Initial response to RC1

Corinna Gall (Reviewer 1)'s original text in black with our initial response in blue.

In this study, surface runoff and soil erosion are measured for three different combinations of grass species and a bare soil control sample in degraded alpine hillsides on the Qinghai-Tibetan Plateau, using runoff plots under natural rainfall. The goal is to find a grass mixture for grassland restoration that is best adapted to the needs of the ecosystem. This is a very important approach to grassland restoration that has not been sufficiently studied. Therefore, I consider this study worth publishing within the scope of HESS, however, it needs to be considerably revised in terms of comprehensibility.

Unfortunately, it is difficult to follow the structure in the introduction and in some parts to understand the reasoning in the discussion. In the introduction, it is challenging to find a common thread. In general, the introduction needs to be modified in order to lead the reader specifically to the goal or hypotheses of the study. I propose to explain the problems regarding surface runoff and soil erosion in this alpine grassland ecosystem in more detail at the beginning before pointing out the specific research gaps. Also, it would be good to end the introduction with hypotheses that you will Response throughout the manuscript. In the discussion, it is not always clear how the conclusions are reached. Some statements are too strong on the basis of the data presented and should be considered in a more differentiated way.

Additionally, I have the following comments and questions for the authors to consider:

We thank Corinna Gall for the positive words about our manuscript and constructive feedback and suggestions that will help refine our paper.

Abstract

Line 19: Please rephrase "effectiveness of the effects".

This should have been "the effects" and will be updated in the resubmitted manuscript.

Lines 21-22: Are you sure the size is still micro-runoff plots?

This should have been "runoff plots" and will be updated in the resubmitted manuscript.

Lines 21-24: If you measured surface runoff and soil loss, what can you say about the regional water availability mentioned above? It seems to me here that the representation of the knowledge gap and the research objective do not fit together properly.

Vegetation restoration is probably not always positive for the sustainability of hydrological effects, such as soil water conditions, runoff and evapotranspiration, and in some cases due to the excessive water comsupmtion by plants that lead to soil drying in some soil layers. The Qinghai-Tibetan Plateau is the headwater for many of Asia's major rivers. Hence, it is necessary to evaluate whether vegetation restoration maintains or undercuts the gains of downstream water resources. To avoid confusing the reader, we have revised the sentence as follows: "Nevertheless, few studies have been undertaken to analyze the effects of plant restoration on maintaining the stability of the hydrological cycle, especially, in alpine degraded hillsides where mixed-cultivated grasslands predominate in the landscape."

Line 25: What is meant here by "conserve water"?

This should have been "maintain runoff" and will be updated in the resubmitted manuscript.

Lines 30-35: There are too much values for the abstract section. Maybe only list significant changes.

We will only list significant changes in the Abstract.

Introduction

Line 58: What do you mean with "maintaining runoff" here? Wouldn't it be desirable to reduce runoff and promote water retention in the soil?

Thank you for your valuable suggestion. "Maintaining runoff" in this study refers to a relatively lower runoff reduction effect. Large-scale vegetation restoration generally reduces the local runoff coefficient (ratio between the amount of runoff to the amount of rainfall depth), which is not conducive to the health of river ecosystems, especially in arid and semi-arid regions.

Line 59: I recommend "considered" instead of "viewed".

The word "viewed" will be replaced by "considered" in the resubmitted manuscript.

Line 61: I recommend "plant species" instead of "plant types".

The word “plant types” will be replaced by “plant species” in the resubmitted manuscript.

Line 68: This reference deals with tree restoration. Does this statement also apply to grasslands? Please provide a reference.

Thank you for this observation. We will erase the tree restoration reference and add more specific references for grassland restoration like Huang et al. (2017; 2019).

Line 70: Please change to “Grass communities … are …”.

We will rephrase this sentence in the resubmission as follows: “Grasses communities with multiple stratified structures are better at maintaining surface water and decreasing soil loss than that with a single composition and structure (Mohammad and Adam, 2010).”

Lines 70-72: What do you mean with “conserve water” in this context? Maybe use “retain” instead?

The word “conserve water” will be replaced by “maintain surface water” in the resubmitted manuscript.

Line 73: Please rephrase “biomass grasses plant and litter cover”.

This should have been “grasses above- and below-ground biomass and litter cover” and the text will be updated in the resubmitted manuscript.

Lines 74-78: This sentence is difficult to understand. Please consider rephrasing.

We will rephrase this sentence as follows: “Grasslands can control water erosion relying on the role of the aboveground biomass in dissipating flow energy (Bochet and García-Fayos, 2004), living roots in decreasing soil detachment capacity (Zhang et al., 2013), grass plant cover in intercepting rainfall (Liu et al., 2019), and litter cover in enhancing rainwater infiltration (Liu et al., 2022).”

Line 83: Please specify “changing” here.

The word “changing” will be replaced by “decreasing” in the resubmitted manuscript.

Lines 84-86: A dense root system is more effective than what? Please clarify.

The sentence will appear rewritten as follows: “For example, numerous recent studies have confirmed that a grass with shallow yet dense fibrous root system appears to be more effective at controlling

water erosion than a grass with good ground cover but low root density (Liu et al., 2022; De Baets et al., 2007; Bochet et al., 2006)."

Line 87: I would suggest referring to alpine grassland as an ecosystem or landscape unit rather than a plant type.

The words "plant type" will be replaced by "ecosystem".

Lines 94-96: This sentence explains my question in Line 58. This explanation must be given earlier.

Precipitation is the main water source in semi-arid areas and the conversion of precipitation to runoff is influenced by vegetation restoration, which in turn influences river flow recharge. To avoid misleading the reader, this information will be inserted before line 58 of the introduction section in the resubmitted manuscript.

Methods

Line 110: It is unclear what the term "representative area" refers to.

Zhique Village is the model area to study the artificial restoration of the severely degraded meadows (https://www.sohu.com/a/489177164_362042). The term "representative area" will be replaced by "model area" in the resubmitted manuscript.

Line 112: What means "Three Rivers" here? Is it a landscape unit or a district?

The study area is the headwater for many of Asia's major rivers, including Yangtze, Yellow and Lancang River in China. Therefore, the study area is also known as the Three Rivers Source in China. To avoid misleading the reader, we have erased the words "in the Three Rivers"in the resubmitted manuscript.

Lines 113-118: Please be more specific here. Perhaps provide additional averages for temperature and precipitation per season to illustrate the differences between warm and cold seasons.

We will add the following specific information in the resubmitted manuscripts: "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). The average annual precipitation is 416 mm, with the majority of it falling from July to September."

Line 129: Please use “climate” instead of “climatic”.

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

Lines 129-130: I would suggest to change the wording to “…have complementary morphological characteristics and habits”.

The wording will change to “have complementary morphological characteristics and habits” in the resubmitted manuscript.

Line 149: Figure 1 shows that the control plot is not completely bare, but is degraded grassland. Please mention this in the text as well.

Thank you for this comment. We will carefully checke the whole text and replace the expression “bare land” by “severely degraded meadows” in the resubmitted manuscript.

Line 154: Please use “runoff plot” instead of “runoff area”.

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

Lines 93 +113 + 152 + 157: Please make clear which part of Figure 1 you are referring to (a, b, c, or d).

Thank you for noticing this. We will indicate this in the resubmitted manuscript.

Line 169: Does this mean that all precipitation events outside the growing season were snow and therefore measurements were only taken during the growing season? How did you deal with melt water erosion in the time between the growing seasons?

There are only two distinct seasons in the study area —cold and warm— due to its high altitude (average elevation of 4000 m above sea level). Hence, solid precipitation is mainly distributed in the cold season, whereas rainfall (85.2% of the annual precipitation) is distributed in the warm season (i.e., plant-growing season, which ranges from May to September) (Shi et al., 2020; Ren et al., 2010; Zheng et al., 2022). Meltwater erosion is an important type of soil erosion in the Qinghai-Tibet region, which is very serious from March to May due to the soil freeze-thaw effect and low vegetation cover (Zheng et al., 2022; Shi et al., 2020). Our experiment were conducted during the peak growing season, and little snowmelt erosion occurred in the study area during this period. Additionally, spring

meltwater is one of the major drivers of soil erosion in alpine meadows, and further studies of meltwater erosion will be conducted in the future.

Lines 174-175: How did you ensure that the water and sediment in the tank were evenly mixed in order to collect two representative 500-ml samples?

To ensure that the water and sediment were uniformly mixed in the tank, we thoroughly swirled with a stirring bar.

Lines 178-179: I think there is an incorrect description of the drying of the sediment here. Air drying to a constant weight at 105°C does not fit together.

This is a typo, and the word “air-dried” will be replaced by “oven-dried” in the resubmitted manuscript.

Line 184-188: In my opinion, scaling to km² is not appropriate for such small runoff plots. I would recommend expressing soil erosion in kg / g m^{-2}. Moreover, it is confusing to extrapolate only soil erosion and not surface runoff within the same sample.

Thank you for your valuable suggestion. After each rainfall-runoff event, both runoff and sediment were collected right away. The water level in the calibrated tank was first measured to calculate the runoff volume. Then, runoff was fully mixed inside the calibrated tank using a stirring bar to thoroughly whirl, and two 500 ml bottles were used to obtain mixture samples of sediment and runoff. We will expresse soil erosion in g m^{-2} in the resubmitted manuscript.

Lines 191-193: It is not clear how and when vegetation cover and plant litter biomass were obtained. Was the vegetation coverage estimated for August 2022 only or after each rainfall event? What do you mean by "collection techniques" in the context of plant litter biomass? Was the plant litter biomass determined randomly in the 50x50cm frames or for the entire plot? Please specify and provide references for your methods.

Vegetation cover (VC) was measured monthly from 2019 to 2022 growing seasons using a steel wire frame (50 cm × 50 cm) subdivided into 25 plots of 10 cm × 10 cm. After collecting runoff samples each year, the quadrats (50 cm × 50 cm) were positioned in the up., -, mid-, and down-slope areas in

late August 2022. Litter in each quadrant was collected and oven-dried to determine litter biomass (LB) (Zhu et al., 2021). This information will be added in the methods in the resubmitted manuscript.

Line 202: Please provide the primary source for these indices. They were also used in Zhao et al. 2014. The dynamic effects of pastures and crop on runoff and sediments reduction at loess slopes under simulated rainfall conditions.

The primary source for the indices (RRE, SRE, CRE and $RRSR$) will be added in the resubmitted manuscript.

Lines 207-210: Be sure to use a consistent spelling of "mixed cultivated grassland". Sometimes you use it with a dash, sometimes without.

We have carefully checked the whole paper, and will replace “mixed cultivated grassland” by “mixed-cultivated grassland” in the resubmitted manuscript.

Line 215: I suggest the expression “to test for significant differences between”.

This will be updated in the resubmitted manuscript.

Figure 1: Please use your abbreviations for the treatments also in Figure 1. The runoff plots appear a bit distorted and of different sizes in the illustration, perhaps a simple top view would be more appropriate here. Please check the spelling and punctuation in the figure caption again (line 541-546).

Thank you for these recommendations. All treatment descriptions will be abbreviated and explained in the figure caption, and the illustration in Figure 1 has also been replaced with a top view. We will update Fig. 1 to reflect this change in the resubmitted manuscript.

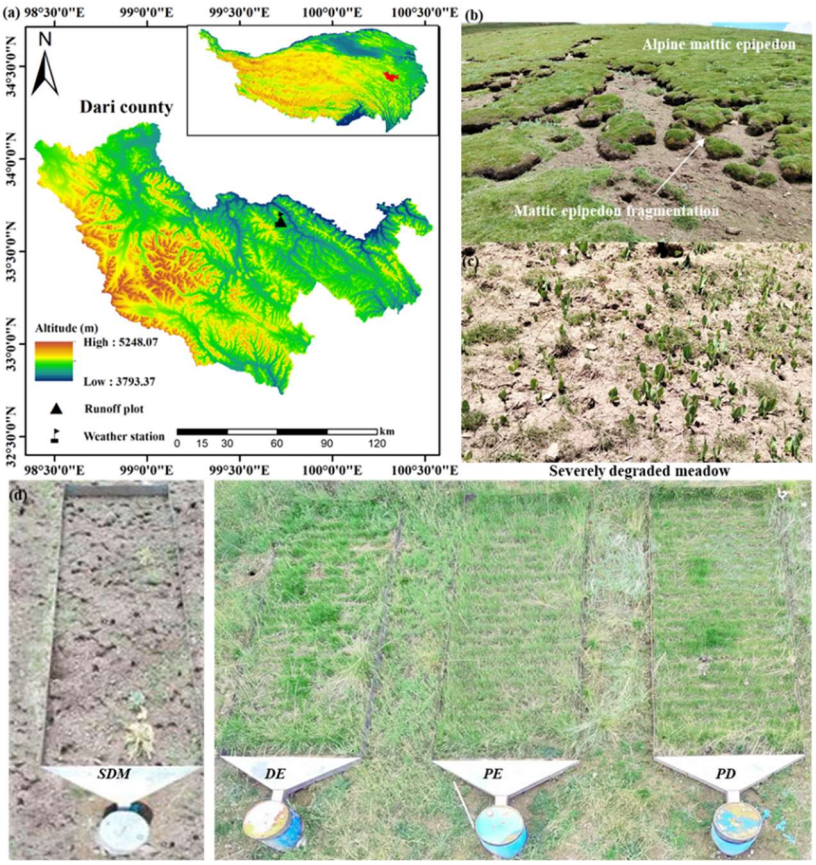

Figure 1. Location of the study area on the Qinghai-Tibetan Plateau, and location of the runoff plots in the study area (a). The fragmenting mattic epipedom on the alpine hillslope (b) and the severely degraded meadows formed by the disappearance of mattic eppipedom (c). Runoff plots of severely degraded meadows (SEM) and mixed-cultivated grasslands (d). A typical severely degraded meadows with a slope of 20° was selected to plant mixed grasses. Runoff plots were photographed with a drone in the early stages of the 2022 growing season. DE, *Deschampsia cespitosa* and *Elymus nutans*; PE, *Poa pratensis L.cv.* Qinghai and *Elymus nutans*; and PD, *Poa pratensis L.cv.* Qinghai and *Deschampsia cespitosa*.

Results

Line 225: Please be consistent with the designation of your treatments. Usually you have used the term "bare land" or the abbreviation "BL".

As control plots were not completely bare, but rather severely degraded meadows, we will replace the expression “bare land” by “severely degraded meadow”, and abbreviation will be “*SDM*” in the resubmitted manuscript.

Lines 221-234: It would be very valuable here to additionally provide a diagram with the values of vegetation cover per year and plot. Especially, it would be good to know the vegetation cover of the bare land treatment, as it was not completely bare. In addition, information is needed on how you managed the bare land treatment during the three-year experiment. If there were no human impacts as described in the methods, surely the vegetation cover on the bare land was lower in 2019 than in 2022?

Vegetation cover (VC) was measured monthly from 2019 to 2022 during the growing seasons using a steel wire frame (50 cm × 50 cm) subdivided into 25 plots of 10 cm × 10 cm. The cover of bare land (in the resubmitted manuscript, "bare land" will be replaced by "severely degraded meadow") has not changed significantly, and the bare land plots in Figure 1 of the manuscript were captured in 2022. We will provide a diagram with the values of vegetation cover per year in the the resubmitted manuscript.

Figure 2 and 3: In general, the illustrations are a bit overloaded with information. Therefore, I suggest to remove the jitter points and instead indicate the number of measurements per year, which should be the same for all treatments. Furthermore, I would remove the written mean values because they are already mentioned in the text. It would also be a good idea to choose different colours for your treatments, as they are indistinguishable to readers with colour vision deficiencies. Please also explain your boxplots in more detail in the figure caption, e.g., the line inside boxplots sometimes refers to median, sometimes to mean values, which is not explained here.

We will delete the jitter points, illustrate the number of measurements per year, erase the written mean values, and choose different colours for the different treatments in Figures 2 and 3.

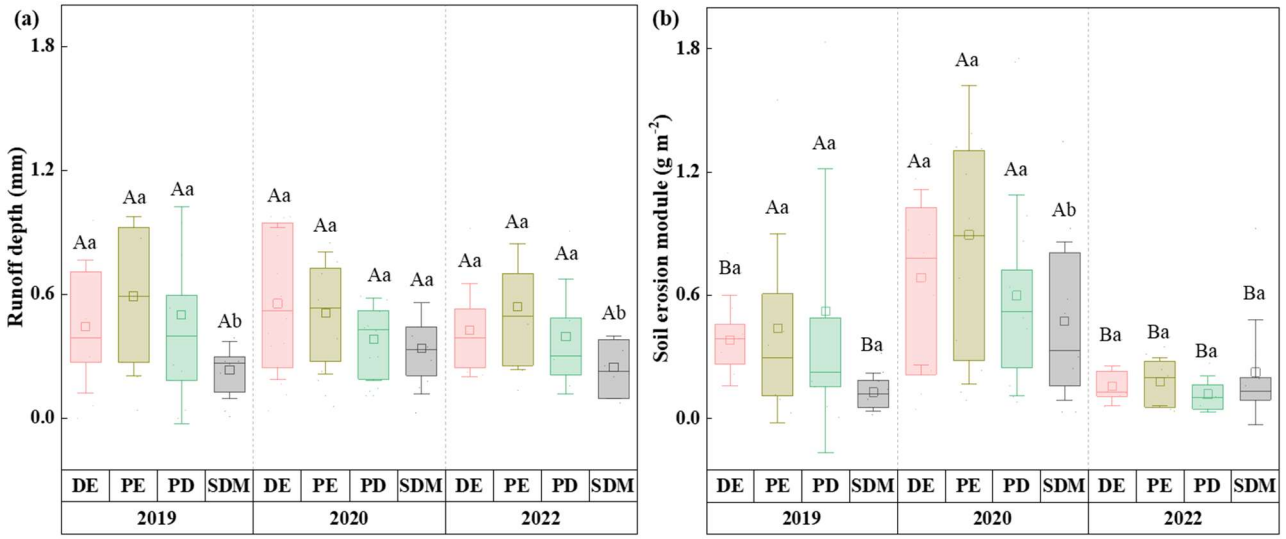

Figure 2. Changes in soil erosion and runoff under various mixed-cultivated grasslands from 2019 to 2022. (a) Runoff depth and (b) soil erosion module. Note: For the four treatment runoff plots, runoff and sediment were measured 14, 18, and 10 times, respectively, during the growing season of 2019, 2020, and 2022. Different capital letters mean that differences were significant in different years for the same grassland community, and different lowercase letters mean that differences were significant between different communities in the same year. *SDM*, severely degraded meadows, *DE*, *Deschampsia cespitosa* and *Elymus nutans*; *PE*, *Poa pratensis L.cv.* Qinghai and *Elymus nutans*; and *PD*, *Poa pratensis L.cv.* Qinghai and *Deschampsia cespitosa*. The lines in the middle of the box represent the median values. The squares in the box represent the average value.

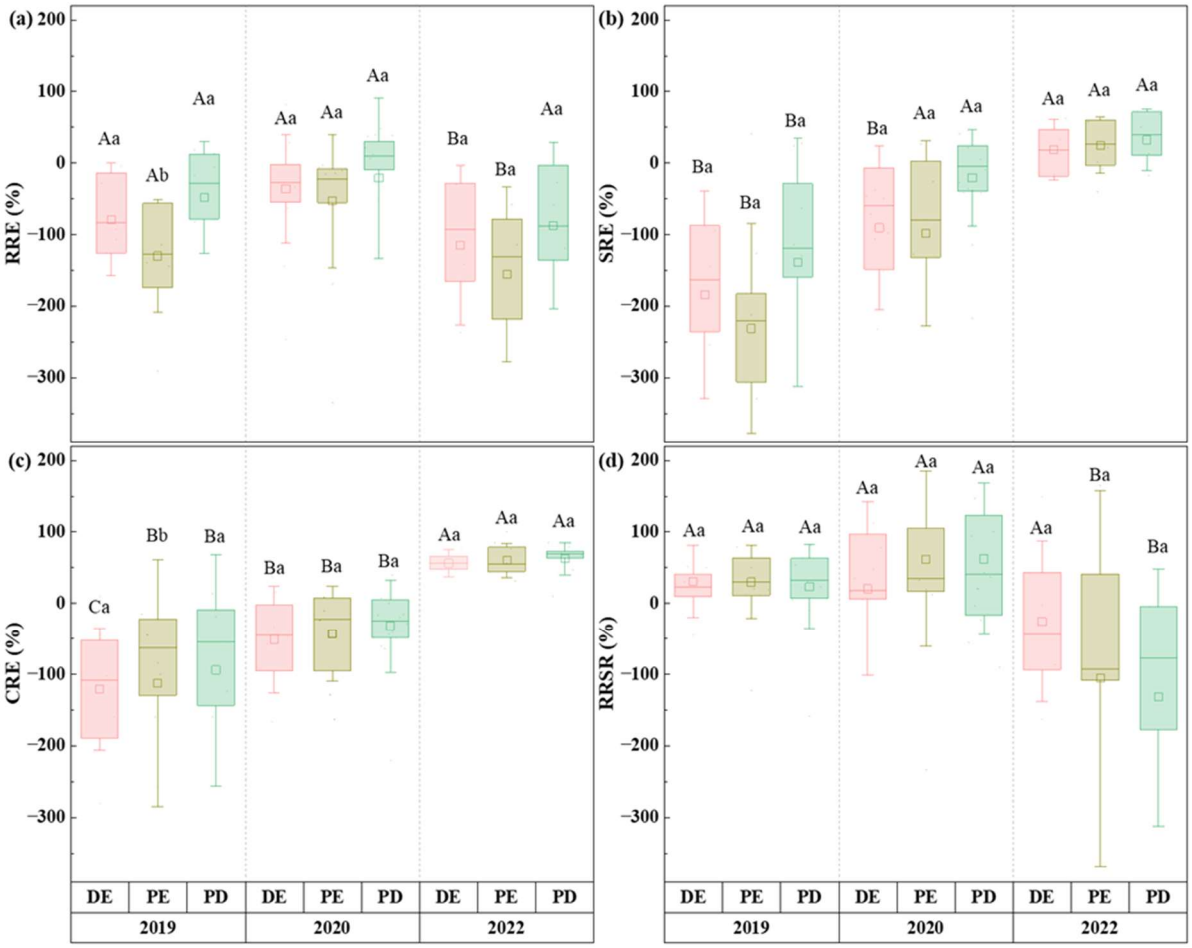

Figure 3. Runoff, soil loss and sediment concentration reduction ratio under different mixed-cultivated grasslands from 2019 to 2022. (a) Runoff reduction ratio (*RRE*), (b) soil loss reduction ratio (*SRE*), (c) sediment concentration reduction ratio (*CRE*) and (d) the percent of runoff reduction ratio to soil loss reduction ratio (*RRSR*). Note: Different capital letters mean that differences were significant in different years for the same grassland community, and different lowercase letters mean that differences were significant between different communities in the same year.

Figure 3: Please change the y-axis label of part (d) to “RRSR”.

We will replace the y-axis label of part (d) “RRSE” by “RRSR” in the resubmitted manuscript.

Lines 232-234: Please explain how you came to this conclusion based on the results.

We will rewrite the sentence as follows: “The results showed that three mixed-cultivated grasslands (*DE*, *PE*, and *PD*) could be effective in controlling soil loss and maintaining runoff.”

Lines 244-245: This sentence rather belongs to the discussion section.

We will erase this sentence in the resubmitted manuscript.

Line 247: Space is missing between “were” and “PD”.

This will be corrected in the resubmitted manuscript.

Lines 251-252: This was only the case in 2022. From 2019 to 2020 the RRSR was higher than 1, is this right?

I am sorry maybe a misunderstanding exists. As shown in Fig. 3d, the mean *RRSR* values of the cultivated-grassland communities *DE*, *PE*, and *PD* were 30.3%, 29.5% and 22.8% in 2019, 20.0% 61.6%, and 62.0% in 2020, -26.0% -105.7%, and -132.2%, respectively.

Lines 254-264: Instead of listing all the values of the path analysis, it would be more comprehensible to list only the values of the most important parameters.

Thank you for your valuable suggestion. To be more understandable to the reader, we will only list the values of the most important parameters in the resubmitted manuscript.

Table 1: Please include the explanation of “*” in Table 1 instead of Table 2.

We will add the explanation of “*” in Table 1 and erase its explanation in Table 2 in the resubmitted manuscript.

Table 1 and 2: Sometimes the description of parameters in the caption is not clear, e.g., “ARI is average intensity” should be average rainfall intensity. Please check and clarify.

We have checked the whole paper and the words “average intensity” will be replaced by “average rainfall intensity” in the resubmitted manuscript.

Line 265: Please change to “with R being the most relevant”.

This will be updated in the resubmitted manuscript.

Line 271: In Table 2 the indirect path coefficient of LB is -0.02, in the text it is -0.03. Please check again.

We have carefully checked the data processing and will correct the data in Table 2 and list the values of the relatively important parameters in the resubmitted manuscript.

Discussion

Lines 275-276: What do you mean by "conserve water"? Perhaps retaining or storing water? Also, it is not clear to me how you conclude that soil loss was minimized, since soil erosion on bare land was lower than on grassland in 2019 and 2020 after all, and in 2022 the difference was not significant (Figure 2b).

The word “conserve water” will be replaced by “maintain runoff”. The sediment concentration reduction ratio (CRE) and soil erosion reduction ratio (SRE), which reflected reductions in soil loss, continue to increase from 2019 to 2022. These results supported our conclusions.

Lines 291-293: Are these percentages based on the average values from Table 3? If this is the case, I assume, the percentages are not correct.

Maybe there has been a misunderstanding. We have carefully checked the data processing and did not find mistakes. Yes, the increase rate of root mass density and soil cohesion was obtained based on the average values from Table 3. Increase rate = (V_{MCG}-V_{SDM})/V_{SDM}), where V_{SDM} and V_{ACG} are the mean values of root mass density and soil cohesion of three mixed-cultivated grasslands (*DE*, *PE*, and *PD*) and severely degraded meadow (*SDM*), respectively.

Lines 301-302: I do not really understand what is meant by this sentence.

We will revise the sentence in the resubmitted manuscript as follows: “Surface runoff and erosion process is influenced and constrained by rainfall depth, intensity and duration, and by vegetation cover as well (Mohamadi and Kavian, 2015b; Bochet et al., 2006).”

Line 321: Please correct the spelling of Poa pratensis here and in the whole paragraph.

This should have been “*Poapratensis*” to “*Poa pratensis*” and will be corrected in the resubmitted manuscript.

Lines 322-323: It is unclear to me how you come to this conclusion, since there were no significant differences between the grass mixtures.

Thank you for this comment. We will revise the too strong statement as follows: “When the mixed-cultivated grasslands could act as a consolidation effect on the surface soil (the 4th year of planting after tilling), the community of *PD* (0.12 g m^{-2}) was probably more effective than the communities of *PE* (0.18 g m^{-2}) and *DE* (0.16 g m^{-2}) in reducing soil loss (Fig. 3), which could likely be due to two

reasons."

Lines 348-352: This part rather belongs to the introduction section to underline the importance of this study.

We will erase this part in the discussion section in the resubmitted manuscript.

Line 353-354: I suggest deleting the term "Overland flow turbidity" here, as this is the first time it has been used and it is confusing when new terms are introduced at the end of the discussion.

The term "Overland flow turbidity" will be deleted in the resubmitted manuscript.

Conclusions

Lines 356-359 + 361-364: These are too strong statements for the data you presented in your manuscript.

We will revise the too strong statement as follows: "Based on the measured data during the 2019, 2020 and 2022 growing seasons, the planting of mixed-cultivated grassland on the 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."

References:

Bochet, E., and García-Fayos, P.: Factors controlling vegetation establishment and water erosion on motorway slopes in Valencia, Spain, Restor. Ecol., 12(2), 166–174, https://doi.org/10.1111/j.1061-2971.2004.0325.x, 2004.

Bochet, E., Poesen, J., and Rubio, J.L.: Runoff and soil loss under individual plants of a semi-arid Mediterranean shrubland: influence of plant morphology and rainfall intensity. Earth Surf. Proc. Land 31, 536–549, https://doi.org/10.1002/esp.1351, 2006.

De Baets, S., Poesen, J., Knapen, A., Barberá, G.G., and Navarro, J.A.: Root characteristics of representative Mediterranean plant species and their erosion-reducing potential during concentrated runoff, Plant Soil, 294(1–2), 169–183, https://doi.org/10.1007/s11104-007-9244-2, 2007.

Huang, Z., Liu, Y.F., Cui, Z., Liu, Y., Wang, D., Tian, F.P., and Wu, G.L.: Natural grasslands maintain soil water sustainability better than planted grasslands in arid areas. Agr. Ecosyst. Environ., 286(1), 106683, https://doi.org/10.1016/j.agee.2019.106683, 2019.

Huang, Z., Tian, F.P., Wu, G.L., Liu, Y., and Dang, Z.Q.: Legume grasslands promote precipitation infiltration better than gramineous grasslands in arid regions, Land Degrad. Dev., 28(1), 309–316, https://doi.org/10.1002/ldr.2635, 2017.

Li, W., Wang, J.L., Zhang, X.J., Shangli, S., and Wenxia, C.: Effect of degradation and rebuilding of artificial grasslands on soil respiration and carbon and nitrogen pools on an alpine meadow of the Qinghai-Tibetan Plateau, Ecol. Eng., 111, 134–142, https://doi.org/10.1016/j.ecoleng.2017.10.013, 2018.

Liu, Y., Zhao, L.R., Liu, Y.F., Huang, Z., Shi, J.J., Wang, Y.L., Ma, Y.S., Lucas-Borja, M.E., L´opez-Vicente, M., and Wu, G.L.: Restoration of a hillslope grassland with an ecological grass species (*Elymus tangutorum*) favors rainfall interception and water infiltration and reduces soil loss on the Qinghai-Tibetan Plateau, Catena, 219, 106632, https://doi.org/10.1016/j.catena.2022.106632, 2022.

Liu, Y.F., Liu, Y., Wu, G.L., and Shi, Z.H.: Runoff maintenance and sediment reduction of different grasslands based on simulated rainfall experiments., J. Hydrol., 572, 329–335, https://doi.org/10.1016/j.jhydrol.2019.03.008, 2019.

Ren, F., Zhou, H.K., Zhao, X.Q., Han, F., Shi, L.N., Duan, J.C., and Zhao, J.Z.: Influence of simulated warming using OTC on physiological–biochemical characteristics of Elymus nutans in alpine meadow on Qinghai-Tibetan plateau, Acta Ecol. Sinica, 30(3), 166–171, https://doi.org/10.1016/j.chnaes.2010.04.007, 2010.

Shi, X.N., Zhang, F., Wang, L., Jagirani, M.D., Zeng, C., Xiao, X., Wang G.X.: Experimental study on the effects of multiple factors on spring meltwater erosion on an alpine meadow slope. International Soil and Water Conservation Research, 8(2): 116-123. https://doi.org/10.1016/j.iswcr.2020.02.001, 2020.

Zhang, G.H., Tang, K.M., Ren, Z.P., and Zhang, X.C.: Impact of grass root mass density on soil detachment capacity by concentrated flow on steep slopes, T. ASABE, (56), 927–934, 2013.

Zheng, Y., Shi, X. N., Zhang, F., Lei, T. W., Zeng, C., Xiao, X., Wang, L., and Wang, G. X.: Field experimental study on the effect of thawed depth of frozen alpine meadow soil on rill erosion

by snowmelt waterflow. *International Soil and Water Conservation Research*, in press. https://doi.org/10.1016/j.iswcr.2022.12.001, 2022.