$ 13.4 <b>a</b>	53.6 $\pm$ 15.7 <b>ab</b>	58.0 $\pm$ 19.2 <b>b</b>
<i>Rv</i>	<0.0001	<b>0.0009</b>	0.4449	14.9 $\pm$ 5.0 <b>B</b>	10.7 $\pm$ 4.3 <b>A</b>	10.8 $\pm$ 4.2 <b>a</b>	12.9 $\pm$ 5.4 <b>ab</b>	14.6 $\pm$ 5.1 <b>b</b>

<i>Rd</i>	0.3072	0.1237	0.3875	0.45 ± 0.10	0.43 ± 0.13	0.45 ± 0.13	0.41 ± 0.08	0.46 ± 0.12
<i>S/R</i>	<b>0.0062</b>	0.3922	0.3637	0.71 ± 0.25 <b>B</b>	0.59 ± 0.22 <b>A</b>	0.68 ± 0.24	0.61 ± 0.29	0.67 ± 0.19
<i>SLA</i>	<b>0.0104</b>	0.2676	<b>0.0005</b>	73.6 ± 8.0 <b>B</b>	70.5 ± 5.5 <b>A</b>	73.2 ± 7.6	70.7 ± 7.1	72.2 ± 6.4
<i>Ln</i>	<b>&lt;0.0001</b>	<b>0.0140</b>	0.3323	49.4 ± 15.6 <b>B</b>	30.0 ± 11.1 <b>A</b>	38.6 ± 16.2 <b>ab</b>	36.0 ± 13.6 <b>a</b>	44.5 ± 19.0 <b>b</b>
<i>Lb</i>	<b>&lt;0.0001</b>	<b>0.0040</b>	0.1082	5.2 ± 1.5 <b>B</b>	2.9 ± 1.2 <b>A</b>	3.7 ± 1.5 <b>a</b>	3.9 ± 1.8 <b>ab</b>	4.6 ± 2.0 <b>b</b>

225

226

227

228

229

230

231

232

233

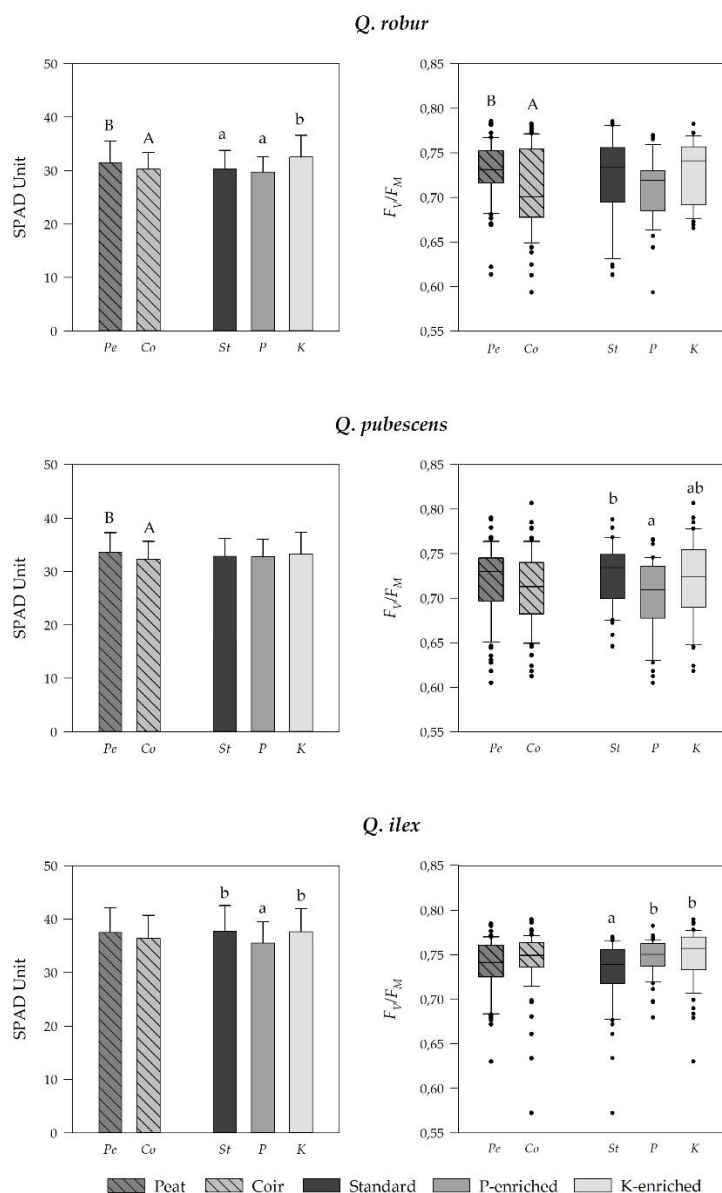
234

235

236

In general, in all species, in August (Figure 1), both substrate ( $Pe > Co$ ) and fertilization ( $K$  generally higher) affected ChlF content, generally with no interactions (data not shown). In *Q. robur* and *Q. pubescens*, seedlings in peat showed higher values of  $F_v/F_m$  than in coir (significant in *Q. robur*, Figure 1), and K enriched fertilization generally resulted in higher  $F_v/F_m$  values (significant in *Q. ilex*).

**Figure 1.** Multifactorial ANOVA and Tukey post-hoc test results of  $F_v/F_m$  values (box whisker plot) and SPAD units (mean and SD) analyzed for substrate and fertilization ( $N_{obs}=81$  for substrate;  $N_{obs}=54$  for fertilization) in August. Capital and lowercase letters indicate homogenous groups for substrate and fertilization, respectively.  $Pe=$  Peat;  $Co=$ Coir;  $St=$ Standard fertilization;  $K=$ K-enriched fertilization;  $P=$ P-enriched fertilization



237

238

## 239 3.2 Morphological traits

240

241 In *Q. robur*, both substrate and fertilization affected most of the analysed variables without any  
 242 interaction (Table 1 and 2), and, generally, *Pe* and K-enriched fertilization were more effective in  
 243 promoting seedling growth. For total dry biomass, the differences were as follows: *Pe*>*Co* by +22.6%,  
 244 K>*P* and *St* by +13.4% and +36.6%, respectively (Figure 2). Peat also promoted shoot-system and leaf  
 245 biomass, *SLA*, as well as *FOLR1-5* and roots total biomass. K-enriched fertilization positively  
 246 influenced shoot development, *SLA*, *FOLR1-5* and root system and leaf biomass. *Pe* stimulated  
 247 biomass accumulation more in shoot- than in root-system with *S/R* values >0.5 (Table 2), and K-  
 248 enriched fertilization promoted higher *S/R* than *St*. Root volume was affected by substrate (*Pe*>*Co*)  
 249 and fertilization (*K*>*St*); root density was influenced only by fertilization (*Co*-*St*>*Pe*-*K*).

250 In *Q. pubescens*, substrate affected morphological variables more than fertilization, and,  
 251 generally, in the case of significant differences, seedlings in peat and K-enriched fertilization were  
 252 better developed (Table 1 and 2, Figure 2). Total biomass in *Pe* was higher than in *Co* by +78.3%, and  
 253 the gap between *K* and *St* and *P* was +19.3% and +20.1%, respectively. *Pe* significantly promoted all  
 254 biomass variables excluding *FOLR*>5. Fertilization with K promoted biomass growth in the shoot-  
 255 system, leaves and in *FOLR1-5* over *St* fertilization. Shoot to root ratio was lower than 0.51 in all  
 256 stocktypes (Table 1) and was affected by both substrate (*Pe*>*Co*) and fertilization (*K*>*P* and *St*). Root  
 257 volume of *Q. pubescens* seedlings raised with peat was higher than that of coir, while the opposite  
 258 occurred for root density.

259 As per previous species, in the case of *Q. ilex*, substrate affected the majority of the analysed  
 260 variables (with a *Pe*>*Co* pattern), and generally, when fertilization was significant, seedlings grown  
 261 in K-enriched fertilizer had higher values (Tables 1 and 2, Figure 2). Total biomass was affected by  
 262 both factors (*Pe* +63.5% than *Co*; *K* +36.2% and +50.2% than *P* and *St*, respectively). Similar differences  
 263 (*Pe*>*Co*) occurred for shoot-system and leaf biomass, main root, *FOLR*<1, *FOLR1-5*, and root biomass.  
 264 Fertilization affected leaf, main root, *FOLR1-5*, and root biomass (*K*> *P* and *St*). *S/R* ratio was affected  
 265 only by substrate (Table 2), both in *Co* and *Pe* it resulted higher than 0.50 (Table 2). Root volume was  
 266 affected by both substrate (*Pe*>*Co*) and fertilization (*K*>*P* and *St*).

267

268 **Table 2.** *p* values from multifactorial ANOVA test results: (*p* < 0.05 in bold) for seedlings biomass allocation  
 269 (*N*<sub>obs</sub> =20 per stocktype per species). Sources of variation: substrate (*S*), fertilization (*F*), and their interaction  
 270 (*Sx**F*). *Sb*: shoot-system biomass; *MRb*: main root biomass; *FOLRb*: First Order Lateral Root biomass split by  
 271 diameter class (<1 mm, 1-5 mm, >5 mm); *Rb*: total root-system biomass; *Sb* + *Rb*: total seedling biomass.

272

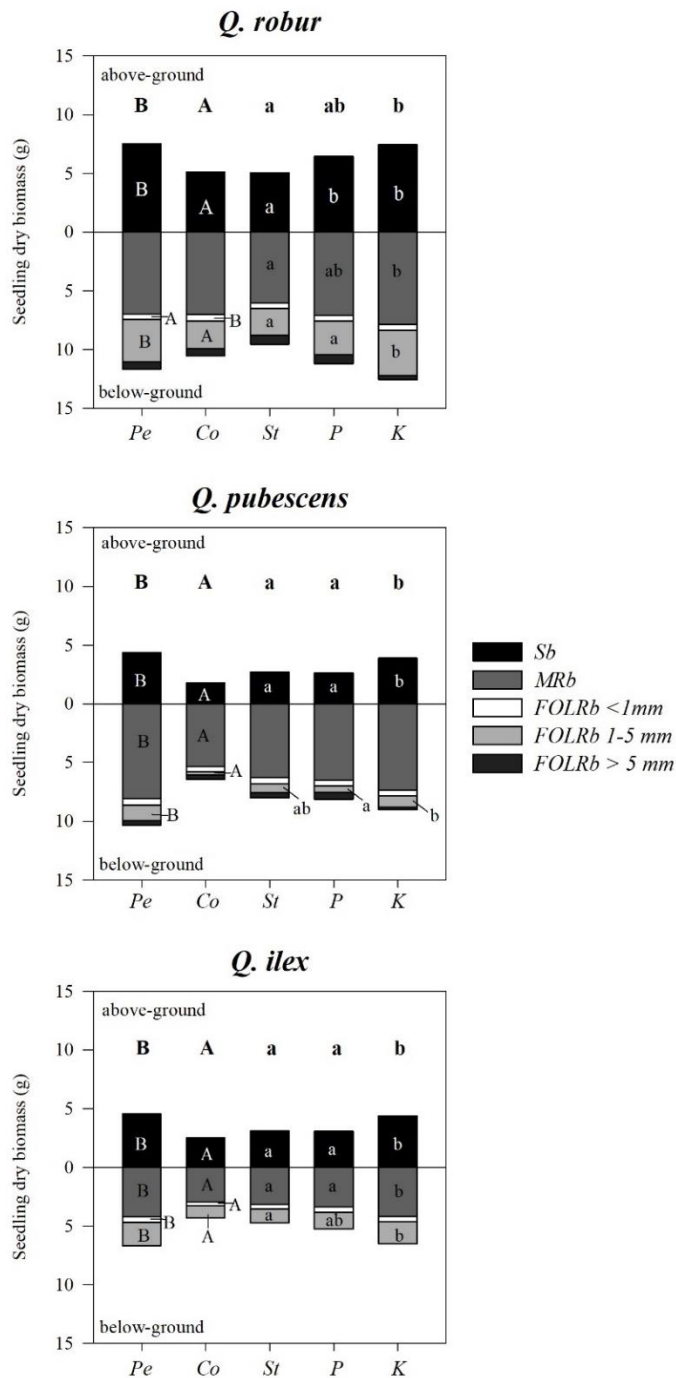
<i>Q. robur</i>	<i>S</i>	<i>F</i>	<i>Sx</i> <i>F</i>
<i>Sb</i>	<0.0001	<0.0001	0.6355
<i>MRb</i>	0.9205	0.0610	0.7401
<i>FOLRb</i> <1	<b>0.0212</b>	0.5548	0.9441
<i>FOLRb</i> 1-5	<0.0001	<0.0001	0.1665
<i>FOLRb</i> >5	0.8056	0.2704	0.6460
<i>Rb</i>	<b>0.0454</b>	<b>0.0001</b>	0.7101
<i>Sb</i> + <i>Rb</i>	<b>0.0001</b>	<0.0001	0.9119
<i>Q. pubescens</i>			
<i>Sb</i>	<0.0001	<b>0.0002</b>	0.2060
<i>MRb</i>	<0.0001	0.1275	0.2324
<i>FOLRb</i> <1	<b>0.0081</b>	0.1637	<b>0.0127</b>
<i>FOLRb</i> 1-5	<0.0001	<b>0.0075</b>	0.1767
<i>FOLRb</i> >5	0.8859	0.3703	0.4351
<i>Rb</i>	<0.0001	0.3417	0.4148
<i>Sb</i> + <i>Rb</i>	<0.0001	<b>0.0438</b>	0.4563
<i>Q. ilex</i>			
<i>Sb</i>	<0.0001	<0.0001	0.1204
<i>MRb</i>	<0.0001	<b>0.0005</b>	<b>0.0230</b>
<i>FOLRb</i> <1	<b>0.0059</b>	0.5604	0.0674



<i>FOLRb</i> 1-5	<0.0001	0.0013	0.1812
<i>FOLRb</i> >5	-	-	-
<i>Rb</i>	<0.0001	0.0001	0.0389
<i>Sb</i> + <i>Rb</i>	<0.0001	<0.0001	0.0424

273  
274  
275  
276  
277  
278  
279  
280  
281

**Figure 2.** Multifactorial ANOVA and Tukey post hoc test results ( $p \leq 0.05$ ) for seedling dry biomass (g) allocation at the end of the growing season ( $N_{obs}=20$  per stocktype per species). Source of variation substrate (S), fertilization (F). *Sb*: shoot-system dry biomass; *MRb*: main root dry biomass; *FOLRb*: dry biomass of First Order Lateral Root split by diameter class (<1 mm, 1-5 mm, >5 mm). Capital letters indicate homogenous groups for substrate, while lowercase letters indicate homogenous groups for fertilization; letters in the upper part indicate groups for total biomass. Pe= Peat; Co=Coir; St=Standard fertilization; K=K-enriched fertilization; P=P-enriched fertilization.



282

## 283 3.3 N, P, K concentration in seedlings and substrate at the end of cultivation

284

285 In *Q. robur*, N concentration was not affected by treatments excluding fertilization on root-  
 286 system (*St* and *P>K*), while both substrate (*Pe>Co*) and fertilization (*P* and *K>St*) affected P  
 287 concentration in seedling parts (excluding substrate on shoot; Table 3, Figure 3). *Pe-P* had higher P  
 288 concentration than other stocktypes in leaves and in shoot (Figure S2). Both *S* and *F* did not influence  
 289 K concentration. In *Q. pubescens*, N concentration in any tissue was not influenced by either treatment  
 290 (Table 3, Figure 3); P concentration was affected by both substrate (*Pe>Co*) and fertilization (*P* and  
 291 *K>St*; excluding substrate on shoot-system Table 3, Figure 3). *Pe-P* had generally higher P content  
 292 than other stocktypes in leaves, shoot and roots (Figure S2). Differences in K concentration were  
 293 found between substrates in leaves (*Pe>Co*). In *Q. ilex*, both substrate (*Co>Pe*) and fertilization (*St>K*)  
 294 influenced plant N concentration in all tissues (Table 3, Figure 3). Substrate affected leaf P  
 295 concentration (*Co>Pe*) and fertilization affected root-system concentration (*P>St*), K concentration  
 296 was influenced by substrate in roots (*Co>Pe*), and by fertilization in shoot-system (Table 3, Figure 3).

297

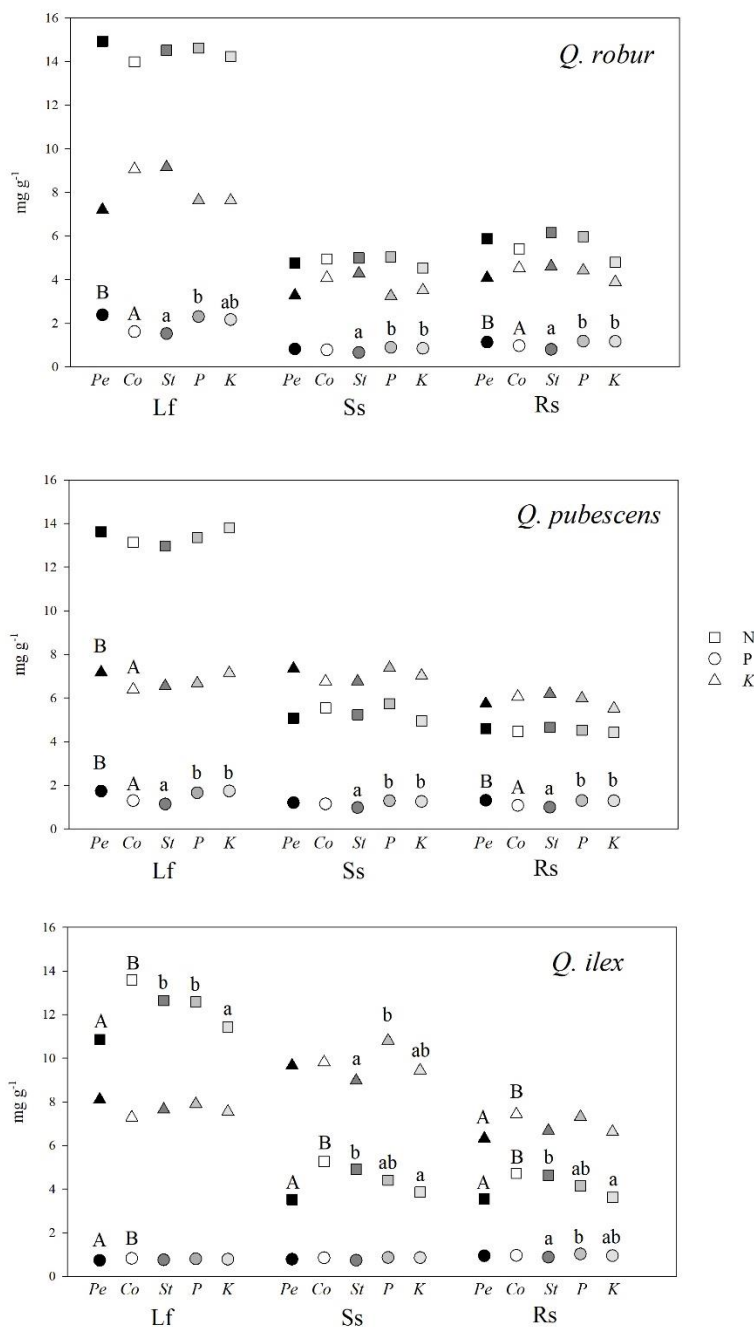
298 **Table 3.** *p* values of multifactorial ANOVA (*p*≤0.05 in bold) for and for macro-element concentration (N, P, K) in  
 299 leaves, shoot-system and root-system at the end of the growing season (N=6 couples per stocktype). Source of  
 300 variation: substrate (*S*), fertilization (*F*), and their interaction (*SxF*). For chlorophyll content (SPAD) and Fv/Fm,  
 301 and PI<sub>ABS</sub> we reported *p*-values calculated from data of each data collection (June, July, and August).

		<i>Q. robur</i>			<i>Q. pubescens</i>			<i>Q. ilex</i>		
		<i>S</i>	<i>F</i>	<i>SxF</i>	<i>S</i>	<i>F</i>	<i>SxF</i>	<i>S</i>	<i>F</i>	<i>SxF</i>
N (mg/g)	Leaves	0.1398	0.8712	0.3971	0.2220	0.2340	0.2340	<b>&lt;0.0001</b>	<b>0.0067</b>	0.3531
	Shoot	0.3956	0.1357	0.1760	0.0922	0.0681	0.0681	<b>&lt;0.0001</b>	<b>0.0027</b>	0.1779
	Root	0.0711	<b>0.0002</b>	0.9724	0.5779	0.6927	0.6927	<b>&lt;0.0001</b>	<b>0.0017</b>	0.2128
P (mg/g)	Leaves	<b>0.0036</b>	<b>0.0317</b>	0.4204	<b>0.0002</b>	<b>0.0001</b>	<b>0.0001</b>	<b>0.0020</b>	0.3830	0.4956
	Shoot	0.4027	<b>0.0013</b>	<b>0.0439</b>	0.3254	<b>0.0001</b>	<b>0.0001</b>	0.1794	0.0923	0.9658
	Root	<b>0.0088</b>	<b>&lt;0.0001</b>	<b>0.0208</b>	<b>0.0034</b>	<b>0.0024</b>	<b>0.0024</b>	0.7227	<b>0.0381</b>	0.5865
K (mg/g)	Leaves	0.1448	0.5164	0.1323	<b>0.0469</b>	0.4150	0.4150	0.0751	0.7980	0.2119
	Shoot	0.4515	0.7074	0.1073	0.2170	0.5737	0.5737	0.8051	<b>0.0423</b>	0.6514
	Root	0.4930	0.6484	0.1861	0.4115	0.3866	0.3866	<b>0.0188</b>	0.3926	0.1645

302

303 **Figure 3.** Macro-element concentration (mg g<sup>-1</sup> for N, P, K) in leaves (Lf), shoot (stem, Ss) and root-system (Rs)  
 304 analyzed for substrate and fertilization (mean ± SD). Source of variation substrate (*S*), fertilization (*F*), and their  
 305 interaction (*SxF*). Capital letters and lowercase letters indicate homogenous groups for *S* and *F*, respectively. *Pe*=  
 306 Peat; *Co*=Coir; *St*=Standard fertilization; *K*=K-enriched fertilization; *P*=P-enriched fertilization.

307



308  
309

310 Nitrate N concentration of the growing media with *Q. robur* was affected by substrate and  
 311 fertilization ( $Pe > Co$ ;  $P > K$ ), and only by fertilization for ammonium N ( $P > K$ , Table 4). In *Q. pubescens*,  
 312 fertilization affected P concentration ( $P > K$ ), and both nitric and ammonium N ( $P > K$ ). In *Q. ilex*, nitrate  
 313 N was affected by fertilization ( $P > K$ ) and ammonium N by both factors ( $Co > Pe$ ;  $P > K$ ), and P  
 314 concentration resulted not affected by substrate and fertilization, while both affected K concentration  
 315 ( $Co > Pe$ ;  $K > P$  and  $St$ ). No interaction among factors occurred.

316

317 **Table 4.** Multifactorial ANOVA and Tukey post-hoc test results ( $p \leq 0.05$  in bold) for (mean  $\pm$  SD, N = 6) macro-  
 318 element concentration (N, P, K) in meq/l contained in the growing medium at the end of the season (N=12 per  
 319 combination). Source of variation substrate (S), fertilization (F), and their interaction (SxF). Lowercase letters  
 320 indicate homogenous groups.  $Pe$ = Peat;  $Co$ =Coir;  $St$ =Standard fertilization;  $K$ =K-enriched fertilization;  $P$ =P-  
 321 enriched fertilization.

<i>Q. robur</i>	<i>S</i>	<i>F</i>	<i>SxF</i>	<i>Pe</i>	<i>Co</i>	<i>St</i>	<i>P</i>	<i>K</i>
Nitrate N	<b>0.0160</b>	<b>0.0004</b>	0.5459	1,32 ± 0.49 <b>B</b>	0.86 ± 0.66 <b>A</b>	1.11 ± 0.36 <b>ab</b>	1.65 ± 0.47 <b>b</b>	0.52 ± 0.39 <b>a</b>
Ammonium N	0.9211	<b>0.0029</b>	0.2031	1,02 ± 0.34	1.01 ± 0.54	0.92 ± 0.26 <b>ab</b>	1.44 ± 0.37 <b>b</b>	0.69 ± 0.29 <b>a</b>
P	0.2960	0.9878	0.3515	0,26 ± 0.08	0.22 ± 0.06	0.24 ± 0.06	0.23 ± 0.05	0.24 ± 0.11
K	0.3836	0.0821	0.9781	0,89 ± 0.24	0.79 ± 0.25	0.66 ± 0.13	0.88 ± 0.26	0.98 ± 0.23
<i>Q. pubescens</i>								
Nitrate N	<b>0.0612</b>	<b>0.0020</b>	0.3632	1,22 ± 0.70 <b>B</b>	0.83 ± 0.48 <b>A</b>	0.84 ± 0.42 <b>a</b>	1.64 ± 0.54 <b>b</b>	0.61 ± 0.35 <b>a</b>
Ammonium N	0.7522	<b>0.0036</b>	0.6327	0,96 ± 0.55	0.91 ± 0.37	0.81 ± 0.26 <b>ab</b>	1.39 ± 0.38 <b>b</b>	0.60 ± 0.28 <b>a</b>
P	0.9340	<b>0.0222</b>	0.6351	0,19 ± 0.07	0.19 ± 0.04	0.18 ± 0.04 <b>ab</b>	0.24 ± 0.05 <b>b</b>	0.15 ± 0.04 <b>a</b>
K	0.5296	0.1437	0.5819	0,73 ± 0.25	0.87 ± 0.64	0.50 ± 0.13	1.07 ± 0.70	0.83 ± 0.26
<i>Q. ilex</i>								
Nitrate N	0.7839	<b>0.0212</b>	0.4642	0,65 ± 0.51	0.71 ± 0.51	0.77 ± 0.35 <b>ab</b>	1.02 ± 0.55 <b>b</b>	0.25 ± 0.20 <b>a</b>
Ammonium N	<b>0.0299</b>	<b>0.0260</b>	0.3370	0,44 ± 0.36 <b>A</b>	0.83 ± 0.46 <b>B</b>	0.65 ± 0.39 <b>ab</b>	0.93 ± 0.53 <b>b</b>	0.32 ± 0.14 <b>a</b>
P	0.0824	0.3603	0.8507	0,15 ± 0.06	0.21 ± 0.08	0.17 ± 0.05	0.22 ± 0.11	0.16 ± 0.05
K	<b>0.0295</b>	<b>0.0005</b>	0.7127	0,68 ± 0.34 <b>A</b>	0.90 ± 0.28 <b>B</b>	0.59 ± 0.23 <b>a</b>	0.65 ± 0.25 <b>a</b>	1.14 ± 0.14 <b>b</b>

322

323

324 **4. Discussion**

325

326 Our study highlighted effects of substrate on seedling growth that began quite early (2 months  
327 after sowing in *Q. robur* and *Q. pubescens*; 3 months in *Q. ilex*) and persisted through cultivation. The  
328 absence of any fertilization effect on early growth phases was expected in all species: dependence of  
329 *Quercus* seedlings on acorn nutrients decreases as seedlings develop [7,71] and plants start to rely on  
330 soil/substrate properties. Thus, the development of the first growth flush in many *Quercus* species is  
331 to a higher extent related to acorn size and nutrients in the seed [72,73], rather than to the quality of  
332 the growing medium or soil to [7,71]. Our results are in line with those of Villar-Salvador et al. [71]  
333 in *Q. ilex*: fertilization effect was significant just at the end of the second growth flush and beyond.  
334 The delayed effect observed in *Q. ilex* in comparison with the other species can be explained by a later  
335 emergence of holm oak seedlings, which could have altered the occurrence of the substrate effect.  
336 From late spring to the end of cultivation, seedlings of all species grown in peat were taller than those  
337 grown in coir. However, height of seedlings in coir were at least equal to that of comparable forest  
338 nursery production systems of *Quercus* species [27,74–76]. Our results confirmed those of Rose and  
339 Haase [61] with Douglas fir, in which seedlings grew more with peat than coir. Tsakalidimi and  
340 Ganatsas [11], using similar containers as in this study, also reported that *Q. ilex* seedlings grown in  
341 a peat-perlite mixture (3:1) were taller than in peat-coir mixture (1:1). Radjagukguk et al. [62] showed  
342 high mortality and delayed growth for two *Eucalyptus* species grown in coir, while Offord et al. [77]  
343 did not observe differences between plants grown in peat with sand and perlite, and in coir in the  
344 same mixture in several species, including *Eucalyptus melliodora*. The reduced growth rate observed  
345 in seedlings grown in coir could be due to the lower CEC than in peat, which reduces nutrients  
346 availability for seedlings. This could explain the smaller size of the vast majority of the studied  
347 morphological traits in all coir stocktypes in all species regardless of fertilization. Additionally,  
348 according to Handreck [78], there is a greater immobilization of soluble nitrogen in coir than peat..  
349 Grantzau [79] similarly highlighted that the microbial activity in coir caused nitrogen immobilization,  
350 suggesting the need to add extra N fertilization during cultivation [78,79]; however, in our study we  
351 did not find reductions in tissue concentration of seedlings raised with coir, suggesting an absence of  
352 nitrogen deficiency. The common mixtures and fertilization protocols used by nursery companies in  
353 horti-flori-fructiculture sector have been optimized [80] and plants in coir grow equally as peat  
354 mixtures [29,77,81,82]. Other studies aim at excessive salinity, which often characterizes coir [9,61],  
355 to explain the negatively affected root development and physiology [83], and thereby altered growth.  
356 However, in our study, coir EC was in line with the values reported in literature [84,85], with similar  
357 or lower values than in peat.

358 According to our results, morphological traits variability was explained more by substrate than  
359 by fertilization. Fertilization effects on growth occurred later than those of growing medium, in mid-

360 summer for *Q. pubescens* and *Q. ilex* and near the end of the growing season in *Q. robur*. In all species  
361 and in both growing media, the K-enriched fertilization improved the growth rate during the  
362 growing season and promoted taller plants. Apart from N fertilization, scarce literature is available  
363 on the effect of the other macro-elements on growth of forest species in the nursery [7]. K is  
364 recognized as a key element of many metabolic processes [86], some of which are related to plant  
365 stress responses. Direct connections of K with seedling growth are less investigated, but in a meta-  
366 analysis of forest species (including plants at seedling stage), Tripler et al. [87] highlighted that plant  
367 growth responded positively to an increase in K availability. Studies on tropical forest species  
368 highlighted a direct effect of K fertilization in promoting plant growth with a higher shoot/root ratio  
369 [88,89]. Similar to height responses, seedlings in all species grown in peat and K-enriched fertilization  
370 allocated more resources to above-ground dry biomass (leaves and shoot system). Similar results for  
371 substrate effects were obtained by Rose and Haase [61] in Douglas-fir. Soto Castelblanco [90], who  
372 studied seedlings of *Q. ilex* and three *Pinus* species grown in peat and in coir, found higher, despite  
373 non-significant, values of shoot-system biomass in peat. Coir K content is usually higher than that in  
374 peat [31,61]. However, in our study, despite the tested rates of K are high compared to literature on oaks  
375 [91–93] we observed an outstanding effect of such fertilization on plant growth regardless  
376 species or substrate, suggesting K deficiency status. K enriched fertilization included an additional  
377 amount of P as compared to Standard fertilizer, which could have been helpful in sustaining seedling  
378 growth. However, fertilization with P was not as effective as K in promoting height and biomass in  
379 these studied species, although, generally, it was better than standard fertilization. P plays a key role  
380 in plant metabolism, being a critical element for many physiological reactions [94]. In agriculture and  
381 forestry, the action of P is linked to several root morphological traits, such as root-system structure,  
382 growth and articulation, rather than to above-ground development [49,50,94–96]. Thus, a non-  
383 pronounced effect on shoot system growth was expected.

384 In all studied species and treatments, peat and K-enriched fertilization promoted the greatest  
385 below-ground development. In all cases, shoot/root ratio was <1, and cultivation in coir reduced this  
386 ratio further, particularly for *Q. pubescens*. Other studies on flowering species pointed out that  
387 cultivation in coir can promote a proportionally higher root system component [81,97]. The same  
388 effect occurred on Douglas fir, with higher root biomass for seedlings in coir and a decreasing trend  
389 in S/R ratio from peat, to a mixture of coir and peat, to coir [61]. In contrast, Tsakalimi and Ganastas  
390 [11] found a higher S/R ratio in 1-year-old seedlings of *Q. macrolepis* and *Q. ilex* grown in a mixture  
391 of peat and coconut fiber than in peat with perlite. A lower shoot to root ratio has been linked to  
392 survival under drought condition in holm oak [98], in Mediterranean shrubs [99] and savanna species  
393 [100]. On the contrary, Villar-Salvador et al. [40] highlighted that *Q. ilex* seedlings with a higher S/R  
394 had lower mortality and larger growth than those with the opposite attributes; however, we found  
395 quite similar shoot to root values for holm oak produced in coir to the highest values observed in this  
396 study (0.59 vs 0.63, respectively).

397 Peat also promoted main root biomass and favored root fibrosity, especially the two smaller  
398 classes of *FOLR* (>1 mm and 1-5 mm). The proportion of *FOLR* on total root biomass was statistically  
399 affected by substrate (data not showed) in *Q. robur* and *Q. ilex*; however, the gap between substrates  
400 in all species was slight. This result suggests that plants grown in coir, despite a lower absolute root-  
401 system biomass, maintained comparable root fibrosity to peat in a proportionally higher below-  
402 ground component. This result is inconsistent with Chulaka et al. [101] and Wilson et al. [102] who  
403 reported the effects of coir-based substrates on S/R ratio with non-significant results *versus* peat-based  
404 substrates and with Colla et al [97], who found a higher S/R ratio in horticultural species grown in  
405 peat. Studies on tropical tree species and in alpine and dryland environment [88,89] reported that K  
406 promoted shoot biomass and less *FOLR*, resulting in a lower S/R ratio. Our results partially confirmed  
407 such observations, as with K enriched fertilization the S/R ratio was higher, but the biomass allocated  
408 to *FOLR* was positively influenced by such fertilization. P-enriched fertilization did not promote the  
409 growth and articulation of the root-system as expected, even though this study did not compare  
410 different levels of P and K, but rather three different fertilizations. Scarce literature has focused on  
411 the direct effect of P on detailed morphological below ground traits in *Quercus*. According to Pemán

412 [7], root systems of *Quercus* species can be affected by available P; Sardans et al. [103] found that P  
413 fertilization can promote root growth in *Q. ilex* ssp. *ballota* and Villar-Salvador et al. [40] linked P  
414 concentration to capacity of regenerating roots in holm oak. Oliet et al. [47] highlighted a clear effect  
415 of root P concentration at final nursery sampling and root growth potential (RGP) in *Q. ilex* seedlings.

416 Physiological results are in agreement with morphology, demonstrating an overall better  
417 performance of photosynthetic machinery (considering SPAD and  $F_v/F_m$  in conjunction) of seedlings  
418 in peat and seedlings fertilized with enriched K in most species. Chlorophyll fluorescence, even  
419 though measured values show absence of stress, has proven to be a sensitive technique to detect  
420 differences among stocktypes, especially those from different fertilization treatments. Results for  
421 Chlorophyll content were generally consistent with what was observed in morphology, and peat and  
422 K-enriched fertilization promoted higher values in all species. The values of Chlorophyll content  
423 observed for deciduous oaks were in line with those in other studies [104,105].

424 We did not find a marked effect of substrate or fertilization on N concentration in plant tissues,  
425 and results were quite variable among species. At the end of cultivation, N concentration of *Q. robur*  
426 and *Q. pubescens* did not depend on substrate and only sporadically on fertilization, whereas both  
427 factors affected *Q. ilex*. Despite a higher N content per seedling than that from other studies on the  
428 same species [91,106], N concentration in holm oak roots and shoot-system was lower. In our study,  
429 N supply per seedling was higher than the sufficiency level in *Q. ilex* (125 mg in exponential  
430 fertilization rate) according to Uscola et al. [91], and higher than 200 mg indicated as an optimum  
431 target by the same study. Uscola et al. [91] applied fertilizer via irrigation with an exponential regime,  
432 which could contribute to increase uptake efficiency [107]. In *Q. petraea*, a European temperate  
433 *Quercus* species, Berger and Glatzer [108] reported 400 mg per seedling as an N amount for luxury  
434 consumption; we supplied 27% less N, which was insufficient to affect *Q. robur* tissue N  
435 concentration. However, levels of consumption can vary not only in relation to experimental factors,  
436 but also to intrinsic ecological differences among species, such that, even among *Quercus*  
437 Mediterranean species, the sufficiency levels are quite different [91,93]. This makes speculation on *Q.*  
438 *pubescens* difficult, as this issue is not well represented in the literature for this species. Peat as well  
439 as P-enriched fertilization were effective in increasing the level of P in all plant tissues in *Q. robur* and  
440 *Q. pubescens*, while in *Q. ilex* such fertilization was effective only for P concentration in roots, and in  
441 contrast to the other species, holm oak seedlings in coir performed better than in peat. Higher soil P  
442 availability [109–113] and root tissue concentration are important to promote root growth capacity  
443 after planting. Del Campo et al. [98], in a study designed to define quality standards for *Q. ilex* nursery  
444 stock, indicated that values of N and P foliar concentration should be higher than 10 and 0.9 mg g<sup>-1</sup>,  
445 respectively, to improve growth performance after planting. Considering this target, our results for  
446 N were higher and better in peat and in P-enriched and Standard fertilization, and for P were about  
447 10% lower and higher in peat. No references are available for *Q. robur* and *Q. pubescens*; however, in  
448 our study, foliar N and P concentrations in these deciduous species were higher than the standard  
449 values for the evergreen *Q. ilex*. In our study, K concentration in plant tissues was generally not  
450 affected by both substrate and fertilization in all species suggesting that K-enriched fertilization did  
451 not increase K concentration. Considering the higher performance of seedlings grown in K-enriched  
452 fertilization regardless species or substrate, this result strengthens the hypothesis that *Quercus* species  
453 benefit from high K availability and that the amount provided in Standard and in P-enriched  
454 fertilization was deficient. According to [92], K is the most responsive nutrient at deficiency status.  
455 The vast majority of literature on fertilization of forest nursery stock has focused on N effects; thus,  
456 more investigations on optimal K rates to maximize growth is needed. Del Campo et al. [98]  
457 concluded that nursery stock with higher K concentration can exhibit improved establishment  
458 success due to K retranslocation. Andivia et al. [114] observed that fertilization with K positively  
459 influenced morphological development and NPK content. K effects on field performance on *Pinus*  
460 *halepensis* have been observed with conflicting results [115,116]. Del Campo et al. [117] suggested that  
461 these multiple responses could be related to the interference of K with other nutrients, particularly  
462 nitrogen. The interaction between K fertilizers and different types of substrate requires further  
463 investigation.

464

465 **5. Conclusions**

466

467 Peat and coir in combination with different fertilization treatments affected above- and below-  
468 ground morphology and, to a lesser extent, physiological traits of *Quercus* seedlings in forest nursery  
469 production. The three studied species, despite being ecologically diverse, provided similar results,  
470 with peat and K-enriched fertilization resulting in larger seedlings and slightly improved  
471 physiological responses. The smaller size of seedlings in coir could be linked to deficiencies in the  
472 chemical properties of this material, which should be balanced by fertilization. Nevertheless,  
473 seedlings produced in coir in this study were compatible with the size of standard *Quercus* forest  
474 stocktypes and with root system development and fibrosity. According to the Target Plant Concept  
475 [3,5], functional traits driving planting performance vary according to environmental and operational  
476 conditions; and plants with a lower shoot to root ratio may perform better under water stress or in  
477 semiarid/arid environments [98,118]. Coir may thus serve as an acceptable material for seedling  
478 cultivation in such cases, despite the tendency to produce smaller seedlings. NPK content was slightly  
479 influenced by treatments, although P-enriched fertilization in peat was the only combination that  
480 promoted a higher amount of this element in tissues at the end of cultivation; the strong effect of K-  
481 enriched fertilization on seedling growth and biomass suggested a K deficiency in the other  
482 fertilization treatments; however, macro-element content in relation to varying fertilization should  
483 be further investigated by comparison of the single element rates.

484

485 **Supplementary Materials:** The following are available online at [www.mdpi.com/xxx/s1](http://www.mdpi.com/xxx/s1), Table S1: Macro-  
486 elements (NPK) content (per volume and per seedling) in the studied fertilizations; Table S2: Multifactorial  
487 ANOVA and Tukey post hoc test results ( $p \leq 0.05$  in bold) for seedling morphological traits (mean  $\pm$  SD) at the  
488 end of the season ( $N_{\text{obs}} = 20$  seedlings per stocktype); Table S3: Multifactorial ANOVA and Tukey post-hoc test  
489 results ( $p \leq 0.05$  in bold) for (mean  $\pm$  SD) macro-element concentration (N, P, K) in meq/l contained in the growing  
490 medium at the end of the season ( $N=3$  couple per combination); Figure S1: Multifactorial ANOVA and Tukey  
491 post hoc test results ( $p \leq 0.05$ ) for seedling dry biomass (g) allocation at the end of the growing season ( $N_{\text{obs}}=20$   
492 per stocktype per species); Figure S2: Macro-element concentration (mg g<sup>-1</sup> for N, P, K) in leaves, shoot-system  
493 and root-system in stocktypes (mean  $\pm$  SD).

494

495 **Author Contributions:** Conceptualization, A.T., B.M., A.M., S.R., D.F.J., and J.O.; Methodology, B.M., A.T., A.M.,  
496 S.R., S.M., and J.O.; Software, S.M., B.M., and S.R.; Validation, S.M., B.M., and S.R.; Formal Analysis, B.M. and  
497 S.M.; Investigation, B.M., S.M., A.M., and S.R.; Resources, B.M., S.M., A.M., and S.R.; Data Curation, S.M., and  
498 B.M.; Writing – Original Draft Preparation, B.M. and S.M.; Writing – Review & Editing, B.M., S.M., A.M., S.R.,  
499 D.F.J., and J.O.; Visualization, B.M. and S.M.; Supervision, A.M.; Project Administration, B.M., A.T., and A.M.;  
500 Funding Acquisition, A.T., A.M., and B.M.

501

502 **Funding:** This study was funded in Italy in the framework of Regione Toscana PSR FEASR 2014-2020 Regione  
503 Toscana - PIF Verdi Conessioni – Mis. 16.2 VIAA.

504

505 **Acknowledgements:** Fabio Bandini and Stefano Teri assisted with study maintenance and lab measurements.  
506 Vannucci Piante nursery company hosted the experimental and provided nursery materials. We particularly  
507 want to thank Dr. Emilio Resta of Vannucci Piante for sharing his valuable expertise.

508

509 **Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the  
510 study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to  
511 publish the results.

512

513

514 **References**

515

- 516 1. Wilson, B.C.; Jacobs, D.F. Quality assessment of temperate zone deciduous hardwood seedlings.  
517 *New For.* **2006**, *31*, 417–433.
- 518 2. Pinto, J.R.; Dumroese, R.K.; Davis, A.S.; Landis, T.D. Conducting seedling stocktype trials: a new  
519 approach to an old question. *J. For.* **2011**, *109*, 293–299.
- 520 3. Dumroese, K.R.; Landis, T.D.; Pinto, J.R.; Haase, D.L.; Wilkinson, K.W.; Davis, A.S. Meeting  
521 forest restoration challenges: using the target plant concept. *Reforesta* **2016**, *1*, 37–52.
- 522 4. Duryea, M.L. Nursery cultural practices: impacts on seedling quality. In *Forestry Nursery Manual:*  
523 *Production of Bareroot Seedlings*; Springer, 1984; pp. 143–164.
- 524 5. Landis, T.D. The target plant concept—a history and brief overview. In *National Proceedings: Forest*  
525 *and Conservation Nursery Associations-2010*; Riley, L.E, Haase, D.L, Pinto, J.R; Proc. Proc. RMRS-  
526 P-65. Fort Collins, CO, USDA Forest Service, Rocky Mountain Research Station, 2011; 65, pp. 61–  
527 66.
- 528 6. Haase, D.L.; Davis, A.S. Developing and supporting quality nursery facilities and staff are  
529 necessary to meet global forest and landscape restoration needs. *Reforesta* **2017**, 69–93.
- 530 7. Pemán, J.; Chirino, E.; Espelta, J.M.; Jacobs, D.F.; Martín-Gómez, P.; Navarro-Cerrillo, R.; Oliet,  
531 J.A.; Vilagrosa, A.; Villar-Salvador, P.; Gil-Pelegrín, E. Physiological keys for natural and  
532 artificial regeneration of oaks. In *Oaks Physiological Ecology. Exploring the Functional Diversity of*  
533 *Genus Quercus L.*; Springer, 2017; pp. 453–511.
- 534 8. Landis, T.D.; Jacobs, D.F.; Wilkinson, K.M.; Luna, T. *Growing media*. In *Tropical Nursery Manual-*  
535 *A Guide to Starting and Operating a Nursery for Native and Traditional Plants*; Wilkinson, K.M.,  
536 Landis, T.D., Haase, D.L., Daley, B.F., Dumroese, R.K; Agriculture Handbook; USDA Forest  
537 Service, Washington DC, USA, 2014; 732, pp. 101-122.
- 538 9. Barrett, G.E.; Alexander, P.D.; Robinson, J.S.; Bragg, N.C. Achieving environmentally sustainable  
539 growing media for soilless plant cultivation systems—A review. *Sci. Hortic.* **2016**, *212*, 220–234.
- 540 10. Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. Containers and Growing Media. In *The*  
541 *Container Tree Nursery Manual*. Landis, T.D., Nisley, R.G.; Agriculture Handbook; USDA Forest  
542 service, Washington DC, USA, 1990; Vol. 2, pp. 41-85.
- 543 11. Tsakalimi, M.; Ganatsas, P. A synthesis of results on wastes as potting media substitutes for the  
544 production of native plant species. *Reforesta* **2016**, *1*, 147–163.
- 545 12. Caron, J.; Rochefort, L. Use of peat in growing media: State of the art on industrial and scientific  
546 efforts envisioning sustainability. *Acta hortic.* **2013**, *982*, 15-22.
- 547 13. Ángeles-Argáiz, R.E.; Flores-García, A.; Ulloa, M.; Garibay-Orijel, R. Commercial Sphagnum  
548 peat moss is a vector for exotic ectomycorrhizal mushrooms. *Biol. Invasions* **2016**, *18*, 89–101.
- 549 14. Schmilewski, G. Growing media constituents used in the EU in 2013. *Acta Hortic.* **2017**, *1168*, 85–  
550 92.
- 551 15. Apodaca, L.E. Peat in 2015. *Min. Eng.* **2016**, *68*, 3030.
- 552 16. Clarke, D.; Rieley, J. *Strategy for Responsible Peatland Management*, 6<sup>th</sup> ed.; International Peat  
553 Society, Jyväskylä, Finland, **2010**. pp. 10-25.
- 554 17. Schmilewski, G. The role of peat in assuring the quality of growing media. *Mires Peat* **2008**, *3*.
- 555 18. Michel, J.-C. The physical properties of peat: a key factor for modern growing media. **2010**.
- 556 19. Maher, M.; Prasad, M. Organic soilless media components. In *Soilless culture: Theory and practice*,  
557 1<sup>st</sup> ed.; Raviv, M., Lierh, J.H.; Elsevier Science, Amsterdam, 2008; 479-481.
- 558 20. Alexander, P.D.; Bragg, N.C.; Meade, R.; Padelopoulos, G.; Watts, O. Peat in horticulture and  
559 conservation: the UK response to a changing world. *Mires Peat* **2008**, *3*.
- 560 21. Carlile, B.; Coules, A. Towards sustainability in growing media. *Acta Hortic.* **2013**, 341–349.
- 561 22. Bonn, A.; Reed, M.S.; Evans, C.D.; Joosten, H.; Bain, C.; Farmer, J.; Emmer, I.; Couwenberg, J.;  
562 Moxey, A.; Artz, R. Investing in nature: Developing ecosystem service markets for peatland  
563 restoration. *Ecosyst. Serv.* **2014**, *9*, 54–65.
- 564 23. Rochefort, L.; Lode, E. Restoration of degraded boreal peatlands. In *Boreal peatland ecosystems*;  
565 Wieder, R.K., Vitt, D.H.; Springer, Berlin, Heidelberg, 2006; Volume 188, pp. 381–423.
- 566 24. Kimmel, K.; Mander, Ü. Ecosystem services of peatlands: Implications for restoration. *Prog. Phys.*  
567 *Geogr.* **2010**, *34*, 491–514.



- 568 25. Parry, L.E.; Holden, J.; Chapman, P.J. Restoration of blanket peatlands. *J. Environ. Manage.* **2014**,  
569 133, 193–205.
- 570 26. Dunn, C.; Freeman, C. Peatlands: our greatest source of carbon credits? *Carbon Manag.* **2011**, *2*,  
571 289–301.
- 572 27. Ugolini, F.; Mariotti, B.; Maltoni, A.; Tani, A.; Salbitano, F.; Izquierdo, C.G.; Macci, C.;  
573 Masciandaro, G.; Tognetti, R. A tree from waste: Decontaminated dredged sediments for  
574 growing forest tree seedlings. *J. Environ. Manage.* **2018**, *211*, 269–277.
- 575 28. Wallace, P.; Holmes, S.; Alexander, R.; England, J.; Gaze, R. *Review of growing media use and*  
576 *dominant materials (peat and alternatives) for growing media in other countries (European and*  
577 *International)*. Final Report, DEFRA project SP1206; **2010**.
- 578 29. Ceglie, F.G.; Bustamante, M.A.; Amara, M.B.; Tittarelli, F. The challenge of peat substitution in  
579 organic seedling production: optimization of growing media formulation through mixture  
580 design and response surface analysis. *PloS One* **2015**, *10*.
- 581 30. Gruda, N.S. Increasing sustainability of growing media constituents and stand-alone substrates  
582 in soilless culture systems. *Agronomy* **2019**, *9*, 298.
- 583 31. Handreck, K.A. Properties of coir dust, and its use in the formulation of soilless potting media.  
584 *Commun. Soil Sci. Plant Anal.* **1993**, *24*, 349–363.
- 585 32. Schmilewski, G. Peat covers 77 percent of the growing media production in the EU. *Peatl. Int.*  
586 **2008**, *1*, 39–43.
- 587 33. Nichols, M.A. Coir - A XXIst Century sustainable growing medium. *Acta Hortic.* **2007**, *747*, 91–  
588 95.
- 589 34. Blok, C.; Wever, G. Experience with selected physical methods to characterize the suitability of  
590 growing media for plant growth. *Acta Hortic.* **2008**, *779*, 239–250.
- 591 35. Poulter, R. Quantifying differences between treated and untreated coir substrate. *Acta Hortic.*  
592 **2014**, *1018*, 557–564.
- 593 36. Gruda, N. Current and future perspective of growing media in Europe. *Acta Hortic.* **2012**, *960*, 37–  
594 43.
- 595 37. Poorter, H.; Nagel, O. The role of biomass allocation in the growth response of plants to different  
596 levels of light, CO<sub>2</sub>, nutrients and water: a quantitative review. *Funct. Plant Biol.* **2000**, *27*, 1191–  
597 1191.
- 598 38. Poorter, H.; Niklas, K.J.; Reich, P.B.; Oleksyn, J.; Poot, P.; Mommer, L. Biomass allocation to  
599 leaves, stems and roots: meta-analyses of interspecific variation and environmental control. *New*  
600 *Phytol.* **2012**, *193*, 30–50.
- 601 39. Domínguez, M.T.; Aponte, C.; Pérez-Ramos, I.M.; García, L.V.; Villar, R.; Marañón, T.  
602 Relationships between leaf morphological traits, nutrient concentrations and isotopic signatures  
603 for Mediterranean woody plant species and communities. *Plant Soil* **2012**, *357*, 407–424.
- 604 40. Villar-Salvador, P.; Planelles, R.; Enriquez, E.; Rubira, J.P. Nursery cultivation regimes, plant  
605 functional attributes, and field performance relationships in the Mediterranean oak *Quercus ilex*  
606 L. *For. Ecol. Manag.* **2004**, *196*, 257–266.
- 607 41. Hernández, E.I.; Vilagrosa, A.; Luis, V.C.; Llorca, M.; Chirino, E.; Vallejo, V.R. Root hydraulic  
608 conductance, gas exchange and leaf water potential in seedlings of *Pistacia lentiscus* L. and  
609 *Quercus suber* L. grown under different fertilization and light regimes. *Environ. Exp. Bot.* **2009**,  
610 *67*, 269–276.
- 611 42. Grossnickle, S.C. Why seedlings survive: influence of plant attributes. *New For.* **2012**, *43*, 711–738.
- 612 43. Cortina, J.; Vilagrosa, A.; Trubat, R. The role of nutrients for improving seedling quality in  
613 drylands. *New For.* **2013**, *44*, 719–732.
- 614 44. Grossnickle, S.C.; MacDonald, J.E. Seedling Quality: History, application, and plant attributes.  
615 *Forests* **2018**, *9*, 283.
- 616 45. Oliet, J.A.; Planelles, R.; Artero, F.; Jacobs, D.F. Nursery fertilization and tree shelters affect long-  
617 term field response of *Acacia salicina* Lindl. planted in Mediterranean semiarid conditions. *For.*  
618 *Ecol. Manag.* **2005**, *215*, 339–351.

- 619 46. Ovalle, J.F.; Arellano, E.C.; Oliet, J.A.; Becerra, P.; Ginocchio, R. Linking nursery nutritional status  
620 and water availability post-planting under intense summer drought: the case of a South  
621 American Mediterranean tree species. *IForest-Biogeosciences For.* **2016**, *9*, 758.
- 622 47. Oliet, J.A.; Salazar, J.M.; Villar, R.; Robredo, E.; Valladares, F. Fall fertilization of Holm oak affects  
623 N and P dynamics, root growth potential, and post-planting phenology and growth. *Ann. For.*  
624 *Sci.* **2011**, *68*, 647–656.
- 625 48. Villar-Salvador, P.; Valladares, F.; Domínguez-Lerena, S.; Ruiz-Díez, B.; Fernández-Pascual, M.;  
626 Delgado, A.; Peñuelas, J.L. Functional traits related to seedling performance in the  
627 Mediterranean leguminous shrub *Retama sphaerocarpa*: insights from a provenance,  
628 fertilization, and rhizobial inoculation study. *Environ. Exp. Bot.* **2008**, *64*, 145–154.
- 629 49. Lambers, H.; Shane, M.W.; Cramer, M.D.; Pearse, S.J.; Veneklaas, E.J. Root structure and  
630 functioning for efficient acquisition of phosphorus: matching morphological and physiological  
631 traits. *Ann. Bot.* **2006**, *98*, 693–713.
- 632 50. Trubat, R.; Cortina, J.; Vilagrosa, A. Plant morphology and root hydraulics are altered by nutrient  
633 deficiency in *Pistacia lentiscus* (L.). *Trees* **2006**, *20*, 334.
- 634 51. Lynch, J.P. Root phenes for enhanced soil exploration and phosphorus acquisition: tools for  
635 future crops. *Plant Physiol.* **2011**, *156*, 1041–1049.
- 636 52. Trubat, R.; Cortina, J.; Vilagrosa, A. Root architecture and hydraulic conductance in nutrient  
637 deprived *Pistacia lentiscus* L. seedlings. *Oecologia* **2012**, *170*, 899–908.
- 638 53. Lugli, L.F.; Anderson, K.M.; Aragão, L.E.; Cordeiro, A.L.; Cunha, H.F.; Fuchslueger, L.; Meir, P.;  
639 Mercado, L.M.; Oblitas, E.; Quesada, C.A.; Rosa, J.S.; Schaap, K.J.; Valverde-Barrantes, O.;  
640 Hartley, I.P. Multiple phosphorus acquisition strategies adopted by fine roots in low-fertility  
641 soils in Central Amazonia. *Plant Soil*, **2019**, 1–15.
- 642 54. Fernández, M.; Marcos, C.; Tapias, R.; Ruiz, F.; López, G. Nursery fertilisation affects the frost-  
643 tolerance and plant quality of *Eucalyptus globulus* Labill. cuttings. *Ann. For. Sci.* **2007**, *64*, 865–  
644 873.
- 645 55. Oliet, J.A.; Planelles, R.; Artero, F.; Valverde, R.; Jacobs, D.F.; Segura, M.L. Field performance of  
646 *Pinus halepensis* planted in Mediterranean arid conditions: relative influence of seedling  
647 morphology and mineral nutrition. *New For.* **2009**, *37*, 313–331.
- 648 56. Oliet, J.A.; Puértolas, J.; Planelles, R.; Jacobs, D.F. Nutrient loading of forest tree seedlings to  
649 promote stress resistance and field performance: a Mediterranean perspective. *New For.* **2013**, *44*,  
650 649–669.
- 651 57. Egilla, J.N.; Davies, F.T.; Drew, M.C. Effect of potassium on drought resistance of *Hibiscus rosa-*  
652 *sinensis* cv. Leprechaun: Plant growth, leaf macro- and micronutrient content and root longevity.  
653 *Plant Soil* **2001**, *229*, 213–224.
- 654 58. Egilla, J.N.; Davies, F.T.; Boutton, T.W. Drought stress influences leaf water content,  
655 photosynthesis, and water-use efficiency of *Hibiscus rosa-sinensis* at three potassium  
656 concentrations. *Photosynthetica* **2005**, *43*, 135–140.
- 657 59. Asgharipour, M.R.; Heidari, M. Effect of potassium supply on drought resistance in sorghum:  
658 plant growth and macronutrient content. *Pak J Agri Sci* **2011**, *48*, 197–204.
- 659 60. Ragel, P.; Raddatz, N.; Leidi, E.O.; Quintero, F.J.; Pardo, J.M. Regulation of K<sup>+</sup> nutrition in plants.  
660 *Front. Plant Sci.* **2019**, *10*.
- 661 61. Rose, R.; Haase, D.L. The use of coir as a containerized growing medium for Douglas-fir  
662 seedlings. *Native Plants J.* **2000**, *1*, 107–111.
- 663 62. Radjagukguk, B.; Soeseno, O. A comparative study of peats and other media for containerized  
664 forest tree seedlings. *Acta Hort.* **1983**, 449–458.
- 665 63. Oliet, J.A.; Jacobs, D.F. Restoring forests: advances in techniques and theory. *New For.* **2012**, *43*,  
666 535–541.
- 667 64. Leverkus, A.B.; Castro, J.; Delgado-Capel, M.J.; Molinas-González, C.; Pulgar, M.; Marañón-  
668 Jiménez, S.; Delgado-Huertas, A.; Querejeta, J.I. Restoring for the present or restoring for the  
669 future: enhanced performance of two sympatric oaks (*Quercus ilex* and *Quercus pyrenaica*)  
670 above the current forest limit. *Restor. Ecol.* **2015**, *23*, 936–946.

- 671 65. Madrigal-González, J.; Ruiz-Benito, P.; Ratcliffe, S.; Rigling, A.; Wirth, C.; Zimmermann, N.E.;  
672 Zweifel, R.; Zavala, M.A. Competition Drives Oak Species Distribution and Functioning in  
673 Europe: Implications Under Global Change. In *Oaks Physiological Ecology. Exploring the Functional*  
674 *Diversity of Genus Quercus L.*; Gil-Pelegrín, E., Peguero-Pina, J.J., Sancho-Knapik, D.; Springer,  
675 New York, USA, 2017; pp. 513–538.
- 676 66. Löf, M.; Castro, J.; Engman, M.; Leverkus, A.B.; Madsen, P.; Reque, J.A.; Villalobos, A.; Gardiner,  
677 E.S. Tamm Review: Direct seeding to restore oak (*Quercus* spp.) forests and woodlands. *For.*  
678 *Ecol. Manag.* **2019**, *448*, 474–489.
- 679 67. Gil-Pelegrín, E.; Saz, M.Á.; Cuadrat, J.M.; Peguero-Pina, J.J.; Sancho-Knapik, D. Oaks under  
680 Mediterranean-type climates: functional response to summer aridity. In *Oaks Physiological*  
681 *Ecology. Exploring the Functional Diversity of Genus Quercus L.*; Gil-Pelegrín, E., Peguero-Pina, J.J.,  
682 Sancho-Knapik, D.; Springer, New York, USA, 2017; pp. 137–193.
- 683 68. Ducouso, A.; Bordacs, S. *EUFORGEN Technical Guidelines for genetic conservation and use for*  
684 *Pedunculate and sessile oaks (Quercus robur) and (Quercus petraea)*; International Plant Genetic  
685 Resources Institute, Rome, Italy, 2004.
- 686 69. Löf, M.; Bolte, A.; Jacobs, D.F.; Jensen, A.M. Nurse trees as a forest restoration tool for mixed  
687 plantations: effects on competing vegetation and performance in target tree species. *Restor. Ecol.*  
688 **2014**, *22*, 758–765.
- 689 70. Strasser, R.J.; Tsimilli-Michael, M.; Srivastava, A. Analysis of the Chlorophyll a Fluorescence  
690 Transient. In *Chlorophyll a Fluorescence: A Signature of Photosynthesis*; Papageorgiou, G.C.,  
691 Govindjee, Eds.; Advances in Photosynthesis and Respiration; Springer Netherlands: Dordrecht,  
692 2004; pp. 321–362 ISBN 978-1-4020-3218-9.
- 693 71. Villar-Salvador, P.; Heredia, N.; Millard, P. Remobilization of acorn nitrogen for seedling growth  
694 in holm oak (*Quercus ilex*), cultivated with contrasting nutrient availability. *Tree Physiol.* **2010**,  
695 *30*, 257–263.
- 696 72. García-Cebrián, F.; Esteso-Martínez, J.; Gil-Pelegrín, E. Influence of cotyledon removal on early  
697 seedling growth in *Quercus robur* L. *Ann. For. Sci.* **2003**, *60*, 69–73.
- 698 73. Quero, J.L.; Villar, R.; Marañón, T.; Zamora, R.; Poorter, L. Seed-mass effects in four  
699 Mediterranean *Quercus* species (Fagaceae) growing in contrasting light environments. *Am. J.*  
700 *Bot.* **2007**, *94*, 1795–1803.
- 701 74. Chirino, E.; Vilagrosa, A.; Hernández, E.I.; Matos, A.; Vallejo, V.R. Effects of a deep container on  
702 morpho-functional characteristics and root colonization in *Quercus suber* L. seedlings for  
703 reforestation in Mediterranean climate. *For. Ecol. Manag.* **2008**, *256*, 779–785.
- 704 75. Mariotti, B.; Maltoni, A.; Jacobs, D.F.; Tani, A. Container effects on growth and biomass allocation  
705 in *Quercus robur* and *Juglans regia* seedlings. *Scand. J. For. Res.* **2015**, *30*, 401–415.
- 706 76. Mariotti, B.; Maltoni, A.; Jacobs, D.F.; Tani, A. Tree shelters affect shoot and root system growth  
707 and structure in *Quercus robur* during regeneration establishment. *Eur. J. For. Res.* **2015**, *134*,  
708 641–652.
- 709 77. Offord, C.A.; Muir, S.; Tyler, J.L. Growth of selected Australian plants in soilless media using  
710 coir as a substitute for peat. *Aust. J. Exp. Agric.* **1998**, *38*, 879–887.
- 711 78. Handreck, K.A. Immobilization of nitrogen in potting media. *Acta Hort.* **1993**, *342*, 121–126.
- 712 79. Grantzau, E.; Gennrich, J.; DP, D. Mit Kokos Substrate verbessern. *Gb Gw* **1993**, *11*, 538–541.
- 713 80. Noguera, P.; Abad, M.; Noguera, V.; Puchades, R.; Maquieira, A. Coconut coir waste, a new and  
714 viable ecologically-friendly peat substitute. *Acta Hort.* **2000**, *517*, 279–286.
- 715 81. Meerow, A.W. Growth of two subtropical ornamentals using coir (coconut mesocarp pith) as a  
716 peat substitute. *HortScience* **1994**, *29*, 1484–1486.
- 717 82. Stamps, R.H.; Evans, M.R. Growth of *Dracaena marginata* and *Spathiphyllum 'Petite'* in  
718 sphagnum peat-and coconut coir dust-based growing media. *J. Environ. Hort.* **1999**, *17*, 49–52.
- 719 83. Jacobs, D.F.; Timmer, V.R. Fertilizer-induced changes in rhizosphere electrical conductivity:  
720 relation to forest tree seedling root system growth and function. *New For.* **2005**, *30*, 147–166.
- 721 84. Evans, M.R.; Konduru, S.; Stamps, R.H. Source variation in physical and chemical properties of  
722 coconut coir dust. *HortScience* **1996**, *31*, 965–967.

- 723 85. Noguera, P.; Abad, M.; Puchades, R.; Noguera, V.; Maquieira, A.; Martinez, J. Physical and  
724 chemical properties of coir waste and their relation to plant growth. *Acta Hort.* **1997**, *450*, 365-  
725 374.
- 726 86. Wang, M.; Zheng, Q.; Shen, Q.; Guo, S. The critical role of potassium in plant stress response. *Int.*  
727 *J. Mol. Sci.* **2013**, *14*, 7370–7390.
- 728 87. Tripler, C.E.; Kaushal, S.S.; Likens, G.E.; Todd Walter, M. Patterns in potassium dynamics in  
729 forest ecosystems. *Ecol. Lett.* **2006**, *9*, 451–466.
- 730 88. Santiago, L.S.; Wright, S.J.; Harms, K.E.; Yavitt, J.B.; Korine, C.; Garcia, M.N.; Turner, B.L.  
731 Tropical tree seedling growth responses to nitrogen, phosphorus and potassium addition. *J. Ecol.*  
732 **2012**, *100*, 309–316.
- 733 89. Soliveres, S.; Maestre, F.T. Plant–plant interactions, environmental gradients and plant diversity:  
734 a global synthesis of community-level studies. *Perspect. Plant Ecol. Evol. Syst.* **2014**, *16*, 154–163.
- 735 90. Soto Castelblanco, C.V. Comparación de los componentes orgánicos Fibra de Coco y Turba  
736 Rubia, para la producción de planta forestal de vivero en las especies; *Pinus pinaster*, *Pinus*  
737 *nigra*, *Pinus halepensis* y *Quercus ilex*. Master thesis, Universidad Politecnica de Madrid, 2016.
- 738 91. Uscola, M.; Salifu, K.F.; Oliet, J.A.; Jacobs, D.F. An exponential fertilization dose–response model  
739 to promote restoration of the Mediterranean oak *Quercus ilex*. *New For.* **2015**, *46*, 795–812.
- 740 92. Salifu, K.F.; Jacobs, D.F. Characterizing fertility targets and multi-element interactions in nursery  
741 culture of *Quercus rubra* seedlings. *Ann. For. Sci.* **2006**, *63*, 231–237.
- 742 93. Villar-Salvador, P.; Peñuelas, J.L.; Nicolás-Peragón, J.L.; Benito, L.F.; Domínguez-Lerena, S. Is  
743 nitrogen fertilization in the nursery a suitable tool for enhancing the performance of  
744 Mediterranean oak plantations? *New For.* **2013**, *44*, 733–751.
- 745 94. Niu, Y.F.; Chai, R.S.; Jin, G.L.; Wang, H.; Tang, C.X.; Zhang, Y.S. Responses of root architecture  
746 development to low phosphorus availability: a review. *Ann. Bot.* **2013**, *112*, 391–408.
- 747 95. Postma, J.A.; Dathé, A.; Lynch, J.P. The optimal lateral root branching density for maize depends  
748 on nitrogen and phosphorus availability. *Plant Physiol.* **2014**, *166*, 590–602.
- 749 96. Péret, B.; Desnos, T.; Jost, R.; Kanno, S.; Berkowitz, O.; Nussaume, L. Root architecture responses:  
750 in search of phosphate. *Plant Physiol.* **2014**, *166*, 1713–1723.
- 751 97. Colla, G.; Roupheal, Y.; Possanzini, G.; Cardarelli, M.; Temperini, O.; Saccardo, F.; Pierandrei, F.;  
752 Rea, E. Coconut coir as a potting media for organic lettuce transplant production. *Acta Hort.*  
753 **2007**, *747*, 293–296.
- 754 98. Del Campo, A.D.; Navarro, R.M.; Ceacero, C.J. Seedling quality and field performance of  
755 commercial stocklots of containerized holm oak (*Quercus ilex*) in Mediterranean Spain: an  
756 approach for establishing a quality standard. *New For.* **2010**, *39*, 19.
- 757 99. Lloret, F.; Casanovas, C.; Penuelas, J. Seedling survival of Mediterranean shrubland species in  
758 relation to root: shoot ratio, seed size and water and nitrogen use. *Funct. Ecol.* **1999**, *13*, 210–216.
- 759 100. Zida, D.; Tigabu, M.; Sawadogo, L.; Odén, P.C. Initial seedling morphological characteristics and  
760 field performance of two Sudanian savanna species in relation to nursery production period and  
761 watering regimes. *For. Ecol. Manag.* **2008**, *255*, 2151–2162.
- 762 101. Chulaka, P.; Maruo, T.; Takagaki, M.; Shinohara, Y. Organic substrates of tropical origin as an  
763 alternative to growing media for chili and cucumber transplant production. *Jpn. J. Trop. Agric.*  
764 **2004**, *48*, 79–87.
- 765 102. Wilson, S.B.; Muller, K.L.; Wilson, P.C.; Incer, M.R.; Stoffella, P.J.; Graetz, D.A. Evaluation of new  
766 container media for *Aglaonema* production. *Commun. Soil Sci. Plant Anal.* **2009**, *40*, 2673–2687.
- 767 103. Sardans, J.; Peñuelas, J.; Rodà, F. Plasticity of leaf morphological traits, leaf nutrient content, and  
768 water capture in the Mediterranean evergreen oak *Quercus ilex* subsp. *ballota* in response to  
769 fertilization and changes in competitive conditions. *Ecoscience* **2006**, *13*, 258–270.
- 770 104. Vollmar, A.; Gunderson, C. Physiological adjustments of leaf respiration to atmospheric  
771 warming in *Betula alleghaniensis* and *Quercus rubra*. *J. Undergrad. Res.* **2006**, *6*.
- 772 105. Salifu, K.F.; Apostol, K.G.; Jacobs, D.F.; Islam, M.A. Growth, physiology, and nutrient  
773 retranslocation in nitrogen-15 fertilized *Quercus rubra* seedlings. *Ann. For. Sci.* **2008**, *65*, 101–101.

- 774 106. Oliet, J.A.; Tejada, M.; Salifu, K.F.; Collazos, A.; Jacobs, D.F. Performance and nutrient dynamics  
775 of holm oak (*Quercus ilex* L.) seedlings in relation to nursery nutrient loading and post-  
776 transplant fertility. *Eur. J. For. Res.* **2009**, *128*, 253–263.
- 777 107. Dumroese, R.K.; Page-Dumroese, D.S.; Salifu, K.F.; Jacobs, D.F. Exponential fertilization of *Pinus*  
778 *monticola* seedlings: nutrient uptake efficiency, leaching fractions, and early outplanting  
779 performance. *Can. J. For. Res.* **2005**, *35*, 2961–2967.
- 780 108. Berger, T.W.; Glatzel, G. Response of *Quercus petraea* seedlings to nitrogen fertilization. *For.*  
781 *Ecol. Manag.* **2001**, *149*, 1–14.
- 782 109. Bigg, W.L.; Schalau, J.W. Mineral nutrition and the target seedling. In *Target seedling symposium:*  
783 *proceedings, Combined Meeting of the Western Forest Nursery Associations, Roseburg, Oregon,*  
784 *August 1990; USDA Forest Service, Fort Collins, Colorado; USA; 1990, pp. 139-160.*
- 785 110. Folk, R.S.; Grossnickle, S.C. Stock-type patterns of phosphorus uptake, retranslocation, net  
786 photosynthesis and morphological development in interior spruce seedlings. *New For.* **2000**, *19*,  
787 27–49.
- 788 111. Sardans, J.; Peñuelas, J. Increasing drought decreases phosphorus availability in an evergreen  
789 Mediterranean forest. *Plant Soil* **2004**, *267*, 367–377.
- 790 112. Sun, Y.; Gu, J.-C.; Zhuang, H.-F.; Wang, Z.-Q. Effects of ectomycorrhizal colonization and  
791 nitrogen fertilization on morphology of root tips in a *Larix gmelinii* plantation in northeastern  
792 China. *Ecol. Res.* **2010**, *25*, 295–302.
- 793 113. Pascual, S.; Olarieta, J.R.; Rodríguez-Ochoa, R. Development of *Quercus ilex* plantations is  
794 related to soil phosphorus availability on shallow calcareous soils. *New For.* **2012**, *43*, 805–814.
- 795 114. Andivia, E.; Fernández, M.; Vázquez-Piqué, J. Autumn fertilization of *Quercus ilex* ssp. *ballota*  
796 (Desf.) Samp. nursery seedlings: effects on morpho-physiology and field performance. *Ann. For.*  
797 *Sci.* **2011**, *68*, 543.
- 798 115. Oliet, J.A.; Planelles, R.; López, M.; Artero, F. Efecto de la fertilización en vivero sobre la  
799 supervivencia en plantación de *Pinus halepensis* Mill. *Investig. Agrar. Sist. Recur. For.* **1997**, *8*,  
800 207–228.
- 801 116. Puértolas, J.; Gil, L.; Pardos, J.A. Effects of nutritional status and seedling size on field  
802 performance of *Pinus halepensis* planted on former arable land in the Mediterranean basin.  
803 *Forestry* **2003**, *76*, 159–168.
- 804 117. Del Campo, A.D.; Hermoso, J.; Flors, J.; Lidón, A.; Navarro-Cerrillo, R.M. Nursery location and  
805 potassium enrichment in Aleppo pine stock 2. Performance under real and hydrogel-mediated  
806 drought conditions. *Forestry* **2011**, *84*, 235–245.
- 807 118. Grossnickle, S.C. Importance of root growth in overcoming planting stress. *New For.* **2005**, *30*,  
808 273–294.
- 809



© 2020 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

811 **Supplementary Material**

812

813 **Table S1:** Macro-elements (NPK) content (per volume and per seedling) in the studied fertilizations.

814

	Content per volume mg/l			Content per seedling (mg per pot)		
	N	P	K	N	P	K
<i>Standard</i>	450	270	330	292,5	175,5	214,5
<i>P enriched</i>	450	690	330	292,5	448,5	214,5
<i>K enriched</i>	440	440	720	286	286	468

815

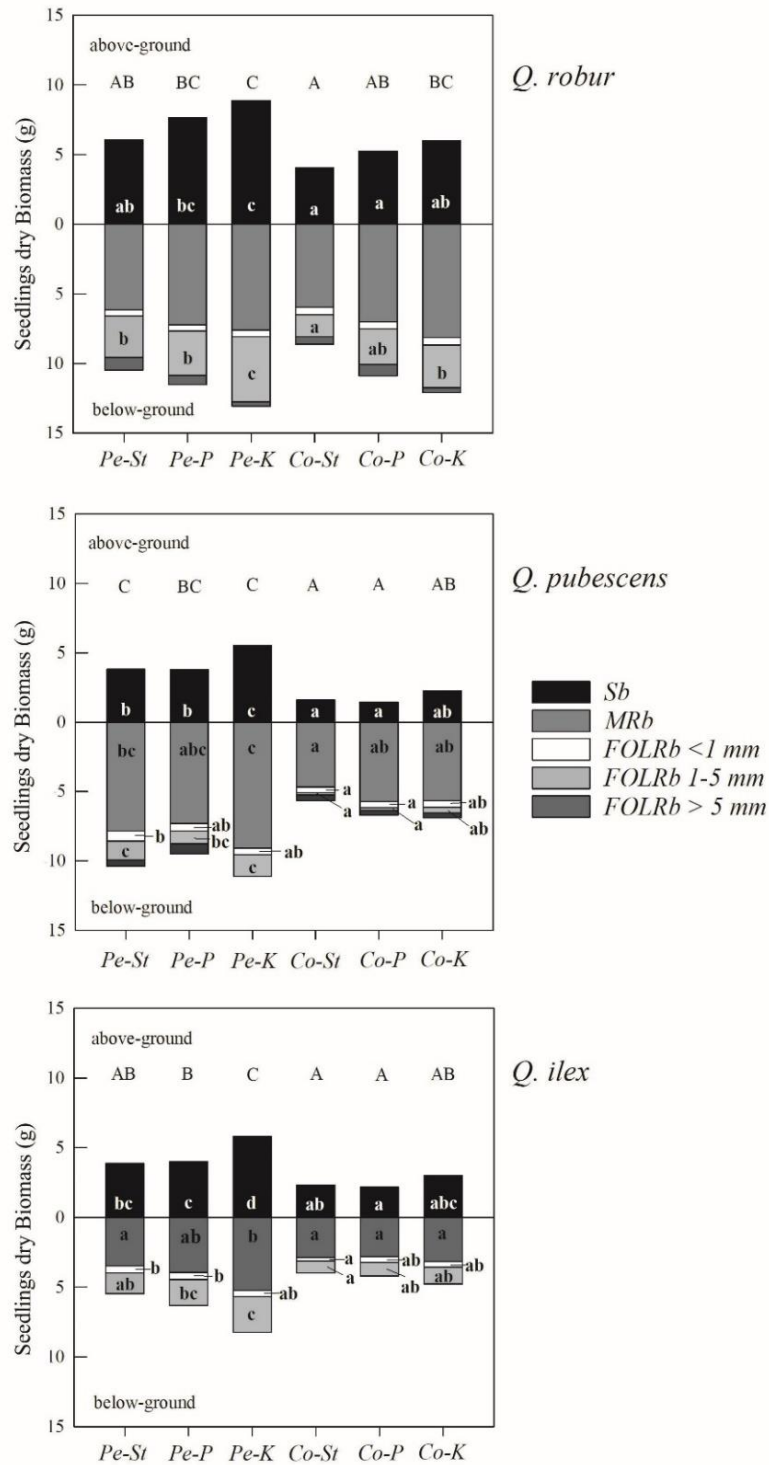
816

817

**Table S2:** Multifactorial ANOVA and Tukey post hoc test results ( $p \leq 0.05$  in bold) for seedling morphological traits (mean  $\pm$  SD) at the end of the season ( $N_{\text{obs}} = 20$  seedlings per stocktype). Source of variation: substrate (S), fertilization (F), and their interaction (SxF). Lowercase letters indicate homogeneous groups. Variables: *H*: height; *RcD* (root collar diameter in mm); *H/RcD* (seedling taper); *Rv* (root-system volume in  $\text{cm}^3$ ); *Rd* (root-system density= $\text{Rb/Rv}$  in  $\text{g cm}^{-3}$ ); *S/R* (shoot-root ratio); *SLA* (specific leaf area, in  $\text{cm}^2 \text{g}^{-1}$ ); *Ln* (number of leaves); *Lb* (leaf dry biomass in g).

<i>Q. robur</i>	<i>Pe-St</i>	<i>Pe-P</i>	<i>Pe-K</i>	<i>Co-St</i>	<i>Co-P</i>	<i>Co-K</i>
<i>H</i>	53.51 $\pm$ 9.94 <b>abc</b>	58.12 $\pm$ 10.91 <b>bc</b>	61.15 $\pm$ 10.67 <b>c</b>	43.09 $\pm$ 10.62 <b>a</b>	44.82 $\pm$ 9.61 <b>a</b>	49.60 $\pm$ 10.08 <b>ab</b>
<i>RcD</i>	10.3 $\pm$ 1.8 <b>ab</b>	11.6 $\pm$ 1.9 <b>b</b>	11.6 $\pm$ 1.9 <b>b</b>	9.9 $\pm$ 1.8 <b>a</b>	10.9 $\pm$ 1.6 <b>ab</b>	11.6 $\pm$ 1.2 <b>b</b>
<i>H/RcD</i>	53.2 $\pm$ 13.8 <b>b</b>	50.7 $\pm$ 8.9 <b>ab</b>	53.8 $\pm$ 11.7 <b>b</b>	43.7 $\pm$ 9.4 <b>a</b>	41.6 $\pm$ 8.5 <b>a</b>	43.3 $\pm$ 9.7 <b>a</b>
<i>Rv</i>	22.6 $\pm$ 6.4 <b>ab</b>	27.0 $\pm$ 8.2 <b>b</b>	34.4 $\pm$ 8.7 <b>c</b>	19.4 $\pm$ 5.2 <b>a</b>	26.9 $\pm$ 7.9 <b>b</b>	27.6 $\pm$ 7.6 <b>b</b>
<i>Rd</i>	0.46 $\pm$ 0.08 <b>ab</b>	0.43 $\pm$ 0.06 <b>ab</b>	0.38 $\pm$ 0.05 <b>a</b>	0.47 $\pm$ 0.12 <b>b</b>	0.41 $\pm$ 0.07 <b>ab</b>	0.44 $\pm$ 0.06 <b>ab</b>
<i>S/R</i>	0.59 $\pm$ 0.15 <b>bc</b>	0.66 $\pm$ 0.08 <b>c</b>	0.70 $\pm$ 0.16 <b>c</b>	0.46 $\pm$ 0.16 <b>a</b>	0.49 $\pm$ 0.13 <b>ab</b>	0.52 $\pm$ 0.16 <b>ab</b>
<i>SLA</i>	155.2 $\pm$ 22.8 <b>ab</b>	145.9 $\pm$ 38.5 <b>ab</b>	167.0 $\pm$ 20.5 <b>b</b>	138.8 $\pm$ 13.4 <b>a</b>	138.6 $\pm$ 24.4 <b>a</b>	148.8 $\pm$ 13.0 <b>ab</b>
<i>Ln</i>	46.2 $\pm$ 12.4 <b>ab</b>	51.1 $\pm$ 25.2 <b>ab</b>	72.5 $\pm$ 30.0 <b>c</b>	37.1 $\pm$ 12.7 <b>a</b>	44.9 $\pm$ 18.2 <b>ab</b>	59.8 $\pm$ 20.7 <b>bc</b>
<i>Lb</i>	3.58 $\pm$ 1.06 <b>ab</b>	4.40 $\pm$ 1.15 <b>b</b>	5.56 $\pm$ 1.50 <b>c</b>	2.75 $\pm$ 1.06 <b>a</b>	3.60 $\pm$ 1.25 <b>ab</b>	3.91 $\pm$ 1.25 <b>b</b>
<i>Q. pubescens</i>	<i>Pe-St</i>	<i>Pe-P</i>	<i>Pe-K</i>	<i>Co-St</i>	<i>Co-P</i>	<i>Co-K</i>
<i>H</i>	34.29 $\pm$ 10.13 <b>bc</b>	33.38 $\pm$ 10.06 <b>bc</b>	42.75 $\pm$ 12.39 <b>c</b>	21.41 $\pm$ 6.78 <b>a</b>	20.67 $\pm$ 8.08 <b>a</b>	25.14 $\pm$ 9.17 <b>ab</b>
<i>RcD</i>	10.1 $\pm$ 1.8 <b>abc</b>	10.3 $\pm$ 2.0 <b>bc</b>	11.6 $\pm$ 1.6 <b>c</b>	9.4 $\pm$ 1.9 <b>ab</b>	8.4 $\pm$ 2.3 <b>a</b>	10.2 $\pm$ 2.2 <b>abc</b>
<i>H/RcD</i>	34.5 $\pm$ 11.0 <b>c</b>	32.8 $\pm$ 9.6 <b>bc</b>	37.1 $\pm$ 10.4 <b>c</b>	23.2 $\pm$ 6.5 <b>a</b>	24.8 $\pm$ 7.5 <b>ab</b>	24.5 $\pm$ 7.8 <b>a</b>
<i>Rv</i>	28.7 $\pm$ 13.5 <b>c</b>	22.7 $\pm$ 8.0 <b>bc</b>	25.9 $\pm$ 8.8 <b>c</b>	13.1 $\pm$ 3.5 <b>a</b>	15.0 $\pm$ 7.4 <b>ab</b>	16.7 $\pm$ 6.5 <b>ab</b>
<i>Rd</i>	0.38 $\pm$ 0.07 <b>a</b>	0.42 $\pm$ 0.06 <b>ab</b>	0.42 $\pm$ 0.06 <b>ab</b>	0.45 $\pm$ 0.07 <b>b</b>	0.45 $\pm$ 0.06 <b>b</b>	0.41 $\pm$ 0.04 <b>ab</b>
<i>S/R</i>	0.37 $\pm$ 0.10 <b>bc</b>	0.42 $\pm$ 0.14 <b>cd</b>	0.51 $\pm$ 0.13 <b>d</b>	0.28 $\pm$ 0.10 <b>ab</b>	0.19 $\pm$ 0.07 <b>a</b>	0.33 $\pm$ 0.13 <b>bc</b>
<i>SLA</i>	102.7 $\pm$ 8.6	105.5 $\pm$ 17.5	105.7 $\pm$ 13.1	100.0 $\pm$ 9.4	102.1 $\pm$ 8.8	99.7 $\pm$ 8.2
<i>Ln</i>	62.8 $\pm$ 34.6 <b>c</b>	51.6 $\pm$ 24.2 <b>bc</b>	67.2 $\pm$ 19.8 <b>c</b>	30.2 $\pm$ 7.5 <b>a</b>	31.8 $\pm$ 8.8 <b>a</b>	42.7 $\pm$ 21.7 <b>ab</b>
<i>Lb</i>	4.41 $\pm$ 1.49 <b>b</b>	3.74 $\pm$ 1.30 <b>b</b>	4.82 $\pm$ 1.69 <b>b</b>	1.88 $\pm$ 0.78 <b>a</b>	1.95 $\pm$ 0.92 <b>a</b>	2.52 $\pm$ 1.39 <b>a</b>
<i>Q. ilex</i>	<i>Pe-St</i>	<i>Pe-P</i>	<i>Pe-K</i>	<i>Co-St</i>	<i>Co-P</i>	<i>Co-K</i>
<i>H</i>	48.36 $\pm$ 10.90 <b>bc</b>	49.90 $\pm$ 12.00 <b>cd</b>	59.93 $\pm$ 13.80 <b>d</b>	33.37 $\pm$ 10.38 <b>a</b>	33.65 $\pm$ 8.95 <b>a</b>	37.87 $\pm$ 11.31 <b>ab</b>
<i>RcD</i>	8.3 $\pm$ 0.8	8.4 $\pm$ 1.4	8.8 $\pm$ 1.0	7.9 $\pm$ 1.7	7.4 $\pm$ 1.6	8.2 $\pm$ 1.5
<i>H/RcD</i>	58.4 $\pm$ 11.8 <b>bc</b>	60.1 $\pm$ 12.9 <b>c</b>	69.6 $\pm$ 18.8 <b>c</b>	41.8 $\pm$ 9.2 <b>a</b>	47.0 $\pm$ 15.9 <b>ab</b>	46.3 $\pm$ 11.0 <b>ab</b>
<i>Rv</i>	12.2 $\pm$ 4.1 <b>ab</b>	15.4 $\pm$ 6.0 <b>bc</b>	17.0 $\pm$ 3.3 <b>c</b>	9.4 $\pm$ 3.8 <b>a</b>	10.3 $\pm$ 3.2 <b>a</b>	12.2 $\pm$ 5.5 <b>ab</b>
<i>Rd</i>	0.46 $\pm$ 0.12	0.41 $\pm$ 0.09	0.49 $\pm$ 0.07	0.45 $\pm$ 0.14	0.42 $\pm$ 0.07	0.43 $\pm$ 0.15
<i>S/R</i>	0.73 $\pm$ 0.23 <b>b</b>	0.71 $\pm$ 0.36 <b>ab</b>	0.70 $\pm$ 0.10 <b>ab</b>	0.62 $\pm$ 0.25 <b>ab</b>	0.51 $\pm$ 0.13 <b>a</b>	0.65 $\pm$ 0.25 <b>ab</b>
<i>SLA</i>	78.0 $\pm$ 7.3 <b>b</b>	70.7 $\pm$ 8.7 <b>a</b>	71.9 $\pm$ 6.3 <b>a</b>	68.1 $\pm$ 3.6 <b>a</b>	70.7 $\pm$ 5.3 <b>a</b>	72.5 $\pm$ 6.6 <b>ab</b>
<i>Ln</i>	46.9 $\pm$ 14.3 <b>bc</b>	44.5 $\pm$ 13.8 <b>b</b>	56.8 $\pm$ 16.6 <b>c</b>	30.3 $\pm$ 13.7 <b>a</b>	27.5 $\pm$ 6.0 <b>a</b>	32.3 $\pm$ 12.1 <b>a</b>
<i>Lb</i>	4.63 $\pm$ 1.12 <b>b</b>	4.92 $\pm$ 1.81 <b>b</b>	6.15 $\pm$ 1.21 <b>c</b>	2.70 $\pm$ 1.26 <b>a</b>	2.83 $\pm$ 1.03 <b>a</b>	3.08 $\pm$ 1.27 <b>a</b>

**Figure S1:** Multifactorial ANOVA and Tukey post hoc test results ( $p \leq 0.05$ ) for seedling dry biomass (g) allocation at the end of the growing season ( $N_{obs}=20$  per stocktype per species). Source of variation substrate (S) fertilization (F) and their interaction (SxF). *Sb*: shoot-system dry biomass; *MRb*: main root dry biomass; *FOLRb*: dry biomass of First Order Lateral Root split by diameter class (<1 mm, 1-5 mm, >5 mm). Capital letters indicate homogenous groups for total biomass while lowercase letters indicate homogenous groups for the remaining variables. *Pe*= Peat; *Co*=Coir; *St*=Standard fertilization; *K*=K-enriched fertilization; *P*=P-enriched fertilization.





**Figure S2:** Macro-element concentration ( $\text{mg g}^{-1}$  for N, P, K) in leaves, shoot-system and root-system in stocktypes (mean  $\pm$  SD). Source of variation substrate (S), fertilization (F) and their interaction (SxF). Lowercase letters indicate homogenous groups. *Pe*= Peat; *Co*=Coir; *St*=Standard fertilization; *K*=K-enriched fertilization; *P*=P-enriched fertilization.

