Initial response to RC2

Veerle Vanacker (Reviewer 2)'s original text in black with our initial response in blue.

This manuscript describes the results of empirical research on the effectiveness of three different restoration measures in a grassland ecosystem. Given that native grasslands are increasingly subject to degradation, such empirical work can be very relevant for restoration efforts. The strength of this work lies in the collection of empirical data on surface runoff and soil loss rates from 4 runoff plots that were monitored over three years. As there are no replicates, the evaluation of the effectiveness of the treatments is based on a time series of events.

Given a longstanding interest in soil and water conservation measures, and their effectiveness and efficiency, there exists a vast amount of literature on the topic. It includes not only empirical work on e.g. runoff or Wishmeier plots, but also regional synthesis on the effectiveness of conservation measures. This manuscript would be strengthened by embedding it better in the international literature, using e.g. the terminology that was established in soil erosion research, and using standardised methods for measuring the effectiveness of treatments.

Four major points caught my attention, and they might guide the revisions. Besides these points, I have some detailed comments that are listed below.

We thank Professor Veerle for her positive comments and for the critical and constructive suggestions. We believe that the reviewers addressed important points and that these comments allowed us to further clarify and strengthen the manuscript.

1-The methodological aspects need to be better explained to the reader as to avoid confusion. The effect of the measures is quantified through "reduction ratios" of runoff, soil erosion and sediment concentration. Is it not entirely clear why the authors have chosen to focus on the "reduction ratios" rather than the absolute values of runoff quantity, and soil erosion rate? What is the added value of introducing such ratios? What is the difference between the effect on soil erosion, and the effect on the "sediment concentration" if both are quantified based on measurements from the sediment that is eroded from the plots, and captured in the tank? Given that the size of the plots is the same, the

"sediment concentration" measure would be redundant if the "runoff depth" and "soil erosion rate" were given. Can you explain why you keep "concentration" as an indicator?

Runoff reduction ratio, sediment concentration reduction ratio, soil erosion reduction, could directly reflect the efficiencies of the three mixed-cultivated grasslands in maintaining runoff and reducing soil erosion (Zhao et al., 2014; Zhu et al., 2021). The study area is located in a headwater catchment, supplying significant freshwater resources to the Mekong, Yangtze and Yellow rivers. Hence, the primary objective of restoration measures is to effectively maintain runoff while minimizing its concentration. The measurement of sediment concentration serves as a crucial indicator for assessing water conservation practices in the study area.

I can see that the authors want to compare treatments, with the "control" of bare land, but are the experimental plots in a comparable initial state? From the text, one might have the impression that the "control" site is left untouched while the other plots have been prepared for seeding, including ploughing of the site. Ploughing might have a strong impact on the soil physical properties, and change surface roughness, break up soil crusts and enhance infiltration. As such, there is an effect of ploughing and then of the vegetation. If the "control" plot is not ploughed, how do you differentiate between the effect of mechanical ploughing (and breaking up soil crusts) and the effect of vegetation?

Thank you for this valuable comment for further research. Ploughing has a significant effect on the soil physical properties, and changes surface roughness, breaks up soil crusts and enhances infiltration. We employed bare land (in the resubmitted manuscript, “bare land” will be replaced by “severely degraded meadow”), as control to quantify the increase in soil erosion within the mixed-cultivated grassland compared to the control during the initial planting stages. Additionally, we evaluated the effectiveness of the mixed-cultivated grassland in maintaining runoff and reducing soil erosion when it exerted soil consolidation in the unrecovered degraded grasses. We will add this explanation in the revised version of the manuscript.

2-There is some confusion in the text with regard to vegetation restoration as a measure to control water runoff and soil erosion. This can be due to the framing of the research, and the use of terminology. For example, the authors often refer to "control runoff and sediment" but it would be good to have more precise use of the terminology that is commonly used in soil erosion studies. Are

the authors referring to "in-situ runoff" and "soil erosion"? or "sediment mobilisation and lateral transport"? In the methods (L184 and following), the authors also introduce another term to express the soil loss rate, which is the "soil erosion modulus". It is not clear to me why a new term is introduced.

To avoid confusing the reader, we will modify the use of terminology in the resubmitted manuscript, such as “soil erosion” instead of “sediment”, as well as “soil erosion amount” instead of “soil erosion modulus”.

3-The authors describe the soil and water conservation treatments in different ways, which is somehow confusing for the reader. A clear description of the vegetation composition of the alpine grasslands would be helpful, as well as an explanation of the human alterations of these grasslands. What are "artificial grasslands", "mixed artificial grasslands", mixed cultivated grasslands"? What are the differences between them in plant species composition?, How are "artificial grassland restoration" projects (L106) done? In the methods, the experiments are rather well described, but it remains unclear if the grasses that are used in the restoration project are native grasses if they are common/abundant in the region, and if the plant composition (two grass species) is common in the region.

Also, it is necessary to describe the initial state of the plots (see comment above). What are the soil physical properties of the plots before running the experiments? Do you have information on bulk density, soil crusts, and topographic roughness? Are these properties similar between the plots?

Thank you for your valuable suggestions. The words “artificial grassland”, “mixed artificial grassland” and “mixed cultivated grassland” in the manuscript refer to mixed-cultivated grassland. To avoid confusion for the readers, we will revise them uniformly to “mixed-cultivated grassland” in the resubmitted manuscript. The projects of artificial grassland restoration have been carried out in 2019 via mixing grass seeds after plowing on the severely degraded alpine hillside. We will provide a detailed illustration in the resubmitted version of the manuscript.
All four runoff plots are situated on the same hillside at the same elevation. As a result, the topsoil properties in the bare land (in the resubmitted manuscript, “bare land” will revise to “severely

degraded meadow") plots in Table 3 can represent the topsoil properties of the three mixed cultivation meadow plots prior to plowing.

4-In the description of the results, there is a tendency to overstate the results (and the effect of the treatments). The authors have realised an ANOVA analysis (with posthoc comparison->?) to verify if the treatments lead to different runoff or soil erosion rates (or different ratios). As there are no replicate plots/samples, the authors take the response to individual events as their observations. Wouldn't you expect that the response to these events is somehow autocorrelated? Is there a way to deal with this? It also makes the analyses very sensitive to the definition of the events, which makes me wonder how events were defined/delimited in time. This would merit further explanation in the methods, including a discussion of how consecutive events are used as independent observations.

The description of the results was indeed slightly overstated because the differences were not significant, but the three mixed-cultivated grasslands did exhibit a clear reduction in soil loss in 2022 compared to the bare ground (in the resubmitted manuscript, "bare land" will appear as "severely degraded meadow"). We will revise the description of the results from Figs. 2 and 3 in the resubmitted manuscript. In this experiment, precipitation events were determined by the presence of a no-rain period between them longer than 3 h. This will be updated in the resubmitted manuscript.

From Figures 2 and 3, it is clear that the three interventions lead to responses that are often statistically different from the "control" bare land, but that there is rarely a statistical difference between the interventions (they are most of the time all part of the "a" group in Fig 2 and 3). The authors might need to revise the text (section 3.1, and section 3.2) to highlight only significant differences. Also, with regard to the ratios, the text needs to be revised after verifying that the responses are statistically different from 1.

Thank you for noticing this. As a result, we will carefully check the letters in Figures 2 and 3 and modify the expressions of the results in those figures in the resubmitted manuscript. In our opinion, the presence of clear differences, although not significant, also represents a relevant result that gives value to our study.

The path analyses merit to be further explained in the method section. What are the variables that go into the path analyses, and what are the observations? In the results, the authors mention that

"vegetation cover" and "litter biomass" are explanatory factors, but it is not clear to me how the authors compared the information that you collect at event basis with information that is collected at the start/end of the experiments (VC and LB). Also, some variables like the precipitation (P) would be automatically related to the runoff depth for a given treatment. This merits further explanation and development in the text to understand the results of the path analysis presented in section 3.3.

The runoff depth and soil erosion modulus were response variable, and explanatory variable included maximum 60-minute intensity, average rainfall intensity, rainfall duration, rainfall amount, vegetation coverage and litter biomass. Despite some factors having a correlation, the path analysis was unaffected by this. For instance, there is a correlation between rainfall and runoff depth, thus rainfall directly impacts the soil loss (direct path coefficient), but it also indirectly affects the amount of soil loss through runoff depth (indirect path coefficient). To provide the reader with a better understanding of the path analysis results, the path analyses merit and the methods of vegetation cover and plant litter biomass will be added in the resubmitted manuscript.

Detailed comments

L10: check "4" instead of "d"

This should have been “4” and will be updated in the resubmitted manuscript.

L18: Please rephrase "control runoff and sediment (?)". Do you mean sediment transport?

The word "sediment" in the manuscript refers to “soil erosion”. We will modify this sentence in the resubmitted manuscript.

L19: "objectively" is not the correct term. do you suggest that previous work was subjective?

We will erase the word “objectively” in the resubmitted manuscript.

L22: The effectiveness of measures is often scale-dependent. What is the size of the plots?

The runoff plots have a size of 10 m^2, with a width of 2 m and a length of 5 m. We will erase the word “effectiveness” in the resubmitted manuscript.

L25: What do you mean by "conserve water"?

To avoid confusing the reader, the words “conserve water” will revise to “maintain runoff” in the resubmitted manuscript.

L46: Can you rephrase this sentence? Do you mean that the highest population concentrations on earth are found in grassland ecosystems?

We will modify this sentence in the resubmitted manuscript.

L51: Can you check the wording "analyse...root causes, .. impacts and restoration measures of grassland degradation" doesn't read very well.

We will modify this sentence in the resubmitted manuscript.

L58: Efficiency or effectiveness? Please check.

This should have been “effectiveness” and will be updated in the resubmitted manuscript.

L64: Can you clarify this sentence? What do you mean by "enhancement of soil characteristics with the growth of vegetation"? Which soil properties are improved after vegetation restoration?

Vegetation restoration could encourage the formation of soil aggregates, particularly water-stable aggregates, and increases the soil organic matter content via root growth (Liu et al., 2020; Saxton and Rawls, 2006). We will add a description and references on improved soil properties after vegetation restoration.

L73: Please check the wording of this and the following sentence. The terminology is not always used in the correct way. What do you mean by "grasses below-ground"? Or with the "interaction of soil and rich grassroots"?

This is a typo, and the sentence will appear as “Soil erosion can decrease with grasses above- and below-ground biomass and litter cover, as well as root systems” in the resubmitted manuscript. In addition, the reciprocal cementation and interweaving of plant roots improved soil structure by promoting the formation and stability of large aggregates. The words “interaction of soil and rich grassroots” will be replaced by the words “the reciprocal cementation and interweaving of plant roots”.

L83: What is the effect of the roots on the soil mass? Can you be more explicit here?

Plant roots have the effect of loosening the soil, resulting in the increase of soil pores and the decrease of soil bulk density (Gyssels et al., 2005; Wu et al., 2019). We will provide explanation in the resubmitted manuscript.

L87: Can you check the wording? "alpine grasslands" are not a plant type.

Thank you for noticing this. This should have been “alpine meadow” and will be updated in the resubmitted manuscript.

L90: What do you mean by "non-planned human activities"?

We will specify “non-planned human activities” as “overgrazing” in the resubmitted manuscript.

L87-98: Given the overall concern of increased soil loss in the alpine grasslands, can you give some quantitative data on soil loss rates in the area (and compare them with other regions)?

The study area is characterized for the shallowness of the soil layers, stony soils beneath mattic layer and low-intensity rainfalls, which led to a lower runoff depth and soil erosion modulus of alpine grasslands. Soil erosion in the study area was mainly mild (83.83% of the total eroded area), and the average soil erosion rate and the total erosion were 13.63 t ha^{-1} y^{-1} and 323.58 × 10^6 t y^{-1} respectively, before implementation of the program ‘Subsidy and Incentive System for Grassland Conservation’ (Zhao et al., 2021). However, the cold and harsh environment of the Plateau and the slow rate of microbial decomposition have led to weak soil development, slow soil formation and very thin soil layers in the study area, and thus soil erosion must be really controlled. We will add this information to the introduction section in the resubmitted manuscript.

L114: Can you be more specific? What do you mean by "just cold and warm'?

In the study region, the average annual temperature is -0.1°C, with monthly variations from -18.3 °C in January to 12.4 °C in July (Li et al., 2018). We will add specific information in the resubmitted manuscript.

L122: Can you give the species that were used in restoration efforts?

Thank you for your valuable suggestions. The grass species used for grassland restoration projects have excellent characteristics like strong resistance to stress, rich leaf quantity, good palatability, developed rhizome and strong grazing resistance, such as *Poa pratensis L. cv.* Qinghai and *Elymus nutans* (Shang et al., 2018). They are of rhizomatic type, so they can quickly form turf on degraded alpine hillslope, restore vegetation and stabilize soil surface. We will provide the species names that were used in the restoration efforts in the resubmitted manuscript.

L127: Can you be more specific about the meaning of "concentration areas"?

This should have been “confluence areas” and will be updated in the resubmitted manuscript.

L129: alpine climate (?)

The word “climatic” will be replaced with “climate” in the resubmitted manuscript.

L131: Can you reword "blending complementary grass species"?

The words will reword to “matching of grasses morphological characteristics and habits”.

L137: above-ground "biomass"? instead of "plants"

We think the words “grass stems” are more appropriate.

L150-154: Are there any replicate plots?

The runoff plots were not replicated.

L170: In a conventional rain gauge, snow would also fall in the pluviometer. So, did you account/correct for that?

Yes, snow falls were accounted into the rain gauge. It is worth saying that in this study, we only monitored rainfall events during the growing season (rainy season), and no snowfall occurred during that period.

L172: Average intensity of the rain event? or of the 60-minute interval?

Average intensity refers to the average rainfall intensity of each rainfall event.

L178: Can you check the wording: what is "qualitative filter paper"?

Thank you for noticing this. This should have been “quantitative filter paper” and will be updated in the resubmitted manuscript. When referring to “qualitative analysis filter paper”, qualitative analysis filter paper is relative to quantitative analysis filter paper and chromatographic qualitative analysis filter paper. Qualitative filter paper is a kind of paper with good filtering performance, loose texture, and strong liquid absorption capacity. Quantitative filter paper is mainly used for ashing and gravimetric analysis experiments after filtration. That is gravimetric analysis tests and corresponding analysis tests in quantitative chemical analysis.

L178-179: There is some inconsistency here: either air-dried or dried at 105°C. Please check.

This should have been “oven-dried” and will be updated in the resubmitted manuscript.

L197: Please check the wording.

Soil shear strength was tested using a direct shear (ZJ type). Then, soil cohesion was calculated from the equation of the Mohr-Coulomb line of the soil model. The sentence will be revised to “The soil cohesion was calculated from the equation of the Mohr-Coulomb line based on direct shear test”.

L217: Not entirely clear how this is conceived with 4 plots.

One plot with severely degraded meadow as a control and three plots with mixed-cultivated grasslands, namely *Deschampsia cespitosa* and *Elymus nutans* (*DE*), *Poa pratensis L.cv.* Qinghai and *Elymus nutans* (*PE*), and *Poa pratensis L.cv.* Qinghai and *Deschampsia cespitosa* (*PD*) (Fig. 1). We employed severely degraded meadow as a control to quantify the increase in soil erosion within the mixed-cultivated grassland compared to the control during the initial planting stages. Additionally, we evaluated the effectiveness of mixed-cultivated grassland in maintaining runoff and reducing soil erosion when it exerted soil consolidation compared to the unrecovered degraded meadow. We will add this explanation to the revised version of the manuscript.

L223: Based on the observations, you cannot conclude that the vegetation restoration increased runoff. In fact, you compare 4 plots with different vegetation cover and different levels of soil roughness and sealing. To conclude that the vegetation restoration has increased the runoff, you would need to do a before/during/after evaluation of the effectiveness of the treatment.

Maybe a misunderstanding existed. All four runoff plots are located on the same hillside at the same elevation and soil texture. The interval between plots is 1 m. Observations of severely degraded grassland were comparable to those made prior to treatment; those obtained in 2019 and 2020 of mixed-cultivated grassland were comparable to those made during the treatment; and those obtained in 2022 of the mixed-cultivated grassland were comparable to those made following the treatment. To avoid confusing the reader, we will add an illustration in section 2.2.

L222 and following: This conclusion "grass communities dramatically influence runoff" is not fully supported. There is a difference between the runoff depth between the bare land and the restoration plots, in 4 out of 6 cases. No difference between the other treatments.

“Grass communities dramatically influenced” should have been “Mixed-cultivated grasslands dramatically increased” and will be updated in the resubmitted manuscript.

L238: Can you revise the wording of this sentence? What do you mean by "surface water conservation"?

To avoid confusing the reader, the words “surface water conservation” should have been revised to “maintaining runoff”.

L237-252: Based on the equations provided, the effectiveness is measured using ratios but in the text, the author refers to %. Please check for consistency.

We will modify the formulas (4)-(6) in the resubmitted manuscript.

L280 and the following: What do you mean by "soil erosion modulus"?

We will replace “soil erosion modulus” with “soil erosion amount”.

Section 4.3: The last section of the discussion deals with the "implications of grassland restoration", and discusses differences in surface runoff and soil loss between different treatments. Are the differences significant?

The differences in surface runoff and soil loss between the three mixed-cultivated grasslands were not significant. Hence, we will modify the expression related to this in the resubmitted manuscript.

L356-359: Is this what you observe in your results when you compare the "treated" plots with the "control" plots?

Based on the measured data during the 2019, 2020 and 2022 growing seasons, the planting of mixed-cultivated grassland on severely degraded hillside alpine meadow could effectively maintain surface water and decrease soil loss, especially because the mixed-cultivated grassland played a positive role in consolidating the surface soil. We will modify the text in the resubmitted manuscript.

Figure1: Nice figure especially the pictures on the runoff plots. Is it possible to show the scalebar on all maps, and give some reference on the spatial scale of the pictures?

We will add the size of the runoff plots on Figure 1 in the resubmitted manuscript.

Figure 3: The reduction ratios are mentioned as fractions in the method sections, which should be the case for a "fraction", but they are then displayed as % in Figure 3. Please check.

Thank you for noticing this. We will modify the formulas (4)-(6) in the method sections in the resubmitted manuscript.

Tables 1 &2: Some background info on the path analysis would be welcome. You could add a few sentences in the methods to explain the background of this stat analysis.

Path analysis is a form of multiple regression statistical analysis that is used to evaluate causal models by examining the relationships between a dependent variable and two or more independent variables. By using this method, one can estimate both the magnitude and significance of causal connections between variables. In this study, the path analysis method was utilized to determine the main factors influencing runoff and soil erosion. We will add the background information and merit of path analysis in the resubmitted manuscript.

References

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