Author comments (ACs)

We thank both reviewers for the thoughtful and constructive suggestions, and we provide a detailed response to the comments below. To facilitate the revisions, we provided the reviewers' comments in black font, and our responses are in italic blue font.

Report #1

https://egusphere.copernicus.org/preprints/egusphere-2023-2750#RC1, 06 Jan 2024

The paper deals with the effect of vegetation on nutrient availability in high-elevation ecosystems of the Andes. The subject is interesting and the paper is well written. However a few concerns arise and have been listed below:

Line 22: Why are particularly interesting?

They have low soil microbial decomposition rates, and therefore high soil carbon stocks. We have specified this in the revised version (L23-24).

Line 32: change into ….with effects on nutrient cconcentrations in rivers and high-mountain lakes.

Thanks for this observation, we modified the text (L32).

Line 39: change into….. that releases nutrients into the biological environment (Chadwick et al., 1999; Hedin et al., 2003; Dixon et al., 2016).

Thanks for this observation, we modified the text (L39).

Line 48: do you exclude the input through the wet depositions? I think that rainfall not only influence the vegetative growth cycles but represents also an input of nutrients to the soil, expecially relevant at high elevation.

Atmospheric deposition (including wet and dry deposition) indeed contributes to replenish soil nutrient stocks, and their relative contribution can be pertinent in nutrient-poor soil systems (e.g. study by Hofhansl et al., 2011). We clarified this in L50-51 and provided reference to work by Hofhansl and Ping et al. (2013).

Line 64: change into…. the role of vegetation communities and soil hydrology in influencing the soil nutrient availability

Thanks for this observation, we made this change in L64.

Line 68: change into…..because persistently at cool temperatures, ranging between 2 and 10 °C…..Do these values represent the mean monthly maximum and minimum temperatures? Moreover, do the mean annual precipitation include also the snow water equivalent?

The mean annual temperatures vary between 2 and 10°C, but strong diurnal fluctuations are common, ranging from below freezing to as high as 20 °C. Mean annual precipitation ranges between 500 and 3000 mm including snow water equivalents. Most weather stations are located below 4500 m asl where snowfall is rare. We added information on L69-74 of the revised text.

Lines 71-72: Do you have data on soil carbon stock in the area?

Hribljan et al. (2016, 2024) have established carbon stocks of the peatlands in the high Tropical Andes. In the revised version of the manuscript, we will provide the estimates (total soil organic carbon stock : 1628 Mg ha^{-1}) that they made for the paramo ecosystems in the Tropical Andes (Colombia, Ecuador) based on observations from 8 cores in Colombia and 8 cores in Ecuador. We want to indicate that these cores were all retrieved in areas with deep (> 300 cm deep) polygenetic soils developed on volcaniclastic material (Fig. 1, Hribjan et al., 2024). As our study site is located in southern Ecuador where volcanic soils are developed on andesitic parent material, volcanic soils are generally less than 120 cm deep. Total soil organic carbon stocks for the southern Ecuadorian Andes are not yet available, and more research is needed on the effect of substrate lithology on total carbon stocks in the High Andes. We added information on L76-79.

Lines 73-75: Do you assume that the dissolved organic carbon is leached from the soil particularly rich in organic carbon?

Many thanks for pointing this out. We know that the dissolved organic carbon fluxes that are leached from the organic-rich soils can be particularly high based on empirical work on soil solute biogeochemistry that is currently ongoing in the High Andes (Páez-Bimos et al. 2023). Various authors of this manuscript are involved in these long-term monitoring sites. In Páez-Bimos et al. (2023), we showed that the soil solutes are particularly charged in dissolved organic carbon: we measured mean annual DOC concentrations in soil solutes in the topsoil horizons of 47.3 ± 2.3 mg L^{-1}. By integrating the measurements in a hydrological model, we obtained mean annual dissolved organic carbon fluxes of 17.4 g m^{-2} yr^{-1} despite relatively low water fluxes. We added this information on L76-79 of the revised manuscript.

Line 92: change into asl

Done

Line 97: this value of precipitation is significantly different from what reported in line 68

This might have been confusing. On L68, we gave the mean annual precipitation rates for the High Andes, while we mentioned the mean annual precipitation for the study area on L97. We made necessary changes to the text, and now give the precipitation range for paramo environments in the introduction (« mean annual precipitation between 500 and 3000 mm »); and kept the sentence on L103-104 with the mean annual precipitation in the study area of 911 mm.

Figure 1 Caption: Since the forest is present only in poorly accessible sites (by humans?) means that the other land covers (cushion-forming plants, tussock grasses) have been shaped by human activity? Moreover in the figure maybe better soil profiles than soil samples.

Forest patches are above the continuous forest line, and they are now found in poorly accessible areas by humans. Whether the vegetation pattern is determined by anthropogenic disturbance and/or microclimate is often unclear, and hard to determine. In the tropical High Andes, all land covers have experienced human influence to some extent as a result of livestock grazing, use of fire and (ancient) roads. Besides, microclimatic conditions also contribute to shape vegetation development, particularly in these regions with rapid and strong variations in temperature and solar irradiance (Bader et al., 2007). We added a sentence in the text (L122-123) to clarify that vegetation patterns are the result of human land use and natural processes.

Thanks for the observation on the legend, the points are indeed the profiles and multiple samples were taken at one profile. We changed the legend of Figure 1.

Line 131: please add the standard deviation to the average soil depths.

We added this information on L139-141, and report mean (± 1 SD) of soil depths.

Lines 132-133: How did you calculate the depletions in base cations?

This is based on a chemical mass balance approach where we estimated mass losses and gains in soil compared to the underlying parent material using Ti as reference element. This information is added on L141.

Line 177: Please specify what kind of genetic horizons are the upper horizons

We added this information on L186. They sample water from the overlying A and AC horizons.

Line 222: model & Line 228: was

Correction made

Line 266: Caption Figure 1. Maybe better Depth-distribution

We rephrased the caption : « depth-distribution of root development ». (L254)

Line 268: Caption Table 1: explain the meaning of Y and N. Yes? No?

This might have been confusing. Also reviewer#2 suggested to remove the 'Yes' – 'No' statement, as this information is redundant when giving the p-values. We modified the table.

Line 274: Table 2. Did you test if the mean concentrations were different between the vegetation types?

Yes, this is given in Table 1 as now mentioned in the caption.

Line 299: Does this impermeable layer origin from pedogenetic processes?

The low permeability of the C horizon is observed under cushion-forming plants where the effective root depth is limited to 33 ± 4 cm. Limited biological activity can enhance the development of a massive horizon.

Figure 7: I think that the sentence "the high values recorded at the beginning of the measurement period (October 2022) are likely due to the incomplete stabilization of the lysimeters before the first sampling" should be moved in the text and better explained. For example it seems that this phenomenon is particularly relevant in the forest, for Mg, Ca and K. Why?

We preferred to keep this comment in the caption of Figure 7 as the effect is mostly visible here. Even after a 2-months equilibration period during which samples were discarded, there might be an effect of incomplete stabilization under forest (due to e.g. preferential flow after insertion of the lysimeters), as the cation concentration measurements under forest are higher-than-expected during the first month of the measuring campaign. This is not observed under cushion-forming plants or tussock grasses where the effect of macro-porosity and preferential flow might be less an issue. This is now added in the caption of Figure 7 (L361-363).

Line 385: Is this a native forest?

This sentence was confusing, and reformulated the sentence (L395-396). The work by Rada et al. (2019) is on plant functional diversity in tropical Andean páramos, and is based on ecological research on native species.

Line 434: Do you exclude for P a potential contribution of soil microbial immobilization?

Thank you for this comment. The formation of metal-humus complexes in the nonallophanic Andosols can increase the P fixing capacity by protecting P from microbial and enzymatic decomposition (Delfim et al., 2018; Borie et al., 2019), and we added this on L450-452.

Line 457: Here and previously in the Introduction, please specify better what kind of anthropogenic disturbances could be expected in the area

This concerns future changes in land use as a result of changing policies for livestock grazing, soil labor and use of fire, and we added this info on L469-470.

Report #2

https://doi.org/10.5194/egusphere-2023-2750-RC2, Anonymous Referee #2, 15 Jan 2024

Very nice work on the effects of vegetation types on nutrient availability and supply in the paramo.

I have only one general concern which relates to the ´Discussion´ section. I feel it may be reduced to some extent. As I read this section, it seemed I was reading a ´Results and Discussion´ section as many of the results were again described. Additionally, I am not used to finding so many figure and table referenced in a Discussion section.

I have also added some comments, suggestions and corrections on the manuscript itself, which the authors need to consider before publication.

We highly appreciate the constructive review, and the detailed comments on the manuscript. We have revised the 'discussion section' to avoid repetition, and also reduced the number of references to figures and tables in the discussion. Detailed comments are addressed below.

L49 : How about nutrient inputs through rainfall ?

Correct, this was missing in the text and is now added (L50-51).

L67 : I completely agree with the authors in that the Andes are particularly very interesting, However, these few lines do not really describe high altitude grasslands in the Andes (paramos)… Average cool air temperatures occur, however, extreme oscillations and very high temperatures (especially close to the ground) do constantly occur. Mean annual precipitation is also variable between paramos, and ´above 500 mm´ does not really describe it. Under clear skies, extremely high evaporative demands occur so ground evaporation and transpiration rates may not be necessarily low…

We added more information on the specificities of the high Andean ecosystems on L69-74 with the diurnal oscillations in air temperature, regionally variable precipitation amounts and temporally variable evaporative demands (Carabajo-Hidalgo et al., 2023 ; Páez-Bimos et al., 2023).

L141 : At what height were temperature and humidity sensors placed?

The meteorological station is installed by ETAPA following the WMO guidelines. The sensors are placed at 2.5 m height above the terrain (see now in L106).

L145 : It would help to know what the authors mean by ´most´… maybe in terms of %…

The effective rooting depth corresponds to the zone where the majority (estimated at > 90%) of the root biomass is present, and corresponds to the maximum depth at which vegetation used plant-available water. We added this information on L255-256.

Table 1 : Are Y and N necessary in this table? The significance level is enough to indicate wether it is Y or N…

Yes, that is correct. We simplified the table, and now only mention the p-values.

L289 : « Forests experienced more water stress » -> this information is not enough to refer to «water stress ».

The soil water content is systematically lower under forests than cushion-forming plants and tussock grasses (Fig. 4). In the driest month, the soil water content drops to 0.45 cm^3 cm^{-3} in some forested sites. Soil water retention curves established in the laboratory showed that the SWC at the permanent wilting point (pF = 4.2) of soils under forests is about 0.33 – 0.43 cm^3 cm^{-3}. As such, during the driest months, trees might experience water stress. We added information on L298-299 to clarify that this is based on the data on SWC variations and the water retention curves.

L457 : Relationship between vegetation types, soil characteristics and land use? How may anthropogenic disturbances influence these relationships?

We now specify land use policies related to livestock grazing, soil labor and use of fire (L469-470).

We checked the missing references, and corrected a few typos.

References cited herein

Bader, M.Y. and Ruijten, J.J.A.: A topography-based model of forest cover at the alpine tree line in the tropical Andes. Journal of Biogeography, 35: 711-723, https://doi.org/10.1111/j.1365-2699.2007.01818.x, 2008.

Borie, F., Aguilera, P., Castillo, C., Valentine, A., Seguel, A., Barea, J. M., and Cornejo, P.: Revisiting the nature of phosphorus pools in Chilean volcanic soils as a basis for arbuscular mycorrhizal management in plant P acquisition, Journal of Soil Science and Plant Nutrition, 19, 390-401, https://doi.org/10.1007/s42729-019-00041-y, 2019.

Carabajo-Hidalgo, A., Sabaté, S., Crespo, P., Asbjornsen, H.: Brief windows with more favorable atmospheric conditions explain patterns of Polylepis reticulata tree water use in a high-altitude Andean forest, Tree Physiology, 43(12), 2085–2097, https://doi.org/10.1093/treephys/tpad109, 2023.

Delfim, J., Schoebitz, M., Paulino, L., Hirzel, J., and Zagal, E.: Phosphorus availability in wheat, in volcanic soils inoculated with phosphate-solubilizing Bacillus thuringiensis, Sustainability, 10, 144, https://doi.org/10.3390/su10010144, 2018.

Hofhansl, F., Wanek, W., Drage, S., Huber, W., Weissenhofer, A., and Richter, A.: Topography strongly affects atmospheric deposition and canopy exchange processes in different types of wet lowland rainforest, Southwest Costa Rica. Biogeochemistry 106, 371–396, https://doi.org/10.1007/s10533-010-9517-3, 2011.

Hribljan, J. A., Suárez, E., Heckman, K. A., Lilleskov, E. A., and Chimner, R. A.: Peatland carbon stocks and accumulation rates in the Ecuadorian paramo, Wetlands Ecol. Manage., 24, 113-127, https://doi.org/10.1007/s11273-016-9482-2, 2016.

Hribljan, J.A., Hough, M., Lilleskov, E.A., Suarez, E., Heckman, K., Planas-Clarke, A.M., Chimner, R.A.: Elevation and temperature are strong predictors of long-term carbon accumulation across tropical Andean mountain peatlands. Mitig Adapt Strateg Glob Change 29, 1, https://doi.org/10.1007/s11027-023-10089-y, 2024

Páez-Bimos, S., Molina, A., Calispa, M., Dellmelle, P., Lahuatte, B., Villacís, M., Muñoz, T., and Vanacker, V.: Soil–vegetation–water interactions controlling solute flow and chemical weathering in volcanic ash soils of the high Andes, Hydrol. Earth Syst. Sci, 27, 1507–1529, https://doi.org/10.5194/hess-27-1507-2023, 2023.