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Fruit characteristics, defoliation, forest floor and soil properties of sweet chestnut (*Castanea sativa* Mill.) forests in İstanbul-Turkey

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Abstract: The defoliation and fruit characteristics of natural *Castanea sativa* Mill. forests were annually monitored between 2014 and 2016 in İstanbul, Turkey. The soil and forest floor properties were also investigated and evaluated according to the stand development stages. Comparisons were made with ANOVA and Tukey HSD tests; the relationship between fruit yield and the properties of the soil and forest floor were tested with correlation analysis; and allometric regression models were developed for fruit yield with DBH (diameter at breast height) and $(DBH)^2H$. The total mass was 509–652 g/m^2, N mass was 7.67–9.70 g/m^2 and C mass was between 165.75 g/m^2 and 183.28 g/m^2 in the forest floor in the development stages. The soil texture was loam–clay loam, soil C concentration was between 0.3% and 1.92%, N concentration was 0.08–0.32%, the EC was very low (33–84 µS/cm), and the pH was acidic (5 pH). The properties of the forest floor and soil were not significantly different from the development stages. The defoliation rates increased significantly every year in each development stage. The fruit yield was between 183.51 kg/ha and 298.27 kg/ha, and fruit was not detected in the smallest development stage (SDF). The fruit yields were quite low in comparison with other natural *C. sativa* forests. However, in each year in the study period, fruit yields were negatively correlated with mass and C and N content and positively correlated with N concentration in the H layer of the forest floor. There was not a significant difference in fruit yield over the years, and it had a low relation with DBH and $(DBH)^2H$ ($R^2 = 0.34$ and $R^2 = 0.23$, respectively). The fruits' characteristics significantly fluctuated over the years. As a result, low fruit yield and low relationships with properties of the forest floor and soil might be attributed to the former coppice management and possible health problems.

Key words: Carbon, development stage, morphometric, nitrogen, nonwood

1. Introduction

The sweet chestnut tree (*Castanea sativa* Mill.) has been an important source of income for centuries, having been cultivated since ancient times for its valuable wood and fruit (Soylu, 2004; Öztürk, 2006). Sweet chestnut is an important starchy food worldwide, due to its low fat content and high nutritional value (Kan et al., 2017; Benedetti et al., 2018). In addition to its wood and fruit, the chestnut tree's leaves, flowers, and bark are also intensively utilized (Mangil, 2017).

In 2018, 2.3 million tons of chestnut fruit was produced worldwide, with China producing the most at 1.8 million tons, or 83% of total production, Turkey produced about 65 thousand tons, making it the third largest producer and accounting for approximately 3% of the world's production (Özer, 2020).

Europe and Turkey are widely distribution area of sweet chestnut. The site characteristics for sweet chestnut trees include a maritime climate; annual precipitation of 600–1500 mm; a mean annual temperature of 9–13 °C; and a mean annual maximum temperature of 27 °C (Heiniger and Conedera, 1992; Gomes-Laranjo et al., 2008). Karadeniz (2013) stated that the amount of precipitation is an important factor in the natural distribution of sweet chestnut trees. Although it is found in its natural habitat in Turkey, former silvicultural treatments, such as coppicing, clearcutting, and anthropogenic factors, have a tremendous impact on the tree's quality and yield (Özer, 2020). Chestnut shows good growth in well-drained, loamy textured, deep soils. The soils in its natural spreading area generally show an acidic character (5–6.3 pH), as it avoids alkaline soils, while its nutrient-rich litter fall improves the soil quality (Erdem, 1951; Saatçioğlu, 1969). Soylu (1984) indicated that soils should be well-aerated, water permeable, and deep for good chestnut growth; however, heavy clay soils, low land with pseudogley soils, and valleys with stabilized cold air are not suitable. Gallardo-Lancho (2001) outlined the optimum conditions for chestnut

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growth: sufficient rainfall in the growing period, water available in the soil throughout the summer, moderate clay and stoniness in the soil, deep and permeable soils, slightly acidic soil reaction, and a sufficient amount of organic matter. Dinis et al. (2012) researched the effects of different soil and climatic conditions on the chemical and technological properties of chestnut fruits and found that trees in the same variety can produce nuts of a different quality, depending on the growing conditions.

Atasoy and Altıngöz (2011) stated that the intensive use of chestnut trees' fruit and timber is leading to the reduction and destruction of chestnut fields, worldwide. Furthermore, fruit yield decreases, and defoliation and tree decline increases as a result of diseases, pests, and intensive use of chestnut forests. In summary, chestnut stands are known to be unhealthy, and research on chestnut trees is gaining importance (Soylu, 2004; İpekdal et al., 2014; Altun et al., 2018). Evaluation of ecological characteristics as being an important deficiency in these areas has not been investigated sufficiently. There are few studies on the morphological characteristics of chestnut fruit yield and the fruits themselves, particularly with environmental variables and site characteristics (Dinis et al., 2011; Silvanini et al., 2014). Additionally, there are very few studies on chestnut trees' fruit characteristics and ecological conditions in natural chestnut forest areas, rather than orchards (Ertan, 2007; Mujić et al., 2010; Poljak et al., 2012; Atar and Turna, 2018; Benedetti et al., 2018; Beccaro et al., 2021; Nicoletti et al., 2021).

For these reasons, the main aims of this study were to investigate the characteristics and yield of fruits, the forest floor characteristics, soil properties and the trees' defoliation rates of sweet chestnut stands in İstanbul, Turkey. Data were determined between 2014 and 2016 according to the stand development stages, classified by mean tree diameter at breast height (DBH) of the stand. The results were evaluated according to the development stages and annual changes.

2. Materials and methods

2.1. Research site

Pure chestnut stands within the borders of the İstanbul Province cover an area of 3016.3 ha (Figure 1). These chestnut forests are mostly coppice originated, and traditional Turkish coppice management were periodical clear cuts of deciduous forests aiming just to produce fuel wood. Coppice management was abandoned in 2006, however, there was not any management or fruit production plans for these chestnut forests, as it is still. The sample plots for the present study are the chestnut forests within Beykoz's and Sahilköy's Forest Management Directorates. Sample plots in Beykoz's chestnut forests are located between 41°06′53″–41°13′34″N and 29°04′10″–29°13′55”E. Sample plots in Sahilköy's chestnut forests are located between 41°13′03″–41°06′02″N and 29°19′09″–29°33′55″E (Figure 1).

The study area is located in the Marmara region in Turkey and has the specific site characteristics of this region. Summers are hot and dry, and winters are cool and rainy. According to the meteorological data of the area, the mean annual temperature is 14.8 °C, with a maximum monthly temperature of 35.8 °C in June and July and a minimum monthly temperature of –5.9 °C in January. The total mean annual rainfall is 934.5 mm. The soils are generally moderately deep, have a clay loam–loam texture, are acidic, have no calcium carbonate reaction, and are Luvisols (IUSS Working Group, 2006; Özer, 2020).

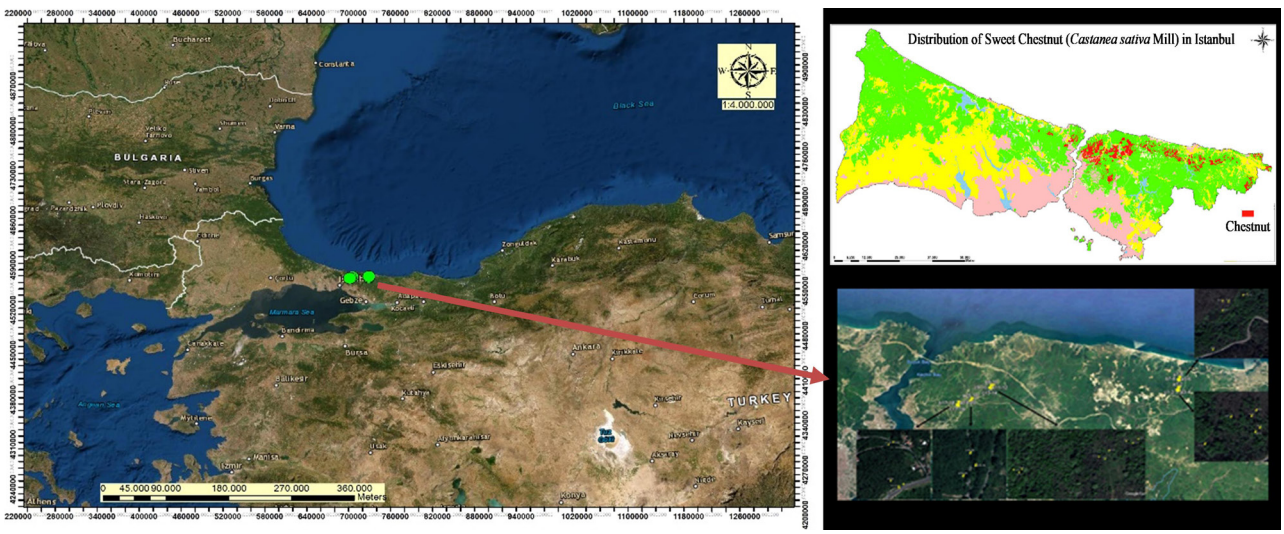

Figure 1. Distribution of pure chestnut forests in İstanbul-Turkey and research site.

2.2. Sample plots and sampling

The sample plots were selected from different stand development stages (Figure 1), which are stated in the regulations of the Turkish General Directorate of Forestry and classified according to the mean DBH of the standing tree. The classifications of the development stages according to the DBH are small-diameter forests (SDF) (DBH = 0–8 cm), medium-diameter forests (MDF) (DBH = 8–20 cm), and large-diameter forests (LDF) (DBH = 20–36 cm). In the preliminary field surveys, sample plots were selected from pure chestnut stands, which included all three development stages and were in common site conditions; thus, we randomly found ten different sample plots that fit these criteria. All of the areas in the İstanbul Province that met these criteria were sampled in this study. A total of 60 sample plots (ten sample plots × three development stages × two replications) were selected. Sample plots were 400 m^2 (20 × 20 m) in the MDF and LDF development stages and 100 m^2 (10 × 10 m) in the SDF development stages. Some site characteristics (slope gradient and altitude) were determined, and the DBH and height of all the trees in each plot were measured (Table 1).

Forest floor samples were collected from 1/4 m^2 (50 × 50 cm) with five replications from each sample plot by collecting all organic material on the mineral soil. One soil pit was dug in replicated sample plots, with a total number of 30 soil pits, including ten replications in each development stage. Soil samples were taken with steel cylinders from depths of 0–10 cm, 10–40 cm, 40–70 cm, and 70–100 cm.

The areas where the fruit samples were collected were chosen for being under the least pressure, such as from wild animals feeding on the fruit (pigs, etc.) or people collecting it. It was observed that there were no such pressures throughout the study. Collecting, counting, and measuring fruit took place in the MDF and LDF development stages because no fruit was found in the SDF development stage over the research period. Five replicated permanent sampling points (1 × 1 m) were set and marked with wooden sticks in each sample plot, all fruits were collected, and the number of fruits per m^2 was recorded in each sample at least twice a week from the beginning of the fruit senescence to the end of fruit abscission, every year (usually from 15th September to 15th October in İstanbul) (Özer, 2020).

2.3. Defoliation rates (crown condition observation)

At the beginning of the study, ten trees which have healthy-looked and closest to the center of each sample plot were selected and marked. Defoliation rates were recorded each year (2014–2016) by observing the evaluable crowns of these trees, according to the European Union and ICP Forests' crown condition monitoring method (UNECE, 1998). Repeated observations for defoliation rates were made in clear, visible conditions at approximately the same date each year (e.g., late July and mid-August). Observations of selected trees were made from multiple directions by at least two people and from a distance of approximately tree height. For crown condition evaluation and reference tree comparison, photograph catalogs from the Forest Ecosystems Crown Condition Assessment and Sanasilva Tree Crown Photos were used, which were prepared for the Turkey Forest Health Monitoring program (ICP Forests) (Müller and Stierlin, 1990; OGM, 2009; Özer, 2020).

2.4. Laboratory analysis

Air-dried forest floor samples were sieved with 1 mm mesh sieves to separate the humus (H) and litter and fermentation (L+F) layers. The samples were dried at 70 °C until at a constant weight; thus, oven-dried masses were determined (Karaöz, 1992).

Soil samples were sieved through 2 mm sieves and separated from the stones and roots. Subsamples were

Table 1. Site and stand characteristics of sample plots in pure chestnut forests in İstanbul-Turkey (Özer 2020).

Parameters	Development stages			p
	SDF	MDF	LDF	
Altitude (m)	159.40 ± 25.88	162.20 ± 27.13	162.20 ± 27.30	0.964
Slope (%)	23.50 ± 8.83	24.5 ± 13.01	22.00 ± 12.51	0.889
Mean tree DBH (cm)	4.22 ± 1.51 [a]	14.97 ± 2.15[b]	20.18 ± 2.45[c]	0.000
Mean tree height (m)	6.10 ± 1.67 [a]	12.59 ± 0.78[b]	14.12 ± 1.43[c]	0.000
Density (trees/ha)	2675 ± 464	2600 ± 685	2505 ± 439	0.612

± standard deviation, rows following with same small letter are not statistically different ($p > 0.05$). SDF: small-diameter forests (DBH = 0–8 cm), MDF: medium diameter forests (DBH = 8–20 cm), LDF: large-diameter forests (DBH = 20–36 cm).

dried at 105 °C, and the oven-dried bulk density (<2 mm) was determined. The texture (sand, silt, and clay ratios) was analyzed with the Bouyoucos hydrometer method. Soil acidity (pH) was measured in a 1/2.5 suspension (soil/distilled water (w/v)), and electrical conductivity (EC) was determined in 1/5 soil/distilled water (w/v) solutions (Karaöz, 1989a; b).

Chestnut fruit samples were dried at 105 °C, and their oven-dried weights were determined (ISTA, 1996). The morphometric parameters (width, length and thickness) of 30 randomly selected fruits for each plot and their weights were measured and recorded separately for each measurement year. Despite randomly selection, fruits were in good shape, no any damage or scars were observed and they were mostly from sides of burs (one fruit side is flat and another side is round).

The nitrogen (N) and carbon (C) concentrations of all samples (forest floor, soil, and fruits (without the pericarp)) were analyzed on the LECO TruSpec 2000 CN analyzer (LECO, 2000).

2.5. Data analysis

In the forest floor samples, the total forest floor mass was found by the sum of both L+F and H layers. The C and N contents (g/m^2) were calculated by proportioning the C and N concentrations (%) with the unit area mass. The soil's C and N contents (g/L) were determined by proportioning the soil's C and N concentrations to the bulk density (<2 mm). To calculate soil pedon (for 1 m soil depth), N and C volume values (g/L) at each soil depth were converted into unit area values, and the pedon value (t/ha) was obtained by summing the values of all soil depths at 1 m. The fruits collected from the sample plots were converted to fruit weight per unit area (kg/ha) by taking the average of five replicated counts.

The development stages were statistically compared with the analysis of variance (ANOVA) regarding the properties of the forest floor and soil, site, and stand characteristics of sample plots (altitude, slope, mean DBH of stand, mean stand height, and tree density of stand). A Tukey HSD posthoc test was used to determine the different groups because the variances were homogeneous. The ANOVA and Tukey tests were also used for annual comparison of the defoliation rates and fruit characteristics, and significant effects were reported at the 0.05 level. Based on the data from each year (2014, 2015, and 2016), the relationship between fruit yield and investigated characteristics was tested with correlation analysis. Because plots in SDF development stages have not fruits, differences of fruit characteristics between MDF and LDF development stages in each year were tested by independent t-test. Allometric regression models were developed by correlating fruit yield with DBH and tree diameter with height ((DBH)^{2}H). IBM SPSS 21.0 (IBM, 2012) was used to analyze the data.

3. Results

3.1. Forest floor properties

Forest floor properties did not significantly differ among the development stages ($p > 0.05$). The mean total forest floor amount was between 509.40 g/m^2 and 652.14 g/m^2, and the L+F layer constituted a significant part of the total forest floor. The concentrations of N in the forest floor in the development stages were approximately 1.5% in both the L+F and H layers. The mean concentration of C in the development stages was 35%–38% in the L+F layer and 16%–19% in the H layer. Accordingly, the mean N content of the forest floor was found to be 7.67–9.70 g/m^2, and the C content was between 165.75 g/m^2 and 183.28 g/m^2 (Table 2).

3.2. Soil properties

Similar to the forest floor results, there was no significant difference in the development stages in terms of all investigated soil properties in all soil depths (Table 3). Soil texture types were loam–clay loam according to the ratio of sand, silt, and clay in the soils. The average soil bulk densities (<2 mm) at different soil depths and development stages were between 887 g/L and 1104 g/L. C concentration was generally 1.8%–1.9% at the topsoil depth and decreased towards the lower depths, recorded as 0.3% in the bottom soil layer (70–100 cm). Similar to C, the mean N concentration also decreased from 0.3% (0–10 cm deep) to 0.08% (70–100 cm deep). The pedon mass of C was 62–73 t/ha, and the pedon mass of N was between 15 t/ha and 19 t/ha for 1 m soil depth. In all development stages and soil depths, the soil reaction showed a severe acidic character of approximately 5pH, and EC values were very low, between 33 µS/cm and 84 µS/cm (Table 3).

3.3. Defoliation rates

Increasing defoliation rates have been determined every year in all development stages. Young SDF stands showed the highest rates of increase from 31% to 54%, defoliation rates increased from 37% to 49% in the MDF stands, and rates changed from 35% to 46% in the LDF development stage from 2014 to 2016 (Figure 2).

3.4. Fruit yield and characteristics

There was no statistically significant difference over the years in terms of fruit yield per unit area. The fruit yields on average ranged from 169 kg/ha to 348 kg/ha between 2014 and 2016. However, there were some exceptions (fruit length at the LDF development stage and fruit C concentration at the MDF development stage), as significant differences were found between the years in terms of morphometric (width, thickness, and length) and chemical fruit characteristics (C and N) (Table 4). Nonetheless, these significant differences did not show a clear trend in the study period. For example, the lowest average weight of a single fruit was recorded in the MDF

Table 2. Forest floor properties of sweet chestnut forests in development stages.

Forest floor properties	Development stages			p
	SDF	MDF	LDF	
Mass (g/m²) – L+F	430.17 ± 92.40	410.50 ± 60.62	399.13 ± 65.97	0.645
Mass (g/m²) – H	221.98 ± 208.08	150.88 ± 65.20	110.27 ± 51.27	0.167
Mass (g/m²) – total	652.14 ± 284.29	561.38 ± 85.63	509.40 ± 88.40	0.214
N (%), L+F	1.58 ± 0.27	1.57 ± 0.30	1.48 ± 0.98	0.614
C (%), L+F	35.99 ± 6.56	35.25 ± 5.11	37.80 ± 4.56	0.570
N (%), H	1.51 ± 0.22	1.51 ± 0.21	1.65 ± 0.22	0.260
C (%), H	16.74 ± 5.15	15.93 ± 4.74	19.28 ± 3.73	0.252
N (g/m²), L+F	6.68 ± 1.41	6.52 ± 1.97	5.92 ± 1.14	0.517
C (g/m²), L+F	153.87 ± 42.04	143.59 ± 23.79	151.15 ± 29.76	0.772
N (g/m²), H	3.02 ± 2.14	2.20 ± 0.8	1.75 ± 0.7	0.142
C (g/m²), H	29.40 ± 14.14	22.16 ± 7.05	20.15 ± 8.27	0.127
N (g/m²), total	9.70 ± 3.06	8.72 ± 2.03	7.67 ± 1.39	0.156
C (g/m²), total	183.28 ± 54.52	165.75 ± 26.21	170.30 ± 31.63	0.593

± standard deviation, L+F: litter + fermentation, H: humus, N: nitrogen, C: carbon, SDF: small-diameter forests (DBH = 0–8 cm), MDF: medium diameter forests (DBH = 8–20 cm), LDF: large-diameter forests (DBH = 20–36 cm).

development stage (1.46 g) in 2014, while the highest average weight (2.39 g) was recorded in the LDF stage in 2016. The lowest fruit lengths and widths were in the MDF stage in 2014, despite the highest values being in the LDF stage in 2015. Fruit thickness varied between 10.74 mm (MDF in 2014) and 19.73 mm (MDF in 2016). The C concentrations of the fruit did not differ significantly over the years in the MDF development stage, while they varied significantly between 42.58% (2014) and 43.84% (2015) in the LDF stage. Fruit N concentrations were between 1.43% (LDF in 2016) and 2.58% (LDF in 2015), and the annual variation was significantly different (Table 4). When fruit characteristics are tested according to development (between MDF and LDF) stages in the same year; statistically significant differences were found on unit fruit weights (kg/ha) in each year and LDF stage have significantly higher fruit yield. Other significant differences were between single fruit weights in 2014 and 2016, fruit width in 2014, fruit thickness in 2014 and 2016 and both fruit C and N in 2015 and 2016 (Table 4). In addition, fruit yield had a low relation with DBH and $(DBH)^2H$ ($R^2 = 0.34$ and $R^2 = 0.23$, respectively) (Figure 3).

All stand, forest floor, and soil properties examined with the fruit yield in the correlation analysis, including the general evaluation of the three-year data; mean stand DBH; N and C concentrations of the forest floor H layer; the N concentration of 0–10 cm and 10–40 cm soil depths; and the EC value of 70–100 cm soil depth, had a significantly positive relationship with the fruit yield per unit area. However, some investigated parameters showed a significant negative relationship with the fruit yield per unit area in the correlation analysis: the defoliation rates of 2015 and 2016; the mass; the C and N contents of the forest floor H layer and the total forest floor mass; the C concentrations of the soil depths of 10–40 and 40–70 cm; the soil's pH at 10–40 and 70–100 cm soil depth; the C content in the soil pedon; and the soil bulk densities (<2 mm) of 0–10 cm and 10–40 cm soil depths. Nonetheless, the significant parameters over the three years were mass, N concentration, and C and N contents in the H layer of the forest floor (Table 5).

4. Discussion

As will be discussed in detail, there was no significant difference between the development stages in terms of forest floor and soil properties in addition to the site characteristics, such as the altitude and slope of the sample plots. The traditional former coppicing of sweet chestnut forests is thought to be influential in this issue because the development stages in the sample plots were not formed naturally but by human interference. Periodic clearcutting has occurred in different time periods in these forests, which have been coppiced for years; this likely caused an old root system and a structure consisting of younger trees on the aboveground section (Özer, 2020).

Table 3. The soil properties of sweet chestnut forests in development stages.

Soil parameters	Depth (cm)	Development stages			p
		SDF	MDF	LDF	
C (%)	(0–10)	1.84 ± 0.55	1.81 ± 0.51	1.92 ± 0.78	0.914
	(10–40)	1.04 ± 0.42	1.05 ± 0.36	0.81 ± 0.27	0.234
	(40–70)	0.45 ± 0.13	0.41 ± 0.11	0.42 ± 0.21	0.831
	(70–100)	0.30 ± 0.11	0.36 ± 0.07	0.35 ± 0.19	0.599
Pedon C (t/ha)	(1 m)	73.44 ± 19.95	71.38 ± 17.30	61.61 ± 19.19	0.115
N (%)	(0–10)	0.32 ± 0.07	0.29 ± 0.08	0.29 ± .0.11	0.736
	(10–40)	0.25 ± 0.08	0.21 ± 0.08	0.21 ± 0.10	0.462
	(40–70)	0.13 ± 0.03	0.14 ± 0.06	0.13 ± 0.05	0.879
	(70–100)	0.11 ± 0.03	0.08 ± 0.05	0.08 ± 0.04	0.330
Pedon N (t/ha)	(1 m)	18.71 ± 4.89	15.48 ± 6.25	15.36 ± 7.48	0.171
Bulk density (g/L) (<2 mm)	(0–10)	960.51 ± 119.93	917.78 ± 141.96	918.81 ± 136.56	0.718
	(10–40)	1049.42 ± 144.15	1021.15 ± 161.39	887.90 ± 273.34	0.179
	(40–70)	1026.17 ± 135.16	952.68 ± 172.84	995.66 ± 203.69	0.638
	(70–100)	1104.12 ± 196.68	946.33 ± 173.12	1024.92 ± 217.69	0.219
pH	(0–10)	5.38 ± 0.69	5.72 ± 0.52	5.61 ± 0.62	0.470
	(10–40)	5.44 ± 0.39	5.46 ± 0.34	5.40 ± 0.61	0.958
	(40–70)	5.31 ± 0.34	5.23 ± 0.23	5.08 ± 0.26	0.214
	(70–100)	5.32 ± 0.41	5.26 ± 0.29	5.03 ± 0.25	0.124
EC (µS/cm)	(0–10)	64.29 ± 29.68	84.15 ± 26.92	66.37 ± 24.32	0.215
	(10–40)	45.16 ± 9.71	47.23 ± 11.40	45.80 ± 23.55	0.958
	(40–70)	41.55 ± 21.26	50.20 ± 35.18	42.16 ± 17.38	0.707
	(70–100)	32.63 ± 7.86	49.03 ± 35.02	37.16 ± 10.13	0.231
Sand (%)	(0–10)	57.45 ± 22.17	58.38 ± 16.53	59.62 ± 17.88	0.968
	(10–40)	54.48 ± 23.58	52.90 ± 15.20	59.07 ± 18.33	0.762
	(40–70)	44.57 ± 16.96	43.32 ± 14.89	55.69 ± 13.93	0.158
	(70–100)	44.69 ± 14.42	42.61 ± 10.36	54.44 ± 15.45	0.150
Silt (%)	(0–10)	23.17 ± 13.32	21.56 ± 10.45	22.97 ± 10.69	0.944
	(10–40)	21.54 ± 12.59	21.81 ± 6.94	17.69 ± 10.29	0.607
	(40–70)	24.71 ± 14.91	23.20 ± 8.42	19.58 ± 12.26	0.630
	(70–100)	25.51 ± 13.64	24.66 ± 7.43	22.04 ± 15.65	0.819
Clay (%)	(0–10)	19.37 ± 10.18	20.06 ± 6.92	17.40 ± 8.11	0.771
	(10–40)	23.98 ± 11.86	25.29 ± 9.99	23.24 ± 10.75	0.914
	(40–70)	30.71 ± 6.78	33.47 ± 10.19	24.73 ± 7.54	0.073
	(70–100)	28.80 ± 7.77^{ab}	32.72 ± 8.57^{b}	23.51 ± 7.59^{a}	0.050

± standard deviation, means followed by the same uppercase small letter do not differ significantly ($p > 0.05$) in rows. EC: electrical conductivity, C: carbon, N: nitrogen, SDF: small-diameter forests (DBH = 0–8 cm), MDF: medium diameter forests (DBH = 8–20 cm), LDF: large-diameter forests (DBH = 20–36 cm).

4.1. Forest floor

Jawed (2017) found the forest floor of chestnut forests to be 990–1740 g/m^2 in north-west Turkey, and Makineci (1999) reported it as being between 895 g/m^2 and 1205.5 g/m^2 with an average of 1018.4 g/m^2 in İstanbul's chestnut forests —both values are considerably higher than those

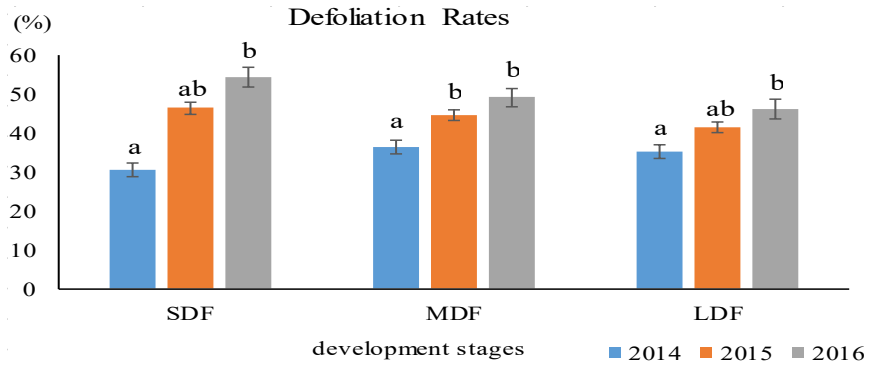

Figure 2. Temporal comparison (2014–2016) of defoliation rates of sweet chestnut forests in development stages. Bars on columns indicate standard deviation, means followed by the small letter in each development stage do not differ significantly ($p > 0.05$).

Table 4. Fruit characteristics in sweet chestnut forests.

Fruit characteristics	Development stages	Sampling years			P
		2014	2015	2016	
Fruit yield (kg/ha)	MDF	169.41 ± 60.42A	197.01 ± 76.54A	184.12 ± 126.76A	0.642
	LDF	243.94 ± 110.94B	302.75 ± 187.53B	348.09 ± 256.86B	0.245
	P	0.012	0.025	0.015	
Single fruit weight (g)	MDF	1.46 ± 0.27^{a}A	2.21 ± 0.40^{b}	1.84 ± 0.47^{c}A	0.000
	LDF	1.70 ± 0.36^{a}B	2.29 ± 0.42^{b}	2.39 ± 0.42^{b}B	0.000
	P	0.022	0.556	0.000	
Fruit length (mm)	MDF	19.69 ± 0.91^{a}	20.83 ± 1.01^{b}	19.75 ± 1.98^{a}	0.018
	LDF	20.22 ± 0.89	20.96 ± 1.14	20.40 ± 1.32	0.103
	P	0.071	0.705	0.227	
Fruit width (mm)	MDF	19.55 ± 1.06^{a}A	22.00 ± 1.15^{b}	20.31 ± 1.67^{a}	0.000
	LDF	20.45 ± 1.23^{a}B	22.27 ± 1.20^{b}	21.04 ± 1.05^{a}	0.000
	P	0.018	0.476	0.108	
Fruit thickness (mm)	MDF	10.74 ± 0.51^{a}A	12.21 ± 0.77^{b}	19.73 ± 3.04^{c}B	0.000
	LDF	11.36 ± 0.70^{a}B	12.73 ± 1.07^{a}	15.51 ± 3.51^{b}A	0.000
	P	0.003	0.087	0.000	
Fruit N (%)	MDF	1.69 ± 0.14^{a}	1.48 ± 0.15^{b}A	2.22 ± 0.23^{c}B	0.000
	LDF	1.67 ± 0.08^{a}	2.58 ± 0.14^{b}B	1.43 ± 0.17^{c}A	0.000
	P	0.606	0.000	0.000	
Fruit C (%)	MDF	42.89 ± 0.98	42.84 ± 1.23A	42.29 ± 1.11A	0.175
	LDF	42.58 ± 1.52^{a}	43.84 ± 1.12^{b}B	43.58 ± 1.40^{ab} B	0.012
	P	0.457	0.010	0.003	

Fruits were dried at 105 °C, ± standard deviation, means followed by the same uppercase small letter do not differ significantly ($p > 0.05$) in rows, means followed by the same capital letter do not differ significantly ($p > 0.05$) in columns. C: carbon, N: nitrogen, MDF: medium diameter forests (DBH = 8–20 cm), LDF: large-diameter forests (DBH = 20–36 cm).

from the present study. Increased defoliation rates and the decline of chestnut trees can cause less forest floor mass than other chestnut forests. However, with a simple calculation in the research results, the C/N ratios of the H layer were found to be between 7.20 and 14.47, indicating a relatively rapid rate of decomposition (Kantarcı, 2000).

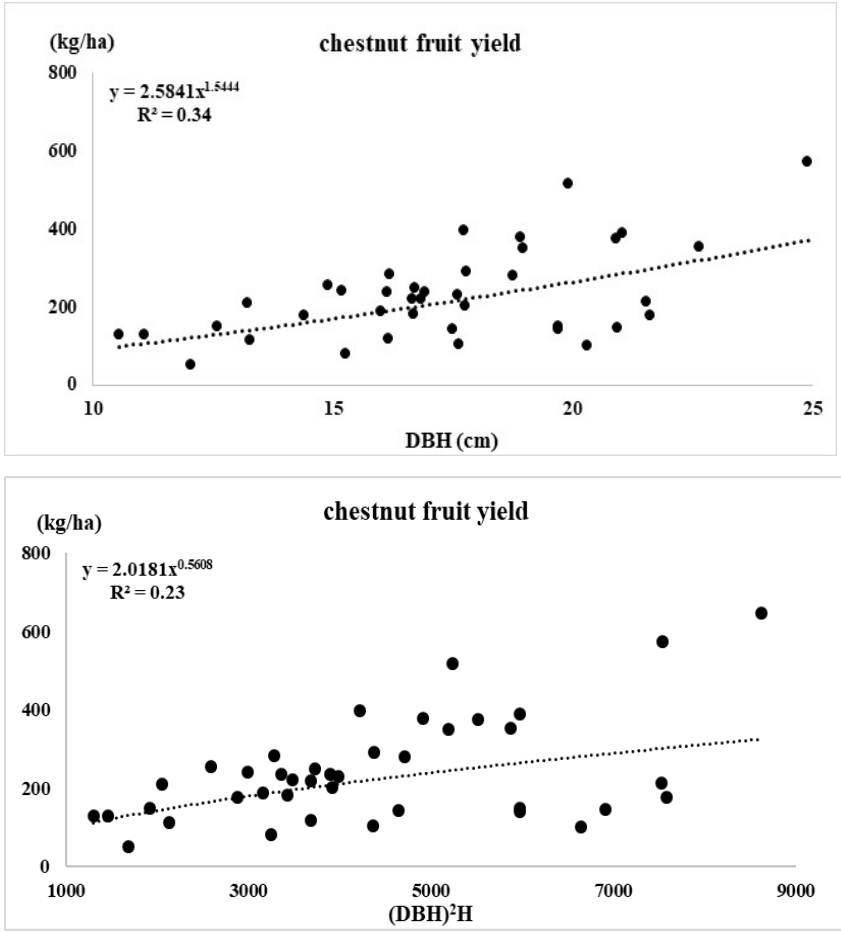

Figure 3. Regression models of fruit yield with DBH and $(DBH)^2H$ in sweet chestnut forests.

Thus, rapid decomposition will also reduce forest floor accumulation, causing less anticipated forest floor amount.

While the N content of the total forest floor in the sample plots was found to be between 7.67 g/m^2 and 9.7 g/m^2 with an average of 8.7 g/m^2, Makineci (1999) found the N content of the forest floor to be between 12.6 g/m^2 and 17.2 g/m^2 with an average of 14.7 g/m^2 in chestnut forests in İstanbul —the results of the present study were lower than these values. These differences in amount and N content of the forest floor are likely due to differences in site characteristics (such as climate, altitude, aspect, slope, or soil properties), increased defoliation rates, or tree decline over time.

In addition to these changes in the forest floor, the results of the correlation analysis that tested the fruit yield along with the other examined characteristics draw attention to the properties of the forest floor, particularly that the H layer was an important factor each year. Based on these results, it can be concluded that the properties of the forest floor and the H layer should be evaluated as important factors affecting the fruit yield.

4.2. Soil

As repeatedly documented, the soil properties for each soil depth were not significantly different between development stages. In evaluation of the general soil properties, the average electrical conductivity values at different soil depths were between 33 µS/cm and 84 µS/cm, indicating the soils of the sample plots were in the nonsaline class (0–98 µS/cm) according to the salinity classification of the Soil Quality Institute (1998). Furthermore, Seferoğlu and Ertan (2009) indicated low salinity values in chestnut-growing areas. The average values of soil acidity were around 5 pH in a narrow range, indicating the soil has a strongly acidic character, which chestnut forests are known to have (Kara, 1998; Makineci, 1999; Kantarcı, 2000; Gallardo-Lancho, 2001; Jawed, 2017). Dominant soil texture types were loam–clay loam depending on the sand, silt, and clay rates of the soils. Similarly, Kara (1998) stated that the clay ratio of soils in their chestnut research areas varied between 1.30% and 24.48%, with clay and silt within certain limits, positively affecting the

Table 5. Correlation coefficients of parameters in significant relationships with sweet chestnut fruit yield.

Parameters		Fruit yield (kg/ha)			
		2014	2015	2016	Mean (2014–2016)
DBH (cm)		0.387**	NS	0.326**	0.349**
Defoliation rate 2015 (%)		NS	NS	NS	–0.276*
Defoliation rate 2016 (%)		NS	NS	–0.407**	–0.296**
Mass of H layer (g/m^2)		–0.431**	–0.390**	–0.481**	–0.533**
N of H layer (%)		0.338**	0.546**	0.268*	0.397**
N content of H layer (g/m^2)		–0.374**	–0.312**	–0.460**	–0.475**
C content of H layer (g/m^2)		–0.332**	–0.249*	–0.449**	–0.403**
C of H layer (%)		NS	0.358**	NS	0.273*
Mass of total forest floor (g/m^2)		NS	–0.260*	NS	–0.231*
Soil C (%)	10–40 (cm)	–0.275*	NS	–0.247*	–0.262*
	40–70 (cm)	–0.218*	–0.239*	NS	–0.221*
Soil N (%)	0–10 (cm)	0.281*	0.384**	NS	0.242*
	10–40 (cm)	0.312**	0.426**	NS	0.262*
Soil pH	10–40 (cm)	–0.249*	–0.384**	NS	–0.247*
	70–100 (cm)	–0.270*	–0.317**	–0.304**	–0.294**
EC (µS/cm)	70–100 (cm)	0.282*	NS	0.300**	0.321**
Pedon C (t/ha)		–0.249*	NS	–0.299**	–0.288**
Bulk density (<2 mm), (g/L)	0–10 (cm)	–0.223*	NS	–0.226*	–0.283*
	10–40 (cm)	NS	NS	–0.352**	–0.237*

NS: nonsignificant, * p (significance) = 0.05–0.01, **p (significance) = 0.01–0.001, N: nitrogen, C: carbon, EC: electrical conductivity.

development of chestnut stands. Gallardo-Lancho (2001) reported that the soil should be deep and permeable with low clay content for healthy chestnut tree growth because clay prevents the water and air permeability of soils and reduces the root development of trees. In these soils, water drainage is generally prevented, and the water may become stagnant, so plant roots cannot develop well, even if the soils are deep (Kantarcı, 2000). Some researchers have also stated that chestnut trees do not show good development in heavy, clayey, and low water-permeable soils and can be infected easily by chestnut diseases (Özbek, 1988; Soylu, 2004; Özçağran et al., 2007). While the average C concentration of the soil was found between 0.3% and 1.92% and the N concentration at 0.08–0.32%, data from other literature gives us generally higher values. Zhiyanski and Glushkova (2013) found the C concentration of chestnut soils in Bulgaria to be 0.24%–5.33% and the N concentration to be between 0.036% and 0.333%, while Jawed (2017) determined the organic C level in chestnut soils to be between 1.91% and 2.65% at different elevations. Seferoğlu and Ertan (2009) stated that low levels of N in the soil causes poor development in chestnut forests.

4.3. Defoliation rates

Defoliation rates have increased significantly every year. Since a decrease in leaf mass with defoliation will directly reduce the photosynthesis assimilation capacity of a tree, all functions related to this can regress. Although no determination was made in this study, based on our observations, the increase in these losses was caused by damage from biological pest agents, such as chestnut blight disease (The pathogen earlier known as *Endothia parasitica* Murr. is now called *Cryphonectria parasitica*), ink disease (*Phytophthora* spp.), and chestnut gall wasps (*Dryocosmus kuriphilus* (Yasumatsu)), which can be considered important factors (Özer, 2020).

According to the former studies, the most important problem in chestnut tree health is chestnut blight caused by a fungus (*E. parasitica)*, the presence of which has been identified in Turkey since 1968 (Karahocagil and Tosun, 2004; Atasoy and Altıngöz, 2011). Another problem

that damages chestnut trees is ink disease (*Phytophthora* spp.), and the struggle to control these two important factors still continues (Yaltırık, 1997). Currently, another major problem affecting the health of chestnut trees is the oriental chestnut gall wasp (*Dryocosmus kuriphilus*), which is reported to have caused significant losses in tree growth and fruit yield in cultivated sweet chestnut orchards in Turkey in recent years (İpekdal et al., 2014; Altun et al., 2018). In addition to this damage, the potential impact of an insect, the chestnut weevil (*Curculio elephas*), can also cause severe fruit losses (Altun et al., 2018; Caliskan et al., 2020). Akıllı et al. (2012) additionally detected fungi damage by *Phytophthora cinnamomi* in İstanbul's chestnut forests. If the climate and other conditions are favorable, fungal diseases become epidemic and cause great losses, and the possible effects of climate change can even affect the natural distribution of chestnut forests (Abatay, 1988; Usta and Yılmaz, 2020). Biological effects on chestnut forests are quite high, and the threat on the health of forests has an increasing severity.

In addition, chestnut forests in the research area originated from coppices. This is an important factor in the unhealthy tree conditions and low fruit yield because long-term coppicing and periodic clearcutting cause decreases in the growth rate of trees. In general, it can be expected that the chestnut tree may present a self-renewing mechanism of the stump maintaining the availability of vigorous growth of the new shoots over many years. Also, the hardwood coppice sprout very fast after cutting protecting the soil when a sustainable management is applied. However, in the present study, chestnut tree stems are damaged by the external effects of cutting, and trunk rot begins in old coppice-originated stands. Therefore, the trees' biological lives can be shortened by coppicing, as it causes an imbalance between the natural vegetation and site characteristics of the forest; makes the soil bare without tree cover from periodical clearcutting; and decreases soil nutrients, fertility, and the yield of the forest and trees (Odabaşı, 1976; Kalıpsız, 1988; Makineci et al., 2015; Ozdemir et al., 2019; Saglam et al., 2021).

4.4. Fruit yield and characteristics

The average fruit yield per unit area was 183.51 kg/ha in the MDF stage and 298.27 kg/ha in the LDF stage from 2014–2016. The average fruit yield in that time was 5700 kg/ha in Turkey, according to data from the Turkish Statistical Institute (TÜİK, 2021). However, these values were not for forest areas but for chestnut orchards and private gardens (Serdar et al., 2018). In this case, the average fruit yield per unit area in the research site was up to approximately 3%, which was extremely low compared to the average value in Turkey. As described above, the main purpose of chestnut coppices was fuel wood production, and no management plan for fruit yield in Turkey. Otherwise, orchards are usually grafted with fruit varieties and have low density, high density of trees (2500–2600 trees/ha), in the present study cannot cause a significant fruit production. Turna et al. (2017) found that the average fruit weight of chestnut forests in south-west Turkey (Simav, Kütahya) was between 1250 kg/ha and 1500 kg/ha, and the fruit weight determined in the present study was less than 20% of these values. Gürer (2000) stated that 1350 kg/ha of fruit was taken in Michigan, USA and approximately 10,000 kg/ha in Korea, with an expected amount of 2250–4500 kg/ha from a well-maintained chestnut orchard. It is obvious that healthy stands and the production of chestnut fruit with suitable techniques are the main effective factors in fruit yield. Similar to our results, Bucak (2006) indicated that chestnut forests in İstanbul have very low fruit yield, despite İstanbul Province having the third highest distribution of sweet chestnut stands in Turkey. Furthermore, Bucak (2006) emphasized that 43.3% of chestnut forests in Turkey cannot be managed for fruit production despite being in the fruit production stage because these forests are degraded, and Özer (2020) documented that Turkey's average annual production of chestnut fruits decreased annually by approximately 3000 tons after 1990. These results confirm our research results in the present study: it is obvious that a deterioration in the general health of chestnut trees. There was, however, no significant difference in fruit yields over the years of our study. In addition, the relationship between the fruit yield and the DBH or $(DBH)^2H$ did not have a high regression value ($R^2 = 0.34$ and $R^2 = 0.23$, respectively) in the regression models. The significant relationships with fruit yields in each year in the correlation analysis were that the mass, N, and C contents of the H layer of the forest floor had negative correlation and the N concentration in the H layer of the forest floor had a significantly positive correlation, although many factors showed significantly negative and positive correlations with fruit yields in general (2014–2016). As a result of the increase of organic matter in the soil, the increase in N nutrition in trees is a possible natural process with the increase in N ratio, indicating the importance of N and the decomposition of organic matter (Makineci, 1999). Accordingly, fruit production is thought to be high with the effect of N, as it significantly affects plant growth relationships by playing an important role in root respiration, flowering, and the formation and ripening of fruit. The resistance of trees against pests also increases with N nutrition (Kantarcı, 2000). Seferoğlu and Ertan (2009) stated that for chestnut trees, N is a very effective and indispensable element for fruit yield and quality. However, the relationship between soil variables and fruit yields did not show a clear trend, and there were not clear relationships, which concluded that unhealthy conditions and increasing defoliation in

trees were generally effective on the ephemeral results (Özer, 2020).

The average weight of single fruits in the development stages was between 1.46 g and 2.39 g. Other examples of recorded fruit weights in existing literature were 1.24–17.66 g (Altun et al.,2018); 2.48–13.63 g (Aslan et al., 2019); 4.8–16.3 g (Serdar et al., 2008); 6.73–7.45 g (Serdar, 2002); and 9.7–11.8 g (Serdar, 1998). Single fruit's weights in the present study were quite low compared with these values. In the development stages, the average fruit length, width, and thickness were determined as 20.31 mm, 20.94 mm and 13.71 mm, respectively. However, Serdar et al. (2008) gave an average fruit length, width, and thickness of 22.3–30.1 mm, 23.2–37.0 mm, and 13.6–22.2 mm, respectively, while Ertan (1999) reported values of 27.6–40.1 mm, 29.8–43.5 mm, and 18.4–24.8 mm, respectively. Serdar (1994) found that the average fruit length, width, and thickness was 26.20–30.38 mm, 26.76–33.63 mm, and 17.09–20.89 mm, respectively. The fruit sizes in the present study were lower than these values, despite the values listed above generally coming from chestnut orchards. Higher values in orchards compared to natural forest areas were thought to be a normal result, depending on cultivation.

In natural chestnut forest areas, and similar to our results, Benedetti et al. (2018) reported that fruit characteristics (mean length of 26.8–28.6 mm, mean width of 28.9–29.43 mm, and mean thickness of 16.1–17.5 mm) were not significantly varied in different site conditions in Chile, and they declared that their results were similar to those from Portugal (Dinis et al., 2008). Values from a study by Benedetti et al. (2018) were also higher than our results. Silvanini et al. (2014) found that values for fruit length (2.495–2.771 cm), width (2.964–3.368 cm), thickness (1.753–1.898 cm), and single fruit weight (8.457–11.783g) were also significantly higher than in the present study. Atar and Turna (2018) found that in eight different chestnut populations in Turkey, the mean single fruit weight ranged from 3.815 g to 10.516 g, and the average fruit length, width, and thickness were 25.96 mm, 32.43 mm, and 16.51 mm, respectively. Atar and Turna (2018) reported that their results on fruit sizes are similar to the results from chestnut forests in Bosnia Herzegovina (Mujić et al., 2010), Croatia (Idžojtić et al., 2012; Poljak et al., 2012), and Slovenia (Solar et al., 2005); however, single fruit weight values in Turkey were lower. Similarly, Caliskan et al. (2020) and Aslan et al. (2019) determined the average width, length, thickness, and weight in four different chestnut populations in Turkey to be 24.8 mm, 23.1 mm, 15.3 mm, and 3.4 g, respectively. The respective values in the present study were also lower than these values.

Similar to our results, Tuğ et al. (2021) and Kulaç et al. (2015) stated that the morphological characteristics of chestnut fruits can be very variable. In addition, Atar and Turna (2018) emphasized the large variations in fruit characteristics of chestnut forests in Turkey, as indicated in this study, because the chestnut forests in Turkey were degraded, which led to a lower fruit yield compared to nondegraded or healthy chestnut forests in other countries. It is likely that the negative biological effects on the health of chestnut forests also have an effect on fruit quantity and morphometric parameters, as it has been established that the biological pests of chestnut trees are very effective and spread rapidly.

The concentration of N in the fruit had a similar result to other studies; indeed, in some chestnut populations in Turkey, it was found to be between 0.88% to 1.152% and 0.704% to 1.008% (calculated from the ratio of crude protein) (Er et al., 2013; Ozel, 2015). The concentration of C in the fruit was found to be approximately 42%–43% in the present study, in line with Caliskan and Makineci (2020), who indicated that N is a vital, convertible, and mobile nutrient, while C is more stable in forest tree seeds.

In addition, the results based on annual differences showed that there might be significant differences between the years in terms of natural fruit availability and amount, as well as physical and chemical properties of these fruits in chestnut forests. In addition, differences between development stages can change in different years regarding fruit characteristics. A similar result was presented by Silvanini et al. (2014) who stated that chestnut fruit characteristics may differ depending on the year, as different years determine different morphological fruit characteristics.

5. Conclusion

In conclusion, a clear relationship could not be found between the investigated variables and fruit yield. However, defoliation rates increased in stands during the study period and the health conditions deteriorated, and for these reasons, fruit yields were very low. It is known that chestnut stands have unhealthy conditions, are accelerating the decline, and have decreasing fruit yields as a result of diseases, pests, irregular exploitation, and defoliation. Similar results obtained in this study concluded that the trees are unhealthy, and the fruit yield is very low, since all of the chestnut stands in the study area originated from coppices. On the other hand, as a limitation of study, there is a lack of information regarding the type of coppice forest management, dendrometric characterization of the coppice, the number of stools or stumps/shoots, age stools/shoots, number of shoots per ha, number of shoots per stool, percentage of stools/shoots affected by diseases. Also the LAI (leaf area index), percentage of canopy cover and mean tree crown area are important variables to analyze fruit production, which is clearly recommended for further research.

The most serious factor affecting chestnut fruit yield is biological pests (chestnut blight cancer, ink disease, and gall wasps). For these reasons, integrated research with different disciplines is recommended to achieve more reliable results for chestnut health and sustainable productivity and management of these forests. Sampling of ecological site characteristics according to the health conditions of the trees or comparative studies between resistant areas and rapidly affected areas are also suggested. It is suggested to present alternative silvicultural management models or another type of forest management to improve the productivity and health of sweet chestnut stands.

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Conflicts of interest
The authors have no conflicts of interest to declare.

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