This manuscript investigates the interplay between deep subsurface water availability (TAW_{Deep}) and vertical fine-root distribution (f_{DR}) in governing tree water use and drought survival across Mediterranean karst forests. By calibrating the mechanistic soil–plant–atmosphere hydraulic model SurEau-Ecos against a two-year dataset (2014–2015) of predawn leaf water potentials (Ψ_p) and $\delta^{18}O$ xylem water isotopic mixing fractions (f_{DW}) for three tree species, the authors estimate the effective proportion of fine roots residing in the deep weathered bedrock reservoir and quantify seasonal and annual deep water extraction volumes. Through theoretical dry-down sensitivity analyses, the authors formalize a "rare-root strategy," showing that a small, intermediate fraction of deep fine roots (0.4%to 3%) maximizes the Time to Hydraulic Failure (THF) by inducing timely stomatal closure while sustaining sufficient deep water uptake to match residual conductance without prematurely exhausting finite deep water reserves.

The manuscript has a number of notable strengths:

- The data-model fusion approach - jointly calibrating a trait-based cavitation and post-stomatal-closure hydraulic model against predawn leaf water potentials and stable isotope mixing fractions-offers a practical and transferable methodology to infer unobservable deep fine-root proportions and quantify absolute subsurface water extraction in rocky karst substrates where deep root excavations are physically impossible.
- The mechanistic formalization of the "rare-root strategy" provides a compelling, non-linear biophysical explanation for how rhizosphere hydraulic resistance at the deep soil–root interface regulates the onset of stomatal closure and meters out finite deep vadose reserves during prolonged droughts.
- Demonstrating that vertical fine-root partitioning exerts an influence on survival time (Time to Hydraulic Failure) comparable in magnitude to major species-specific aboveground hydraulic traits (such as embolism resistance P_{50} or turgor loss point) provides a valuable benchmark for forest vulnerability assessments and Earth System Model parameterizations.

I also identify a number of weaknesses:

- The vertical fine-root profile is constrained using a single-parameter monotonic power-law decay (β), which artificially couples root allocation between the shallow layers ($0-20cm$ and $20-60cm$) and the deep karst layer ($60-400cm$); the authors might consider testing or discussing a decoupled or bimodal root distribution baseline to ensure the inferred optimal f_{DR} is not an artifact of forcing an exponential curve across compartments (A continental scale analysis reveals widespread root bimodality, Mingzhen Lu et al., 2025; A global analysis of root distributions for terrestrial biomes, Robert B. Jackson et al., 1996).
- The calibration workflow applies a fixed 5-day moving average for root-to-leaf hydraulic transit time uniformly across species of vastly different heights and varying drought intensities, and does not evaluate how the flat optimization plateau for beech or the large late-season discrepancies in November 2015 influence parameter identifiability in the Combined RMSE objective function (Application of the deuterium tracing method for the estimation of tree sap flow and stand transpiration of a beech forest (Fagus silvatica L.) in a mountainous Mediterranean region, Vincent Marc and Mark Robinson, 2004).
- In the theoretical sensitivity analyses, Fagus sylvatica is uniquely allowed to undergo drought-induced defoliation while Quercus ilex and Abies alba maintain fixed leaf areas under standardized Rustrel environmental conditions; clarifying how much of beech's

elevated survival peak in Figure 6 stems from canopy shedding versus the rare-root hydraulic mechanism alone, alongside explaining how the optimal f_{DR} scales with different TAW_{Deep} capacities, would strengthen the interspecific comparisons.

- The manuscript contains several mathematical, indexing, and cross-referencing inconsistencies-including duplicate numbering of Equation (4), an extraneous summation symbol in Equation (3), swapped panel callouts between beech and fir in Figure 2, missing annual water-balance tabulations in Table 1 to support the headline annual percentages, and several mismatched or missing bibliographic entries-that should be resolved for clarity and reproducibility.

Having that said, the finding that “a limited proportion of deep roots maximizes tree survival under drought” as such is not novel by any means. However, the implementation of plant hydraulic into an explanatory framework is. I therefore strongly suggest to publish the study after addressing the outlined improvements. I genuinely enjoyed reading and appreciate the more holistic perspective on deep water uptake.

Major cimments and observations:

- Inconsistent Variable Terminology and Notation Between the Abstract and Main Text: In the Abstract (lines 21–32), the study's two core belowground drivers are introduced and repeatedly referred to using the abbreviations SWC_{Deep} (deep soil water storage; lines 21, 27, 31) and $FineRoot_{Distrib}$ (fine-root distribution; lines 22, 32). However, neither of these abbreviations appears anywhere in the remainder of the manuscript. Instead, starting in Section 2.1 (lines 115–119) and continuing throughout the Results and Discussion, deep water storage capacity is parameterized and referred to as TAW_{Deep} (Total Available Water in the deep compartment), while fine-root distribution in the deep reservoir is parameterized via the power-law exponent β (Section 2.2, lines 162–164) and analyzed as the proportion of deep roots f_{DR} (Section 2.4.2, line 312). This shift in notation is a potential concern for clarity, as readers attempting to map the headline variables from the Abstract to the equations, sensitivity analyses, and figures in the main text may be confused. Harmonizing the terminology by replacing SWC_{Deep} and $FineRoot_{Distrib}$ in the Abstract with TAW_{Deep} and f_{DR} (or explicitly cross-referencing them) would improve end-to-end consistency.

- Potential Mismatch Between the Introduction's Framing of Simultaneous Volume Quantification and the Calibration Methodology: In the Introduction (lines 86–97), the authors critique prior isotopic and model-inversion approaches for not allowing "simultaneous quantification of water volumes available and their effective use over time," and state Objective (ii) as: "develop and evaluate a method to quantify the volume of water used from the deep reservoir as drought progresses." While the calibrated SurEau-Ecos model estimates the transpired flux/volume extracted from the deep layer over time (Table 1) and explores the theoretical effect of varying TAW_{Deep} in sensitivity analyses (Section 3.2), the actual size of the available deep water reservoir (TAW_{Deep}) at the study sites is not estimated or constrained during the field calibration. Instead, as noted in Section 2.3.2 (lines 234–237), TAW_{Deep} is fixed a priori to a non-limiting value (150 mm, with simulation results being insensitive for $TAW_{Deep} > 75mm$) so that calibration depends solely on root distribution (β). Consequently, the framing in lines 86–94 (and later in the Discussion, lines

534–535, stating that the study quantifies "both transpired volumes and the size of deep reservoirs") represents a potential overstatement of what the model inversion constrains. Clarifying lines 86–98 in the Introduction to distinguish between (a) calibrating fine-root distribution to quantify extracted deep water volumes under non-limiting deep storage during 2014–2015, and (b) evaluating the theoretical role of deep storage capacity (TAW_{Deep}) via sensitivity scenarios, would align the study's problem framing with its methodology.

- Layer vs. Whole-Soil Summation Indexing in Equation (3) (Lines 153–155): The text states: "The conductance between a soil layer (j) and the apoplasm of the stem can be expressed as," followed by Equation (3):
  - $K_{soil_j-SApo} = \sum_j \quad \frac{1}{\frac{1}{K_{R_j-SApo}}+\frac{1}{K_{soil_j-R_j}}}$

  There is an indexing discrepancy here: the left-hand side (K_{soil_j-SApo}) is indexed for an individual soil layer j, whereas the right-hand side sums over all soil layers j ($\sum_j$). Because each soil layer j is connected in series through $K_{soil_j-R_j}$ and K_{R_j-SApo} and the layers operate in parallel to supply the stem apoplasm, the summation symbol $\sum_j$ should either be removed so that Equation (3) defines the single-layer series conductance K_{soil_j-SApo}, or the subscript j on the left-hand side should be omitted ($K_{soil-SApo}$) and the accompanying text updated to describe the total whole-soil conductance.

- Depth indexing: Lines 163–164 define $z_{h,j}\ (m)$ as "the depth from the soil surface to the top of layer (j)." Under Jackson et al.'s (1996) cumulative root fraction formulation ($Y = 1 - \beta^d$, with depth d in cm, explaining the $\times 100$ conversion factor), the root fraction within layer j is the difference between the cumulative fraction at the bottom boundary of layer j and the top boundary of layer j. For standard layer indexing ($j = 1,2,3$ with $z_{h,0} = 0m$ at the soil surface), $z_{h,j-1}$ represents the depth to the top of layer j and $z_{h,j}$ represents the depth to the bottom (lower boundary) of layer j. Defining $z_{h,j}$ as the top of layer j shifts the integration bounds by one layer and leaves the lower boundary of the deepest layer undefined. Furthermore, the explicit depth boundaries of the three soil layers (which appear in the figure legends as $0-20cm$, $20-60cm$, and $60-400cm$) should be explicitly stated in Section 2.2 or Section 2.3.2.

- Single-Parameter Monotonic Root Profile Constraint, Calibration Equifinality, and β-to-f_{DR} Mapping (Sections 2.2, 2.3.2, 1.4.1 [2.4.1], and 2.4.2, Pages 8, 10, and 12
  A potential methodological concern is that fine-root vertical distribution is parameterized solely through Jackson et al.'s (1996) single-parameter (β) monotonic exponential decay across three fixed layers ($0-20cm$, $20-60cm$, and $60-400cm$). In Section 4.1 (lines 454–459), the authors state that their findings regarding an optimal deep root fraction (0.4% to 2.6%) are consistent with recent continental-scale evidence of vertical root profile bimodality by Lu et al. (2025), noting that vertical root distributions often show a dominant concentration near the soil surface and a "secondary peak in deeper soil layers, facilitating complementary acquisition of water and nutrients." However, because β is the sole adjustable parameter governing the entire vertical profile simultaneously in Equation (4), varying β to adjust f_{DR} in the deepest layer ($60-400cm$) inherently alters the relative root allocation between the first two shallow layers ($0-20cm$ vs. $20-60cm$) and mathematically

precludes a bimodal secondary peak at depth. Explicitly clarifying in Sections 2.2 and 4.1 that the model enforces a monotonic decay across all three layers via β, and discussing whether decoupling the deep-layer root fraction from the shallow root distribution (or implementing a bimodal root profile) could affect the rate of shallow reservoir depletion and the resulting optimal f_{DR}, would strengthen the methodological justification.

- Potential Parameter Compensation (Equifinality): During calibration, all 15 species-specific vegetation hydraulic traits, the assumption $RAI = LAI$ (line 163), $TAW_{Deep} = 150mm$ (line 235), and the Van Genuchten–Mualem water retention parameters and saturated hydraulic conductivity (assumed uniform across the entire profile from topsoil down to $400cm$, lines 228–230) are held strictly fixed while β is calibrated as the sole free parameter. Because the hydraulic retention and conductivity properties of fractured/weathered limestone epikarst (layer 3) likely differ from those of the surface silty rendisol (layers 1–2), the calibrated β (and resulting f_{DR}) may act as an effective hydraulic tuning parameter that partially compensates for unmodeled differences in epikarst hydraulic conductivity (k_{REW_3}), root-to-rock contact resistance, or intraspecific trait variation. Explicitly noting in Section 2 that the calibrated f_{DR} represents an effective hydraulic root fraction within the uniform Van Genuchten parameterization would prevent over-interpretation.

- In Section 2.3.1, the field-estimated shallow available water capacity ($TAW_{Shallow}$) at Rustrel is reported as ranging "from $0mm$ to $65mm$" (lines 198–199), and at Mont-Ventoux as "about $80mm$" (lines 209–210). However, in Section 2.3.2 (lines 230–231), the text states: "The values of $TAW_{Shallow}$ retained are $50mm$ in Rustrel and $90mm$ in Mont-Ventoux." While selecting $50mm$ for Rustrel falls within the $0–65mm$ field range, retaining $90mm$ for Mont-Ventoux exceeds the $80mm$ field estimate cited on the preceding page without explanation. Since $TAW_{Shallow}$ directly controls the timing of shallow reservoir depletion and the onset of deep water reliance (f_{DW}), the rationale for retaining $50mm$ and $90mm$ (or a correction if $80mm$ vs. $90mm$ is a typographical discrepancy) should be explicitly provided.

- Shallow Endmember Definition ($\delta^{18}O_{SW}$) and Evaporative Enrichment (Lines 255–260, 271–282): The two-endmember linear mixing model (Equations 5–7) defines the shallow water isotopic signature ($\delta^{18}O_{SW}$) as the "average of understory precipitation and soil drainage water" collected via a rain gauge and a mini-lysimeter. Two methodological aspects represent potential concerns that warrant clarification: (i) what temporal averaging window was used to compute $\delta^{18}O_{SW}$ prior to each summer xylem sampling date, especially during rainless summer drought periods when zero-tension mini-lysimeters typically cease yielding gravity drainage; and (ii) how potential evaporative $\delta^{18}O$ enrichment of residual water residing in the top $0–60cm$ of drying soil during summer drought was accounted for. If the shallow soil water available to roots in mid-to-late summer is evaporatively enriched relative to meteoric precipitation and wet-period percolate, using unenriched precipitation/drainage averages in Equation (7) could bias the inferred field f_{DW}.

- Standardized Boundary Conditions and Selective Beech Defoliation in the Sensitivity Analysis (Section 2.4.2, Pages 12–13, Lines 304–321): In the theoretical drought sensitivity scenarios,

all three species (Q. ilex, F. sylvatica, and A. alba) are subjected to the identical Rustrel mean summer climate, Rustrel soil parameters ($TAW_{Shallow} = 50mm$), and Rustrel LAI (lines 305–307), while "Beeches trees were able to defoliate in order to represent the reduction of transpiration" (line 308). While standardizing environmental boundary conditions is a valid modeling choice to isolate intrinsic species differences, two aspects require clarification for reproducibility: 1. Defoliation parameterization: Neither Section 2.2 nor Section 2.4.2 specifies the mathematical function or physiological threshold (e.g., leaf/stem Percentage Loss of Conductivity PLC or water potential) governing drought-induced defoliation in F. sylvatica, why drought-induced canopy shedding was disabled for A. alba and Q. ilex, or whether defoliation was also active during the 2014–2015 Mont-Ventoux calibration runs. 2. Imposed Rustrel LAI and climate:Subjecting temperate montane species native to Mont-Ventoux ($1340m$ ASL, $TAW_{Shallow} = 80–90mm$) to the hotter Mediterranean climate, shallower soil ($50mm$), and sparse evergreen oak LAI of Rustrel ($530m$ ASL) alters whole-plant evaporative demand relative to their native stand structure. Explicitly reporting the standardized LAI value and the defoliation formulation in Section 2.4.2 (or cross-referencing Table S1) would improve transparency.

- Statistical Constraint on f_{DW} in Figure 3c: For Q. ilex at Rustrel-the best-constrained site in the study-Figure 3c shows that the linear regression between measured and simulated f_{DW} is based on only $n = 6$ visible campaign points with wide vertical error bars on the isotopic mixing measurements, yielding RMSE= 12.59%, $R = 0.74$, and a marginally non-significant $p - value = 0.091$ at the $\alpha = 0.05$ threshold (in contrast to Ψ_p in Figure 3d, where $RMSE = 0.31$, $R = 0.9$, $p - value = 0.0021$, $n = 8$). Moreover, the model underestimates measured f_{DW} during intermediate drought conditions. Explicitly reporting the sample sizes (n), RMSE, R, and p-values for all three species in Section 3.1.1/3.1.2 and discussing the relative contributions of Ψ_p and f_{DW} to the combined RMSE sensitivity in Figure 2 would improve transparency.

- Expanding Table 1 (or adding a companion block of rows/columns) to present both the summer (21 June–21 September) and full annual simulation outputs (annual precipitation, annual PET, annual transpiration, and annual deep uptake in mm and % for each species in both 2014 and 2015)-and briefly noting why evergreen Q. ilex at Rustrel has the lowest summer transpiration in 2015 ($96mm$) yet the highest annual transpiration ($454mm$)-would make the water balance results self-contained and transparently reconciled across the Abstract, Section 3.1.3, Section 4.3, and Table 2.

- Unmodeled Drought Processes: Static Root Architecture and Carbon Starvation Caveats (Sections 4.1–4.2, Pages 20–21, lines 460 and 494–500: Two methodological assumptions in the modeling framework warrant explicit discussion as caveats when interpreting the ecological implications of the rare-root strategy in Sections 4.1 and 4.2: Static root architecture vs. dynamic root plasticity: Although line 460 connects the results to root system plasticity (Fan et al., 2017), the model treats β as static over time and does not simulate hydrotropic root proliferation into moist deep layers or fine-root mortality in desiccated surface soil during drought progression.
- Carbon starvation and belowground construction costs: In lines 494–500, the authors note the trade-off between prolonged stomatal closure and carbon assimilation. Because SurEau-

Ecos defines mortality strictly via hydraulic failure without modeling non-structural carbohydrate (NSC) depletion, leaf thermal damage when transpirational cooling ceases, or the carbon costs of constructing and maintaining roots within fractured karst bedrock, surviving for $150-300 days$ at $g_s \approx 0$ (Fig. 6) may overestimate actual survival time under carbon-limited conditions. Suggested improvement: Expand Sections 4.1 and 4.2 to clarify the model's assumptions regarding static root profiles and pure hydraulic-failure mortality.

- In the Conclusion (line 565), the optimal proportion of deep roots is summarized as being "on the order of a few percent of the root system located below a depth 70 cm. "However, throughout the model setup and figures (e.g., Figures 3a, 4, and 5), the three modeled soil layers are defined as $0-20cm$, $20-60cm$, and $60-400cm$ (placing the top boundary of the deep layer at $60cm$), while Section 2.3.1 states that maximum soil thickness is about $60cm$ at Rustrel (line 197) and $60-80cm$ at Mont-Ventoux (line 209).
  Suggested improvement: Reconcile the $70cm$ depth threshold stated in the Conclusion with the $60cm$ model layer boundary used to define Layer 3 in the simulations and figures.

Minor comments:

l. 99-100: Please provide at least a rudimentary explanation of what the authors did.
l.112-113: which in situ measurements? Provide details, e.g., which parameters were monitored, which soil depths etc.
l.142: I think disaggregate would be the more appropriate word
l.163: (supposed equal to LAI), → please explain and justify this assumption or provide a citation