Comparative growth and yield performance of sweet chestnut in high-forest and coppice systems in young plantations

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Introduction

In Portugal, sweet chestnut (*Castanea sativa* Mill.) is predominantly found in inland mountain areas in the North and Center of the country (Patrício et al., 2022), covering an estimated area of over 48,000 hectares (ICNF, 2015), including orchards and forest woodlands. Chestnut forests have been managed for wood production in both coppice and high-forest systems, with coppice offering flexibility in producing wood of various calibers to meet market demands. However, extensive areas of healthy coppices remain unmanaged or lack clear technical and economic objectives, resulting in reduced forest health and productivity. Comparing the growth patterns of coppice and high-forest systems during the juvenile phase is essential, as coppice shows higher initial productivity but faces limited market demand for small-sized chestnut material. Exploring management alternatives to enhance long-term rotation and utilize juvenile biomass can incentivize the recovery of abandoned areas and improve the quality and value of chestnut timber for long-lived products for a more sustainable management.

Main Objective: compare growth and yield of young chestnut stands, up to 24 years of age, in coppice and high-forest systems from mountain areas of Northern Portugal.

Materials and Methods

- The growth data of chestnut for the coppice system were obtained from a trial carried out in Serra da Padrela, located in Northeast Portugal (Figure 1).

P3 – no intervention

P1 – small diameters

P2 – medium diameters

P4 – large diameters

- The trial consists of 4 permanent research plots, each with an area of about 1000 m^2. These plots were established in an even-aged coppice with 2 years old shoots by the year 1994. The plots were randomly submitted to management models based on Bourgeois (1992) (P1, P2, P4), including a plot without intervention (P3).
- Thinning operations were carried out on Plots P1, P2, and P4. The first thinning occurred at 7 years old. A second thinning, which also served as the final thinning for P1 and P2, took place at 11 years old. Additionally, a third thinning was exclusively applied to Plot P4 (large diameters) at 16 years old. Detailed information about this trial can be found in Patrício et al. (2020).

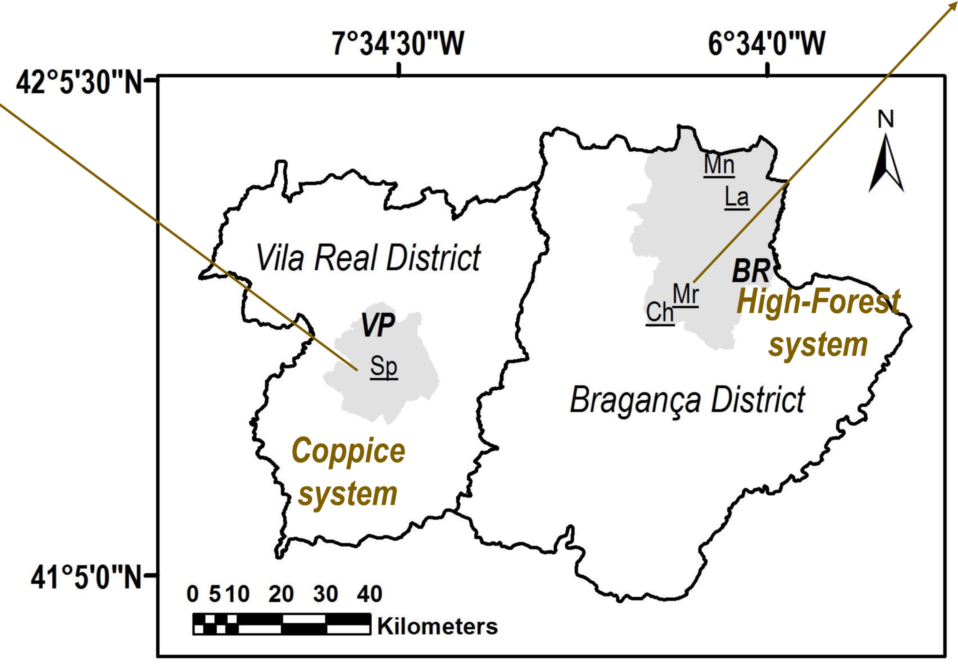
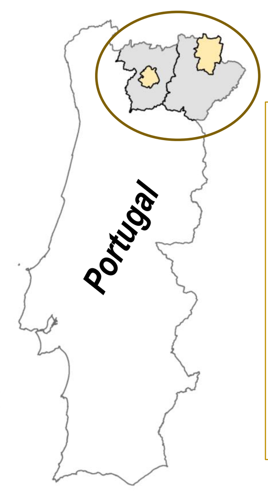


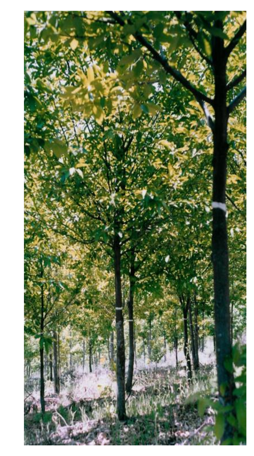
Figure 1. – Location of the sweet chestnut stands



Coppice system:
Sp – Serra da Padrela in Vila Pouca (VP) region;

High-Forest system:
BR – Bragança region with Montesinho (Mn), Laviados (La), Moredo (Mr) and Chãos (Ch)

- Data from permanent research plots located in the region of Bragança, Northeast Portugal, were utilized for the high-forest system (BR in Figure 1).
- Plots were established in 2002 in young stands, ranging from 3 to 7 years of age. Plot area is 3000 m^2. A management model proposed by Bourgeois et al. (2004) and adapted to local conditions is being applied to produce mainly high-quality timber. The plots have been regularly inventoried over time.



- STEP 1. selection of high-forest stands with similar site index (SI) to that of coppice. Equations used: Menéndez-Miguélez et al., 2015) for coppice and Patrício (2006) for high-forest.
- STEP 2. Volume estimation. Equations used: Patrício et al. (2020) for coppice and Patrício (2006) for high-forest.
- STEP 3. Biomass estimation. Conversion of volume using wood density value in Luís and Monteiro (1998). Mean annual increment (MAI) and periodic current increment (CI) were computed.

Results and Discussion

- The estimated average site index for the coppice trial was SI_{20} = 15 m. A high-forest stand located in Moredo (Moredo-B), Bragança, presenting similar SI and measurement dates closely matching those in the coppice system, was selected for growth and yield comparisons.

Table 1. Summary of dendrometric variables up to 24 years in the coppice system.

Plot	Age	N_{st}	N_{sh}	hg	hdom	G	g_{sh}	dg	ddom	h/d	d_{mean}
P1	7	636	3473	7.0	7.9	11.6	0.003	6.5	11.3	111.8	6.2
P1	11	636	1501	9.6	11.2	12.6	0.008	10.3	14.9	98.6	10.1
P1	16	623	1450	12.5	13.4	20.5	0.014	13.4	18.3	93.0	13.1
P1	24	611	1399	13.0	15.4	30.4	0.022	16.6	23.2	80.7	16.2
P2	7	654	3778	7.5	9.1	13.6	0.004	6.8	11.9	117.1	6.4
P2	11	654	761	10.3	11.1	6.2	0.008	10.2	13.8	109.4	10.0
P2	16	654	761	12.7	13.7	13.5	0.018	15.0	19.8	86.3	14.7
P2	24	654	761	15.9	17.2	22.7	0.030	19.5	25.6	85.8	19.0
P3	7	618	6305	6.8	8.1	14.6	0.002	5.4	11.6	137.1	5.0
P3	11	618	5788	8.9	11.4	24.7	0.004	7.4	15.6	144.7	6.6
P3	16	593	3455	9.9	14.6	30.0	0.009	10.5	19.0	117.5	9.7
P3	24	454	1866	13.5	17.8	30.9	0.017	14.5	23.6	114.9	13.7
P4	7	574	2523	8.4	10.7	10.1	0.004	7.1	12.5	123.7	6.9
P4	11	531	534	10.3	11.7	4.3	0.008	10.1	13.3	110.8	10.0
P4	16	320	320	12.8	13.1	5.9	0.018	15.3	18.1	85.8	15.0
P4	24	320	320	16.7	16.9	10.8	0.034	20.8	24.3	81.0	20.0

Table 2. Summary of dendrometric variables up to age 24 in the high-forest system

Plot	Age	N	hg	hdom	G	g_{sh}	dg	ddom	h/d	d_{mean}
HF Moredo-B	7	933	5.7	6.5	3.8	0.006	7.5	11.1	83.3	7.0
	13	923	8.6	10.4	12.4	0.014	13.7	18.2	79.9	12.7
	15	907	10.6	11.6	15.1	0.017	15.2	19.5	81.1	13.9
	23	890	14.1	14.8	22.9	0.026	19.1	24.0	83.6	17.5

Age of measurement (years), ***Nst*** number of stools per hectare, ***Nsh*** number of shoots per hectare, ***hg*** height of the mean tree (m), ***hdom*** dominant height (m), ***G*** basal area of the stand (m2 ha-1), g_{sh} basal area of the mean tree (m2 ha-1), ***dg*** quadratic mean diameter or diameter of the mean tree (cm), ***ddom*** dominant diameter (cm), ***h/d*** mean stability coefficient, ***dmean*** average diameter of the plot (cm), ***N*** number of trees per hectare.

- The model prescribed in P4 (1 single shoot at the end of rotation) converges to a condition similar to the high-forest.
- At the age 24, the mean tree height (hg) and dominant height (hdom) in the high-forest system are lower than those in the coppice system, particularly in the management model with similar targets (P4).
- The diameter of the mean tree (dg) and dominant diameter (ddom) are quite similar in plot 4 (P4) of the coppice and in the high-forest up to age 24.
- There is however some differentiation of dg (and dmean) between high-forest and both P1 (small diameters) and P3 (no intervention) of coppice, despite having a similar growth pattern for ddom.
- The coefficient (h/d) of the trees in the management models applied in the coppice, approached that of the high-forest as the stand aged.

- Coppice, for similar ages and site index, produces more stem volume than high-forest in all situations.
- The management model for large diameters (P4) in the coppice system produced more 100 m3 ha^{-1} of stem volume than the high-forest at age 24 (Figure 1). However, mean annual increment (MAIv) in stem volume in high-forest is still increasing as opposed to the trend of MAIv in the coppice (Figure 2).
- The maximum values of MAIv occurred near the age 11 in P1 and P2, and earlier (before age 7) in P4. This is in accordance to what is reported by Bourgeois et al. (2004). In P3 maximum MAIv was achieved later, after age 15 (Figure 2).

Table 3. Stem volume and Biomass (yield and growth) in the coppice system up to age 24.

		Stem volume						Stem biomass		
Plot	Age	V_th	V_ms	V_cum	MAI_v	CI_v		W_cum	MAI_w	CI_w
P1	7	63.1	40.7	103.8	14.8	---		56.8	8.1	---
P1	11	45.6	60.8	169.5	15.4	16.4		92.7	8.4	9.0
P1 a)	16	2.9	121.5	233.1	14.6	12.7		127.5	8.0	7.0
P1 a)	24	3.3	194.3	309.2	12.9	9.5		169.1	7.0	5.2
P2	7	64.2	52.6	116.8	16.7	---		63.9	9.1	---
P2	11	94.2	32.9	191.3	17.4	18.6		104.6	9.5	10.2
P2	16	0	82.4	240.8	15.1	9.9		131.7	8.2	5.4
P2	24	0	178.8	337.2	14.1	12.1		184.4	7.7	6.6
P3 b)	7	27.0	53.3	80.3	11.5	---		43.9	6.3	---
P3 b)	11	1.3	123.7	152.0	13.8	17.9		83.1	7.6	9.8
P3 b)	16	21.0	176.4	225.7	14.1	14.7		123.5	7.7	8.1
P3 b)	24	27.5	243.3	320.1	13.3	11.8		175.1	7.3	6.5
P4	7	72.7	43.7	116.4	16.6	---		63.7	9.1	---
P4	11	68.6	23.2	164.5	15.0	12.0		90.0	8.2	6.6
P4	16	38.4	36.4	216.1	13.5	10.3		118.2	7.4	5.6
P4	24	0	84.9	264.6	11.0	6.1		144.7	6.0	3.3

Table 4. Stem volume and Biomass (yield and growth) in the high-forest system up to age 24.

		Stem volume				Stem biomass		
Plot	Age	V_cum c)	MAI_v	IC_v		W_cum c)	MAI_w	IC_w
HF Moredo-B	7	22.2	3.2	---		12.1	1.7	---
	13	63.6	4.9	6.9		34.8	2.7	3.8
	15	81.7	5.4	9.1		44.7	3.0	5.0
	23	148.6	6.5	8.4		81.3	3.5	4.6

V_th volume from thinning (m3 ha^{-1}), ***V_ms*** volume in the main stand (m3 ha^{-1}), V_cum cumulative stem volume obtained in each measurement age, ***W_cum*** cumulative stem biomass (t ha^{-1}) calculated similarly to V_cum, ***MAIv*** and ***MAIw*** are mean annual increment in stem volume and stem biomass (m3 ha^{-1} year^{-1} and t ha^{-1} year^{-1}, respectively), ***CIv*** and ***CIw*** are periodic current increment in stem volume and stem biomass (m3 ha^{-1} year^{-1} and t ha^{-1} year^{-1}, respectively). **a)** V_th values in P1 at ages 16 and 24 refer to mortality, not thinning. **b)** volume reduction in P3 is only due to mortality. c) ***V_cum*** (and ***W_cum***) refers to the natural growth of main stand as no thinning were applied (m3 ha^{-1})

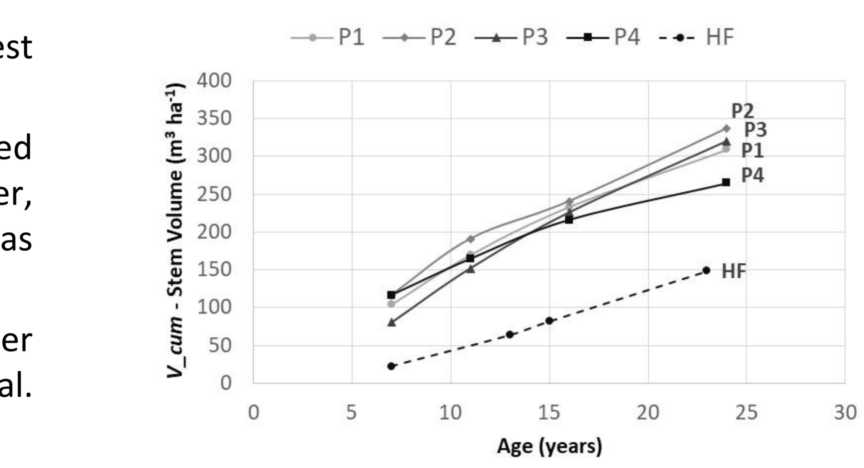


Figure 1. Cumulative stem volume in coppice (P1-P4) and high-forest (HF) up to 24 years of age

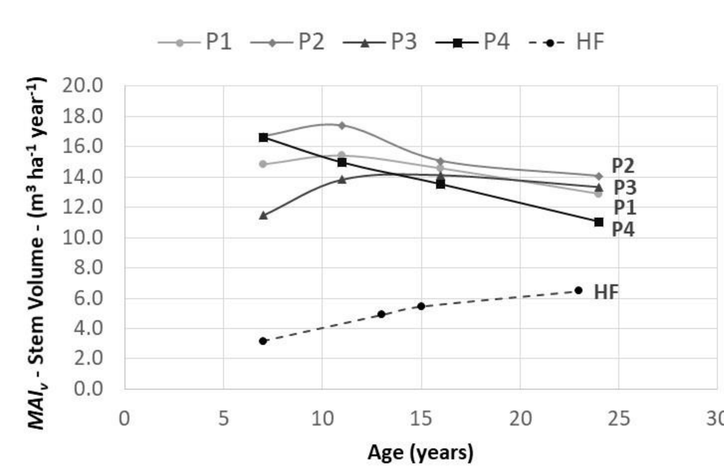


Figure 2. MAI of cumulative stem volume in coppice (P1-P4) and high-forest (HF) up to 24 years of age

- In the coppice system, a mean annual increment in biomass (MAIw) of 9 t ha^{-1} year^{-1} was achieved in P4, before 10 years of age. At age 24 MAIw in P4 is of 6 t ha^{-1} year^{-1}.
- In the high-forest system MAIw has been increasing approaching the value of 4 t ha^{-1} year^{-1} at age 24.
- Managing coppice for a final target similar to high-forest introduces flexibility in sylviculture. This approach enables allowing both high amount of biomass production in young stages, and long-lived products at the end of rotation.
- By maintaining or even increasing the benefits derived from ecosystem services related to environment (including GHG emissions mitigation benefits), this flexible and tree-oriented sylviculture can improve the returns for landowners and contribute to the sustainability and development of the bioeconomy in mountain regions.

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Sharing is encouraged

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