

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. The experimental site has been the subject of previous publications (Niu et al., 2022; Liu et al, 2019; 2022) that focused on soil mitigation by vegetation restoration.

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

Response: We thank Professor Veerle for her positive comments and 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 abstract is informative but contains very specific terms that are not commonly used in hydrology or soil sciences. As such, it is hard to understand the main findings based on the abstract alone. This could be addressed by using standard hydrology or soil science terms in the abstract, or by defining clearly new terms like 'mixed-cultivated grasslands', 'runoff reduction ratio' and 'mean sediment concentration reduction ratio'.

Response: Thank you for your valuable suggestion. To avoid confusing the reader, we have explained the term “mixed-cultivated grasslands” in the abstract section, as shown in lines 23–25: “each sowing two grass species per plot (*Deschampsia cespitosa* and *Elymus nutans* (DE), ...”. In

addition, we have replaced the words “runoff reduction ratio” with “average runoff depth” and “sediment concentration reduction ratio” with “soil loss per unit area”, as shown in lines **29–31**: “the values of the average runoff depth for *DE*, *PE*, *PD* and *SDM* were 0.47, 0.55, 0.45 and 0.27, ...”.

2-The study emphasizes the need to measure the effectiveness of vegetation restoration on runoff and erosion in (degraded) grasslands, and the authors make the point that the degradation of grasslands is poorly studied. The introduction contains general statements of the importance of grasslands, and the issue of environmental degradation of these ecosystems. As they are written, the statements are rather general (such as 'water and soil are crucial for human survival'), and merit to be further specified. How much of the grasslands are degraded worldwide? Which degradation is most common (physical, chemical, biological)? How severe is the degradation, what are the declines in soil fertility or soil structure, soil erosion or soil quality reported for grasslands globally, and specific regions? What are the erosion rates commonly reported for specific regions?

Response: The extent of degraded grassland worldwide has been described in lines **45–47**: “Despite the importance of grasslands, about half of them are degraded globally, ...”. Also, the effects of grassland degradation on soil structure and soil erosion have been added in lines **48–55**: “Grassland degradation causes the loss of up to 90% of the soil structure that facilitates ...”.

3-Degradation of grassland ecosystems is worthwhile to document and study, and the authors make this point. They also emphasize the need to study alpine meadows as they are fragile ecosystems (L106). This point could be further developed by including quantitative data on grassland degradation in the paragraph on L104-117. What is the decline in vegetation cover over the region,

and what are the main degradation processes? In how far this affects river hydrology downstream? The authors mention that the degradation of the meadows reduced runoff and river streamflow, but what are the processes involved? How was runoff reduced by grassland degradation? Can the authors provide data from the literature to show the effects on streamflow? As this study is part of a larger programme on soil erosion in the area, reference to previous studies (and their results) is necessary to show the added value of this particular contribution.

Response: Thank you for your valuable suggestion. We have added the main degradation processes of alpine meadows, as well as the processes involving meadows degradation and the reduction of river streamflow, as shown in lines **117–142**: “Over 50% of the alpine meadows have been subject to an increasing degree of degradation (Bardgett et al., 2021), with the extent of degradation depending”.

4-Throughout the manuscript, the authors refer to the 'maintenance of runoff' as one of the fundamental objectives of restoration efforts (L88-89). This merits to be further explained and contextualised, as this might be very specific for arid and semi-arid regions such as the region under study. In most regions, restoration efforts aim to reduce runoff generation through e.g. buffer strips or revegetation (see e.g. Vanacker et al., 2022) as runoff enhances entrainment and transport of sediment. Therefore, the combination of soil loss reduction and runoff maintenance is somewhat unexpected and could benefit from some additional explanation and framing.

Response: Thank you for your valuable suggestion. We have added the explanation of the maintenance of runoff in arid and semi-arid regions, as shown in lines **56–61**: “Precipitation is the

main water source of soil moisture supply in semi-arid areas and the conversion of precipitation to runoff is one of the major contributors to river streamflow ...”.

5-The effect of the measures is quantified through "reduction ratios" of runoff, soil erosion and sediment concentration. The authors compared the reduction ratios between the three treatments to assess their effectiveness. In the discussion, reference is also made to 'significant increased surface runoff' compared to the SDM-reference site. It is not entirely clear how this was assessed as this would imply demonstrating that the reduction ratios are significantly different from '0' while fig4 shows the results of the ANOVA - with significance of difference in reduction ratios between the three treatments. An analysis like the one presented in Fig5 (using absolute values of soil loss, runoff and sediment concentration) would be an alternative solution.

Response: I am sorry maybe a misunderstanding exists. "The surface runoff volume of the three mixed grasslands was significantly increased compared to that of SDM" this result is derived from **Fig. 3a**. Whereas, **Fig. 4a** displayed the effectiveness of the three mixed grasslands in maintaining runoff. As shown in **Fig. 3a**, the average runoff depths of *SDM* in 2019, 2020, and 2022 were 0.23, 0.34 and 0.25 mm, respectively, all significantly less than (except for 2020) the average runoff of mixed-cultivated grassland *DE PE* and *PD*, which measured 0.44, 0.59 and 0.50 mm in 2019, 0.55, 0.51 and 0.38 mm in 2020, 0.43, 0.54 and 0.40 mm in 2022. To avoid confusing the reader, we have revised the expression of the findings in Figure 3, as shown in lines **352–317**: “The average runoff depths of *SDM* in 2019, 2020, and 2022 were 0.23, 0.34 and 0.25 mm, ...”.

6-The soil erosion measurements on the experimental site with its 4 runoff plots have been described in earlier work by e.g. Niu et al. (2021) and previous publications by Liu et al. (2019,

2022). Previous studies mostly focused on plant characteristics and how they affect runoff rates and soil losses, and it would be worthwhile to indicate how this particular study is related to previous work. This can be done in the description of the experimental site, or at the end of the introduction.

Response: The earlier work Niu et al. (2021) focused on the effect of different degrees of alpine meadow degradation, i.e., different meadow patch coverage, on runoff and soil loss; Liu et al. (2019) investigated the effects of gramineae and legume grasses on runoff and sediment reduction runoff and sediment reduction under rainfall simulation scenarios in the Loess Plateau. Yes, the soil erosion measurements on the experimental site with its 4 runoff plots in the manuscript have been described in our previous publication (Liu et al., 2022), but the work focused on the effects of plant morphological characteristics on runoff and soil loss. Hence, we have added a description of the previous work as shown in lines **138–140**: “Recent studies by Niu et al. (2021) and Ma et al. (2023b) ...”, and in lines **163–165**: “Only Liu et al. (2022) the effects of plant morphological characteristics on runoff ...”.

Detailed comments

L20: What do the authors mean by the "stability of the hydrological cycle", "runoff reduction ratio", "sediment concentration reduction ratio"? Can they refer to commonly used terminology in the discipline?

Response: The words “stability of the hydrological cycle” have been replaced with “stability of the local runoff amount” as shown in line **20**. Meanwhile, the terms “sediment concentration reduction ratio (*CRE*)”, “sediment reduction ratio (*SRE*)” and “runoff reduction ratio (*RRE*)” have been

replaced with sediment concentration reduction benefit (*CRB*)”, “sediment reduction benefit (*SRB*)” and “runoff reduction benefit (*RRB*)”, respectively, based on the previous studies Zhao et al. (2014) and Liu et al. (2019), such as in lines **311–314**, **317–318**, and **371–373**.

L22: Can the authors rephrase the sentence? What do they mean by "strategy"?

Response: The word “strategy” means three mixed-cultivated grasslands. To avoid confusing the reader, we have rephrased the sentence, as shown in lines **21–26**: “In this research, we conducted *in situ* monitoring using runoff plots to investigate the impact of three mixed-cultivated grasslands, each sowing two grass species per plot (*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*)), on a 20-degree slope, assessing the activation and volume of surface runoff and soil loss in alpine degraded hillsides over three years (2019, 2020 and 2022).”.

L42: Are the grasslands always 'natural habitats', or just 'habitats'? What do they mean by 'natural'?

Response: We have erased the word “natural” as shown in line **42**.

L45-46: Some quantitative data on degradation are necessary here to back up these statements. What do the authors understand with 'severe degradation'? Can they include some data on soil erosion rates? compaction? productivity decline?

Response: Thank you for your valuable suggestion. The assessment method of grassland degradation by Gang et al. (2014) cited in this study was based on net primary productivity. Global grassland net primary productivity (NPP) has declined by 58.84 Tg C per year. The aforementioned information has been incorporated into lines **46–48**: “... (based on net primary productivity), which

has become a major issue for humanity to overcome (Gang et al., 2014; Török et al., 2021). Global grassland net primary productivity (NPP) has declined by 58.84 Tg C per year.”.

L48: Please rephrase 'threatening drivers'

Response: We have erased the sentence in the resubmitted manuscript in line **48**.

L79: Can the authors refer to a standard definition of surface runoff here, for example from handbook on soil erosion?

Response: We have revised the sentence as shown in line **98**: “Surface runoff – also known as stormwater runoff or overland flow ...”.

L81: Rainfall intensity (instead of 'rate')?

Response: The words “rainfall rate” have been replaced with “rainfall intensity” as shown in line **101**.

L83: Can the authors rephrase runoff is 'carrier of sediment transport'?

Response: The words “carrier of sediment transport” have been replaced with “serves as the main agent for sediment transport” as shown in lines **103–104**.

L84: Please check sentence 'such as vegetation restoration'

Response: The sentence “such as vegetation restoration” has been revised to “such as through vegetation restoration” as shown in line **105**.

L86: The reference to a specific study region is a bit of the context here.

Response: We have revised the sentence as shown in lines **106–108**: “However, for the arid and semi-arid regions, surface runoff is the major water supply source to the river streamflow, thereby it is vital for ensuring the sustainability of ecosystems (Liu et al., 2020; Robinson et al., 2003).”.

L88-89: Here, the authors mention that 'the fundamental objective of restoration efforts is to maintain runoff while reducing its level of sediment concentration'. This statement needs to be better framed/explained, as many restoration activities focus on runoff reduction through e.g. enhanced infiltration. Therefore, this statement cannot be written as such, and needs to be contextualised and explained. Please refer here to specific contexts including sufficient scientific references.

Response: Thank you for your valuable suggestion. The scientific references have been added in lines **56–61**: “Precipitation is the main water source of soil moisture supply in semi-arid areas and the conversion of precipitation to runoff is one of the major contributors to river streamflow ...”.

L95: Please rephrase 'reciprocal cementation'

Response: We have erased the words “reciprocal cementation and” in line **115**.

L111: this statement is counter-intuitive, please provide some data (from literature) to show the effects.

Response: We have added references on alpine meadow degradation disrupting the soil water balance and reducing surface runoff, as shown in line **144**.

L115: The term "artificial grasslands" needs to be explained/defined here

Response: We have defined the term “artificial grassland” in lines **147–149**: “Artificial grassland – also known as tamed grassland, sowed grassland and cultivated grassland – refers to fields that have been broken up and replanted with exotic grasses and forbs and utilized for hay crop production or cattle grazing (Fisher et al., 2018).”

L123-125: Please check that you define the abbreviations 'DE, PE and PD and SDM' before using them.

Response: We have added the explanation of the abbreviations of the three mixed-cultivated grassland types and *SDM*, as shown in lines **167–169**: “... *Deschampsia cespitosa* and *Elymus nutans* (*DE*), *Poa pratensis* L.cv. Qinghai and *Elymus nutans* (*PE*) ...”.

L136-137: It is common practise to refer to the meteorological station(s) (and the period of measurements) when mentioning meteorological data. Can the authors provide the name and location of the station (and mention the reference period)?

Response: we have added the period of measurements and date resource in lines **183–187**: “In the study region, the average annual temperature is -3.1°C, with monthly variations from -14.7°C in January to 7.5°C in July between 1981 and 2018, according to data sourced from the European Centre for Medium-Range Weather Forecasts. ...”.

L137: 'not showing distinct seasons, just cold and warm ones' -> this is not clear, please check.

Response: We have revised the sentence, as shown in lines 182–183: “... not showing the typical four-season pattern (spring, summer, autumn, winter), but rather just two main seasons: cold and warm.”

L147: 'mattic epipedom' -> this is not clear, please check.

Response: This is a typo, we have carefully checked the whole paper and replaced the words “mattic epipedom” with the words “mattic epipedon”, such as in lines **195, 756** and **757**.

L149: It is very good to have these numbers, it would be interesting to contextualise them (compare them with rates in other regions)

Response: Thank you for your valuable suggestion. The erosion rates in other regions have been added in lines **52–55**: “For example, in the Swiss alpine uplands, water erosion ranges from 0.14 to 1.25 t ha⁻¹month⁻¹ according to the phenological ...”.

L152: Can the authors define 'mixed-cultivated grasslands'? why 'mixed'? why 'cultivated'?

Response: We have added the explanation of the terms “cultivated grasslands” in lines **147–149**: “Artificial grassland – also known as tamed grassland, sowed grassland and cultivated grassland – refers to fields that have been broken up and replanted with exotic grasses and forbs and utilized for hay crop production or cattle grazing (Fisher et al., 2018).”. Also, we have added the explanation of “mixed” in line **23** “... each sowing two grass species per plot ...”, and in lines **200–201**: “mixed-cultivated grasslands – fields were ploughed and replanted with two grass species ...”

L156: The abbreviations could be defined here.

Response: To enhance reader comprehension of the paper, we have provided definitions of abbreviations in lines **23–25, 167-169, and 240–242**.

L161: Please clarify: Is the objective to prevent soil loss, and water loss? So, one is searching for vegetation with low evaporative demand?

Response: To avoid confusing the reader, the word “prevent soil and water loss” have been revised to “prevent soil loss and maintain surface runoff” in line **218**.

L163: habits?

Response: The word “habits” has been revised to “living habits”, as shown in line **220**.

L173: please check the wording here. the authors probably refer to animal grazing, not entirely clear what is considered to be 'artificial grassland construction'

Response: I am sorry maybe a misunderstanding exists. Artificial grassland – also known as tamed grassland, sowed grassland and cultivated grassland – refers to fields that have been broken up and replanted with exotic grasses and forbs and utilized for hay crop production or cattle grazing (Fisher et al., 2018). In this study, owing to overgrazing and rodent activity, the matic epipedon of the alpine meadow has been completely removed, exposing the subsoil and forming a severely degraded meadow. Establishing artificial grassland is widely used to restore severely degraded meadows in the study area (Li et al., 2023; Shang et al., 2008; Wu et al., 2010).

L205: can the authors specify where there was no snowfall during the monitoring period, or whether the gauge did not sample snow? In a conventional rain gauge, snow would also fall in the pluviometer.

Response: I am sorry maybe a misunderstanding exists. We only monitored surface runoff and soil erosion during the growing season of four runoff plots, and analyzed the corresponding rainfall

conditions during that period. We intend to clarify that within the study area's growing season (spanning from June 15 to August 25), there was no occurrence of snowfall, solely rainfall. To avoid confusing the reader, the sentence has been revised to “Snow was not collected, and only rainfall was recorded during the growing season (from June 15 to August 25).” in lines **262–263**.

L207: is the average rainfall intensity corresponding to rainfall amount divided by duration of event?
please specify.

Response: Yes. We have added the explanation in lines **264–265**: Average rainfall intensity (*ARI*) was calculated by dividing the total rainfall amount by the duration of the rainfall event.

L214: one could refer here to the pore size of the filter paper.

Response: We have added the pore size of the filter paper in line **272**.

L227: Did the authors include the dead and/or living vegetation in the assessment of the vegetation cover?

Response: Yes. Dead (standing litter) and surviving vegetation were included in the assessment of vegetation cover. We have added the information in line **289**: “Vegetation cover (*VC*), including dead (standing litter) and living vegetation, ...”.

L229: each year? or each month? as the authors refer to 'monthly measurements' on

Response: We measured vegetation cover in the middle of June, July, and August.

L239: 'NCP' is not defined, please check

Response: We have added the definition of *NCP* in line **301**.

L272: 'dramatically' not needed here

Response: We have erased the word “dramatically” in line **348**.

L273: $p < 0.05$

Response: we have carefully checked the whole paper and replaced “ $P < 0.05$ ” with “ $p < 0.05$ ”, such as in lines **349**, **353** and **359**.

L278: influenced by planting age

Response: We have erased the words “the age of the” in line **358**.

The description of the experimental design and the monitoring is very detailed and includes valuable information on the rationale behind the plant selection.

Response: Thank you so much for your kind encouragement.

L309: runoff amount?

Response: The words “runoff yield” have been replaced with “runoff amount” in line **402**.

L314: Why is *R* the most relevant one? Is this because it has the highest influence?

Response: We have revised the sentence in line **407**: “Soil loss was significantly influenced by *R*, *RI*₆₀, *ARI* and *LB*.”.

L326: Can the authors specify the added value of this study compared to Liu et al (2019, 2022). Are these studies conducted on similar plots, and yield similar results?

Response: The earlier work Liu et al. (2019) investigated the effects of gramineae and legume grasses on runoff and sediment reduction runoff and sediment reduction under rainfall simulation scenarios in the Loess Plateau. Yes, the soil erosion measurements on the experimental site with its 4 runoff plots in the manuscript have been described our previous publication (Liu et al., 2022), but the work focused on the effects of plant morphological characteristics on runoff and soil loss. Hence, we have added a description of the previous work as shown in lines **163–165**: “Only Liu et al. (2022) the effects of plant morphological characteristics on runoff ...”.

L356: Can the authors specify if Niu et al. (2021) concerns similar plots or experiments? If so, this needs to be mentioned upfront in the description of the experimental site.

Response: The earlier work Niu et al. (2021) focused on the effect of different degrees of alpine meadow degradation, i.e., different meadow patch coverage, on runoff and soil loss. Hence, we have added a description of the previous work as shown in lines **130–132**: “Recent studies by Niu et al. (2021) and ...”, and in lines **142–144**: “The long-term and widespread degradation of hillside alpine meadows has disrupted ...”.

Figure 1 - nice figure

Response: Thank you so much for your kind encouragement.

Figure 3 - the title of the Y-axis in Fig3b refers to 'soil erosion module' -> is this the same thing as the 'soil erosion' stated above?

Response: We have revised the title of the Y-axis “soil erosion module” to “soil loss per unit area” in **Fig. 3b**.

Data availability: It is common practice to provide the raw data as spreadsheets in the supporting information. A database with the observations and measurements per plot and event would facilitate further research on the topic, and review studies.

Response: Thank you for your comment and feedback. Data availability has been revised to “The data that support the findings of this study are available on request from the corresponding author.”.

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