

Response to Referee 1

Dear Editor and Referee 1,

We sincerely appreciate the opportunity to revise our manuscript (EGUSPHERE-2025-3510) and are grateful for the thorough and constructive feedback provided by the referee. Your comments have been invaluable in helping us improve the clarity, presentation, and scientific rigor of the paper. We have carefully considered all the comments and have revised the manuscript accordingly to enhance its clarity, rigor, and presentation. Below are our point-by-point responses to each suggestion.

Comment 1

L20: The effects of the micro-topographic parameters were investigated through correlations, but it cannot be directly stated that gravity, light exposure, and erosion were the drivers since the study didn't directly investigate those.

Response Comment 1

We thank the referee for this profound and constructive comment. We fully agree that, since this study did not directly measure processes such as gravity, light exposure, and erosion, it is inappropriate to directly label them as driving factors. We have revised the relevant text to more accurately state that our interpretation is based on the known indirect mechanistic roles these factors play in geomorphological and ecological contexts, rather than on direct measurements from this study. The revised text reads as follows:

Microtopographic parameters (slope degree, slope aspect, and slope position) were significantly correlated with nutrient patterns, which is consistent with their known indirect effects mediated by processes such as gravity-driven transport, differential light exposure, and erosion.

Comment 2

L70: The motivations for the study are presented as questions, but not listed in that format. I recommend re-wording accordingly.

Response Comment 2

We thank the referee for this suggestion aimed at enhancing clarity. We fully agree that reformulating the research objectives from declarative statements into explicit research questions can more directly guide the reader and establish a clear argumentative framework for the entire paper. We have revised the concluding segment of the introduction section to explicitly present the research motivations as a set of questions:

1.What are the spatial distribution patterns and heterogeneity of major soil nutrient contents and stoichiometric characteristics in the karst region?

2.How do soil nutrient elements interact with each other, and what is the intrinsic regulatory mechanism governing their stoichiometric balance?

3.What are the relative contributions of microhabitat types, microtopographic features, and vegetation life forms to soil stoichiometric characteristics, and how do these factors interact with each other?

Comment 3

L117-123: The microtopographic classes could instead be listed in a table format with the number of associated plots per class combination.

Response Comment 3

We thank the referee for this constructive suggestion. We agree that a table can more clearly summarize the number of sampling plots corresponding to each category of factors, including microtopography. Accordingly, we have provided a detailed summary in the Supplementary Materials (Table S1), listing the number of plots for all categorical factors (microtopography, microhabitat, and surface plant life forms). We are confident that this addition significantly enhances the readability and transparency of the sampling information, allowing the referee and readers to quickly grasp the full scope of our sampling design. We extend our gratitude once again for the insightful guidance.

Regarding the number of sampling plots across microtopographic categories, we acknowledge that while a perfectly balanced design is theoretically ideal, it was

extremely challenging to establish an equal number of plot replicates for all microtopographic factor classes due to the practical constraints of the natural karst environment in the Maolan National Nature Reserve. The distribution of microhabitats, microtopographic features, and surface plant life forms is highly heterogeneous and patchy. Our sampling strategy prioritized capturing the natural co-occurrence of these factors over artificial balance. Thus, the number of plots in each category was determined by their actual presence and distribution in the field, resulting in an unequal number of replicates. We believe this approach better represents the true structure of the ecosystem.

Table S1. The correspondence between various factors and the number of sample plots.

Environmental factors	Class	Number of Plots
Slope position	Upslope	6
	Midslope	18
	Downslope	49
	Depression	13
Slope degree	Flat slope	16
	Gentle slope	12
	Tilted slope	14
	Steep slope	27
	Sharp slope	17
	Shady slope	6
Slope aspect	Semi-shady slope	22
	Flat land,	16
	Semi-sunny slope	19
	Sunny slope	23
	Stong gully	29
Microhabitat	Stong surface	29
	Soil surface	28
	Evergreen trees	32
Life forms	Deciduous trees	21
	Shrubs	21
	Herbs	12

Comment 4

Fig. 2-5 axis labels are illegible because they are so small. Please increase text size.

Response Comment 4

We thank the referee for pointing out this issue. We have regenerated Figures 2 to 6, significantly increasing the font size of all axis labels and tick-mark labels to ensure that the figures remain clearly legible when scaled to the standard journal column width. The revised figures are provided below:

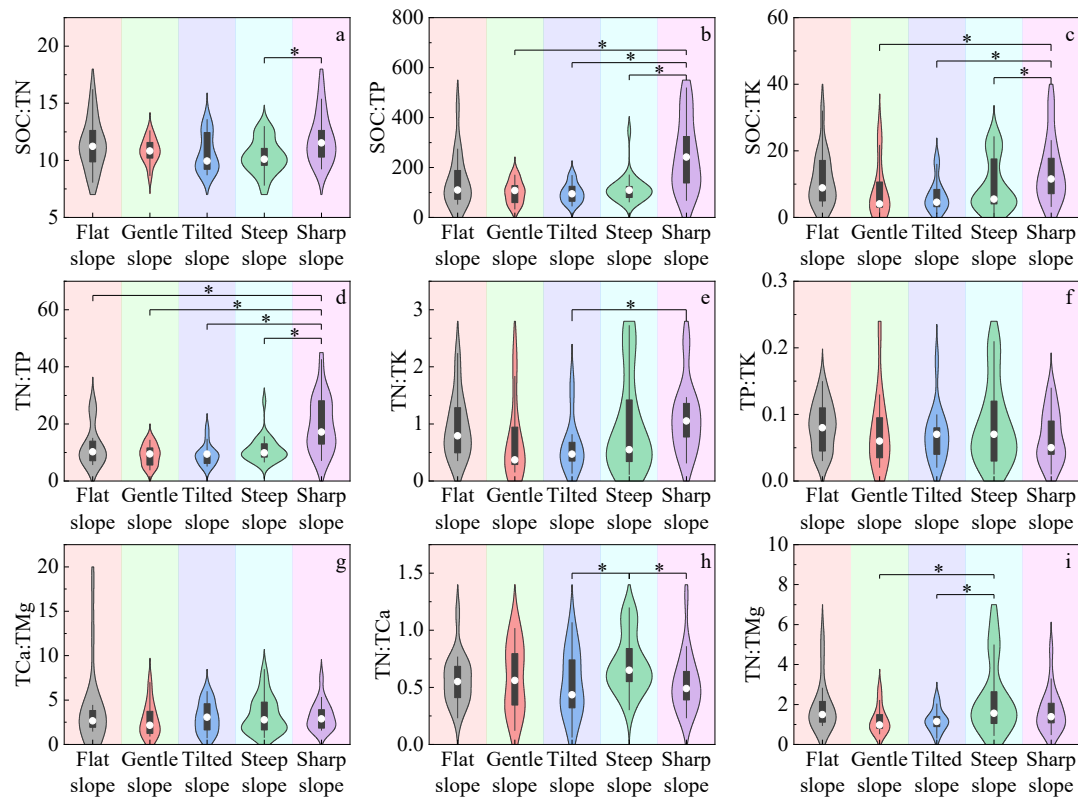


Figure 1. Distribution differences in stoichiometric ratios of major soil nutrients across different slope degree types, presented as violin plots overlaid with box plots. The Y-axis of each subplot denotes the values of corresponding ratios, while the X-axis represents slope degree types. An asterisk (*) indicates significant intergroup differences ($P < 0.05$), with black horizontal lines connecting groups exhibiting differences. The number of samples (n) for each slope degree type is as follows: flat slope ($n=16$), gentle slope ($n=12$), tilted slope ($n=14$), steep slope ($n=27$), sharp slope ($n=17$).

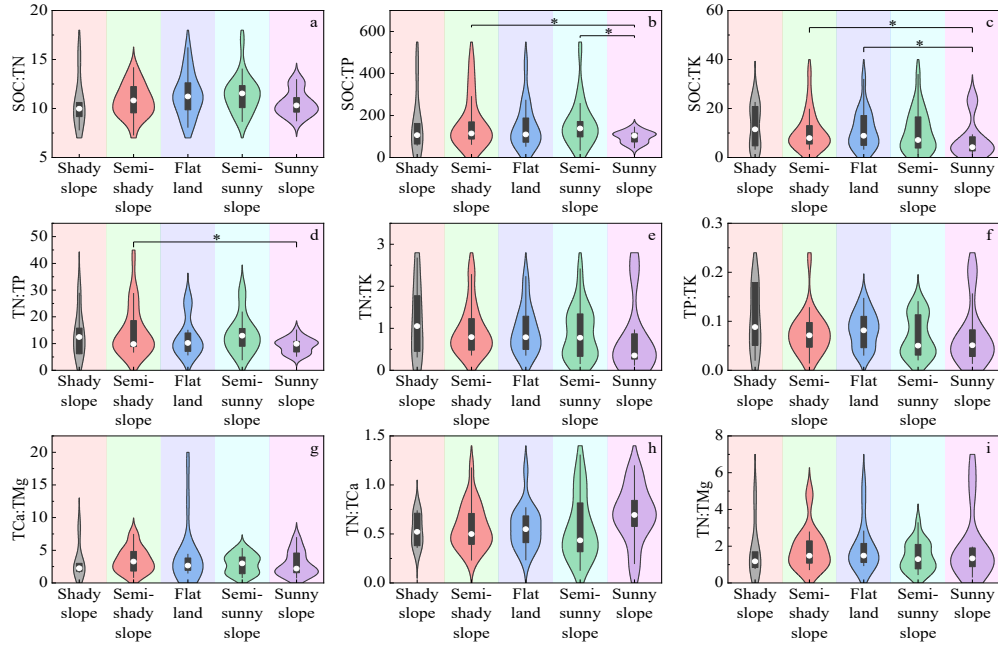


Figure 2. Distribution differences in stoichiometric ratios of major soil nutrients across different slope aspect types, presented as violin plots overlaid with box plots. The Y-axis of each subplot denotes the values of corresponding ratios, while the X-axis represents slope aspect types. An asterisk (*) indicates significant intergroup differences ($P < 0.05$), with black horizontal lines connecting groups exhibiting differences. The number of samples (n) for each slope aspect type is as follows: shady slope ($n=6$), semi-shady slope ($n=22$), flat land ($n=16$), semi-sunny slope ($n=19$), sunny slope ($n=23$).

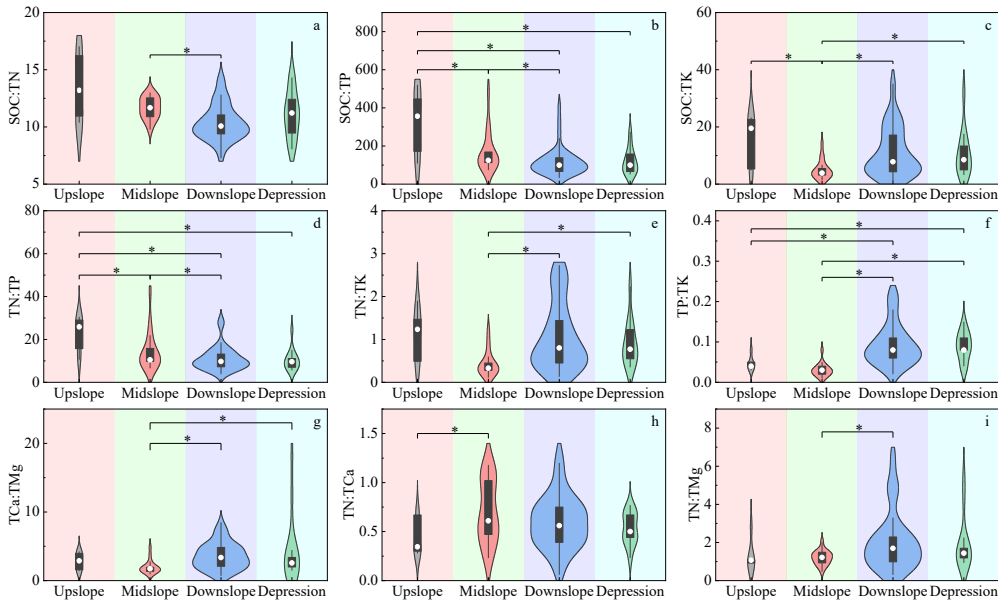


Figure 3. Distribution differences in stoichiometric ratios of major soil nutrients across different slope position types, presented as violin plots overlaid with box plots. The Y-axis of each subplot denotes the values of corresponding ratios, while the X-axis represents slope position types. An asterisk (*) indicates significant intergroup differences ($P < 0.05$), with black horizontal lines connecting groups exhibiting differences. The number of samples (n) for each slope position type is as follows: upslope ($n=6$), midslope ($n=18$), downslope ($n=49$), depression ($n=13$).

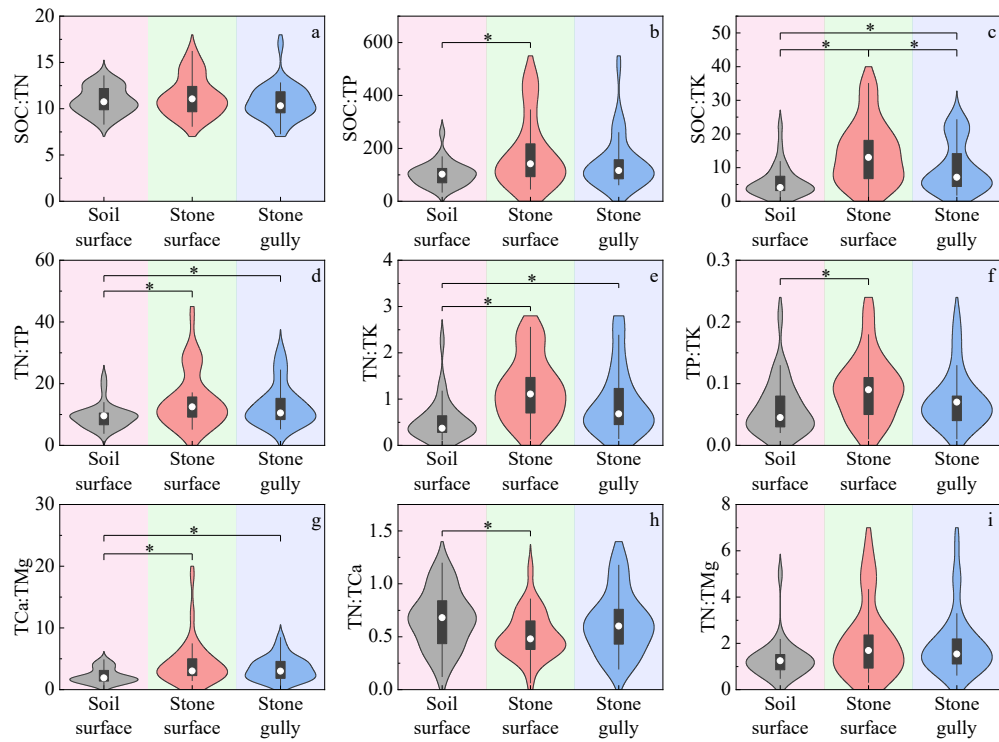


Figure 4. Distribution differences in stoichiometric ratios of major soil nutrients across different microhabitats, presented as violin plots overlaid with box plots. The Y-axis of each subplot denotes the values of corresponding ratios, while the X-axis represents microhabitats. An asterisk (*) indicates significant intergroup differences ($P < 0.05$), with black horizontal lines connecting groups exhibiting differences. The number of samples (n) for each microhabitat type is as follows: soil surface ($n=28$), stone gully ($n=29$), stone surface ($n=29$).

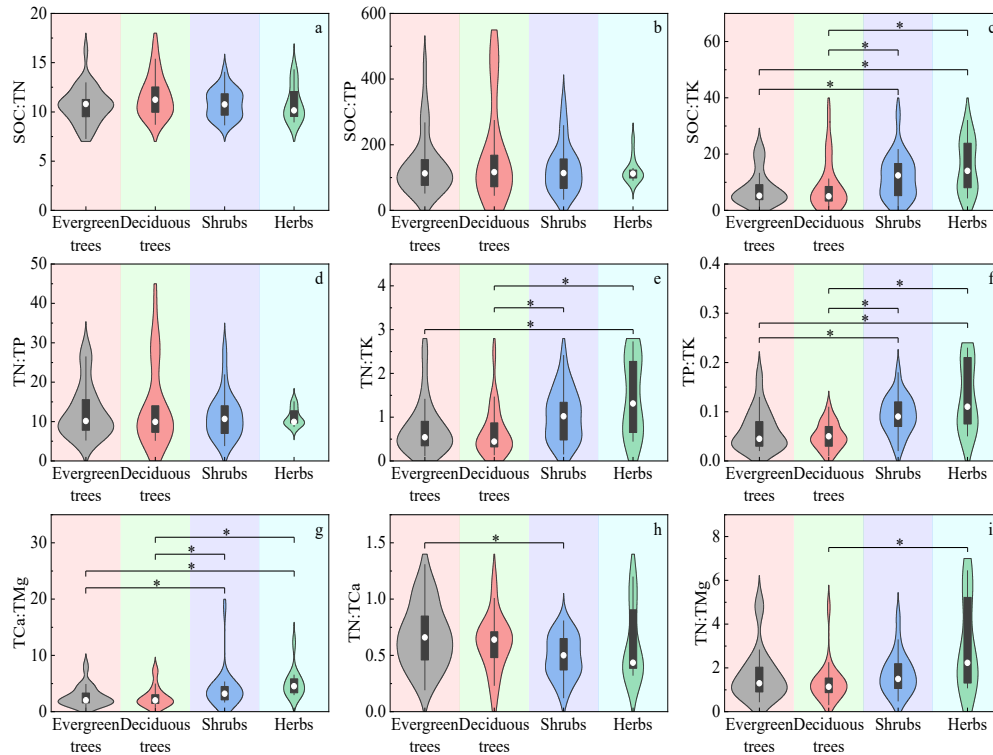


Figure 5. Distribution differences in stoichiometric ratios of major soil nutrients within the rhizosphere zones of different plant life forms, presented as violin plots overlaid with box plots. The Y-axis of each subplot denotes the values of corresponding ratios, while the X-axis represents plant life forms. An asterisk (*) indicates significant intergroup differences ($P < 0.05$), with black horizontal lines connecting groups exhibiting differences. The number of samples (n) for each plant life form is as follows: evergreen trees (n=32), deciduous trees (n=21), shrubs (n=21), herbs (n=12).

Comment 5

What is the sample size per class? It is difficult to assess the strength of the statistical comparisons without the sample numbers. The paper mentions 120+ sampling sites and multiple samples per site, but sample number per stratum is needed.

Response Comment 5

We thank the referee for this constructive suggestion. As rightly pointed out by the referee, providing the detailed sample sizes for each classification level is essential for assessing the robustness of statistical comparisons. Therefore, we have provided a detailed breakdown of the number of sampling plots for each category of micro-topography, microhabitat, and surface plant life forms in the supplementary material (Table S1).

It should be noted that although a perfectly balanced sample design is

theoretically more ideal, it was exceptionally challenging to achieve equal replication across all factor categories in the natural karst environment of the Maolan National Nature Reserve. This difficulty stems from two primary reasons: Firstly, the area is characterized by typical karst peak-cluster depression topography, which is highly fragmented and significantly differs from the continuous and uniform slopes of non-karst regions. Secondly, as a natural forest ecosystem, the distribution and combination of vegetation exhibit a high degree of natural randomness, unlike the regular and homogeneous patterns typical of plantations. Consequently, not all theoretical combinations of factors exist in reality. Under this practical constraint, the sampling strategy of this study prioritized accurately reflecting the natural co-occurrence relationships and spatial heterogeneity of environmental factors over pursuing an artificially set balanced sample size. The number of plots per category was solely determined by their actual presence and distribution in the field, resulting in varying numbers of replicates. We believe this strategy more faithfully represents the true structure and habitat complexity of the karst natural forest ecosystem.

We believe that the supplementary information and explanations provided above sufficiently clarify the distribution of sample sizes. Although the sample sizes are unequal, the number of samples under each classification level meets the basic requirements for robust statistical analysis and is adequate to support the relevant conclusions of this study.

Comment 6

Fig. 7 Suggest moving to supplementary material and increasing the size so the text is more legible.

Response Comment 6

We thank the referee for this suggestion. Figure 7 (the correlation heatmap) has been moved to the Supplementary Materials and is now designated as Figure S1. In the main text, at its original location, we now cite this supplementary figure and provide a concise summary of its key findings in one to two sentences. The supplementary figure itself has been exported at a higher resolution with larger font

sizes to ensure complete clarity.

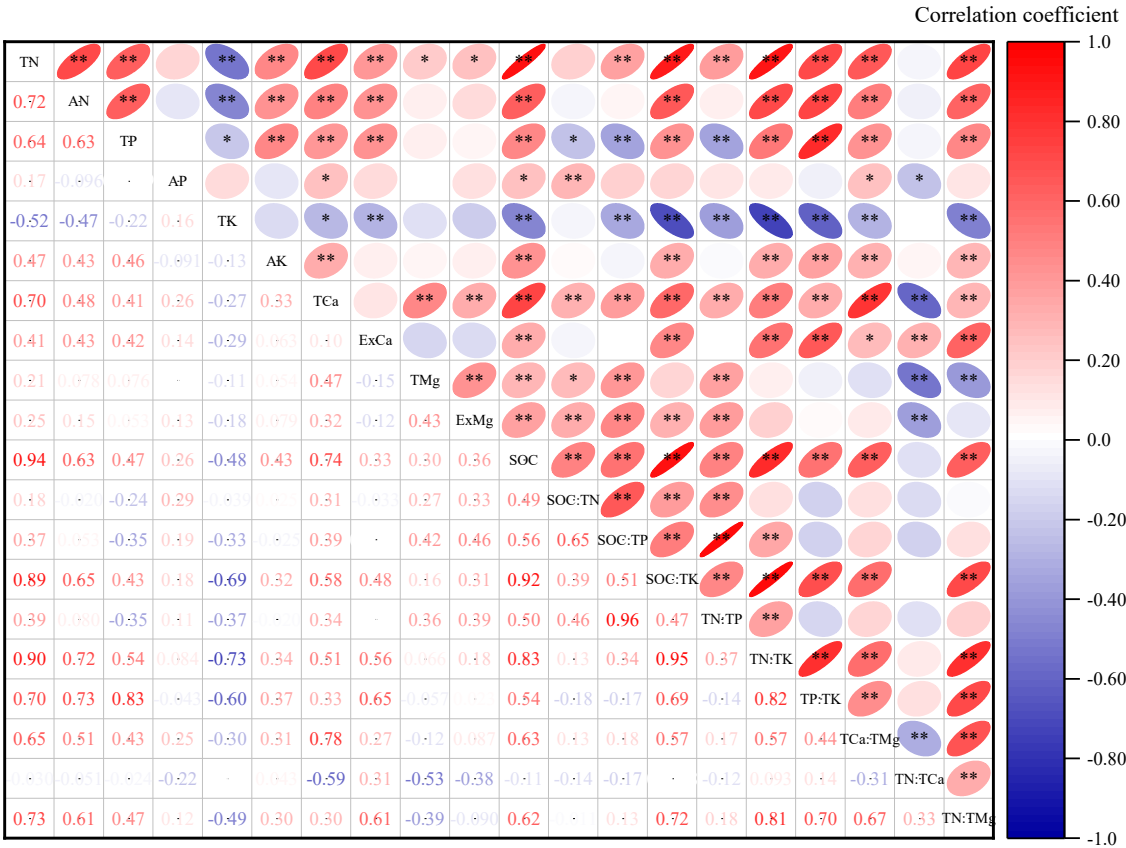


Figure S1. Heatmap of Pearson correlation matrix for soil elemental contents and stoichiometric ratios. Ellipses in the lower triangular matrix represent correlation coefficients (r): Color gradient indicates direction (red: positive correlation; blue: negative correlation); Saturation and eccentricity indicate strength (proportional to $|r|$); Additionally, “*” denotes significant correlation ($P < 0.05$); “**” denotes highly significant correlation ($P < 0.01$) Color scale ranges from -1.0 to 1.0 (“Correlation coefficient”).

Comment 7

Table 4 seems redundant with the correlation matrix presented in Fig. 7.

Response Comment 7

We thank the referee for the thorough review of the tables and figures. We fully understand your concern and provide a more detailed explanation here. Figure 7 (now Figure S1) primarily characterizes the correlations among various soil element contents and stoichiometric ratios. Its purpose is to reveal the synergistic or antagonistic relationships between components within the soil nutrient pool and the

inherent patterns of element balance. In contrast, Table 4 (now Table S9) primarily characterizes the correlations between soil stoichiometric characteristics and external environmental factors (such as microhabitat, microtopography, and surface plant life forms). Its purpose is to quantify and compare the relative influence intensity of these environmental factors on the spatial heterogeneity patterns of soil nutrients.

We believe this clarification better demonstrates the distinction and connection between Figure 7 (now Figure S1) and Table 4 (now Table S9). We extend our sincere gratitude once again for your valuable comment, which has significantly enhanced the clarity and rigor of our Results section.

Comment 8

Perhaps the journal has its own guide on this point, but my preference to ease readability is to present percentages with only one significant digit after the decimal instead of two (both within the text and in tables).

Response Comment 8

We thank the referee for this valuable suggestion. To enhance data readability and align with academic conventions, we have uniformly adjusted all percentage values throughout the manuscript to retain one decimal place, following the referee's suggestion. This revision has been applied to all relevant data in both the main text and tables.

Comment 9

Fig. 9 Consider a more colorblind-friendly color scheme and remove the “Vpa” title at the top since it's described in the caption. Residuals could also be moved to the figure caption.

Response Comment 9

We thank the referee for their valuable suggestion. Following your comments, we have revised Figure 9 as follows:

1. The color scheme has been changed to a colorblind-friendly palette (blue, orange, and purple).

2. The “Vpa” title has been removed from the figure.
3. “Residuals” has been moved from the figure to the end of the figure caption.

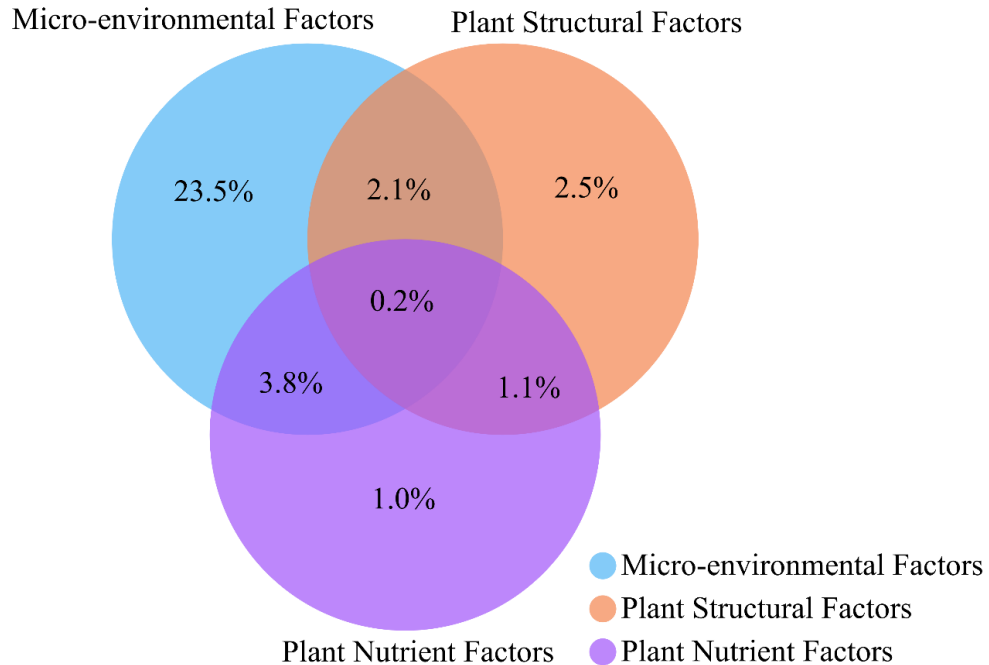


Figure 6. Variance partitioning analysis (VPA) of multi-factor contributions to soil stoichiometric traits. Tri-color overlapping system denotes environmental factor contributions: Yellow: Micro-environmental factors (slope/aspect/position/microhabitat); Blue: Plant structural factors (species/life form); Red: Plant nutrient factors (C/N/P contents); Values in overlapping areas indicate joint explanatory effects. Residuals=65.8%.

Comment 10

It seems that spaces are frequently missing between text and ellipses.

Response Comment 10

We thank the referee for pointing out this oversight. We have carefully reviewed the entire manuscript and corrected all similar instances to ensure that the use of spaces conforms to the required standards. We extend our sincere gratitude once again for your rigorous review.

Comment 11

The statistical analyses seem appropriate to the data types and questions of interest, but there is a heavy reliance on presenting descriptive statistics in the results section. Consider ways to streamline the presentation of key results, and add the

remainder to a supplemental section.

Response Comment 11

We thank the referee for this valuable suggestion. We fully agree that an excessive presentation of descriptive statistics in the Results section can distract readers from the core scientific findings. To enhance the clarity and focus of the results presentation, we have systematically streamlined and restructured the Results section. A substantial amount of detailed grouped descriptive statistical material has been relocated to the Supplementary Materials of the paper, with appropriate citations and references provided in the main text. The main text now retains only the most central and statistically significant findings for each factor. This approach ensures the conciseness and fluency of the main text while providing complete data support for interested readers.

Comment 12

Pairwise comparisons should include confidence intervals when reported in the text.

Response Comment 12

We thank the referee for this valuable feedback. We fully agree that reporting confidence intervals for pairwise comparisons provides more complete and transparent results.

In accordance with the referee's suggestion, we have revised all relevant sections of the manuscript reporting pairwise comparisons. The mean difference (MD), 95% confidence interval (95% CI), and P-value are now consistently provided. We believe this revision presents the statistical findings more comprehensively. Thank you again for the guidance.

Comment 13

The discussion is very long. While it does a good job putting the results of the distributions of plant nutrients in the context of biogeochemical conditions specific to karst regions, it is not necessary to discuss every single result in the discussion section.

They should be grouped into broader categories for a more streamlined discussion.

Response Comment 13

We thank the referee for their constructive comments. We fully agree that discussing each result individually can easily dilute the key points. In accordance with your suggestion, we have comprehensively restructured and streamlined the Discussion section. The key revisions are as follows:

1. We have replaced the original structure of analyzing nutrient types one by one. Instead, core findings are now categorized into key themes based on dominant environmental drivers (microhabitat, microtopography, and plant life forms). Discussions of relevant elements and their stoichiometric ratios are integrated into these thematic sections, each focusing on common patterns and underlying mechanisms.

2. We have removed repetitive background introductions and minor descriptive details. By adhering to a logical framework of “core finding - mechanistic interpretation”, we now emphasize the ecological implications of soil stoichiometric characteristics, thereby more clearly revealing the inherent patterns of nutrient cycling in karst ecosystems.

This revision transforms the discussion from a descriptive listing of results into a comprehensive mechanistic analysis of nutrient heterogeneity in karst ecosystems, significantly enhancing the manuscript’s depth and fluency. We thank the referee once again for their insightful review and guidance.

Comment 14

The broader literature referenced is usually in relation to established biogeochemical relationships, but not those specific to other karst regions. The discussion would benefit from integrating connections to studies in other karst regions globally.

Response Comment 14

We thank the referee for this valuable suggestion! We fully agree that comparing this study with other karst research worldwide can significantly enhance the depth and

breadth of the Discussion. Accordingly, we have systematically incorporated comparisons and analyses with relevant studies from various typical karst regions—such as those in Europe and Asia—into the revised Discussion section. This revision specifically focuses on synthesizing the core conclusions and key findings from different regional studies.

By comparing the patterns observed in our results with those from other regions and conducting cross-regional integration, we have further clarified both the universality and uniqueness of our findings. This effectively expands the scope and academic depth of the Discussion, allowing our research outcomes to be better integrated into the global karst research framework. We extend our gratitude once again for the referee's attentive guidance!

Comment 15

L 615: Is there a citation for this statement “arboreal species often fail to retain even their own litter around smooth trunk bases” or was it only a direct observation from the present study?

Response Comment 15

We thank the referee for this insightful comment and apologize for the previous inaccuracy in our wording. We wish to clarify that the earlier statement—arboreal species often cannot even retain their own litter at the smooth base of the trunk—was imprecise and potentially misleading. The complete and correct explanation should read as follows:

During sampling, we observed significant differences in near-surface litter accumulation among plants of different life forms on karst slopes. Shrubs and herbs, owing to their clumped growth form close to the ground, typically intercept and retain more litter. This litter includes not only material shed by the shrubs and herbs themselves but also a substantial amount of tree-derived litter transported by wind or surface runoff. In contrast, trees, with their generally branchless trunk bases, have a weaker capacity to retain litter compared to understory shrubs and herbs growing densely near the ground. This observed

pattern is consistent with existing literature. For instance, some studies have also indicated that the understory vegetation layer can significantly intercept and regulate the spatial distribution pattern of litter—i.e., litter accumulation decreases with increasing distance from the base of understory plants. The process of litter interception by the understory vegetation may alter the micro-environment (including light, moisture, soil, and microbial communities), thereby influencing its decomposition trajectory.

Comment 16

L625-629: It's great to have this plan, but it is more of a statement for a research proposal than an article. Perhaps something like "Future research directions should explore more dynamic approaches to characterizing karst microenvironments, potentially incorporating real-time environmental monitoring, continuous gradient analysis, and adaptive sampling strategies driven by ecological processes rather than predetermined spatial categories. This could enable better representation of the continuous nature of environmental variation in heterogeneous karst systems."

Response Comment 16

We thank the referee for this highly pertinent and constructive comment. We fully agree that the original description of future work read more like a research plan than appropriate content for the Conclusions section of an academic paper. Following the referee's suggestion, we have completely rewritten this passage, reframing it from a "plan for future work" into an "outlook for future research directions". The revised text reads as follows:

Therefore, future research should transcend this static stratification framework and commit to adopting continuous environmental gradient monitoring and high-resolution sampling strategies to overcome this limitation. This will better capture the complexity of karst ecosystems and facilitate a paradigm shift from discrete stratification to process-driven approaches.