Direct and indirect effects of rainfall and vegetation coverage on runoff, soil loss, and nutrient loss in a semi-humid climate

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Abstract

Soil and nutrient loss play a vital role in eutrophication of water bodies. Several simulated rainfall experiments have been conducted to investigate the effects of a single controlling factor on soil and nutrient loss. However, the role of precipitation and vegetation coverage in quantifying soil and nutrient loss is still unclear. We monitored runoff, soil loss, and soil nutrient loss under natural rainfall conditions from 2004 to 2015 for 50-100 m2 runoff plots around Beijing. Soil erosion was significantly reduced when vegetation coverage reached 20 and 60%. At levels below 30%, nutrient loss did not differ among different vegetation cover levels. Minimum soil N and P losses were observed at cover levels above 60%. Irrespective of the management measure, soil nutrient losses were higher at high-intensity rainfall (Imax30>15 mm/h) events compared to low-intensity events ($p < 0.05$). We applied structural equation modelling (SEM) to systematically analyze the relative effects of rainfall characteristics and environmental factors on runoff, soil loss, and soil nutrient loss. At high-intensity rainfall events, neither vegetation cover nor antecedent soil moisture content (ASMC) affected runoff and soil loss. After log-transformation, soil nutrient loss was significantly linearly correlated with runoff and soil loss ($p < 0.01$). In addition, we identified the direct and indirect relationships among the influencing factors of soil nutrient loss on runoff plots and constructed a structural diagram of these relationships. The factors positively impacting soil nutrient loss were runoff (44-48%), maximum rainfall intensity over a 30-min period (18-29%), rainfall depth (20-27%), and soil loss (10-14%). Studying the effects of rainfall and vegetation coverage factors on runoff, soil loss, and nutrient loss can improve our understanding of the underlying mechanism of slope non-point source pollution.

Dear Editors and Reviewers:

Thank you very much for your attention and the reviewers' evaluation and comments on our paper "**Direct and indirect effects of rainfall and vegetation coverage on runoff, soil loss, and nutrient loss in semi-humid climate** " (HYP-20-0560). Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We have studied comments carefully and have made correction which we hope meet with approval. We invite a native English scientist of relative research to polish and edit our wording and language, the details of the changes can be found in the manuscript. Besides, our current manuscript followed the journal formatting guidelines of Hydrological Processes . We hope the latest version of the manuscript could meet the journal's standard. Revised portion are marked in red throughout the revised manuscript. The main corrections in the paper and the Responses to the reviewer's comments are as flowing:

NOTE: All the Page and Line numbers where revisions were made refer to the Manuscript and Highlight

with marked changes (Manuscript (revised version).pdf and (Graphical abstract (revised version).docx). The Manuscript_Clean Version was the same version of the Manuscript (revised version) with cleaned from all the marks.

Responses to the Reviewer #1's comments:

Thank you for this long-term field study that was interesting to be read. Some minor comments/suggestion to improve the readability and/or presentation quality is given in the attached pdf. Main concerns are the following once:

As you have slightly stressed in the manuscript, your climate framework is arid to semi-arid. Many statements have been selected from literature bearing in mind this setting around Beijing. Therefore, I would suggest to acknowledge this fact by changing adequately the title of the paper by adding in arid (or arid and semi-arid) climate conditions to the title. The possible new title might read: Direct and indirect effects of rainfall and vegetation coverage on runoff, soil loss, and nutrient loss in arid to semi-arid climate.

Response: Thank you very much for your comments and suggestions. We revised the title to "Direct and indirect effects of rainfall and vegetation coverage on runoff, soil loss, and nutrient loss in a semi-humid climate" (Page 1, Line 2)

Vertical water balance can only be guessed from Table 1, looking at Depth and RO data. I would suggest to discuss the elements of the vertical water balance in your runoff plots into in-depth details. You were showing vegetation coverage classes, but not much is given with regard to rainfall partitioning (interception, canopy evaporation, stem flow, trough fall, ...). You are only discussing rainfall (above canopy I assume), soil moisture (changes), and runoff. There are other processes that you (some of them) mention, such as infiltration, evapo-transpiration. But you have not measured them. You have tried in discussion (using references) to explain the effect of vegetation (coverage) on soil moisture, infiltration rates or runoff. To better understand the structure and interrelations in your structural equation models (SEM), further discussion is needed as vegetation does not seem to be very relevant environmental factor, especially for high-intensity rainfall events.

Response: Thank you for your comments. Based on your suggestion, we have discussed in detail the various processes of vertical water balance of rainfall (including interception, evapotranspiration, infiltration, and runoff, etc.) (Page 16, Line 335-341).

You could check soil erosion rates via any soil loss equation, such as RUSLE, at least by introducing rainfall erosivity rather than using separately duration, depth and I30 - this are normally interrelated as a part of rainfall erosivity R. You could even have checked measured soil loss rates and modeled ones. I would suggest to try to use SEM by introducing computed rainfall erosivity R instead of Depth, Duration and Intensity - i.e. only one rainfall factor. In such a way your results will be much more comparable to a vast literature on rainfall erosivity and their effects on soil erosion. As you have measured not only soil loss, but also nutrient, this is important to relate nutrient (P, N) loss to rainfall erosivity. I am sure you can find an adequate equation for rainfall kinetic energy to be used in the expression EI30 for the region of Beijing. As you will use the same equation for all plots and events, the choice of the equation is not critical. The units of R will allow you to compare your results with many other studies.

Response: Thank you for your comments. We found a formula for calculating the rainfall erodibility which is suitable for Beijing[1] and added the rainfall erodibility into the structural equation model (Page 8, Line 155-159; Figure 5,7,8). [1] Liu, B., Bi, X., Fu, S. (2010). Beijing soil loss equation [M]. Science Press. 22-23

Detailed suggestions for revision:

L20 Please, add their size in m2, or their dimensions as well as their total number.

Response: Thank you for your comments. We added the plot size in m^2 (Page 1, Line 21).

L25 define what is high in terms of mm/h.

Response: Thank you for your comments. We added the definition of high-intensity in terms of mm/h (Page 2, Line 26).

L42 I would suggest you to use one and only one type of citing references in the text, i.e. Adimasu et al., 2014. If there are two authors, use Ramos & Martínez-Casasnovas, 2009. For all the rest you preferably use the short version First Author et al., 20xx.

Response: Thank you for your comments. We revised the references according to your suggestion (Page 2, Line 43). And examined the hole manuscript and corrected the references.

L55 Please, check the use of the word "lost". Why rainfall is lost? Why quoting here this 70%? It can be less and it can be more? Please, rephrase and make more relative this number.

Response: Thank you for your comments. We revised this sentence to "about 70% of rainfall is converted to runoff" to make it more accurate (Page 3, Line 58).

L64 there is a vast literature on this topic, only citing one paper it is not enough to gwet away on the topic of rainfall interception and rainfall losses in general (evapotranspiration, interception, stem flow, infiltration,. . . .)

Response: Thank you for your comments. We added references to discuss rainfall interception and rainfall losses more comprehensively (Page 4, Line 77-78).

L77 please, rephrase - evapotranspiration is a process, and can be quantified (in mm), hydrology is field of science. Maybe soil wetness?

Response: Thank you for your comments. We revised "hydrology" to "soil wetness" in the latest version of the manuscript (Page 5, Line 90).

L97 There are many plots, but you have used only those close to Beijing - precisely, only nine of them. Is this so?

Response: Thank you for your comments. We collected data from 31 runoff plots in Beijing for analysis. However, in the analysis of vegetation factors, in order to better make other factors consistent, we selected 9 plots with different vegetation coverage but consistent with other factors for analysis. We revised this sentence to illustrated the number of plots (Page 6, Line 122-124).

L100 give their number. Nine?

Response: Thank you for your comments. We revised this sentence to "We collected 31 runoff plots" to illustrate the number of plots (Page 6, Line 122).

L101 Can you say something about the vegetation coverage types?

Response: Thank you for your comments. We added the vegetation coverage types (Page 6, Line 126-127).

L121 during a year - seasonally, or were these differences all the time in place among the nine plots? You have later in your study used classes for vegetation coverage from 5% to 90%. How were these classes achieved/maintained?

Response: Thank you for your comments. Beijing's rainy season is mainly in July and August. The vegetation coverage of runoff plots is controlled by planting density. Runoff plots are long-term monitoring stations for soil erosion and are maintained every year.

L149 Please, add somewhere the distribution of 997 rainfall events for each vegetation coverage class - or was the coverage different between nine plots and fixed in time, and so, all rainfall events were measured on all nine plots simultaneously?

Response: Thank you for your comments. All rainfall events were measured on all nine plots simultaneously. We added instructions in the manuscript (Page 6, Line 124-125).

L152-153 This is NOT true. Please rephrase: When vegetation coverage was higher than 60%, their effect on runoff and sediment reduction stays the same and does not change any more, even if it is as high as 90%.

Response: Thank you for your comments. When vegetation coverage was higher than 60%, runoff and sediment decrease with the increase of vegetation, but the difference was not significant. By that we mean a statistically insignificant difference. To avoid misunderstanding, we rewritten this sentence (Page 9, Line 192-193).

L172 Start a new paragraph, where you discuss low-intensity rainfall events.

Response: Thank you for your comments. We have described the low-intensity precipitation event in detail in Line 213-222.We added a new section to analyze high-intensity precipitation events (Page 11, Line 223-233).

L198-199 This comes here as a kind of surprise statement. Numerous soil erosion models, such as e.g. RUSLE, use rainfall erosivity as an important soil erosion factor, incorporating directly the highest rainfall intensity of 30-minutes into the equation. Further discussion is badly needed in this regard (maybe in the chapter Discussion).

Response: Thank you for your comments. According to your Suggestions, we incorporated rainfall erodibility into the analysis, and found that rainfall erodibility was highly correlated with soil erosion and nutrient loss, and the rainfall erodibility was incorporated into the equation in the regression model. We added discussion in this regard (Page 12, Line 244-247).

L239-241 You are using plural, but cite only one study? Please, avoid such statements, or find other references that maybe are telling you something different. Please, rephrase, or make this statement more relative, i.e. account for specific study site conditions in this one reference.

Response: Thank you for your comments. According to your suggestion, we revised the sentence (Page 16, Line 330-332).

L248 Another example of a clearly too strong statement to be taken so generally as it is written. Please, rephrase, or add more references in this regard and enlarge the discussion. As you have not studied interception and rainfall losses in canopies, please, be careful with such statements.

Response: Thank you for your comments. According to your suggestion, we rephrased this sentence (Page 16, Line 343-345).

L437 Should be rearranged to be in order alphabetically.

Response: Thank you for your comments. We rearranged the reference in order alphabetically (Page 23, Line 571-573).

L475 This reference is not used in the text. Please, use it in the text or delete in from the list.

Response: Thank you for your comments. We deleted this reference in the list (Page 23, Line 594-596)

Fig.1 Could you, please, adjust the DEM limit values for Low to start at "0" and not "-121"?

Response: Thank you for your comments. We revised the DEM limit value for Low to start at "0" in the Figure 1.

Fig.7 Would the SEM models be different if you split the rainfall events into high- and low-intensity events? Have you tried that?

Response: Thank you for your comments. We made a distinction between high-intensity rainfall events and low-intensity rainfall events for soil erosion (Fig. 5). Similarly, we tried to distinguish soil nutrient loss under high-intensity and low-intensity rainfall events. The results were similar to Figure 5, so we did not distinguish rainfall intensity here.

Fig.8 This Figure 8 is not used in the text - please, use it in the appropriate section of the manuscript.

Response: Thank you for your comments. Figure 8 was explained in the result section for 3.5 (Page 13, Line 269).

Table 1 Please, add a legend below the table to explain acronyms. RO, SL, P, N, COD,... You should use ASCM instead, as in the text, or at least add this explanation ASMC to the "Moisture". This is strange unit. Please, use mm instead, to have the same units as for rainfall.

Response: Thank you for your comments. We added a legend below the table 1 to explain acronyms and we revised "Moisture" to "ASMC" (Table 1).

Graphical abstract You were using the expression "coverage" instead of cover. Why 20%? IS it not only 60% relevant?

Response: Thank you for your comments. According to the author guide, we modified the text for the part of the Graphic Abstract.

Responses to the Reviewer #2's comments:

L14-16 The background should be rewritten more logically with following content, such as: Soil and nutrient loss play a vital role in eutrophication of water bodies.

Response: Thank you for your comments. We rewrote the background to make the context more logical (Page 1, Line 14).

L 46: The authors list that the Ferrreira 2018 study indicates runoff is the main route for nutrient transport. This statement is too general. Nitrogen can be lost in several pathways (including leaching) and many others are not mainly lost via runoff.

Response: Thank you for your comments. We revised this sentence to make it clear (Page 3, Line 46).

L54-57: These descriptions are very broad. They may be found for particular studies in particular regions, but stating 70% of rainfall is lost as runoff needs to be contextualized because this is not a static fact, nor generalized dynamic across regions.

Response: Thank you for your comments. We restricted the area of this sentence to make the expression more accurate (Page 3, Line 58).

L55: which hydrological changes? "Hydrological changes are generally caused by altered rainfall patterns and have a significant impact on soil nutrient loss". This is too broad and leaves out many things.

Response: Thank you for your comments. We revised this sentence in the last version of manuscript (Page 3, Line 58).

L65-66 There should add some references to support this argument.

Response: Thank you for your comments. This sentence is integral to the following sentence, so there is the same reference, we rewrote the sentence (Page 4, Line 78-79).

L93 "effect of each factor on slope runoff and erosion" should be more accurately expressed as "effect of rainfall and environmental factors on runoff and soil nutrient loss".

Response: Thank you for your comments. We revised "various factors" to "rainfall and environmental factors" in the latest version of the manuscript (Page 6, Line 112).

L99-100 Soil types should use an international classification system (e.g. USDA soil taxonomy or FAO system) to be understandable to an international audience. I'm not sure what the listed soil types.

Response: Thank you for your comments. We have described the soil according to USDA soil Taxonomy (Page 6, Line 121).

L101 The sign should be "x".

Response: Thank you for your comments. We revised the sign to "x" (Page 6, Line 122).

L101 According to the description that the plot includes different areas and slops, why these two factors were not included in the analysis.

Response: Thank you for your comments. The area of plots influences the runoff and soil loss, but the scale span is not very large. Under the influence of rainfall and management, the impact of the area was masked. The runoff and soil loss in this study refers to the runoff depth (mm) and soil loss per unit area (t km^{-2}), not to the total runoff and soil loss after the rainfall. Therefore, the effect of area on runoff and sediment was eliminated.

L101 and L121 Repeated introduction of vegetation coverage, it is suggested to delete a place.

Response: Thank you for your comments. We deleted a duplicate part in the latest version of the manuscript (Page 7, Line 153).

L109 "Beijing plots" should be replaced by "experimental sites".

Response: Thank you for your comments. We revised "Beijing plots" to "experimental sites" (Page 7, Line 137).

L112 Delete "classified as".

Response: Thank you for your comments. We revised "classified as" to "was taken as" in the latest version of the manuscript (Page 7, Line 143).

L114 why not choose the average rainfall intensity instead of the max rain intensity of 30 min.

Response: Thank you for your comments. Because the average rainfall intensity was calculated by the duration and intensity of rainfall, Imax30 was selected as the indicator of rainfall intensity in order to avoid collinearity of the data.

L111-115 The indices should be added in units.

Response: Thank you for your comments. We added the unites of indices (Page 7, Line 141-143).

L129-131 It would be better to change the sentence to "Given the complex relationship between hydrological and environmental factors and possible influence of plant coverage on runoff, soil loss, and nutrient loss, we used SEM to test the correlation".

Response: Thank you for your comments. We rewritten this sentence according to your request (Page 8, Line 167-169).

L133 "an a"? Please modify.

Response: Thank you for your comments. We deleted "a" in the latest version of the manuscript (Page 8, Line 173).

L136 Delete sign ",".

Response: Thank you for your comments. We deleted sign "," in the latest version of the manuscript (Page 8, Line 176).

L191 "depth?" It would be better to write the full name here, "rainfall depth".

Response: Thank you for your comments. We added "rainfall" in the sentence (Page 11, Line 237).

L200-201 This is just an introduction to figure 6, but what do the authors get from figure 6? The authors did not specify. In my opinion, in addition to the linear equation, the correlation between soil nutrient loss and runoff was higher than that of soil loss.

Response: Thank you for your comments. We added the result description for figure 6 (Page 12, Line 24-250).

L256 "In . . . events, THE was no . . . " Please check it.

Response: Thank you for your comments. We revised "the" to "there" in the latest version of the manuscript (Page 13, Line 282).

L253 There should be data support here, please calculate the corresponding skewness value, not the conclusion you see directly.

Response: Thank you for your comments. We added the skewness value in the latest version of the manuscript (Page 13, Line 280).

L257-258 "short high intensity and long low-intensity" should be changed to "short duration of high intensity rainfall and long duration of low intensity rainfall".

Response: Thank you for your comments. We modified this sentence according to your requirements (Page 13, Line 284).

L290 I think this conclusion should come from table 3. It needs to be marked out.

Response: Thank you for your comments. We added "Table 3" in this sentence (Page 17, Line 362).

L303 I recommend that "rain" should be written as "rainfall", modified elsewhere.

Response: Thank you for your comments. We revised "rain" to "rainfall" in the latest version of the manuscript (Page 17, Line 374).

Figure 2: the slope factor should be added to the environment variable in the empirical model in figure 1, although the factor was eliminated in subsequent analysis.

Response: Thank you for your comments. We added slope factor in figure 2.

Figure 6: "Ln(y)" should be changed to "Ln(N), Ln(P), Ln (COD)", "Ln(x)" should be changed to "Ln (RO), Ln (SL)".

Response: Thank you for your comments. We changed "Ln(y)" to "Ln(N), Ln(P), Ln (COD)", and changed "Ln(x)" to "Ln (RO), Ln (SL)" in Figure 6.

Figure 6: Notes lack the description of RO and SL.

Response: Thank you for your comments. We added the description of RO and SL in Figure 6.

Figure 8: this figure is problematic. The values are not comparable and appropriate. The sum of the proportions is greater than 1?

Response: Thank you for your comments. We modified the Figure 8 so that the horizontal axis is on a uniform scale (Figure 8).

Responses to the Reviewer #3's comments:

Ln 40-53 - there citation of previous work is minimal in this part of the draft m/s and I think it needs to expanded and especially to include papers from beyond China.

Response: Thank you for your comments. According to your suggestion, we have expanded on the previous literature, especially the literature outside of China (Page 2-3, Line 40-53).

ln 54-62 - this paragraph touches upon some important issues but lacks detail and thorough discussion of rainfall related matters. Rainfall totals, intensity, distribution relative to the cropping calendar and associated ground cover are all important, as are back to back rain days with significant totals. Changes in these rainfall parameters in conjunction with changing weather patterns or climate change are also important.

Response: Thank you for your comments. We discussed in more detail and thorough the effects of rainfall on soil erosion, including rainfall, rainfall intensity, land management practices, and extreme rainfall associated with climate patterns (Page 3, Line 57-66).

ln 81-90 - these lines do not really convince me of the true novelty of the research and I think this really challenges whether this paper should progress more in HP. I am sure that the journal wishes to publish truly novel and progressive science. I think the findings of this study simply confirm what has been known for a long time.

Response: Thank you for your comments. In this study, the shortcomings of previous artificial simulated rainfall experiments were overcome, the influence factors were continuous variables, and the functional relationship of slope hydrological process was established by using structural equation model. And the threshold interval of vegetation coverage was obtained quantitatively (Page 5, Line 94-97; 107-109).

ln 90-93 - no proper research objectives and hypotheses are presented - this must be corrected.

Response: Thank you for your comments. We added research hypotheses and objectives in the latest version of the manuscript (Page 5-6, Line 106-114).

ln 103-121 - scant detail is provided the data collection methods and the associated uncertainties. Scant detail is also provided on the rules used to remove erroneous data.

Response: Thank you for your comments. We added data collection methods and error data deletion rules (Page 7, Line 133-139).

Discussion - the order of the subsections is not consistent with earlier parts of the draft m/s wherein rainfall factors are introduced/discussed first, followed by vegetation factors. I suggest re-ordering subsections in the Discussion section.

Response: Thank you for your comments. We reordered the subsections of the discussion section, reordering the 4.1 and 4.2 sections (Page 13-16, Line 276-348).

Discussion - ln 227-230 - I do feel that this response is not already well known and existing research should therefore be cited here. The use of citations for previous work is extremely scant throughout the Discussion.

Response: Thank you for your comments. We have added references to previous work and discussed this part of the results in depth (Page 15, Line 315-322).

Discussion - ln 242-249 - again the use of citations is very scant and I do not feel that these results are novel or ground breaking.

Response: Thank you for your comments. According to your suggestion, we added references and discussed this section in more depth (Page 16, Line 335-343).

Discussion - ln 284-286 - again there is much existing international literature already reporting the importance of sediment-associated nutrient loss and yet it is not cited here. This result is not novel or ground breaking.

Response: Thank you for your comments. We added internationally important literature and added discussion of nutrient loss related to sediments (Page 16-17, Line 350-358).

Discussion - ln 309-311 - this is a a simplification - as soil becomes saturated and saturation excess overland flow develops, the impact of raindrops is reduced due to the protective effect of the runoff. As a result, erosion is then driven by alternative processes such as slaking or differential swelling of soil aggregates and is therefore controlled by aggregate stability etc.

Response: Thank you for your comments. According to your suggestion, we use the stability of soil aggregates for the explanation (Page 18, Line381-383).

Dicussion - it is unacceptable for this section to not include a subsection discussing the main limitations of the plot scale work - readers need this type of discussion to help them form a more informed opinion as to the value of the research and the findings.

Response: Thank you for your comments. Based on your suggestion, we had a supplementary discussion on the scale effect of erosion and point out the limitations of the results at the plot scale of this study (Page 18-19, Line 397-401).

Discussion - as this is plot scale work I would also expect to see a subsection discussing the wider implications of the experimental/SEM work - what area do the results potentially relate to in China for example?

Response: Thank you for your comments. We added a subsection to extend this study to provide a basis for decisions on vegetation restoration and soil erosion (Page 19, Line 401-408).

Conclusion - I would expect to see this section point to future research needs.

Response: Thank you for your comments. We added the need for future research (Page 20, Line 426-428).

Graphical abstract - I do not like to see so much test in these. Please edit.

Response: Thank you for your comments. We reduced the content of the graphical abstract.

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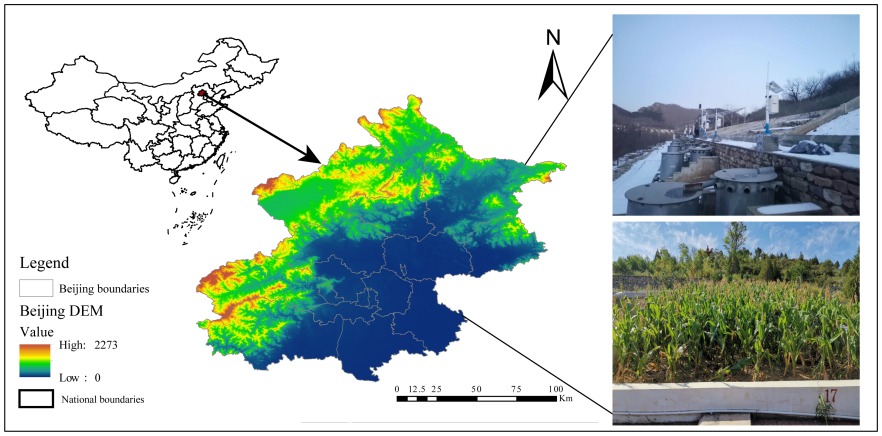

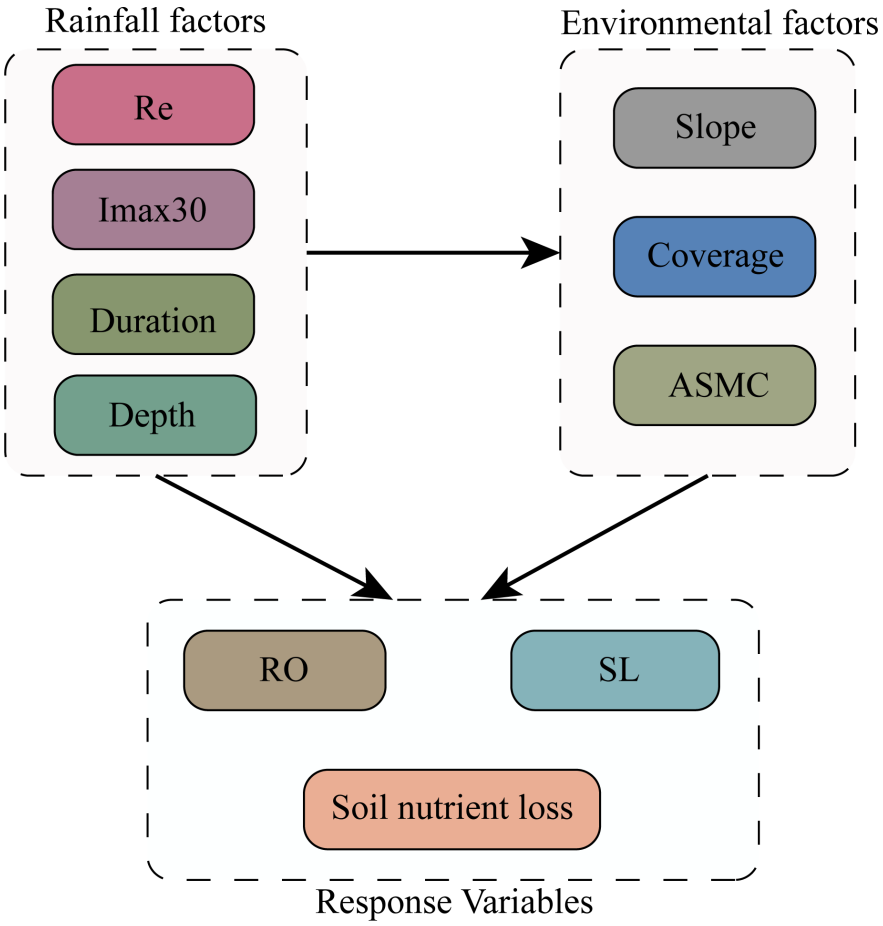

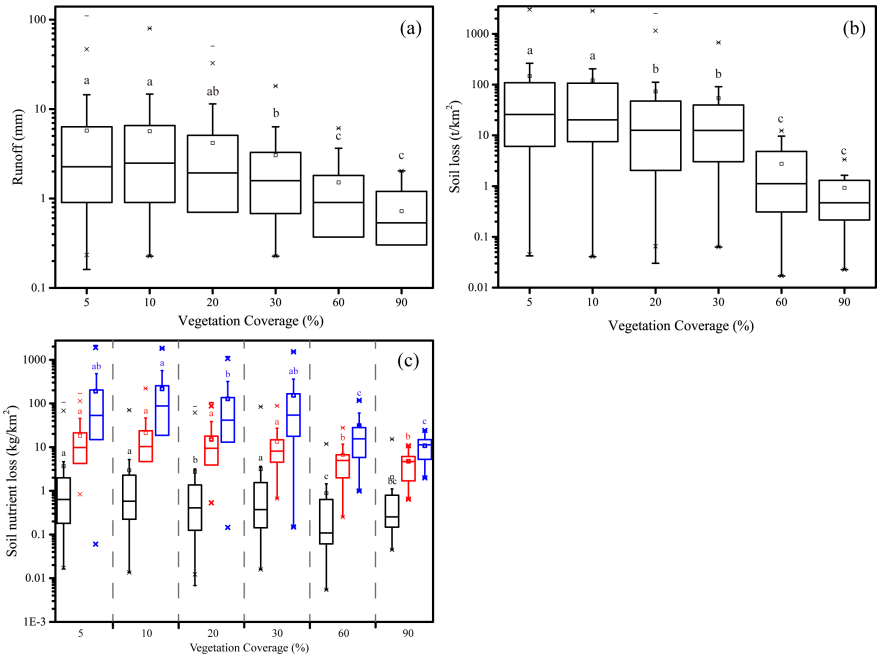

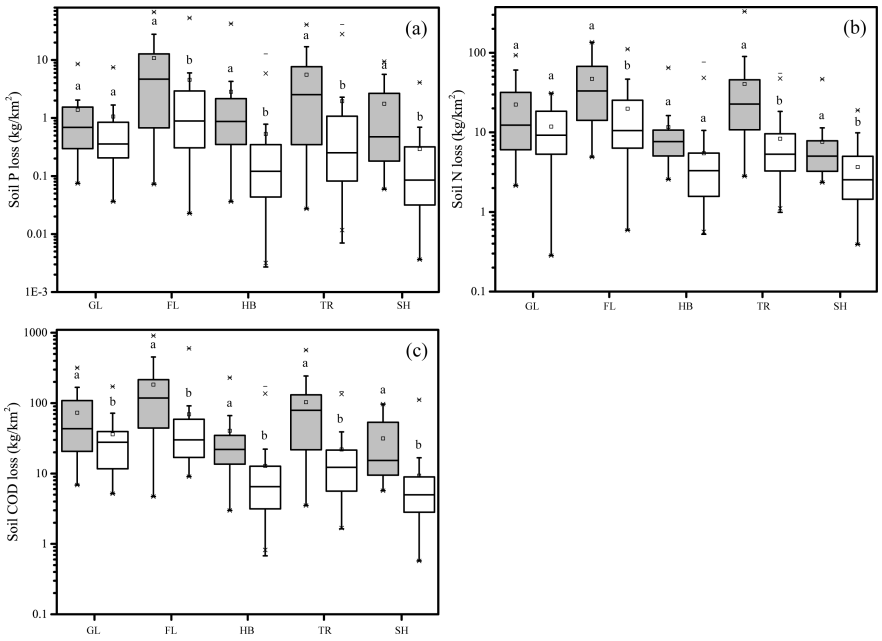

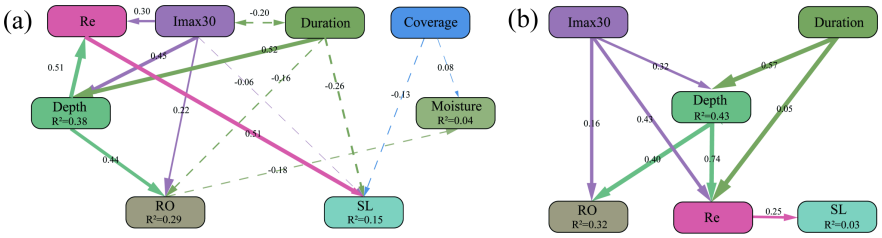

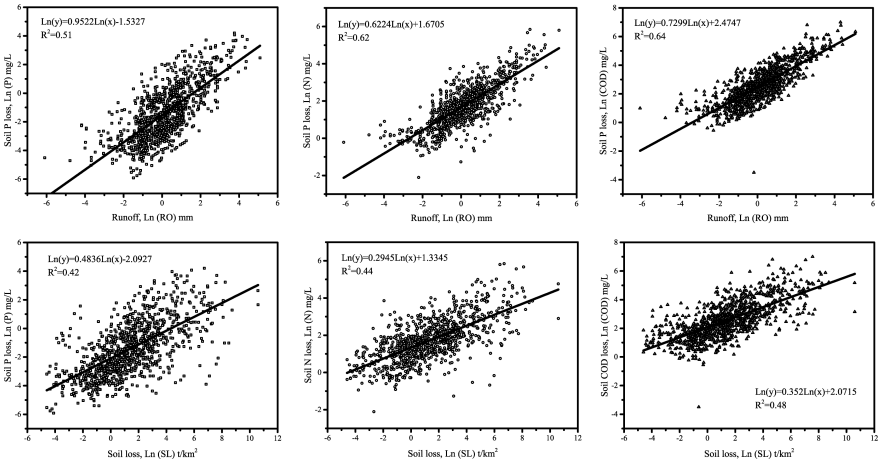

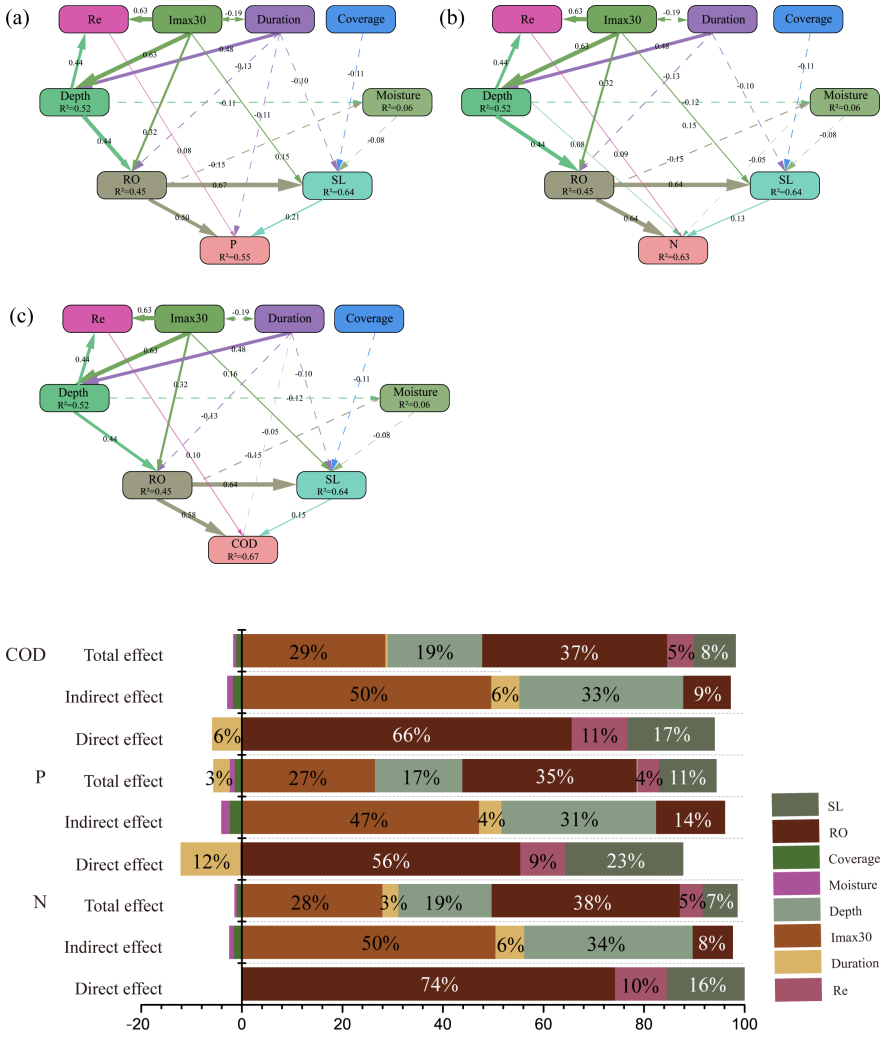

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