

# Carbon sequestration in chestnut coppices: impact of shoot density simulated with the CO2Fix model



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## Introduction

The carbon cycle plays a vital role in maintaining ecosystem stability by regulating the flow of organic matter and influencing global climate dynamics. However, rising CO<sub>2</sub> emissions from human activities have disrupted this balance, driving climate change and increasing the frequency of extreme weather events. Addressing this challenge requires strengthening natural carbon sinks, particularly forests, which store significant amounts of carbon in both biomass and soils.

Sweet chestnut (*Castanea sativa* Mill.) coppice systems are promising for carbon sequestration due to their fast growth and potential for long-term carbon storage. Despite their ecological importance, many chestnut coppices remain unmanaged due to limited economic returns. Innovative strategies, such as payments for ecosystem services, could unlock their potential and enhance their contribution to climate change mitigation while promoting sustainable forest management.

## Objectives

This study assesses the carbon sequestration and storage potential of sweet chestnut coppices using the CO<sub>2</sub>Fix model, calibrated with field data from northeastern Portugal. The main objectives are to:

- Calibrate the CO<sub>2</sub>Fix model to predict biomass and carbon stocks under different management practices.
- Validate model accuracy by comparing simulations with observed field data.
- Optimize parameterization to improve reliability for chestnut coppice systems.
- Identify growth constraints to support sustainable management strategies.

## Modeling approach

### Volume Estimation:

Tree volume was estimated by segmenting the stem as follows:

- The stump was treated as a cylinder ( $V_{0-30}$ );
- The log section up to 1.30 m was calculated using Smalian's formula;
- The upper stem (above 1.30 m) was modeled as a cone ( $V_{>30}$ ).

These field-based volume measurements were compared with values obtained from chestnut-specific volume equations. The dataset was used to calibrate and validate the CO<sub>2</sub>Fix model by comparing its predictions of carbon stocks in aboveground biomass, belowground biomass, and soil organic matter with values obtained from field data under different management scenarios.

## Materials and Methods

The study was based on field data from a chestnut coppice trial established in Mogadouro, northeastern Portugal.

The experimental design included four treatments:

- T1 (A) – One shoot per stool
- T2 (B) – Three shoots per stool
- T3 (C) – Five shoots per stool
- T4 (D) – Control (maintained as high forest)

Treatments were arranged in a randomized block design with three replicates per treatment, totaling 12 plots. Each plot comprised 70 trees over an area of 560 m<sup>2</sup>.

Dendrometric measurements were taken at 2, 4, and 12 years after coppicing and included:

- Shoot diameter at 30 cm above ground ( $D_{0-30}$ )
- Diameter at breast height (DBH)
- Total height
- Shoot density per stool



Figure 1: Location of the Mogadouro region in Portugal (adapted from Tachibayashi (2020), via Wikimedia Commons)



## Results

### Volume & Biomass Trends by Treatment:

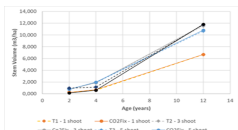


Figure 2: Comparison between observed and CO<sub>2</sub>Fix-modeled stem volumes over time

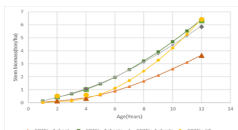


Figure 3: Stem biomass trends by treatment in chestnut coppices: comparison of CO<sub>2</sub>Fix estimates and observed values (years 1-12)

- CO<sub>2</sub>Fix closely matched observed volume and biomass at year 12, with minor underestimations in early years, especially for T4.
- T2 and T3 had higher early growth; T4 overtook later.
- T1 showed the lowest biomass, confirming the effect of shoot density.
- The model proved reliable for long-term carbon simulations in chestnut coppices.

### Biomass Estimation

Biomass components were estimated using published allometric equations: Menéndez-Miguélez et al. (2013) at the stand level; Cutini (2000) and Leonardi et al. (1996) for aboveground compartments; and Ruiz-Peinado et al. (2012) for belowground biomass.

These estimates, based on 12-year growth data, were used to compare with CO<sub>2</sub>Fix outputs and assess the model's ability to produce biomass values consistent with field observations, supporting model calibration and validation.

### Comparative Biomass Estimates: CO<sub>2</sub>Fix vs. Observed and Equation-Based Values

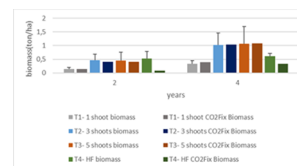


Figure 4: Comparison of observed and CO<sub>2</sub>Fix-modeled aboveground biomass at years 2 and 4, by treatment.

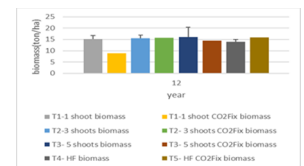


Figure 5: Comparison of observed and CO<sub>2</sub>Fix-modeled aboveground biomass at year 12, by treatment.

- CO<sub>2</sub>Fix estimates aligned well with observed biomass, especially for T2 and T3. At year 12, the model slightly underestimated T1 and overestimated T4, reflecting challenges with low shoot density and high-forest structures. Overall, the model proved reliable, with some limitations under extreme conditions.

### Projections of chestnut coppice biomass production for a 42-year rotation period

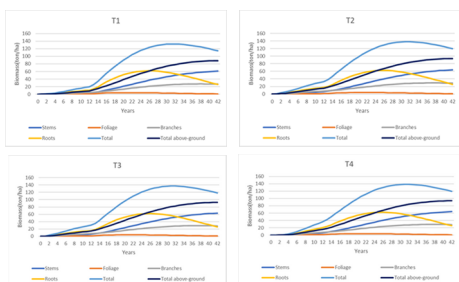


Figure 8: Projected biomass distribution by component over 42 years for treatments T1, T2, T3, and T4

- T2 and T3 showed the highest biomass over 42 years, with T2 slightly ahead.
- T1 underperformed due to low shoot density;
- T4 reached similar levels later.
- Peak biomass occurred between years 30-34, suggesting an optimal harvest window.

### Carbon Content Analysis

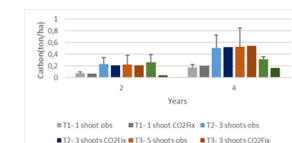


Figure 6: Aboveground carbon observed vs. CO<sub>2</sub>Fix estimates at years 2 and 4 by shoot density

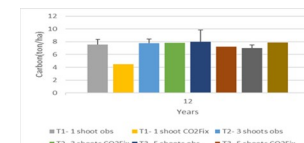


Figure 7: Aboveground carbon observed vs. CO<sub>2</sub>Fix estimates at year 12 by shoot density

- CO<sub>2</sub>Fix estimates aligned well with observed carbon at all stages for T2 and T3. At year 12, it slightly underestimated T1 and overestimated T4.
- The model proved reliable for carbon prediction, with minor deviations under extreme treatments.

### Projections of chestnut coppice carbon stock for a 42-year rotation period:

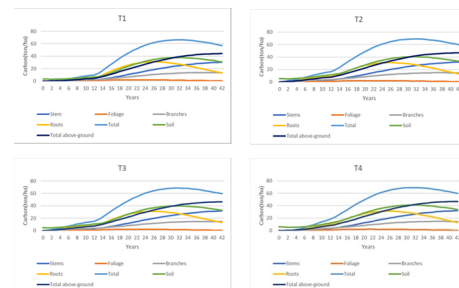


Figure 9: Projected carbon content by component over 42 years for treatments T1, T2, T3, and T4

- T2 and T3 showed the highest long-term carbon storage, with T2 slightly ahead.
- T1 accumulated less carbon, while T4 increased gradually.
- Results highlight shoot density as a key factor for maximizing sequestration and total carbon stocks.

## Conclusions

- Higher shoot densities (T2, T3) enhance biomass and carbon storage. T2 performs slightly better, combining growth with durable timber production.
- T1 shows slower growth and lower carbon, but yields larger stems suitable for long-live wood products.
- T4 accumulates carbon steadily and reaches similar stocks to T2/T3 by year 42, despite slower early growth.
- CO<sub>2</sub>Fix performs well overall, with minor underestimation in T4 roots, suggesting need for calibration in high-forest structures.
- Long-term simulations provided valuable insights into the carbon potential of chestnut coppices under different silvicultural strategies.
- By year 42, total above-ground carbon content reached: 57.18 t/ha (T1); 69.05 t/ha (T2); 59.24 t/ha (T3); 59.83 t/ha (T4). This highlights the superior performance of higher shoot densities in carbon sequestration.
- These findings support adaptive management practices—like shoot thinning and optimized rotation—to maximize biomass, improve timber quality, and strengthen carbon sequestration. They reinforce the role of chestnut coppices in climate mitigation and sustainable forestry.

## Acknowledgements

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