

ARCHIVIO ISTITUZIONALE DELLA RICERCA

Alma Mater Studiorum Università di Bologna Archivio istituzionale della ricerca

Mid-term (30 years) changes of soil properties under chestnut stands due to organic residues management: An integrated study

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version: Mid-term (30 years) changes of soil properties under chestnut stands due to organic residues management: An integrated study / De Feudis M.; Falsone G.; Vittori Antisari L. - In: CATENA. - ISSN 0341-8162. - ELETTRONICO. - 198:March 2021(2021), pp. 105021.1-105021.11. [10.1016/j.catena.2020.105021]

This version is available at: https://hdl.handle.net/11585/792427 since: 2021-01-28

Published:

DOI: http://doi.org/10.1016/j.catena.2020.105021

Terms of use:

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

(Article begins on next page)

This item was downloaded from IRIS Università di Bologna (https://cris.unibo.it/). When citing, please refer to the published version.

Elsevier Editorial System(tm) for Catena Manuscript Draft

Manuscript Number: CATENA11740R1

Title: Mid-term (30 years) changes of soil properties under chestnut stands due to organic residues management: An integrated study

Article Type: Research Paper

Keywords: chestnut management; mountain soil; organic carbon dynamics; litter floor, soil development

Corresponding Author: Dr. Mauro De Feudis,

Corresponding Author's Institution: University of Bologna

First Author: Mauro De Feudis

Order of Authors: Mauro De Feudis; Gloria Falsone; Livia Vittori Antisari

Abstract: Chestnut plantations are worldwide distributed and they are often subjected to intensive management practices such as the removal of the organic residues from the soil surface. The present study aimed to investigate the effect of such practices on soil properties at different depths and on nutrient contents in chestnut leaves. To reach our goal, 6 pits down to 30 cm soil depth were dug in European chestnut (Castanea sativa Mill.) stands where the organic residues such as burrs, leaves and pruned materials are yearly removed (REM), and 9 pits in stands where the organic residues are chopped and left on soil surface (CONS). Both practices began about 30 years ago. The nutrient contents in leaves were assessed on chestnut trees close to each pit. Our findings showed a more intense soil development in CONS than in REM. At soil surface, CONS had thicker mineral horizon than in REM probably due to the protection acted by the organic residues against erosion. In subsoil, organic residues conservation promoted the organic C (soil organic C, water-extractable organic C, fulvic-like C and soil organic C stock) accumulation which further promoted horizon development. Since the role of soil organic matter (SOM) as source of nutrients, the subsoil of CONS study sites had a greater stock of Ca, P and S and a higher exchangeable Ca content than REM. Furthermore, the higher SOM and nutrient contents in CONS subsoil compared to REM promoted the microbial respiration. The organic residues conservation effects on the surface soil horizon properties were, instead, negligible. Despite the generally better soil conditions in CONS than in REM, no differences were observed for the leaf nutrient contents likely due to the chestnut trees adaptability also to the scarcely fertile soils. Overall, our findings highlighted the importance of organic residues conservation for the improvement in deeper soil horizons of the chemical and biological fertility in chestnut plantations. Furthermore, this research pointed out to pay more attention on subsoil since it is a good indicator of the changes caused by external factors.

The final version has been published in Catena Volume 198, March 2021, n. 105021, DOI https://dx.doi.org/10.1016/j.catena.2020.105021

© 2020 Elsevier. This manuscript version is made available under the Creative Commons Attribution-NonCommercial-NoDerivs (CC BY-NC-ND) 4.0 International License (https://creativecommons.org/licenses/by-nc-nd/4.0)

Highlights

- Organic residues removal (ORR) effect on chestnut stand soil properties was tested
- ORR limits the organic C content and nutrient stocks (C, N, P and S) in subsoil
- CONS management promoted the development of AB and Bw horizons
- The limited organic C deepening due to ORR penalised the subsoil microbial activity
- Organic residues should be conserved to maintain soil quality in chestnut stands

Mid-term (30 years) changes of soil properties under chestnut stands due to organic residues

- management: An integrated study
- Mauro De Feudis^{*1,2}, Gloria Falsone^{1,2}, Livia Vittori Antisari^{1,2}
- ¹Department of Agricultural and Food Sciences, Alma Mater Studiorum - University of Bologna,
- Via Fanin, 40; 40127 Bologna, Italy;
- ²Centro Sperimentale per lo Studio e l'Analisi del Suolo (CSSAS), Alma Mater Studiorum -
- University of Bologna, Bologna, Italy.

- *Corresponding author:
- Mauro De Feudis
- Department of Agricultural and Food Sciences
- Alma Mater Studiorum – University of Bologna
- Via Fanin, 40; 40127 Bologna Italy
- e-mail: mauro.defeudis2@unibo.it

27 Abstract

Chestnut plantations are worldwide distributed and they are often subjected to intensive 28 management practices such as the removal of the organic residues from the soil surface. The present 29 study aimed to investigate the effect of such practices on soil properties at different depths and on 30 nutrient contents in chestnut leaves. To reach our goal, 6 pits down to 30 cm soil depth were dug in 31 European chestnut (*Castanea sativa* Mill.) stands where the organic residues such as burrs, leaves 32 33 and pruned materials are yearly removed (REM), and 9 pits in stands where the organic residues are chopped and left on soil surface (CONS). Both practices began about 30 years ago. The nutrient 34 contents in leaves were assessed on chestnut trees close to each pit. Our findings showed a more 35 36 intense soil development in CONS than in REM. At soil surface, CONS had thicker mineral horizon than in REM probably due to the protection acted by the organic residues against erosion. In 37 subsoil, organic residues conservation promoted the organic C (soil organic C, water-extractable 38 39 organic C, fulvic-like C and soil organic C stock) accumulation which further promoted horizon development. Since the role of soil organic matter (SOM) as source of nutrients, the subsoil of 40 41 CONS study sites had a greater stock of Ca, P and S and a higher exchangeable Ca content than 42 REM. Furthermore, the higher SOM and nutrient contents in CONS subsoil compared to REM promoted the microbial respiration. The organic residues conservation effects on the surface soil 43 44 horizon properties were, instead, negligible. Despite the generally better soil conditions in CONS than in REM, no differences were observed for the leaf nutrient contents likely due to the chestnut 45 trees adaptability also to the scarcely fertile soils. Overall, our findings highlighted the importance 46 of organic residues conservation for the improvement in deeper soil horizons of the chemical and 47 biological fertility in chestnut plantations. Furthermore, this research pointed out to pay more 48 49 attention on subsoil since it is a good indicator of the changes caused by external factors.

50

51 Keywords: chestnut management; mountain soil; organic carbon dynamics; litter floor, soil
52 development

53

54 1. Introduction

Chestnut plantations for nut production are widely distributed throughout the world (Conedera et 55 56 al., 2016). Among the European countries, Italy is the largest sweet chestnut producer and importer with about 52,000 Mg (FAOSTAT, 2017). In Italy managed chestnut stands showed a decrease 57 from the second half of the twentieth century to the present time principally due to the rural 58 depopulation (Zlatanov et al., 2013), to the presence of more competitive cultures, such as corn and 59 potatoes, and to the spread of the chestnut blight (Chryphonectria parasitica [Murr.] Barr) and ink 60 61 (Phytophthora cambivora [Petri] Buism.) diseases (Pezzi et al., 2011). More recently, a pivotal role in the chestnust stands abandonment could have played by the reduced precipitations due to the 62 climate change (Pieri et al., 2017) which have promoted the spread of the chestnut diseases 63 64 (Waldboth and Oberhuber, 2009). However, in the last decades old chestnut groves have been recovered, also by replacement of coppices with plantations (Beccaro et al., 2009), with an increase 65 of both socio-economic and environmental interest (Martín et al., 2017). 66

Chestnut stand agroecosystems represent today an important landscape component in the 67 mountainous regions of the European Mediterranean basin. The management of the chestnut stands 68 in a sustainable way is essential to improve or to maintain the soil quality in these areas. Soil 69 organic matter (SOM) is the most frequently used indicator of soil quality, as it affects some soil 70 biological, physical and chemical properties, followed by nutrient content and soil microbial 71 biomass and respiration (Zornoza et al., 2015). Unfortunately, studies concerning the effect of 72 above ground biomass management on SOM are missing for the chestnut ecosystems. Conversely, 73 taking in account other tree species, several are the studies monitoring the influence of forest 74 75 harvesting on soil organic carbon pool (e.g., Homann et al., 2001; Nave et al., 2010). For example, previous studies (James and Harrison, 2016; Johnson and Curtis, 2001; McDonnell et al., 2013; 76 Zetterberg et al., 2016) highlighted how the intense harvesting practices aimed to remove most of 77 the tree biomass significantly reduce the amounts of C and other essential nutrients such as Ca^{2+} , 78

 Mg^{2+} and K^+ in soil. However, in forest ecosystems another key driver of the soil C is the litter 79 layer (Maes et al., 2019). Indeed, litter removal practices could alter the pool sizes of organic 80 compounds and nutrients, and influence the rates of biogeochemical processes which could 81 82 potentially compromise soil fertility (Xiong et al., 2008). Several studies have found that the presence of plant litter can significantly increase both the soil resistance to flowing water erosion 83 and the water holding capacity (Giménez and Govers, 2008; Liu et al., 2017). Furthermore, the litter 84 85 floor could be incorporated into the mineral soil horizons through the soil fauna activities (Yavitt et al., 2015), increasing soil aggregate stability, SOM amount and stabilisation, and decreases soil bulk 86 density (Mandal et al., 2004; Mitchell et al., 2018). Since the positive relationship between soil 87 88 microbial biomass and SOM (van Leeuwen et al., 2017) the removal or alteration of soil organic matter inputs due to the different forest management might change the size and the activity of the 89 soil microbial biomass. 90

Because of the role of soil on plant health, changes of the soil properties could affect plant nutrient
contents. For example, a reduced plant nutritional status was found in soil characterized by poor
SOM (Neilsen et al., 2014) and nutrient contents (Demchik and Sharpe, 2000) and microbial
biomass (Van Der Heijden et al., 2008).

In order to implement those agroforestry practices able to preserve or improve tree health and soil quality, we tested the effect of 30 years chestnut organic residues management practices on soil thickness, amount and quality of SOM, nutrient content and microbial biomass and its activity of top- and subsoil layers, and on nutrient concentrations in chestnut tree leaves.

99 To achieve this goal, we selected chestnut stands where the organic residues such as burrs, leaves 100 and pruned materials are yearly removed, and chestnut stands with more conservationist practices 101 where organic residues are chopped and left on the soil surface. It was hypothesized that the organic 102 residues removal *i*) declines *solum* thickness; *ii*) reduces the contents of soil organic carbon and of 103 SOM pools, and the soil organic carbon stock; *iii*) decreases the stocks of N, Ca, Mg, Na, K, Fe, P

4

and S and the availability of Ca, Mg, Na and K; *iv*) has negative impact on soil microbial biomass
and respiration; *v*) reduces the nutrient contents in plants.

106

107 **2. Materials and methods**

108 *2.1. Study sites*

The study sites included four farms (Figure 1 and Table 1) with uneven-aged chestnut (Castanea 109 110 sativa Mill) stands for fruit production. The chestnut stands were recovered about 30 years ago through a more or less severe pruning of the plants, according to the age of the trees and to the 111 severity of parasitic attacks, necessary to stimulate the growth of a new and vigorous canopy. 112 Furthermore, the recovery actions included the selection of the healthiest trees, to maintain a tree 113 spacing of about 10×10 m, whose dry, senescent, sick parts and overlapping branches were yearly 114 removed in order to open the canopy and allowing a better fruits production on sunny branches 115 (Figure 1). Therefore, the farms included uneven-aged chestnut stands whose average size of trees 116 was about 30-35 cm reflecting the 40-years old age of shoots. In all study sites the chestnut 117 production was about 40 kg tree⁻¹. 118

The study sites are located on the northern Apennine chain in Italy (Figure 1), their locations and climatic characteristics are reported in Table 1. In all investigated sites, the chestnut plantations stand at an altitude ranging from 650 to 750 m above sea level, they are exposed to south, south– east and on slopes with an inclination ranging from 15° to 30°. In all study sites the soil developed from sandstone with similar elemental compositions (ISPRA, 1999).

124

125 2.2. Experimental design

The four farms involved in this study were selected in order to compare the soil properties of chestnut stands in which the organic residues removal (ORR) has been made or not. In two farms, the chestnut stands were subjected to yearly ORR, hereafter called REM, due to the use of small blowing devices during the fruits harvesting which remove from the soil surface both fruits and other organic residues. In two other farms, management was more conservationist which consist to leave on the soil surface the organic residues, hereafter called CONS, which are chopped. In CONS study sites the fruits harvesting was manual or using nets put on trees. Both ORR and the more conservationist practices began at the recovery time of the chestnut stands, therefore about 30 years ago, and concerned the whole surface of the stands.

The soils were classified as Typic Udorthents for REM study sites and Typic Dystrudepts for
CONS ones (Soil Survey Staff, 2014). The description of representative soil profiles are reported in
Table S1 of the supplementary materials (Regione Emilia Romagna, 2000).

In spring 2017, fifteen pits down to 30 cm soil depth were dug (6 pits for REM and 9 for CONS).
Since the high soil variability that generally occurs in mountainous areas (Hoffmann et al., 2014), a
different number of pits were dug for each study area to get a better representation of the soil on the
entire fields. Each pit was dug at a distance of at least 1 m away from the stem of the trees.

142

143 2.3. Sampling and analysis

In each dug pit, each identified genetic horizon down to 30 cm of soil depth has been sampled by collecting at least 2 kg of sample and, once in the laboratory, it was air dried and sieved (<2 mm). For the determination of the bulk density (BD), additional soil samples were taken using steel cylinder cores with an internal diameter of 5.0 cm and 5.0 cm height from the 0-10, 10-20 and 20-30 cm soil depth.

In order to evaluate the effect of ORR practice on nutrient contents in chestnut leaves, the uppermost fully expanded leaves and without visible injury symptoms were collected from randomly selected branches. Specifically, from 20 to 30 leaves were picked from each tree. The leaves were collected from 4 healthy trees located close to each mini-pit and mixed to composed one sample per pit. The leaf samples were oven-dried at 60 °C until constant weight and ground.

The soil particle size distribution was obtained by the pipette method after dispersion of the samplewith a sodium hexametaphosphate solution (Gee and Bauder, 1986). The soil samples collected for

the determination of BD were oven-dried at 105 °C for 24 h, and then weighed (Blake and Hartge, 1986). The dry weight was thereafter divided by volume of the cores. The obtained BD was adjusted by subtracting the mass and the volume of skeleton and roots in order to determine the BD of the fine earth fraction.

The soil pH was determined potentiometrically in a 1:2.5 solution ratio in both deionized water (pH_{H^2O}) and 1M KCl (pH_{KCl}) suspension. Total organic C (TOC) and total nitrogen (TN) were determined by a CHN elemental analyser (EA 1110 Thermo Fisher, USA) without to be pre-treated with hydrochloric acid due to the absence of carbonates. The total amount of Ca, Mg, Na, K, Fe, Mn, P and S were determined by inductively coupled plasma optical emission spectrometer (ICP-OES, Ametek, Spectro Arcos, Germany) after aqua regia extraction (Vittori Antisari et al., 2014).

The cation exchange capacity (CEC) and the exchangeable cation contents were determined according to the method proposed by Orsini and Rémy (1976) and modified by Ciesielski and Sterckeman (1997) using 0.017 M hexamminecobalt(III)chloride as extracting solution and measuring the amounts of Co and exchangeable cations by ICP–OES.

170 Different soil C pools characterized by increasing persistence in soil were sequentially separated according to Agnelli et al. (2014) with some modifications. Briefly, a 1:10 solid:water suspension 171 was shaken on a horizontal shaker for 16 hours at 25°C, centrifuged and the surnatant was separated 172 173 from the precipitate. From the supernatant two C pools have been further separated by sieving it at 53 μ m: the particles >53 μ m which represented the particulate organic matter (POM), namely plant 174 and animal residues at different stages of decomposition, and the surnatant <53 µm which was 175 176 further filtered through 0.45 µm filter paper and it represented the water–extractable organic matter (WEOM), namely the more mobile and labile organic matter pool. To the remaining precipitate into 177 178 the centrifugation tubes, 0.1M NaOH solution was added and the samples were shaken for 24 hours 179 at 25°C and then again centrifuged. The NaOH extract was passed through a 0.45 μ m polycarbonate filter, while the remaining precipitate, containing the humin-like (Hum) compounds was washed 180 using deionized water to remove the excess of Na until the pH of the rinsed solution was ≤ 7 . The 181

0.45 µm filtered NaOH extract was acidified to about pH 1.5 with 6M HCl and allowed to settle 182 183 overnight to separate humic acid-like (HA) and fulvic acid-like (FA) compounds and centrifuged. To remove the excess of Na from the obtained fractions, the surnatant (FA) was dialyzed through 184 1000 Da cut-off membranes (Spectra/Por® Dialysis membrane) against distilled water, while the 185 residual (HA) was washed with 0.002 M HCl. Both purified fractions were freeze-dried. The POM 186 and Hum fractions were instead dried at 40 °C. The organic C (OC) and N contents of POM, FA, 187 188 HA and Hum were determined by a CHN elemental analyser (EA 1110 Thermo Fisher, USA). The OC and N contents of WEOM were recorded by a TOC-V CPN total organic carbon analyzer 189 (Shimadzu, Japan). 190

The C and N concentrations in leaf samples were measured by the CHN elemental analyser (EA 1110 Thermo Fisher, USA). While, for the determination of Ca, Mg, K, Mn, Na, P and S, the ground leaves were mineralized in 4:1 HNO₃ (65 % v/v): H_2O_2 (30% v/v) solution in a microwave oven (START D Microwave Digestion System; Milestone Inc., Sorisole, Bergamo, Italy). The concentrations of the selected elements in the extracts were measured by ICP–OES.

196 The soil respiration during 28 days at 25 °C of incubation was determined according to Falsone et al. (2015) after conditioning of the samples at 60 % of their water holding capacity (WHC) and pre-197 incubating them for 3 days at 4 °C. After 1-3-7-10-14-21-28 days the beginning of incubation, 198 the amount of CO₂ emitted from incubated soils was measured by alkali (1 M NaOH solution) 199 absorption of the evolved CO₂ and titration of the residual OH⁻ with a standardized HCl solution. 200 While the soil basal respiration (SBR) of each soil sample was computed as the average of the 201 202 values measured during the incubation period, the cumulative soil basal respiration (RCUM) was expressed as the total amount of CO₂ evolved during the 28 days of incubation. 203

Soil microbial biomass–C (Cmic) and microbial biomass–N (Nmic) were measured on soil samples at 60% of WHC using chloroform fumigation extraction method with 0.5 M K₂SO₄ solution (Vance et al., 1987). Both fumigated and non–fumigated extracts were analysed using a TOC–V CPN total organic carbon analyzer (Shimadzu, Japan). Cmic was calculated as E_C *2.64, where E_C = difference between organic C extracted from fumigated soils and organic C extracted from non-fumigated soils. Nmic was calculated as E_N *2.22, where E_N =difference between total N extracted from fumigated soils and total N extracted from non-fumigated soils (Vance et al., 1987).

The metabolic (qCO₂) and mineralization (qM) quotients were calculated according to the following
equations (Eq. 1 and 2):

213
$$qCO_2 = 100*SBR/Cmic$$
 (1)

- qM = 28 days cumulative respiration (RCUM)/TOC (2)
- 215

216 2.4. Data analysis

In order to evaluate the effect on soil of the organic residues conservation or removal, the results of the chemical and biological properties are presented separating epipedon (superficial layers) and endopedon (deeper layers), in particular, epipedon (Epi) included superficial A horizons (i.e., A, A1, A2), while endopedon (Endo) included other deeper transition and mineral horizons (i.e., AC, AB, Bw, BC and C).

The stock of OC, TN and nutrients are presented for fixed soil-depth intervals (0–10, 10–20 and 20–30 cm), taking into account the BD value of each soil layer at fixed depth and the OC, TN and nutrients content of each genetic horizon averaged on the basis of horizon thickness.

225 Two-way analysis of variance was performed to assess the effect of chestnut stand management on the selected physical, chemical and biological parameters and the variation of the selected variables 226 with soil depth. Instead, for the plant samples, one-way analysis of variance was carried out to 227 228 assess the effect of chestnut stand management on the leaf nutrient concentrations. Since the graphical analysis of residuals showed the absence of normality and homoscedasticity, the all the 229 data were processed by the Kruskal-Wallis rank sum test to identify statistically significant 230 differences and Holm test was performed as multi-comparison test (p < 0.05). The results 231 presented are based on mean values and their standard error. The data were analyzed using R 232 software (R Core Team, 2016). 233

234

235 **3. Results**

236 3.1. Morphological properties of chestnut stand soils

Our results showed the differences in the *solum* thickness and horizons sequences between REMand CONS study sites.

The mean thickness of superficial A horizons (i.e., A, A1, A2), called Epi horizons, was in fact of 239 5.1 and 9.7 cm in REM and CONS, respectively. The deeper mineral horizons (i.e., AC, AB, Bw, 240 BC and C), called Endo horizons, showed a mean thickness of 12.4 and 20.2 cm in REM and 241 CONS, respectively (Table 2). Both in REM and CONS Epi horizons were thinner than Endo ones 242 243 (p<0.05), and between both practices, CONS allowed a thicker Epi than REM (p<0.05). Similarly, for Endo, CONS showed a larger thickness compared to REM. However, it needs to take in mind 244 that the horizons sequence down to 30 cm was A/AC/C in REM soils, while was A1/A2 or AB or 245 246 Bw or BC in CONS ones. The horizons sequence of *solum* thus showed weak development in REM because of the lack of B horizons, and furthermore the thickness of solum was lower in REM than 247 248 in CONS ones (p<0.05).

249

250 3.2. Physicochemical properties of chestnut stand soils

The occurrence of differences in particle size distribution, BD values, pH, CEC and concentration of exchangeable bases between Epi and Endo in the soils of REM and CONS study sites has been determined.

Our findings showed that the soils of the selected chestnut orchards have sandy–loam/loam texture, with lower amount of clay in CONS than in REM (Table 2). Furthermore, REM soils had similar particle distribution along the soil depth; in CONS soils, instead, Endo horizons had higher silt content than Epi ones (p<0.05). The bulk density, on average, ranged from 1.02 to 1.47 g cm⁻³, but significant differences neither between soil depth nor between soil management practices have been found. The pH_{H2O} values ranged from 4.8 to 5.4, the pH_{KCl} ranged from 3.2 to 4.1 with some differences in CONS where the Endo showed higher values compared to Epi (Table 2).

In both managements, the CEC did not change between Epi and Endo, however, the soils under 262 263 REM management showed higher CEC than those under CONS (Figure 2I). Regarding to the exchangeable bases (Ca, Mg, K, Na), the ExCa always showed higher values in Epi than in Endo 264 (Figure 2II), the ExK had higher concentrations in Epi than in Endo only in REM (Figure 1III), and 265 no differences occurred between Epi and Endo for ExMg and ExNa (Figure 2IV, V). Comparing the 266 two management practices, among the exchangeable bases, only the ExCa showed some 267 differences, in particular higher ExCa values were found in Endo of CONS sites compared to Endo 268 269 of REM (Figure 2II). As expected, the base saturation (BS) values were higher in Epi compared to Endo but only in REM soils (Figure 2VI). In CONS soils, the BS values were similar between Epi 270 271 and Endo, and no differences occurred between the two management practices (Figure 2VI).

272

273 *3.3. SOM pools of chestnut stand soils*

As expected, in both chestnut managements, most of the studied pools of C and N cycles (i.e., total, labile, humic–like and humin substances) were higher in the Epi than in the Endo (Figure 3, Figure 4, Figure S1). Comparing the two chestnut stand managements, some differences occurred for the Endo. Specifically, the concentrations of TOC and of organic C related to WEOM and FA were higher in CONS than in REM (Figure 3I, III, Figure 4II). Similarly, the contents of TN and nitrogen related to WEOM were greater in CONS than in REM (Figure 3II, IV).

280

281 *3.4. Microbial biomass amount and respiration of chestnut stand soils*

Regarding to the soil microbial biomass, in both chestnut stand managements Cmic, Nmic, SBR and RCUM values were higher in Epi than in Endo, while no differences occurred for qR and qM (Figure 5I–VI). Through the comparison of the two chestnut stand managements, some differences occurred for RCUM and qM. In particular, the RCUM was higher in Endo of CONS than in REM
(Figure 5IV), the qM was higher in CONS than in REM both for Epi and Endo (Figure 5VI).

287

288 3.5. Soil organic C and nutrients stocks, and nutrient concentrations in chestnut tree leaves

The stock of elements of organic origin (i.e., C, N, P and S) generally decreased along soil depth, and in deeper layers (10–20 and 20–30 cm) in CONS chestnut stands had higher values than in REM (Table 3). Nutrients mainly derived by parent material (Ca, Mg, Na, K and Fe) did not instead show significant differences between the two different managements (Table 3). However, a certain Mg and Fe redistribution occurred in deeper layers (10-20 cm and 20-30 cm) of CONS soils, having higher stock values than in 0-10 cm layer, while in REM soils Na stocks was higher in deeper layers than in 0-10 cm (Table 3).

Although some differences in soil elements stock occurred, the concentrations of C, N, Ca, Mg, K,
Mn, Na, P and S in chestnut leaves did not differ between the two type of organic residue
managements (Table 4).

299

300 4. Discussion

301 *4.1. Organic residues conservation promotes soil thickness and development in chestnut stands*

302 In the present study, the ORR practice reduced the thickness of superficial A horizons (5.1 vs 9.7 cm in REM and CONS, respectively) which could be attributed to higher soil erosion that probably 303 takes place in the former than in the latter study sites. Indeed, as reported by several works (e.g., 304 Dick et al., 1997; Křeček et al., 2019; Liu et al., 2017) the presence of the litter layer limits the 305 surface runoff and soil erosion. The highest soil erosion that likely occurs in REM study sites could 306 also limit the thickness of solum due to losses of pedogenized material (Mokma et al., 1996). 307 Consequently, the formation of more developed B horizons or transitional AB ones was prevented 308 in REM soils. Our findings are in accordance to Świtoniak (2014) and Jankauskas and Fullen 309 (2002) which, through a pedological investigation of soils subjected to different erosion severity, 310

observed weakly developed soil horizon sequences in eroded sites. In contrast, the reduced erosion
in CONS study sites might promoted the development of their soils allowing to define the CONS
soils as Inceptisol while those of REM as weakly developed Entisols.

314

4.2. Organic residues conservation promotes soil organic matter content and stock in chestnut
stands

317 As reported in several works carried out on Italian mountains soils (e.g., De Feudis et al., 2017; Vittori Antisari et al., 2016), the TOC content was higher in organo-mineral horizons (Epi) than in 318 deeper ones due to input of OC from the litterfall (Boča and Miegroet, 2017). However, the ORR 319 320 practice reduced the soil OC content, in particular we found lower TOC content in Endo of REM than in CONS, in agreement with early studies (e.g., Achat et al., 2015; Tian et al., 2010). This fact 321 might suggest how the ORR limits the incorporation of the organic matter in the subsoil preventing 322 323 any vertical redistribution of organic C. Conversely, the conservation of the organic residues allows it. Specifically, our findings indicated that the incorporation of the organic matter in the subsoil of 324 325 CONS could be assigned to the redistribution along depth of WEOM-C and FA-C fractions which showed higher concentrations in Endo of CONS than in that of REM. Both the water-soluble and 326 the fulvic-like substances represent an important source of organic C for the deeper layers of the 327 328 soils (Aran et al., 2001; Kaiser and Kalbitz, 2012).

Because of the importance of SOM on the development of the subsoil horizons even in poorly developed soils such as Entisols and Inceptisols (Falsone et al., 2012), the deepening of the organic substances in CONS, together with the limited soil erosion, likely promoted the development of AB and Bw horizons.

Although the lower clay content in CONS than in REM, the OC stock was larger in 10–30 cm soil depth section of CONS than in that of REM. This fact emphasizes the leading role of organic matter input amount and rate on soil OC stock (Orgill et al., 2017). Since the subsoil OC generally has a higher residence time compared to topsoil (Jenkinson et al., 2008; Trumbore, 2009), the ORR seemed to reduce the role of soil as stable sink of C reducing the OC stocks below 10 cm of soildepth.

The modification of TOC content and OC stock only in Endo and in 10–30 cm soil depth interval, respectively, might indicate a high sensibility of subsoil OC to management practices. The high sensibility of subsoil OC to external factors, such as management practices, is in accordance with recent studies (Jia et al., 2019; Leuschner et al., 2014; Mobley et al., 2015; Steinmann et al., 2016) which observed meaningful changes of subsoil OC stock caused by climate warming, reforestation and soil managements such as tillage and fertilization.

345

346 *4.3. Organic residues conservation increases soil nutrient contents in chestnut stands*

The similar parent material on which the studied soils developed explains the similar stock of 347 nutrients, with exception of P and S, which exhibited higher values in 10 - 30 soil depth section of 348 349 CONS than of REM probably due to the higher amount of organic matter. Indeed, concerning P, in forest soils most of the soil P is made up of organic P forms (Adams et al., 2018; De Feudis et al., 350 351 2016). As the organic P is the most important P source in forest ecosystems (Turner et al., 2014) and the total P concentration generally decline over time (Chen et al., 2015), litter recycling is 352 essential to avoid an accelerated loss of soil P. The nutrient recycling process seemed to affect also 353 S. In fact, similarly to P, the total amount of S in 10 - 30 cm soil depth interval was higher in 354 CONS than in REM. As for P, the organic S compounds represent the most abundant S forms in 355 soils (e.g., Likens et al., 2002; Vannier and Guillet, 1994). Regarding to the other nutrients, such as 356 exchangeable Mg, K and Na, their amounts did not change between the two managements. 357 Exchangeable Ca, instead, had higher contents in Endo of CONS than in that of REM, following the 358 359 trend of OC content. This is in agreement with Vittori Antisari et al. (2013) who reported that SOM is an important source of available Ca in chestnut stands. The importance of Ca biocycling was 360 further stressed by the lack of differences of Ca stock. In fact, in mountain acid soils the 361 redistribution of Ca-mineral derived is often prevented by the limited Ca-mineral weathering 362

(Ghobadi and Mousavi, 2014), and available Ca derived mainly from litter recycling (Haynes and Swift, 1986; Johnson et al., 1994). Although the higher amounts of some nutrients in CONS than in REM, the lack of differences occurring for the nutrient contents in plant leaves would suggest the unresponsive of chestnut to soil fertility and, therefore, the ability of chestnut plants to grow also on poor sandy-rich soils (Oosterbaan, 1998). The ability of chestnut trees to healthily grow also in soils characterized by low amount of nutrients is confirmed by Ribeiro et al. (2019) which did not find differences in leaf nutrient contents between fertilized and unfertilized *Castanea sativa* plants.

370

4.4. Organic residues conservation improves soil microbial respiration in chestnut stands

The RCUM in Endo of CONS study sites was higher than in REM likely due to the higher C 372 content associated to WEOM (WEOM-C). In fact, because of the most labile organic compounds 373 represent the main substrate for soil microbial communities (Rees and Parker, 2005) and changes of 374 375 WEOM-C quantity affect both microbial activities and composition (Drenovsky et al., 2004), the enhance of WEOM-C can promote the heterotrophic soil respiration (Rees and Parker, 2005). 376 377 Furthermore, since the positive effect of WEOM-C on soil microbial activities, the higher qM in CONS than in REM might be attributed to the priming effect, namely a short-term change in 378 microbial mineralization of SOC in response to labile OC inputs (Kuzyakov, 2010). Unlike RCUM 379 380 and qM, both the microbial biomass and qCO_2 have shown similar values between the two chestnut orchard managements. The lack of differences about microbial biomass and qR might be attributed 381 to the fact that they are driven not only by the amount of TOC but also by other soil properties such 382 383 as BD, soil moisture and temperature, and C:N ratio (Ren et al., 2018; Stefanowicz et al., 2016; van Leeuwen et al., 2017; Xu et al., 2007) which, in our case, were similar among the study sites. 384

385

4.5. Overview of the effects of organic residues management on soil properties in chestnut stands
In the present study, the soil erosion occurring in the mid-term (30 years) in REM study sites due to
the periodic ORR might promoted the thinning of the A horizons and prevented the development of

B or transitional AB horizons. Moreover, ORR practice reduced the SOM content in subsoil of REM study sites because this practice impeded the inclusion of the organic material in soil mineral horizons. Therefore, because of the importance of SOM on the development of soil horizons, the limited amount of organic residues left on soil surface in REM could have further prevented the development of B or transitional AB horizons.

The presence of chopped organic residues on soil surface of CONS promoted a greater soil OC 394 395 stock than in REM. However, it is noteworthy to highlight that the differences about soil OC stock were observed in subsoil layers indicating how the conservation of the organic residues enhanced 396 SOM stabilization. Because of the role of organic matter on soil aggregation, fertility and to store 397 398 water (de Paul Obade and Lal, 2016), the decline of OC content and stock in subsoil due to ORR practice could instead cause a reduction of soil quality. For example, the higher OC stock in Endo 399 400 horizons of CONS than in that of REM resulted in a higher amount of those nutrients, such as P and 401 S, whose cycling is related to SOM. Moreover, our findings showed that the conservation of the organic residues on soil surface improves the soil also from the biological point of view. In fact, the 402 403 higher SOM content and, therefore, the higher amount of labile OC in CONS than in REM 404 increased the activity of soil microbes which are important player on the soil nutrient cycling.

Hence, a chestnut stand management based on the conservation of the litter floor should be 405 406 supported in order to improve the soil quality and, in particular, to increase the volume of *solum*, the SOM and nutrient contents and the soil microbial respiration. However, though not considered in 407 the present work, CONS management could have some negative effects on the spreading of some 408 409 chestnut diseases. For example, the increase of SOM content could benefit the proliferation of the ink disease (Phytophthora cinnamomi) because of its saprotrophic nature (Fonseca et al., 2004). 410 Furthermore, since in CONS study sites the organic residues are chopped, this practice could 411 increase the production costs. Finally, since the ORR and the chipping of the litter floor are yearly 412 performed, both studied managements could have some negative effects on the proliferation of 413 Torymus sinensis Kamijo. In fact, in order to maintain this biological control agent of the chestnut 414

415 gall wasp, the plant material bearing galls (branches, suckers) should not be removed from the stand 416 at least for two years (Ferracini et al., 2015). More researches need however on the assessment of 417 the phytosanitory consequences and on the role that the SOM and microbial activity can have on the 418 enhancement of chestnuts disease resistance.

419

420 **5. Conclusion**

421 In the mid-term (30 years), the common practice of ORR in recovered century chestnut stands has negative impacts on soil quality. In particular, compared to chestnut stands where the organic 422 residues are chopped and left on soil surface, the ORR practices prevent the development of AB and 423 424 Bw soil horizons. The limited soil development in REM was likely due to an accelerated soil erosion leading to loss of pedogenized material, and to a negligible incorporation of organic matter 425 from soil surface into the subsoil limiting mineral weathering. Furthermore, the reduced stock of P, 426 427 S, and organic C and the reduced amount of exchangeable Ca, cumulative basal respiration and mineralization quotient in subsoil of the chestnut stands subjected to ORR practice might suggest 428 429 that the conservation of the organic residues is necessary to maintain the soil chemical and 430 biological fertility in mountainous ecosystems. The improved soil quality, together with the unchanged nutrient contents in chestnut leaves, would suggest that the switch from the common 431 432 management practices in more conservative ones matches with the aims of those agroforestry practices addressed to preserve or improve both tree health and environmental quality. Furthermore, 433 the present study highlighted the higher sensibility of the subsoil to the management practices 434 435 compared to the topsoil. Therefore, for the studies about the effect of management practices in forests ecosystems located in mountainous areas, we suggest to pay more attention on subsoil 436 properties since it is a good indicator of the changes caused by external factors. 437

438

439 Acknowledgments

17

440 This work was partially funded by the European Agricultural Fund for Rural Development through 441 the Rural Development Programme - Emilia Romagna, focus area 5E, Action Group: CASTANI-442 CO, support application number 5015571, project name: Carbon sequestration in the system of 443 chestnut orchards for fruit production. We would like to thank Dr. Carla Scotti of I.TER soc. coop a 444 r.l. for her help during soil pits description and sampling.

445

446 **References**

- Achat, D.L., Fortin, M., Landmann, G., Ringeval, B., Augusto, L., 2015. Forest soil carbon is
 threatened by intensive biomass harvesting. Sci. Rep. 5. https://doi.org/10.1038/srep15991
- Adams, J.L., Tipping, E., Thacker, S.A., Quinton, J.N., 2018. An investigation of the distribution of
 phosphorus between free and mineral associated soil organic matter, using density
 fractionation. Plant Soil 427, 139–148. https://doi.org/10.1007/s11104-017-3478-4
- Agnelli, A., Bol, R., Trumbore, S.E., Dixon, L., Cocco, S., Corti, G., 2014. Carbon and nitrogen in
 soil and vine roots in harrowed and grass-covered vineyards. Agric. Ecosyst. Environ. 193, 70–
 82. https://doi.org/10.1016/j.agee.2014.04.023
- Aran, D., Gury, M., Jeanroy, E., 2001. Organo-metallic complexes in an Andosol: A comparative
 study with a Cambisol and Podzol. Geoderma 99, 65–79. https://doi.org/10.1016/S00167061(00)00064-1
- Beccaro, G.L., Mellano, M.G., Barrel, A., Trasino, C., 2009. Restoration of old and abandoned
 chestnut plantations in Northern Italy. Acta Hortic. 815, 185–190.
 https://doi.org/10.17660/ActaHortic.2009.815.24
- Blake, G.R., Hartge, K.H., 1986. Bulk density, in: Methods of Soil Analysis, Part 1. Madison, pp.
 363–375.
- Boča, A., Miegroet, H. Van, 2017. Can carbon fluxes explain differences in soil organic carbon
 storage under aspen and conifer forest overstories? Forests 8. https://doi.org/10.3390/f8040118
- 465 Chen, C.R., Hou, E.Q., Condron, L.M., Bacon, G., Esfandbod, M., Olley, J., Turner, B.L., 2015.

Soil phosphorus fractionation and nutrient dynamics along the Cooloola coastal dune
chronosequence, southern Queensland, Australia. Geoderma 257–258, 4–13.
https://doi.org/10.1016/j.geoderma.2015.04.027

- Ciesielski, H., Sterckeman, T., 1997. Determination of cation exchange capacity and exchangeable
 cations in soils by means of cobalt hexamine trichloride. Effects of experimental conditions.
 Agronomie 17, 1–7. https://doi.org/10.1051/agro:19970101
- 472 Conedera, M., Tinner, W., Krebs, P., de Rigo, D., Caudullo, G., 2016. *Castanea sativa* in Europe:
 473 distribution, habitat, usage and threats, in: European Atlas of Forest Tree Species. p. e0125e0+.
- 474 De Feudis, M., Cardelli, V., Massaccesi, L., Bol, R., Willbold, S., Cocco, S., Corti, G., Agnelli, A.,
- 2016. Effect of beech (*Fagus sylvatica* L.) rhizosphere on phosphorous availability in soils at
 different altitudes (Central Italy). Geoderma 276, 53–63.
 https://doi.org/10.1016/j.geoderma.2016.04.028
- 478 De Feudis, M., Cardelli, V., Massaccesi, L., Lagomarsino, A., Fornasier, F., Westphalen, D.J., Cocco, S., Corti, G., Agnelli, A., 2017. Influence of altitude on biochemical properties of 479 480 European Beech sylvatica L.) forest soils. Forests 8, 1–14. (Fagus https://doi.org/10.3390/f8060213 481
- de Paul Obade, V., Lal, R., 2016. A standardized soil quality index for diverse field conditions. Sci.
- 483 Total Environ. 541, 424–434. https://doi.org/10.1016/j.scitotenv.2015.09.096
- Demchik, M.C., Sharpe, W.E., 2000. The effect of soil nutrition, soil acidity and drought on
 northern red oak (*Quercus rubra* L.) growth and nutrition on Pennsylvania sites with high and
 low red oak mortality. For. Ecol. Manage. 136, 199–207. https://doi.org/10.1016/S0378-
- 487 1127(99)00307-2
- 488 Dick, R.P., Pankhurst, C., Doube, B.M., Gupta, V., 1997. Soil enzyme activities as integrative
 489 indicators of soil health. Biol. Indic. soil Heal. 121–156.
- 490 Drenovsky, R.E., Vo, D., Graham, K.J., Scow, K.M., 2004. Soil water content and organic carbon
- 491 availability are major determinants of soil microbial community composition. Microb. Ecol.

- 492 48, 424–430. https://doi.org/10.1007/s00248-003-1063-2
- Falsone, G., Bonifacio, E., Zanini, E., 2012b Structure development in aggregates of poorly
 developed soils through the analysis of the pore system. Catena 95, 169–176.
 https://doi.org/10.1016/j.catena.2012.02.014
- Falsone, G., Marinari, S., Vittori Antisari, L., Vianello, G., 2015. Soil processes related to organic
 matter modifications following Douglas-fir mature reforestation. Biol. Fertil. Soils 51, 277–
 287. https://doi.org/10.1007/s00374-014-0971-2
- FAO Food and Agriculture Organization of the United Nations, 2017. Food and Agriculture
 Organization of the United Nations Statistic division. URL
 http://www.fao.org/faostat/en/#data/QC
- 502 Ferracini, C., Gonella, E., Ferrari, E., Saladini, M.A., Picciau, L., Tota, F., Pontini, M., Alma, A.,
- 2015. Novel insight in the life cycle of *Torymus sinensis*, biocontrol agent of the chestnut gall
 wasp. BioControl 60, 169–177. https://doi.org/10.1007/s10526-014-9633-4
- Fonseca,T.F., Abreu, C.G., Parresol, B.R., 2004. Soil compaction and chestnut ink disease. For.
 Path. 34, 273–283. https://doi.org/10.1111/j.1439-0329.2004.00371.x
- Gee, G. W., Bauder, J. W., 1986. Methods of Soil Analysis: Part 1—Physical and Mineralogical
 Methods. SSSA Book Series. Soil Science Society of America, American Society of
 Agronomy. https://doi.org/10.2136/sssabookser5.1.2ed.c15
- 510 Ghobadi, M.H., Mousavi, S., 2014. The effect of pH and salty solutions on durability of sandstones
- of the Aghajari Formation in Khouzestan province, southwest of Iran. Arab. J. Geosci. 7, 641–
- 512 653. https://doi.org/10.1007/s12517-012-0741-0
- Giménez, R., Govers, G., 2008. Effects of freshly incorporated straw residue on rill erosion and
 hydraulics. Catena 72, 214–223. https://doi.org/10.1016/j.catena.2007.05.004
- Haynes, R.J., Swift, R.S., 1986. Effects of soil acidification and subsequent leaching on levels of
 extractable nutrients in a soil. Plant Soil 95, 327–336. https://doi.org/10.1007/BF02374613
- 517 Hoffmann, U., Hoffmann, T., Johnson, E.A., Kuhn, N.J., 2014. Assessment of variability and

- uncertainty of soil organic carbon in a mountainous boreal forest (Canadian Rocky Mountains,
 Alberta). Catena 113, 107–121. https://doi.org/10.1016/j.catena.2013.09.009
- Homann, P.S., Bormann, B.T., Boyle, J.R., 2001. Detecting treatment differences in soil carbon and
 nitrogen resulting from forest manipulations. Soil Sci. Soc. Am. J. 65, 463–469.
 https://doi.org/10.2136/sssaj2001.652463x
- ISPRA, 1999. CARG Project Geological and geothematic cartography. URL
 www.isprambiente.gov.it/en/projects/soil-and-territory/carg-project-geologic-and-geothematic cartography
- James, J., Harrison, R., 2016. The effect of harvest on forest soil carbon: A meta-analysis. Forests 7.
 https://doi.org/10.3390/f7120308
- Jankauskas, B., Fullen, M.A., 2002. A pedological investigation of soil erosion severity on
 undulating land in Lithuania. Can. J. Soil Sci. 82, 311–321. https://doi.org/10.4141/S01-058
- Jenkinson, D.S., Poulton, P.R., Bryant, C., 2008. The turnover of organic carbon in subsoils. Part 1.
 Natural and bomb radiocarbon in soil profiles from the Rothamsted long-term field
- experiments. Eur. J. Soil Sci. 59, 391–399. https://doi.org/10.1111/j.1365-2389.2008.01025.x
- Jia, J., Cao, Z., Liu, C., Zhang, Z., Lin, L., Wang, Y., Haghipour, N., Wacker, L., Bao, H., Dittmar,
- T., Simpson, M.J., Yang, H., Crowther, T.W., Eglinton, T.I., He, J.S., Feng, X., 2019. Climate
 warming alters subsoil but not topsoil carbon dynamics in alpine grassland. Glob. Chang. Biol.
 25, 4383–4393. https://doi.org/10.1111/gcb.14823
- Johnson, A.H., Friedland, A.J., Miller, E.K., Siccama, T.G., 1994. Acid rain and soils of the
 Adirondacks. III.Rates of soil acidification in a montane spruce-fir forest at Whiteface
 Mountain, New York. Can. J. For. Res. 24, 663–669. https://doi.org/10.1139/x94-089
- Johnson, D.W., Curtis, P.S., 2001. Effects of forest management on soil C and N storage: Meta
 analysis. For. Ecol. Manage. 140, 227–238. https://doi.org/10.1016/S0378-1127(00)00282-6
- 542 Kaiser, K., Kalbitz, K., 2012. Cycling downwards dissolved organic matter in soils. Soil Biol.
- 543 Biochem. 52, 29–32. https://doi.org/10.1016/j.soilbio.2012.04.002

- Křeček, J., Novakova, J., Palan, L., Pazourkova, E., 2019. Soil conservation in a forested mountain
 catchment. Int. J. Environ. Qual. 33, 27–36.
- Kuzyakov, Y., 2010. Priming effects: Interactions between living and dead organic matter. Soil
 Biol. Biochem. 42, 1363–1371. https://doi.org/10.1016/j.soilbio.2010.04.003
- Leuschner, C., Wulf, M., Bäuchler, P., Hertel, D., 2014. Forest continuity as a key determinant of
 soil carbon and nutrient storage in beech forests on sandy soils in Northern Germany.
 Ecosystems 17, 497–511. https://doi.org/10.1007/s10021-013-9738-0
- Likens, G.E., Driscoll, C.T., Buso, D.C., Mitchell, M.J., Lovett, G.M., Bailey, S.W., Siccama, T.G.,
 Reiners, W.A., Alewell, C., 2002. The biogeochemistry of sulfur at Hubbard Brook.
- 553 Biogeochemistry 60, 235–316. https://doi.org/10.1023/A:1020972100496
- Liu, W., Luo, Q., Lu, H., Wu, J., Duan, W., 2017. The effect of litter layer on controlling surface
 runoff and erosion in rubber plantations on tropical mountain slopes, SW China. Catena 149,
 167–175. https://doi.org/10.1016/j.catena.2016.09.013
- Maes, S.L., Blondeel, H., Perring, M.P., Depauw, L., Brūmelis, G., Brunet, J., Decocq, G., den
 Ouden, J., Härdtle, W., Hédl, R., Heinken, T., Heinrichs, S., Jaroszewicz, B., Kirby, K.,
- 559 Kopecký, M., Máliš, F., Wulf, M., Verheyen, K., 2019. Litter quality, land-use history, and
- nitrogen deposition effects on topsoil conditions across European temperate deciduous forests.
- 561 For. Ecol. Manage. 433, 405–418. https://doi.org/10.1016/j.foreco.2018.10.056
- Mandal, K.G., Misra, A.K., Hati, K.M., Bandyopadhyay, K.K., Ghosh, P.K., 2004. Rice residuemanagement options and effects on soil properties and crop productivity 2, 224–231.
- Martín, M.A., Mattioni, C., Cherubini, M., Villani, F., Martín, L.M., 2017. A comparative study of
 European chestnut varieties in relation to adaptive markers. Agrofor. Syst. 91, 97–109.
 https://doi.org/10.1007/s10457-016-9911-5
- 567 McDonnell, T.C., Sullivan, T.J., Cosby, B.J., Jackson, W.A., Elliott, K.J., 2013. Effects of climate,
- land management, and sulfur deposition on soil base cation supply in national forests of the
- southern Appalachian Mountains. Water. Air. Soil Pollut. 224. https://doi.org/10.1007/s11270-

570 013-1733-8

- Mitchell, E., Scheer, C., Rowlings, D., Conant, R.T., Cotrufo, M.F., Grace, P., 2018. Amount and
 incorporation of plant residue inputs modify residue stabilisation dynamics in soil organic
 matter fractions. Agric. Ecosyst. Environ. 256, 82–91.
 https://doi.org/10.1016/j.agee.2017.12.006
- Mobley, M.L., Lajtha, K., Kramer, M.G., Bacon, A.R., Heine, P.R., Richter, D.D., 2015. Surficial
 gains and subsoil losses of soil carbon and nitrogen during secondary forest development.
 Glob. Chang. Biol. 21, 986–996. https://doi.org/10.1111/gcb.12715
- Mokma, D.L., Fenton, T.E., Olson, K.R., 1996. Effect of erosion on morphology and classification
 of soils in the North Central United States. J. Soil Water Conserv. 51, 171–175.
- Nave, L.E., Vance, E.D., Swanston, C.W., Curtis, P.S., 2010. Harvest impacts on soil carbon
 storage in temperate forests. For. Ecol. Manage. 259, 857–866.
 https://doi.org/10.1016/j.foreco.2009.12.009
- Neilsen, G., Forge, T., Angers, D., Neilsen, D., Hogue, E., 2014. Suitable orchard floor
 management strategies in organic apple orchards that augment soil organic matter and maintain
 tree performance. Plant Soil 378, 325–335. https://doi.org/10.1007/s11104-014-2034-8
- Oosterbaan, A., 1998. Growth of chestnut (*Castanea sativa*) in the Netherlands. Forestry 71, 267–
 270. https://doi.org/10.1093/forestry/71.3.267
- 588 Orgill, S.E., Condon, J.R., Kirkby, C.A., Orchard, B.A., Conyers, M.K., Greene, R.S.B., Murphy,
- B.W., 2017. Soil with high organic carbon concentration continues to sequester carbon with
 increasing carbon inputs. Geoderma 285, 151–163.
 https://doi.org/10.1016/j.geoderma.2016.09.033
- Orsini, L., Rémy, J., 1976. Utilisation du chlorure de cobaltihexamine pour la détermination
 simultanée de la capacité d'échange et des bases échangeables des sols. Bulletin de
 l'Association Française d'Etude du Sol. 4 : 269–279. Bull. l'Association Française d'Etude du
 Sol. 4 269–279. 4, 269–279.

- Pezzi, G., Maresi, G., Conedera, M., Ferrari, C., 2011. Woody species composition of chestnut
 stands in the Northern Apennines: The result of 200 years of changes in land use. Landsc.
 Ecol. 26, 1463–1476. https://doi.org/10.1007/s10980-011-9661-8
- Pieri, L., Rondini D., Ventura, F., 2017. Changes in the rainfall–streamflow regimes related to
 climate change in a small catchment in Northern Italy. Theor Appl Climatol 129, 1075–1087.
 https://doi.org/10.1007/s00704-016-1834-6
- R Core Team, 2016. R: A language and environment for statistical computing.
- Rees, R.M., Parker, J.P., 2005. Filtration increases the correlation between water extractable
 organic carbon and soil microbial activity. Soil Biol. Biochem. 37, 2240–2248.
 https://doi.org/10.1016/j.soilbio.2005.03.024
- Regione Emilia Romagna, 2000. Cartografia dei suoli della regione Emilia Romagna 1:50,000
 (1994 updates 2000). https://geo.regione.emilia romagna.it/cartografia_sgss/user/viewer.jsp?service=pedologia&bookmark=1%22
- Ren, C., Zhang, W., Zhong, Z.K., Han, X., Yang, G., Feng, Y., Ren, G., 2018. Differential
 responses of soil microbial biomass, diversity, and compositions to altitudinal gradients
 depend on plant and soil characteristics. Sci. Total Environ. 610–611, 750–758.
 https://doi.org/10.1016/j.scitotenv.2017.08.110
- Ribeiro, S.L., Fonseca, T.F., Pires, A.L., 2019. Influence of fertilization on growth of young
 chestnut trees (*Castanea sativa* Mill.) managed for wood production. Cerne 25, 357–364.
 https://doi.org/10.1590/01047760201925042660
- Soil Survey Staff, 2014. Keys to Soil Taxonomy, 12th ed. USDA–Natural Resources Conservation
 Service, Washington.
- Stefanowicz, A.M., Stanek, M., Nobis, M., Zubek, S., 2016. Species-specific effects of plant
 invasions on activity, biomass, and composition of soil microbial communities. Biol. Fertil.
- 620 Soils 52, 841–852. https://doi.org/10.1007/s00374-016-1122-8
- 621 Steinmann, T., Welp, G., Holbeck, B., Amelung, W., 2016. Long-term development of organic

- carbon contents in arable soil of North Rhine–Westphalia, Germany, 1979–2015. Eur. J. Soil
 Sci. 67, 616–623. https://doi.org/10.1111/ejss.12376
- 624 Świtoniak, M., 2014. Use of soil profile truncation to estimate influence of accelerated erosion on
- soil cover transformation in young morainic landscapes, North-Eastern Poland. Catena 116,
 173–184. https://doi.org/10.1016/j.catena.2013.12.015
- Tian, D.L., Peng, Y.Y., Yan, W. De, Fang, X., Kang, W.X., Wang, G.J., Chen, X.Y., 2010. Effects
 of thinning and litter fall removal on fine root production and soil organic carbon content in
 Masson Pine plantations. Pedosphere 20, 486–493. https://doi.org/10.1016/S10020160(10)60038-0
- Trumbore, S., 2009. Radiocarbon and Soil Carbon Dynamics. Annu. Rev. Earth Planet. Sci. 37, 47–
 66. https://doi.org/10.1146/annurev.earth.36.031207.124300
- Turner, B.L., Wells, A., Condron, L.M., 2014. Soil organic phosphorus transformations along a
 coastal dune chronosequence under New Zealand temperate rain forest. Biogeochemistry 121,
 595–611. https://doi.org/10.1007/s10533-014-0025-8
- Van Der Heijden, M.G.A., Bardgett, R.D., Van Straalen, N.M., 2008. The unseen majority: Soil
 microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecol. Lett. 11

638 (3), 296 - 310. https://doi.org/10.1111/j.1461-0248.2008.01199.x

van Leeuwen, J.P., Djukic, I., Bloem, J., Lehtinen, T., Hemerik, L., de Ruiter, P.C., Lair, G.J., 2017.

Effects of land use on soil microbial biomass, activity and community structure at different soil 640 in floodplain. 79. 14-20. depths the Danube Eur. J. Soil Biol. 641 https://doi.org/10.1016/j.ejsobi.2017.02.001 642

- Vance, E.D., Brookes, P.C., Jenkinson, D.S., 1987. An extraction method for measuring soil
 microbial biomass C. Soil Biol. Biochem. 19, 703–707. https://doi.org/10.1016/0038-
- 645 0717(87)90052-6
- 646 Vannier, C., Guillet, B., 1994. Sulphur forms in the organic fractions of an upland forest soil (Mont
- 647 Lozère, France). Soil Biol. Biochem. 26, 149–151. https://doi.org/10.1016/0038-

648 0717(94)90207-0

- Vittori Antisari, L., Bianchini, G., Dinelli, E., Falsone, G., Gardini, A., Simoni, A., Tassinari, R.,
 Vianello, G., 2014. Critical evaluation of an intercalibration project focused on the definition
 of new multi-element soil reference materials (AMS-MO1 and AMS-ML1). EQA Int. J.
 Environ. Qual. 15, 41–64. https://doi.org/10.6092/issn.2281-4485/4553
- 653 Vittori Antisari, L., Falsone, G., Carbone, S., Vianello, G., 2013. Short-term effects of forest
- recovery on soil carbon and nutrient availability in an experimental chestnut stand. Biol. Fertil.
 Soils 49, 165–173. https://doi.org/10.1007/s00374-012-0708-z
- Vittori Antisari, L., Laudicina, V.A., Falsone, G., Carbone, S., Badalucco, L., Vianello, G., 2016.
 Native and planted forest species determine different carbon and nitrogen pools in Arenosol
 developed on Holocene deposits from a costal Mediterranean area (Tuscany, Italy). Environ.
 Earth Sci. 75. https://doi.org/10.1007/s12665-016-5581-x
- Waldboth, W., Oberhuber, W., 2009. Synergistic effect of drought and chestnut blight
 (*Cryphonectria parasitica*) on growth decline of European chestnut (*Castanea sativa*). For.
 Path. 39, 43–55. https://doi.org/10.1111/j.1439-0329.2008.00562.x
- Kiong, Y., Xia, H., Li, Z., Cai, X., Fu, S., 2008. Impacts of litter and understory removal on soil
 properties in a subtropical *Acacia mangium* plantation in China. Plant Soil 304, 179–188.
 https://doi.org/10.1007/s11104-007-9536-6
- Xu, X., Han, L., Wang, Y., Inubushi, K., 2007. Influence of vegetation types and soil properties on
 microbial biomass carbon and metabolic quotients in temperate volcanic and tropical forest
 soils. Soil Sci. Plant Nutr. 53, 430–440. https://doi.org/10.1111/j.1747-0765.2007.00146.x
- Yavitt, J.B., Fahey, T.J., Sherman, R.E., Groffman, P.M., 2015. Lumbricid earthworm effects on
 incorporation of root and leaf litter into aggregates in a forest soil, New York State.
 Biogeochemistry 125, 261–273. https://doi.org/10.1007/s10533-015-0126-z
- 272 Zetterberg, T., Olsson, B.A., Löfgren, S., Hyvönen, R., Brandtberg, P.O., 2016. Long-term soil
- 673 calcium depletion after conventional and whole-tree harvest. For. Ecol. Manage. 369, 102–

- 674 115. https://doi.org/10.1016/j.foreco.2016.03.027
- Zlatanov, T., Schleppi, P., Velichkov, I., Hinkov, G., Georgieva, M., Eggertsson, O., Zlatanova, M.,
- 676 Vacik, H., 2013. Structural diversity of abandoned chestnut (*Castanea sativa* Mill.) dominated
- 677 forests: Implications for forest management. For. Ecol. Manag. 291, 326–335.
 678 https://doi.org/10.1016/j.foreco.2012.11.015
- Zornoza, R., Acosta, J.A., Bastida, F., Domínguez, S.G., Toledo, D.M., Faz, A., 2015. Identification
 of sensitive indicators to assess the interrelationship between soil quality, management
 practices and human health. Soil 1, 173–185. https://doi.org/10.5194/soil-1-173-2015

682









Image Landsat/Copernicus © 2020

701298 mE









Figure captions

Figure 1. The localization of investigated sites (REM1, REM2, CONS1 and CONS2) (on left side) and a recovery chestnut stand where it is visible the 10 x 10 m tree spacing (on right side). REM and CONS study sites are chestnut (*Castanea sativa* Mill.) stands with removal and conservation of organic residues, respectively.

Figure 2. Cation exchange capacity (I), exchangeable calcium (II), magnesium (III), potassium (IV) and sodium (V), and base saturation (VI) in epipedon (Epi) and endopedon (Endo) of soils under chestnut (*Castanea sativa* Mill.) stands with removal (REM; white bars) and conservation (CONS; grey bars) of organic residues. Error bars are the standard errors. According to Kruskal–Wallis test, within each soil layer, different lowercase letters indicate significant differences (p<0.05) between the two managements (REM *vs* CONS), instead, within each management different uppercase letters indicate significant differences (p<0.05) between epipedon and endopedon (Epi *vs* Endo).

Figure 3. Amounts of total organic carbon (I), total nitrogen (II), C associated to water–extractable organic matter (III) and N associated to water–extractable organic matter (IV) in epipedon (Epi) and endopedon (Endo) of soils under chestnut (*Castanea sativa* Mill.) stands with removal (REM; white bars) and conservation (CONS; grey bars) of organic residues. Error bars are the standard errors. According to Kruskal–Wallis test, within each soil layer, different lowercase letters indicate significant differences (p<0.05) between the two managements (REM *vs* CONS), instead, within each management different uppercase letters indicate significant differences (p<0.05) between epipedon and endopedon (Epi *vs* Endo).

Figure 4. Amounts of C associated to particulate organic matter (I), and to fulvic–like (II), humic–like (III) and humin–like (IV) substances in epipedon (Epi) and endopedon (Endo) of soils under chestnut (*Castanea sativa* Mill.) stands with removal (REM; white bars) and conservation (CONS;

grey bars) of the organic residues. Error bars are the standard errors. According to Kruskal–Wallis test, within each soil layer, different lowercase letters indicate significant differences (p<0.05) between the two managements (REM *vs* CONS, instead, within each management different uppercase letters indicate significant differences (p<0.05) between epipedon and endopedon (Epi *vs* Endo).

Figure 5. Content of microbial biomass C (I) and N (II), basal respiration (III), total amount of CO_2 evolved during basal respiration experiments (IV), metabolic (V) and mineralization (VI) quotients in epipedon (Epi) and endopedon (Endo) of soils under chestnut (*Castanea sativa* Mill.) stands with removal (REM; white bars) and conservation (CONS; grey bars) of the organic residues. Error bars are the standard errors. According to Kruskal–Wallis test, within each soil layer, different lowercase letters indicate significant differences (*p*<0.05) between the two managements (REM *vs* CONS), instead, within each management different uppercase letters indicate significant differences (*p*<0.05) between epipedon and endopedon (Epi *vs* Endo).

Table 1Click here to download Table: Table 1.docx

	2			
Study site	Coordinates (UTM 32 T)		MAAT	MAP
	m E	m N	° C	mm
REM 1	686305	4904858	11.7	1136
REM 2	686751	4904078	11.7	1136
CONS 1	690032	4898682	11.0	1251
CONS 2	618314	4927009	10.9	883

Table 1. The study sites locations and climatic characteristics

MAAT = mean annual air temperature; MAP = mean annual precipitations.

Table 2. Thickness, amounts of sand, silt and clay, and pH in water (pH_{H₂O) and in KCl (pH_{KCl}) values measured in epipedon (Epi) and endopedon (Endo) of soils under chestnut (*Castanea sativa* Mill.) stands with removal (REM) and conservation (CONS) of the organic residues. Standard error is reported in parentheses. According to Kruskal–Wallis test: *i*) within each management, the uppercase letters indicate significant differences (p<0.05) between soil layer, the lowercase letters indicate significant differences (p<0.05) between the two managements (REM *vs* CONS).}

Layer	Management	Thickness	Sand	Silt	Clay	$pH_{\rm H_2O}$	рНксі
		cm		$g kg^{-1}$			
Epi	REM	5.1 Bb	564	382	152 a	4.9	3.5
		(0.7)	(67)	(51)	(21)	(0.2)	(0.2)
Epi	CONS	9.7 Ba	522	370 B	89 b	4.8	3.2 B
		(1.8)	(20)	(15)	(11)	(0.1)	(0.2)
Endo	REM	12.4 Ab	545	322	132 a	4.9	3.4
		(1.8)	(58)	(46)	(16)	(0.1)	(0.1)
Endo	CONS	20.2 Aa	467	461 A	71 b	5.4	4.1 A
		(2.1)	(13)	(13)	(3)	(0.1)	(0.1)

Table 3. Stock of organic carbon (OC), N, Ca, Mg, Na, K, Fe, P and S measured at 0 - 10, 10 - 20, 20 - 30 cm soil depth intervals under chestnut (*Castanea sativa* Mill.) stands with organic residues removal (REM) and conservation (CONS). Standard error is reported in parentheses. According to Kruskal–Wallis test: *i*) within each management, different uppercase letters indicate significant differences among the soil depth intervals (p<0.05); *ii*) within each soil depth interval, different lowercase letters indicate significant differences (p<0.05) between the two managements (REM *vs* CONS).

Depth	Management	OC	Ν	Ca	Mg	Na	К	Fe	Р	S
						kg ha ⁻¹				
0 - 10	REM	37183 A	2702 A	1319	3834	313 B	3716	16056	223	207 A
		(8159)	(598)	(255)	(890)	(17)	(642)	(3308)	(36)	(53)
0 - 10	CONS	30734 A	2338 A	2463	4357 B	346	4845	19435 B	295	186
		(3154)	(285)	(349)	(277)	(22)	(304)	(959)	(18)	(17)
10 - 20	REM	9581 Bb	739 Bb	1224	5002	407 A	4720	20897	159 b	84 Bb
		(2202)	(149)	(189)	(1044)	(32)	(801)	(3883)	(21)	(10)
10 - 20	CONS	17242 Ba	1389 Ba	2446	5537 A	393	5552	25697 A	280 a	138 a
		(2390)	(159)	(458)	(215)	(32)	(351)	(1448)	(27)	(12)
20 - 30	REM	6875 Bb	639 Bb	1441	6009	426 A	5431	24214	150 b	72 Bb
		(1354)	(134)	(207)	(1439)	(46)	(1099)	(5288)	(21)	(10)
20 - 30	CONS	13668 Ba	1159 Ba	2393	6027 A	405	5970	27837 A	269 a	118 a
		(1113)	(71)	(448)	(358)	(35)	(421)	(1562)	(14)	(8)

Table 4. Mean ± standard error of C, N, Ca, Mg, Na, K, Fe, P and S contents in chestnut (*Castanea sativa* Mill.) leaves collected from chestnut stands with organic residues removal (REM) and conservation (CONS).

	REM	CONS
$C (g kg^{-1})$	411 ± 11	416 ± 5
N (g kg ^{-1})	21.0 ± 1.0	23.7 ± 1.7
$Ca (g kg^{-1})$	4.31 ± 1.12	5.22 ± 078
$Mg (g kg^{-1})$	1.94 ± 0.09	1.73 ± 0.08
Na (g kg ^{-1})	0.10 ± 0.02	0.19 ± 0.01
$K (g kg^{-1})$	5.63 ± 0.19	7.03 ± 0.55
$Fe (g kg^{-1})$	0.10 ± 0.00	0.13 ± 0.02
$P(g kg^{-1})$	1.34 ± 0.17	1.05 ± 0.07
$S (g kg^{-1})$	0.99 ± 0.07	1.48 ± 0.22

Supplementary material for on-line publication only Click here to download Supplementary material for on-line publication only: Supplementary materials_new.docx

Declaration of interests

 \boxtimes The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

□The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: