## Point-to-point Response to the Reviewers' Comments

### Responses to the comments from the 3rd Reviewer

The efforts that the author made in revising the manuscript is well-appreciated. However, there are still some issues that need serious consideration. I have detailed this below.

**Responses:** We sincerely appreciate for your careful review of our manuscript and for providing further constructive comments. We have carefully examined the data and methodology, and revised the manuscript accordingly. Our detailed responses to your concerns are provided below.

1. Contrary to the claims of the authors, many of the soil layers with very low bulk densities are in the A horizons, some are even in the C horizons. The study by Ostrowska et al. (2010) which was cited by the authors also showed that in the A horizon, the bulk densities of forest soils have increased considerably (> 1 g/cm3) unlike those in the database. What could be the reason for this? It's the same with the moisture content (~200%) and SOC (>20%). Do the authors have any explanation for these?

**Responses:** Thank you for your careful review. We fully understand your concern regarding the relatively low bulk densities observed in some A horizons and even in certain C horizons. In our dataset, bulk densities in the A horizons are often around 0.5 g $cm^{-3}$, which is indeed lower than the values reported by Ostrowska et al. (2010). Several factors may lead to this difference. First, the site-specific soil-forming conditions in various mountains result in different soil depth in such a broad region and across altitudes. Our study areas are located in mountainous ecosystems, where soil development especially in high altitudes is relatively weak and highly heterogeneous. The A horizons in many sites are < 5 cm thickness and still retain physical characteristics similar to surface organic layers. As a result, the bulk density of these shallow mineral horizons remains low. Similarly, our values are comparable to those reported by Zhou et al. (2016) in Gongga Mountain, where the bulk densities in the O, A, and C horizons were approximately 0.2, 0.6, and 1.1 g $cm^{-3}$, respectively. The second reason is likely linked to the method used to analyze the bulk density in forest soils. In our study, bulk density in both the organic horizons and the very thin surface mineral horizons was not determined using the traditional stainless-steel rings due to their small thickness and loose texture. Instead, we employed the volumetric excavation method, which has been widely applied in studies of surface organic-rich soils (Maynard & Curran, 2006). In contrast, Ostrowska et al. (2010) used the core method for all soil layers. Such methodological differences may partly account for the lower values in our database.

With respect to the soil moisture content, the calculation was based on gravimetric methods. Therefore, the values exceeding 100% are reasonable in organic-rich soils. In our dataset, we identified 26 cases with the values >185%, most of which are located in the O horizons and a few in the A horizons. Further analysis revealed that these samples corresponded to the sites with relatively high aridity index values (mean annual precipitation/potential evapotranspiration ranging between 0.9 and 1.8), reflecting generally moist conditions that could support this high soil water retention. Similarly, soil organic carbon (SOC) contents exceeding 20% are not unexpected in forest ecosystems with substantial litter input. In our dataset, 300 out of 1,314 records had SOC contents >20%, primarily concentrated in the O horizons, with a small number observed in shallow A horizons. Importantly, SOC contents exhibited a consistent and robust decreasing trend with soil depth across all profiles, while bulk density increases with depth as expected.

Taken together, although some individual values look extreme, they fall within the plausible range in mountain forest soils, as supported by many previous studies. The general depth-dependent patterns of SOC and bulk density in our dataset are consistent with established pedogenic processes.

References:

Maynard, D. G., and Curran, M. P.: Bulk density measurement in forest soils, Soil sampling and methods of analysis, 863-869, https://doi.org/10.1201/978142000527, 2007.

Ostrowska, A., Porebska, G., and Kanafa, M.: Carbon Accumulation and Distribution in Profiles of Forest Soils, Pol. J. Environ. Stud. 19(6), 1307-1315, 2010.

Zhou, J., Wu, Y., Bing, H., Yang, Z., Wang, J., Sun, H., Sun, S. and Luo, J.: Variations in soil phosphorus biogeochemistry across six vegetation types along an altitudinal gradient in SW China, Catena 142, 102-111, https://doi.org/10.1016/j.catena.2016.03.004, 2016.

2. Even if the protocols and QA/QC procedures were followed, ESSD explicitly states that error estimates and sources of error must be provided. The database failed in this aspect of data quality, which is just as important as the values themselves.

**Responses:** We sincerely thank you for highlighting this important requirement. We fully agree that reporting error estimates and sources of error is crucial for data quality assessment and user confidence. In the revised manuscript, we added a subsection entitled “Data Quality”, which described the uncertainties, sources of error, and the quality control measures during field sampling and laboratory analyses. We believe that these revisions can comply with the journal’s requirements for reporting error estimates and uncertainty sources. The revisions can also be found below.

**2.5 Data quality**

The dataset was derived from extensive field sampling followed by laboratory analyses, and potential data errors may arise from both sampling and analytical procedures. During field sampling, strict adherence to standardized protocols was followed. Sample representativeness was ensured through replicate sampling, random collection within each site, and thorough homogenization of composite samples. Moreover, soil samples were analyzed in certified laboratories following standardized national protocols and rigorous quality assurance and quality control procedures. Analytical precision was evaluated through repeated measurements, with relative standard deviations (RSD) of major elements determined by ICP-AES being below 3%, and RSD of trace elements determined by ICP-MS being below 5%. Accuracy was assessed using the certified reference material (GBW-07405, China), with recoveries ranging from 95% to 105%. Before the analysis of soil data, outlier detection was performed to ensure dataset reliability.

3. I am not sure if it is sound to stack the $R^2$ of each explanatory variable. Some variables could be collinear and stacking the $R^2$ of these variables means that their effects are considered multiple times. That is probably the reason why >200% explanation had been obtained.

**Responses:** Thank you very much for the insightful comments regarding the analysis methods. We agree with your concern that it is fundamentally unsound to "stack" $R^2$ values, especially in the presence of collinearity, which likely led to an overestimation of the explanatory power. To address this issue, we have re-evaluated the explanatory power of the environmental drivers using a more robust approach. Specifically, we used the random forest regression model to assess the relative importance of each environmental factor in explaining the variability of soil elements. The revised Figure 6 reflected this re-evaluation. In the updated figure, we removed the cumulative $R^2$ values and instead presented the explained variation (%) for each element and horizon, along with the relative importance of each environmental factor (%IncMSE). This approach provides a clearer and more accurate representation of the contribution of each environmental driver. The updated Figure 6 is presented below, and we have accordingly updated the sections of methods (Lines 195-198) and results (Lines 287-296) in the revised manuscript.

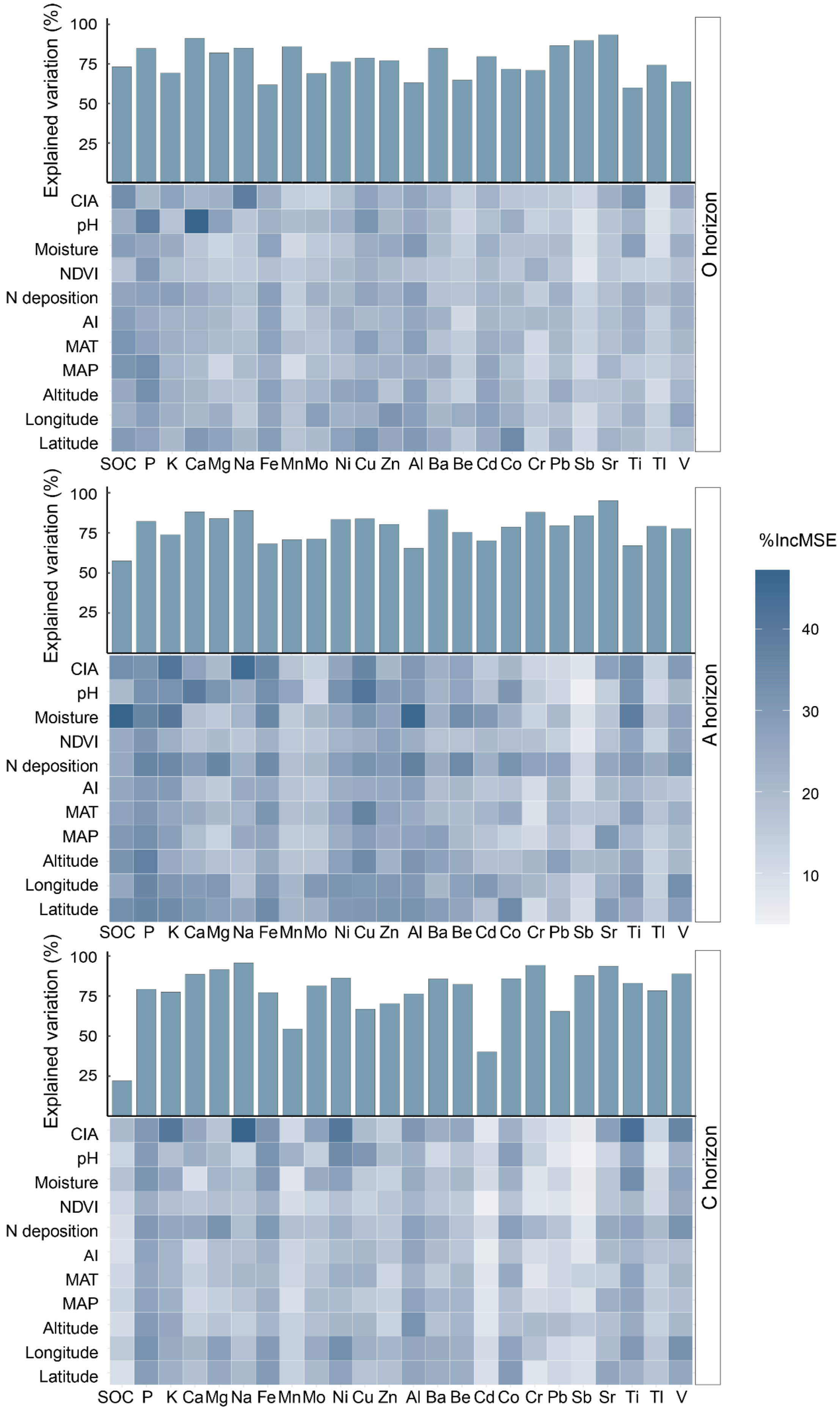
Explained variation (%)
100
75
50
25
CIA
pH
Moisture
NDVI
N deposition
AI
MAT
MAP
Altitude
Longitude
Latitude
SOC P K Ca Mg Na Fe Mn Mo Ni Cu Zn Al Ba Be Cd Co Cr Pb Sb Sr Ti Tl V
O horizon
A horizon
C horizon
%IncMSE
40
30
20
10

**Fig. 6** Effects of environmental factors on elemental variability based on random forest models. The bar plots show the proportion of variance explained for individual elements. The heat maps depict the relative importance of environmental factors in predicting elemental variability, with darker shades indicating greater importance. MAP, mean annual precipitation; MAT, mean annual temperature; AI, aridity index; NDVI, normalized difference vegetation index; CIA, chemical index of alteration.