Response to Reviewer comments (Manuscript No. EGUSPHERE-2024-3602)

Reviewer # 01

The work is very interesting; however, some points need to be rechecked.

We are very grateful to the Editor and referee for taking the time to review our manuscript. We deeply appreciate the reviewer valuable comments, suggestions, and questions to improve our manuscript. Please find below our itemized responses to these suggestive questions. We have revised our manuscript according to the Editor's and reviewers' suggestions and hope our responses will be satisfactory and the manuscript has been improved significantly. We hope the revised manuscript will fully meet publication standards in your journal after this revision.

Abstract

Line 21-23: In southern China, Hainan Island faces land degradation risks due to poor soil physical properties, such as a high proportion of microaggregates (< 0.25 mm), low soil organic matter (SOM) content, and frequent uneven rainfall. *The highlighted terms are not soil physical properties; the author should clarify this distinction.*

Response: Thanks a lot for your suggestion, we appreciate the referee careful assessment of our manuscript and for pointing out the need to clarify the distinction between soil physical properties and other factors influencing land degradation risks. In the revised manuscript, we have refined our statement to clearly differentiate between soil physical properties and other contributing factors. Specifically, we changed that "a high proportion of microaggregates (<0.25 mm)" is a soil physical property, while "low soil organic matter (SOM) content" is a soil chemical property, and "frequent uneven rainfall" is a climatic factor rather than a soil property. Please see line number # 21 – 24 in the revised manuscript. The revised sentence is below

"In southern China, Hainan Island faces land degradation risks due to a combination of soil physical, chemical, and climatic factors. Specifically, soil physical properties like a high proportion of microaggregates (<0.25 mm), chemical properties such as low soil organic matter (SOM) content, and a climatic factor of frequent uneven rainfall"

Line 30: Change *"cm/cm³" to "cm cm⁻³"* and ensure uniformity of unit formatting throughout the manuscript.

Response: Thank you very much for your careful attention to detail and for pointing out the need for consistency in unit formatting. In response, we have thoroughly reviewed the manuscript and replaced all instances of "cm/cm³" with the correct notation "cm cm⁻³" to ensure uniformity in unit representation. Additionally, we have conducted a comprehensive check to ensure that all units are consistently formatted throughout the text, tables, and figures. Any inconsistencies have been corrected accordingly.

Line 41: Add the full term of (CK).

Response: Thank you very much for your suggestion. we have revised the manuscript to include the full term "Control (CK)" at its first occurrence**.** we have also reviewed the manuscript to ensure consistency in the use of (CK) throughout the text.

Introduction

Line 51-55: Land degradation in tropical regions, such as Hainan Island, southern China, is primarily caused by poor soil physical properties (high proportion of microaggregates (< 0.25 mm) and low soil organic matter (SOM)) along with the uneven and high frequency of rainfall events during the summer season (May–October) and current global climate change, leading to severe land degradation in the form of water erosion (Shao et al., 2024; Zhu et al., 2022). *Why does a high proportion of microaggregates lead to soil degradation? High proportion of microaggregates and low soil organic matter (SOM) content are not considered soil physical properties.*

Response: We appreciate the referee insightful comment and the opportunity to clarify the role of microaggregates in soil degradation, as well as the classification of soil properties. Changed the belove information in the revised manuscript. Please see line No: 54 to 64.

Why does a high proportion of microaggregates lead to soil degradation?

A high proportion of microaggregates (<0.25 mm) negatively impacts soil structure and stability. Microaggregates are more prone to disintegration under rainfall impact, reducing soil cohesion and increasing susceptibility to surface sealing and crust formation. This weakens soil permeability, reduces water infiltration, and enhances surface runoff, ultimately accelerating soil erosion and land degradation.

Classification of Soil Properties

We acknowledge the referee concern regarding the classification of low soil organic matter (SOM) content and a high proportion of microaggregates. While SOM is primarily a soil chemical property, it plays a crucial role in soil aggregation and stability. On the other hand, soil aggregation (including microaggregate proportion) is often considered a structural aspect of soil, which is linked to both physical and chemical properties. To improve clarity and precision, we have revised the manuscript to ensure a more accurate classification of these factors, distinguishing soil physical properties from chemical properties and external climatic influences. The revised sentence is below

"Land degradation in tropical regions, such as Hainan Island, southern China, is driven by unfavorable soil conditions, including a high proportion of microaggregates (<0.25 mm), which reduces soil stability, and low soil organic matter (SOM) content, which weakens soil structure. Additionally, the uneven and high frequency of rainfall events during the summer season (May–October), combined with global climate change, further intensifies water erosion and accelerates land degradation (Shao et al., 2024; Zhu et al., 2022)."

Materials and methods

Line 158-159: Soil samples of approximately 2000 g were collected from depths of 0–20 and 20–40 cm during root collection *Please specify the method used for soil collection and the equipment utilized.*

Response: Thank you very much for your valuable feedback and the suggestion to provide more detail regarding the soil collection method and equipment used. Soil samples of approximately 2000 g were collected using a soil auger from two distinct soil depths (0–20 cm and 20–40 cm) during the root collection process. The auger was inserted into the soil at each depth, and samples were carefully extracted and combined to obtain a representative sample. To ensure uniformity and minimize contamination, the auger was cleaned between each sampling point. The samples were then sealed in plastic bags, labeled, and transported to the laboratory for further analysis. The revised sentence is below. Please also see the revised manuscript line No: 181 – 183.

"Soil samples of approximately 2000 g were collected from depths of 0–20 cm and 20–40 cm using a soil auger during the root collection process. The samples were carefully extracted, combined, and sealed in plastic bags for transportation to the laboratory for further analysis."

Reviewer # 02

The study presents interesting findings on the role of rubber plant root properties in enhancing soil aggregate stability and reducing land degradation risk in tropical regions. However, the manuscript requires significant revisions to improve clarity, address inconsistencies, and strengthen the discussion. The authors should carefully address the points raised **below** to enhance the overall quality and impact of the study.

We are very grateful to the Editor and referee for taking the time to review our manuscript. We deeply appreciate the referee valuable comments, suggestions, and questions to improve our manuscript. Please find below our itemized responses to these suggestive questions. We have revised our manuscript according to and reviewers' suggestions and hope our responses will be satisfactory and the manuscript has been improved significantly. We hope the revised manuscript will fully meet publication standards in your journal after this revision.

Introduction:

Line 67, The introduction could benefit from a clearer articulation of the study's novelty, particularly in light of existing research that has already established certain conclusions. It would be helpful to elaborate on how this study builds upon or diverges from previous findings to advance the field.

Response: Thanks a lot for your suggestion, to clarify the novelty of our study about existing research. We agree that a more explicit articulation of how our study builds upon or diverges from previous findings will help to highlight its contribution to the field. While previous studies have established key conclusions regarding land degradation and soil properties in tropical regions, particularly in Hainan Island, our study introduces a novel perspective by examining the combined influence of microaggregate proportion, soil organic matter content, and climate factors (such as rainfall patterns) on soil degradation. Additionally, this research advances the understanding of how these factors interact within the context of ongoing global climate change, which has not been adequately addressed in prior studies. To make this clearer, we have restructured the introduction to emphasize the following points: According to the below points rearranged the introduction part of the manuscript. Please see the revised version.

Previous studies have primarily focused on individual factors (such as soil physical properties or climate change), but few have investigated their combined effects in the specific context of Hainan Island.

Our research integrates these factors and applies them to a regional context, providing a more comprehensive understanding of land degradation in southern China.

By exploring the interaction between soil properties and climate change, our study offers new insights that may inform future land management strategies and ecological restoration efforts.

Your suggestion regarding the novelty, study contribution, and study advancement has been added to the Introduction in the revised manuscript.

(2) The focus on root morphology as a key factor in explaining aggregate stability is intriguing. However, it would strengthen the introduction to provide a more detailed discussion on why root morphology is considered a critical factor among the various external influences (e.g., aboveground litter, root mortality, root exudates) on aggregate formation. Specifically, could the authors elaborate on the unique role of root morphology in this process?

Response: Thanks a lot for your suggestion to further elaborate on the role of root morphology in aggregate stability. Root morphology plays a critical role in aggregate formation and stability because it directly influences the interaction between plant roots and soil particles, which are fundamental to the physical structure of the soil. While other factors, such as aboveground litter, root mortality, and root exudates, certainly contribute to aggregate formation, we believe that root morphology stands out due to its direct, physical interactions with soil particles and its impact on the formation of stable aggregates. Added the given suggestion in the revised file. Please see lines No # 77 – 81 and 87 – 90.

Root morphology, particularly traits like fine root length (FRL), coarse root length (CRL), root diameter (RD), and root length density (RLD), influences the soil matrix by promoting the binding of soil particles. Fine roots, in particular, have a higher surface area, which increases the contact points between roots and soil particles, leading to stronger aggregate formation through physical entanglement and cohesion.

While aboveground litter and root exudates contribute to organic matter inputs, their impact on aggregate stability is often indirect compared to root morphology. Aboveground litter, for example, provides organic material that may eventually contribute to SOM, but it does not directly interact with soil particles in the same way as roots do. Root exudates, though they influence soil chemical properties and microbial activity, are also less directly involved in the mechanical processes of aggregate formation.

Moreover, the role of root mortality in aggregate stability is well-documented, as decaying roots can contribute to SOM and affect soil cohesion. However, root morphology is unique in its ability to continuously modify the soil structure during the plant's growth and development, providing a dynamic and ongoing process that other factors cannot replicate.

We have revised the introduction to include a more detailed discussion of this unique role of root morphology and its distinction from other factors influencing aggregate stability.

(3) The discussion of cohesive forces and their relationship with aggregate stability is a compelling aspect of the study. It might be beneficial to introduce this relationship earlier in the introduction to provide readers with a more comprehensive background and context for the study's objectives.

Response: Thank you very much for your suggestion. We agree that incorporating this information at the beginning of the introduction will enhance the clarity of the study's premise and better guide the reader through the rationale for our research. We have revised the introduction to include a more detailed discussion of the role of cohesive forces in soil aggregate formation and stability.

Experimental Design

The inclusion of the MF treatment is an interesting choice. Could the authors provide additional clarification on the rationale for selecting this treatment and how it contributes to the study's overall goals?

Response: Thank you very much. it is a nice question you raised. We revised and make it clear please revised version file line No: 144 to 148.

The MF treatment represents a mixed forest system consisting of cinnamon (*Cinnamomum verum*) trees (planted in 2014) intercropped with 20-year-old rubber (*Hevea brasiliensis*) trees. This treatment was included to assess the potential benefits of mixed-species plantations on soil aggregation and stability compared to monoculture rubber plantations. Mixed forests can enhance soil properties through diverse root systems, increased litter input, and improved below-ground interactions that influence soil structure.

The rationale for selecting this treatment lies in the hypothesis that plant species diversity, particularly the coexistence of deep-rooted and shallow-rooted species, may improve soil aggregate stability through multiple mechanisms. Cinnamon trees and rubber plants contribute different root traits, organic inputs, and microbial associations, which could enhance soil cohesion and aggregation. Additionally, the mixed forest system may promote greater soil biodiversity and nutrient cycling, leading to improved soil physical properties and resistance to degradation.

By including the MF treatment, this study aims to evaluate whether mixed-species plantations offer advantages over monoculture rubber systems in terms of soil health and stability. This aligns with the broader goal of identifying sustainable land-use strategies to mitigate soil erosion and degradation in tropical regions such as Hainan Island.

Results

(1) Significance Levels: It would be helpful to explicitly state the significance levels (e.g., $p < 0.05$) wherever significant results are mentioned.

Response: We are thankful for highlighting the importance of clearly stating the significance levels in our results. In response, we have revised the manuscript to explicitly indicate significance levels (e.g., $p < 0.05$) wherever significant results are reported.

(2) Line 279, > 0.0053?

Response: Thank you very much for the correction. We have received and corrected it to < 0.053 mm

(3) Table 1: Including significance results in Table 1 and specifying the number of replicates would enhance the transparency and reproducibility of the findings.

Response: Thanks a lot for your comment. Table 1 in our study presents the basic chemical and physical properties of the experimental plots. We collected one composite sample per rubber forest plot at each depth, not in replication. Given that these values represent the general site characteristics rather than treatment comparisons, significance testing was not conducted.

(4) Figure 1, indicating the number of replicates for each treatment and clarifying the meaning of the letters (a, b, c, d) would improve the figure's interpretability.

Response: Thank you very much for your comment. The figure presents replicated data for each treatment. To indicate statistical significance, we have used the following notation: $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***). Additionally, the letters (a, b, c, d) denote each small figure in Figure. 01.

(5) Figures 2 and 5, combining the treatments into a single figure rather than separating them by soil layer might facilitate a more straightforward comparison.

Response: Thank you very much for your suggestion. In the revised manuscript, I have addressed this by combining the treatments into a single figure for both Figure 2 and Figure 5. This adjustment was made to improve clarity and streamline the presentation of the data.

(6) Figure 4, could the authors explain the rationale behind dividing the root chemical components into three categories instead of four?

Response: Thank you for your question regarding the rationale behind dividing the root chemical components into three categories lignin content, cellulose content, and soil organic matter (SOM). The primary objective of categorizing root chemical components was to focus on the key structural and functional elements that significantly influence soil aggregation and stability. Lignin and cellulose are the two major structural components of plant roots, playing critical roles in root decomposition, soil organic matter (SOM) formation, and soil structure stabilization. Furthermore, our categorization aligns with existing literature on root decomposition and soil organic matter dynamics. Previous studies (Ali et al., 2022) emphasize lignin and cellulose as the primary structural components of roots, with SOM being the end product of their decomposition and their inclusion allows us to explore how root chemistry affects soil structure over time. For more details, please see the article below.

Ali, W., Yang, M., Long, Q., Hussain, S., Chen, J., Clay, D., and He, Y.: Different fall/winter cover crop root patterns induce contrasting red soil (Ultisols) mechanical resistance through aggregate properties, Plant and Soil, 477, 461–474, https://doi.org/10.1007/s11104-022-05430-4, 2022

(7) Figures 6, 7, and 8, display the significant results would provide a clearer understanding of the findings.

Response: Thank you very much for your valuable suggestion. I greatly appreciate your feedback, which has helped improve the clarity and presentation of the results in the manuscript. In response to your comment, I have carefully revised the results of Figures 6, 7, and 8 to more clearly present the significant differences observed in the data.

Please see the revised manuscript line No # 321 to 350

(8) To enhance clarity, please use letter labels to indicate the significance of the figures.

Response: Thank you very much for your valuable suggestion regarding the use of letter labels to indicate significant differences in the figures. However, in this study, the significance analysis was conducted at three levels: $p < 0.05$, $p < 0.01$, and $p < 0.001$. Given the current analytical approach, the use of asterisks (*, **, ***) is more appropriate and consistent with the statistical results presented. This method allows for a clear and concise representation of the varying levels of significance across the data.

(9) Consistency in Color: Ensuring that the color schemes for different treatments are consistent across all figures would help avoid potential confusion and improve the overall presentation.

Response: Thanks a lot for the suggestion we have reviewed all the figures and kept the consistent color across all the figures for different treatments.

Discussion

(1) Line 369: The statement that "The soil cohesive force increased aggregate stability (MWD and GMD) at the same soil depth" is an interesting observation. However, Figures 7 and 8a do not appear to show a significant correlation between soil cohesive force and aggregate stability. Could the authors address this apparent discrepancy?

Response: Thanks a lot for your question. I agree with you the results of Figures 7 and 8 did not show the direct relationship of soil cohesive force with aggregate stability (MWD and GMD). But, indirectly the root morphology traits like fine root length (FRL), coarse root length (CRL), root diameter (RD), and root length density (RLD), influence the soil cohesive force and binding of soil particles and then indirectly increase aggregate stability (MWD and GMD). The relationship between cohesive force and aggregate stability was clearly explained in Fig 6. The Pearson correlation analysis indicated that the soil RFCF was positively and strongly associated with MWD and GMD with a correlation coefficient of 0.81 and 0.91 (0–20 cm), and 0.81 and 0.89 (20–40 cm).

(2) Lines 373-374: The observation that "GMD significantly decreased after 27 years of planting, while soil cohesive force did not" seems to contradict the results. Could the authors provide further clarification or revise this statement for consistency?

Response: Thank you very much for pointing out this contradiction in the results I apologize for not clearly presenting the statement and have revised the statement. The soil cohesive force has a positive correlation ($r = 0.81$ to 92) with GMD at both soil depths.

(3) Line 370: The claim that "Cohesive forces governed macroaggregate stability but also played a role in microaggregate formation" is intriguing. Could the authors elaborate on this, particularly in light of the results presented in Figure 4?

Response: Thank you very much it is a very nice question. Below we elaborate on the results presented in Figure 4 and provide additional context to clarify the mechanisms involved.

Please line No: 418 to 424 in the revised manuscript.

Cohesive forces, which arise from interactions between soil particles, organic matter, and root exudates, are critical in maintaining soil structure. Our study highlights that these forces not only govern macroaggregate stability but also contribute to microaggregate formation. This dual role is supported by the observed changes in root-soil composite cohesive force (RFCF) and root-soil interactions across rubber plantations of different stand ages, as shown in Figure 4.

"Macroaggregates are primarily stabilized by cohesive forces derived from organic matter, root exudates, and fungal hyphae. In our study, the significant increase in RFCF with the introduction of rubber plantations (Fig. 4a) indicates that cohesive forces are enhanced by root activity and organic matter inputs. Older rubber plantations (>11 years) exhibited higher RFCF values, suggesting that prolonged root-soil interactions and increased soil organic matter (SOM) contribute to stronger cohesive forces, thereby stabilizing macroaggregates. Furthermore, the order of RFCF improvement (MF > 27Y_RF > 20Y_RF > 11Y_RF > 5Y_RF) aligns with the increasing root density (RD), root length density (RLD), and SOM content in older plantations. These factors enhance the binding capacity of soil particles, leading to greater macroaggregate stability"

"The cohesive force also plays a role in microaggregate formation. Microaggregates are formed through the binding of primary particles (clay, silt, and fine organic matter) by cohesive forces. In our study, the increased RFCF in older plantations (Fig. 4a) suggests that cohesive forces are strong enough to facilitate the formation of microaggregates, particularly in the topsoil (0–20 cm depth). The higher SOM content and root exudates in older plantations provide additional binding agents, which promote the formation of microaggregates. These microaggregates, in turn, contribute to the overall stability of the soil structure by acting as building blocks for macroaggregates."

(4) Line 377: The statement "SOM had a positive effect on soil particles" is somewhat unclear. Could the authors provide additional details on how SOM influences soil particles?

Response: Thank you for your valuable comment. We have provided additional details about how SOM influences soil particles. Added the relevant details in revised manuscript, please see line No # 431 to 435

"Soil organic matter (SOM) influences soil particles in several ways, primarily by enhancing soil aggregation and improving soil structure. SOM contributes to the formation of aggregates by acting as a binding agent between soil particles, especially through its interaction with clay minerals and other soil constituents. The organic compounds in SOM help form cohesive forces that promote the flocculation of fine soil particles, creating larger, more stable aggregates. This process improves soil porosity, water retention, and overall soil structure, which in turn supports plant growth and soil resilience."

(5) Lines 382-383: The conclusion that "MWD of older rubber plants was not adversely affected by the excessive release of SOC from the mechanical breakdown of macroaggregates" is an interesting point. However, it would be helpful to see additional evidence or clarification to support this conclusion.

Response: Thank you very much for your valuable comments**.** We have clarified this point by emphasizing that the stability of soil aggregates in older rubber plantations is not solely determined by the release of soil organic carbon (SOC) during macroaggregate breakdown. Please see line No # 442 to 446 in the revised manuscript.

"The SOC is released during the breakdown process, the enhanced root biomass and higher SOM content in older rubber plantations play a significant role in stabilizing the aggregates and mitigating the adverse effects of SOC loss. Furthermore, the higher root length density (RLD) and root-derived SOM in older plantations foster the formation of microaggregates, which helps maintain overall aggregate stability. These factors contribute to an increase in mean weight diameter (MWD) rather than a decrease, even when there is some release of SOC from macroaggregate breakdown."

Conclusion

To improve readability, it would be helpful to avoid using abbreviations in the conclusion. Additionally, the conclusion could be strengthened by synthesizing the findings and discussing their broader implications for soil aggregate stability and land degradation mitigation in tropical regions, rather than simply restating the results. For example, the statement "Our findings indicate that natural rubber plantations of different stand ages exhibit distinct root distribution patterns, with 27-year-old rubber forests (27Y_RF) and MF showing greater RLD and higher percentages of FRL and MRL RD classes than those of younger plantations" could be expanded to reflect the study's broader significance.

Response: We are sincerely thankful to the referee for the valuable suggestion to improve the conclusion. We have revised the conclusion to minimize the use of abbreviations, opting instead to spell out terms for better readability. Additionally, rather than simply summarizing the results, we have synthesized the key findings to emphasize their broader significance in the context of soil aggregate stability and land degradation mitigation in tropical regions. We are confident that these revisions will provide a more comprehensive and impactful conclusion. Please see line 471 to 487 in revised manuscript. The revised conclusion is also below

"In this study, we investigated how root morphological traits, root-derived soil organic matter (SOM), and chemical composition of rubber plants at different stand ages influence soil aggregate stability through soil cohesive forces. Our findings indicate that natural rubber plantations of different stand ages exhibit distinct root distribution patterns, with older rubber plantations, particularly 27-year-old rubber forests, and mixed forests (MF), demonstrating a more developed root system characterized by greater root length density (RLD) and higher proportions of fine root length (FRL) and medium root length (MRL) diameter classes compared to younger plantations. The higher percentages of FRL and MRL in older rubber plants (> 11 years old), along with their high SOM content, contributed to a stronger soil cohesive force than that observed in younger rubber plants and the control plots. The higher SOM content in older rubber plants was driven by the higher cellulose content and lower lignin percentages in their FRL and MRL. Consequently, rubber plants older than 11 years increased the soil cohesive force (with and without roots) compared to younger rubber plants and the control, thereby enhancing aggregate stability and reducing soil particle dispersion. These findings have valuable practical implications for developing management strategies to restore soil quality in degraded tropical regions of Hainan Island. They highlight the importance of selecting rubber plants with ideal root traits to improve aggregate stability through soil cohesive forces, ensuring long-term agricultural productivity and preserving environmental quality."