We sincerely thank the editor and reviewers for their constructive and insightful comments on our manuscript entitled “Hydrological implications of vegetation-associated precipitation recycling during peak growing season over the Loess Plateau”. We have carefully revised the manuscript in response to all comments and have made substantial improvements to the clarity, structure, and presentation of the paper. In addition to addressing the reviewers’ specific concerns, we have revised the reference list according to the formatting requirements of Hydrology and Earth System Sciences (HESS), carefully checked and corrected grammar, wording, and formatting throughout the manuscript, and further optimized the structure and logical flow of the Abstract and Conclusions. We believe that these revisions have improved the scientific clarity, readability, and overall quality of the manuscript. All major changes are described in detail below, together with point-by-point responses to the reviewers’ comments.

Response to Reviewer #1 – Major Comment 1

Comment 1:

The manuscript states that precipitation over the Loess Plateau is dominated by land-sourced moisture (86.5%), which appears inconsistent with the traditional understanding of the region as being strongly influenced by the East Asian monsoon. The reviewer requests a more mechanistic explanation considering large-scale circulation, monsoon transport pathways, and the inland transition zone characteristics.

Response:

We sincerely thank the reviewer for this insightful comment. We agree that the relatively high fraction of land-sourced moisture (86.5%) may appear counterintuitive under a classical monsoon framework. In the revised manuscript, we have substantially expanded the mechanistic interpretation to clarify this issue from the perspectives of large-scale circulation, inland moisture transformation, and the monsoon–continental transition setting of the Loess Plateau.

First, we clarify that the East Asian summer monsoon provides the initial moisture input, primarily originating from the Indian and Pacific Oceans. However, as moist air masses are transported inland toward northern China, they undergo progressive depletion and transformation due to repeated precipitation events and re-evaporation from the land surface. This process leads to a gradual reduction of the “pure oceanic signal” along the transport pathway.

Second, the Loess Plateau is located in a monsoon-fringe and inland-transition zone, where it is jointly influenced by the East Asian monsoon and mid-latitude westerlies. Moisture reaching the region is therefore not dominated by direct oceanic advection, but by mixed continental air masses that have already experienced substantial land–atmosphere recycling over central and northern China and northwestern Eurasia.

Third, our WAM-2layers results indicate that “land-sourced moisture” largely represents recycled or previously precipitated water vapor within the continental domain, rather than purely locally evaporated moisture. This interpretation is consistent with previous Lagrangian studies showing dominant contributions from Central–Eastern China and inland Asia, while direct oceanic contributions from major ocean basins are relatively small (~10%).

Therefore, the high proportion of land-sourced precipitation reflects the combined effect of (i) monsoon moisture transport, (ii) inland progressive recycling, and (iii) atmospheric mixing along the continental pathway, rather than a weak influence of the oceanic monsoon system. In this framework, the East Asian monsoon remains the driver of moisture supply, while continental recycling reshapes the final precipitation composition over the Loess Plateau.

We have revised the manuscript accordingly to explicitly clarify this mechanism and to avoid possible misinterpretation.

Manuscript Changes

(A) Section 4.1 – Hydroclimatic constraints and precipitation recycling

To clarify the mechanistic interpretation of moisture sources and reconcile the dominance of land-sourced precipitation with monsoon circulation theory, we have revised the description of moisture transport pathways and inland transformation processes.

Original:

Under this hydroclimatic setting, precipitation over the Loess Plateau still depends strongly on external moisture supply. ...

Revised:

Under this hydroclimatic background, precipitation over the Loess Plateau is strongly controlled by large-scale monsoon moisture transport. It is continuously modified by land–atmosphere exchanges along its inland pathway. The WAM-2layers results show that Central China is the predominantly continental-influenced moisture source for precipitation over the Loess Plateau (Fig. 3a). This is consistent with previous Lagrangian studies. These studies indicate that summer moisture mainly comes from Central–Eastern China and northwestern continental Asia. In contrast, direct oceanic contributions from the East China Sea, South China Sea, Bay of Bengal, and Arabian Sea are minor, together accounting for only about 10% of total precipitation (Hu et al., 2016).

The dominance of continental moisture sources reflects progressive changes in monsoon vapor during inland transport. Along this pathway, repeated evaporation–precipitation cycles and boundary layer recycling gradually reshape the original oceanic moisture signal. Recent studies also show that vegetation greening enhances evapotranspiration and strengthens regional moisture recycling (Cao et al., 2024). In this process, the land surface acts both as a moisture source and an intermediate contributor to atmospheric moisture through evapotranspiration and recycling processes. This reinforces the continental component in the monsoon–land coupled system. Therefore, the high fraction of land-sourced precipitation (86.5%) should not be interpreted as a weak oceanic influence. Instead, it reflects the combined effects of monsoon moisture transport and terrestrial recycling. The East Asian monsoon provides the initial moisture input, while continental recycling determines the final precipitation composition over the Loess Plateau.

Within this externally controlled system, internal precipitation recycling contributes about 14.4% of total precipitation during the study period (Fig. 3b–c). This value is higher than those reported in some previous studies, such as 7% from the UTrack Lagrangian moisture-tracking model (Wang et al., 2023) and $9.16 \pm 0.35\%$ to $10.18 \pm 0.28\%$ from the Dynamic Precipitation Recycling Method (Tian et al., 2022). These differences mainly reflect methodological approaches and climatic context rather than physical inconsistency. Most previous studies use annual or long-term averages. In contrast, this study focuses on July–August, when vegetation activity, evapotranspiration, and land–atmosphere coupling are strongest over the Loess Plateau (Li et al., 2024; Guo et al., 2025).

This seasonal amplification agrees with recent findings that vegetation and land use changes regulate atmospheric moisture recycling by affecting evapotranspiration and atmospheric moisture residence time (Wang et al., 2023). In this framework, precipitation recycling is not a fixed ratio. It responds dynamically to land surface conditions and atmospheric moisture supply. Similarly, afforestation has been shown to strengthen land–atmosphere coupling and increase both external and internal moisture contributions to precipitation (Tian et al., 2022). Therefore, the relatively high recycling ratio in this study reflects enhanced seasonal coupling during the peak growing season, rather than overestimation. These results indicate that precipitation over the Loess Plateau is jointly controlled by monsoon moisture transport and terrestrial recycling processes.

(B) Section 3.1 – Results

To better explain the physical meaning of "land-sourced moisture" and its relation to continental recycling during inland transport, we have added a mechanistic interpretation to the results section.

Original:

On average, terrestrial moisture contributes approximately 71.0 mm of precipitation, ...

Revised:

On average, terrestrial moisture contributes approximately 71.0 mm of precipitation, accounting for 86.5% of total growing-season precipitation, whereas oceanic moisture contributes about 11.1 mm, corresponding to 13.5% (Fig. 3b). This land-sourced moisture signal reflects moisture that has undergone substantial transformation through repeated evaporation–precipitation cycles during inland transport, rather than exclusively locally generated evaporation. Such a pattern suggests progressive modification of monsoon-derived moisture along continental transport pathways within a monsoon–inland transition zone, where ocean-origin vapor is continuously mixed with terrestrial evapotranspiration inputs before reaching the Loess Plateau.

(C) Introduction

To emphasize the role of large-scale monsoon circulation and land–atmosphere coupling in shaping atmospheric moisture evolution, we have added a sentence linking these processes explicitly in the introduction.

Original:

On the other hand, stronger evapotranspiration may enhance land–atmosphere coupling, ...

Revised:

On the other hand, stronger evapotranspiration may enhance land–atmosphere coupling, promote atmospheric moisture recycling, and potentially increase precipitation (Yosef et al., 2018; Zhang et al., 2022a; Wei et al., 2019). These processes occur within a monsoon-dominated climatic system, where large-scale moisture transport and land–atmosphere interactions jointly regulate the evolution of atmospheric water vapor along its pathway.

(D) Section 2.1 – Study area description

To better describe the climatic setting of the Loess Plateau as a monsoon-influenced inland transition zone, we have refined the description of precipitation formation processes.

Original:

Under the influence of the East Asian monsoon system...

Revised:

Under the influence of the East Asian monsoon system, precipitation is primarily driven by large-scale moisture transport, which is subsequently modified by regional land–atmosphere recycling processes. Precipitation over the Loess Plateau also shows pronounced interannual variability, with wet years receiving several times more precipitation than dry years and extreme rainfall events occurring frequently (Liu et al., 2025).

Response to Reviewer #1 – Major Comment 2

Comment 2:

The results show that despite increased evapotranspiration following ecological restoration, precipitation is not significantly compensated, leading to a declining trend in surface water availability (SWA). This appears to contradict recent studies (e.g., Zhang et al., Nature Water series), which suggest that vegetation restoration enhances precipitation and increases overall water availability in the Loess Plateau.

Response:

We sincerely thank the reviewer for this insightful and important comment. We agree that our findings may appear different from several recent high-profile studies that report vegetation-induced increases in precipitation and overall water availability. In the revised manuscript, we have clarified this apparent discrepancy by explicitly distinguishing differences in hydrological scale, feedback pathways, and water accounting frameworks.

First, we emphasize that the key distinction lies in the definition of water availability and system boundaries. In this study, surface water availability (*SWA*) is defined as the net balance between precipitation and evapotranspiration at the regional scale. Therefore, it reflects a closed water-budget perspective. In contrast, several recent studies focus on atmospheric feedback processes and precipitation enhancement mechanisms, which emphasize changes in precipitation efficiency under vegetation greening without necessarily quantifying full water-budget closure. Second, our results show that vegetation can indeed enhance land–atmosphere coupling and internally recycled precipitation, consistent with previous studies. However, this increase is constrained by the relatively small proportion of internally recycled precipitation (14.4% of total growing-season precipitation). As a result, even a measurable vegetation-induced enhancement of precipitation recycling is insufficient to offset the concurrent increase in evapotranspiration under water-limited conditions.

Third, we further clarify that the differences between studies largely reflect temporal scale and climatic context. Many previous studies are based on long-term or event-scale atmospheric responses, whereas this study focuses on July–August, when evapotranspiration is strongest and soil moisture constraints are more pronounced. Under such dry-season conditions, the additional moisture recycled through vegetation–atmosphere interactions is generally not sufficient to generate a net increase in surface water availability.

Finally, we emphasize that our results do not contradict previous findings, but rather indicate that vegetation-induced precipitation enhancement does not necessarily translate into positive net surface water gain under water-limited conditions. Instead, vegetation simultaneously increases evapotranspiration and precipitation recycling, leading to a strong compensation effect and a near-neutral or slightly negative net impact on *SWA*.

We have revised Section 4.2 to explicitly incorporate this interpretation and to clarify the consistency and differences with recent literature.

Manuscript Changes

(A) Section 4.2 – Conditional and nonlinear vegetation-associated effects on surface water availability

To address concerns regarding apparent inconsistencies with recent studies on vegetation-induced precipitation enhancement, we have clarified differences in system boundaries, temporal scale, and water-budget interpretation.

Original:

Under water-limited conditions, vegetation influences regional water cycling through two competing pathways. ...

Revised:

Under water-limited conditions, vegetation affects regional water cycling through two competing pathways. First, enhanced vegetation activity increases evapotranspiration and strengthens land–atmosphere coupling. This can promote the return of locally evaporated moisture as precipitation (Sterling et al., 2013). Second, vegetation growth increases terrestrial water consumption. This reduces soil moisture and limits water availability for surface and subsurface hydrological processes (Piao et al., 2020). These two pathways coexist. As a result, vegetation-related effects on internal moisture recycling do not translate into a uniformly positive impact on surface water availability.

Recent work by Tian et al. (2026) provides a complementary system-level view. They show that vegetation greening can enhance precipitation efficiency through albedo-driven energy feedbacks. These feedbacks increase surface radiation, atmospheric instability, and moisture-to-precipitation conversion efficiency. Their results also indicate that greening can simultaneously increase evapotranspiration and streamflow in semi-arid regions. This suggests a coupled energy–moisture mechanism that intensifies the atmospheric water cycle. The results are broadly consistent with the energy–moisture coupling perspective proposed by Zhang (2025), particularly in terms of enhanced atmospheric moisture recycling under greening conditions. We observe strengthened land–atmosphere coupling and enhanced internally recycled moisture. However, the effect on surface water availability depends on temporal scale and hydrological closure assumptions.

At the regional scale, vegetation-associated effects on the evaporation–precipitation cycle largely cancel out over the long term. Vegetation can enhance precipitation during active growth periods. However, this is accompanied by increased evapotranspiration. As also suggested by Tian et al. (2026), this represents a redistribution of water within the system rather than a net gain in water resources. Consequently, the net effect on regional water availability is very small (Fig. 4e; Fig. 5d). This small value should be interpreted carefully. Here, we only quantify the vegetation contribution to precipitation generated from local evaporation and recycled within the Loess Plateau. Internally recycled precipitation accounts for only 14.4% of total growing-season precipitation (Fig. 3c). Therefore, even a detectable vegetation effect on this component becomes strongly diluted when expressed relative to total precipitation and total surface water availability.

In addition, the regional mean signal reflects strong compensation between positive and negative vegetation effects. The strongest positive and negative contributions reach 12.2% and −32.2% of the internally recycled precipitation, respectively (Fig. 3c; Fig. 6a). Thus, the small net effect results not only from the limited share of internal recycling, but also from strong cancellation across vegetation conditions. This compensation is consistent with the nonlinear energy–moisture coupling described by Tian et al. (2026). In that framework, enhanced moisture conversion efficiency coexists with increased evaporative demand. This leads to spatially heterogeneous hydrological responses rather than uniform changes.

A small net effect does not imply that vegetation–atmosphere feedbacks are negligible. Instead, it indicates that under the dry conditions in the Loess Plateau, additional precipitation generated through recycling is generally insufficient to offset increased evapotranspiration caused by vegetation growth. As a result, vegetation does not substantially increase net surface water availability. Instead, it primarily reflects a redistribution of water within a tightly constrained land–atmosphere system.

In this context, the hydrological benefit of vegetation-related recycling is strongly limited by background hydroclimatic conditions. This is different from humid or energy-limited regions, where vegetation-related recycling more easily translates into net water gains (Cui et al., 2022; Meier et al., 2021). The comparison highlights the key role of climate setting in regulating vegetation–water coupling efficiency. It also suggests that small mean effects should not be interpreted as hydrological irrelevance. Rather, they reflect strong compensatory feedbacks under water-limited conditions.

More importantly, vegetation effects on surface water availability show a clear nonlinear pattern along the LAI_w gradient. Two lines of evidence support this. First, the contribution of vegetation-associated recycled precipitation shifts from positive under low-LAI_w to negative under high-LAI_w. This indicates that the hydrological benefit of recycling is mainly limited to sparse vegetation. It weakens when vegetation density exceeds a moderate level (Fig. 5e; Fig. 6a). Second, the temporal evolution of positive and negative components shows asymmetric behavior. Positive contributions are small and intermittent, while negative contributions become more persistent with increasing LAI_w (Fig. 4e; Fig. 5e; Fig. 6b). This pattern is consistent with the limited water storage capacity and strong evaporative sensitivity in the Loess Plateau.

Within the broader framework of Tian et al. (2026), this nonlinear behavior reflects a trade-off between enhanced precipitation efficiency and increased evaporative demand under higher vegetation density. Under such conditions, further vegetation growth is more likely to intensify water consumption than to produce sustained gains in surface water availability. Therefore, the key scientific value of the small regional mean effect lies not in its magnitude, but in revealing the conditions under which vegetation-related recycling shifts from weakly beneficial to increasingly negative under higher LAI_w conditions.

Response to Reviewer #1 – Minor Comment

Comment:

The authors need to include a dedicated discussion section to explicitly address and reconcile this discrepancy. Please elaborate on the following dimensions:

Spatio-temporal scales: This study explicitly isolates the "peak growing season" (July–August), whereas prior works often rely on annual scales or full-growing-season metrics. Does the seasonal focus alter the feedback loop?

Methodological differences and definitions: How do the core assumptions within the -based Budyko-RF framework differ from the climate models (GCMs/RCMs) or statistical diagnostic approaches used in previous studies when defining "water availability" and "vegetation-precipitation feedback"?

Response:

We sincerely thank the reviewer for this constructive suggestion. In the revised manuscript, we have explicitly expanded the discussion to clarify the boundary conditions of our conclusions from two key perspectives: spatio-temporal scale effects and methodological and conceptual differences in water availability definitions and feedback representation.

First, regarding spatio-temporal scales, we clarify that this study focuses specifically on the peak growing season (July–August), when evapotranspiration, vegetation activity, and land–atmosphere coupling are at their annual maximum over the Loess Plateau. As now explicitly discussed in Section 4.1, this seasonal focus leads to a strengthened representation of vegetation–atmosphere interactions and internal moisture recycling compared to studies based on annual or full-growing-season averages. Therefore, differences in temporal aggregation naturally affect the strength and detectability of vegetation–precipitation feedbacks, and may partially explain discrepancies with studies using long-term climatological scales.

Second, regarding methodological differences, we clarify that the Budyko-RF framework used in this study is a diagnostic, constraint-based approach rather than a fully dynamic climate modeling framework. As now detailed in Section 2.3.3, unlike GCM/RCM-based studies that explicitly simulate coupled atmospheric processes (radiation, convection, and moisture transport), our framework quantifies vegetation-associated effects through their contribution to the observed precipitation–evapotranspiration balance under given hydroclimatic conditions. Consequently, “water availability” in this study is defined within a closed surface water budget

(P − ET) perspective, whereas many previous studies emphasize atmospheric feedbacks and precipitation response efficiency, which do not necessarily impose full surface water-budget closure.

Finally, as further discussed in Section 4.2, these differences in scale and methodology imply that apparent inconsistencies with previous findings do not reflect contradictions in physical mechanisms, but rather differences in system boundaries, feedback conceptualization, and definitions of hydrological availability. When these distinctions are explicitly considered, our results are consistent with a framework in which vegetation can simultaneously enhance atmospheric moisture recycling while not necessarily increasing net surface water availability under water-limited conditions.

We have revised the manuscript accordingly to clearly delineate these conceptual and methodological boundaries and to better highlight the specific contribution of this study.

Manuscript Changes

(A) Section 4.1 – Added explicit seasonal scale interpretation

To explicitly address the influence of spatio-temporal scale on vegetation–atmosphere feedback strength, we have clarified the seasonal focus of this study.

(B) Section 2.3.3 – Methodological clarification

To clarify differences between diagnostic and process-based modeling frameworks, we explicitly distinguish the Budyko-RF approach from GCM/RCM simulations.

Original:

In this study, the Budyko framework is applied as a comparative diagnostic tool for the peak growing season (July–August), ...

Revised:

In this study, the Budyko framework is applied as a comparative diagnostic tool for the peak growing season (July–August), rather than as a process-based simulator of the full land–atmosphere system. Unlike climate model (GCM/RCM) approaches, which explicitly resolve coupled vegetation–atmosphere interactions through dynamic representations of radiation, convection, and moisture transport, the Budyko framework provides a constraint-based diagnostic description of surface water balance under observed hydroclimatic conditions. This distinction implies that vegetation–precipitation feedbacks in this study are not simulated dynamically, but are instead quantified through their contribution to the observed precipitation–evapotranspiration balance.

(C) Section 4.2 – Conceptual reconciliation with previous studies

To reconcile differences with previous studies on vegetation-induced precipitation enhancement, we explicitly clarify differences in water availability definitions and system boundaries.

Response to Reviewer #2 – Major Comment

Comment 1:

The manuscript shows that vegetation-associated recycled precipitation contributes only marginally to regional mean precipitation, evapotranspiration, and surface water availability. This is an important result, but its broader hydrological meaning could be further clarified. I suggest that the authors add more explanation on how this small numerical contribution should be interpreted. For example, does it indicate that vegetation-related precipitation recycling is hydrologically negligible at the regional scale, or does it instead reveal that its potential benefits are strongly constrained by the dry background climate of the Loess Plateau? A more nuanced interpretation would help readers understand why a small mean contribution can still be scientifically meaningful, particularly in identifying the limits of land–atmosphere feedbacks in water-limited environments.

Response:

We sincerely thank the reviewer for this insightful comment. We agree that the regional mean magnitude alone does not fully reflect the hydrological meaning of vegetation-associated precipitation recycling, and that a more nuanced interpretation is necessary.

In the revised manuscript, we clarify that the small net regional effect does not imply hydrological irrelevance, but rather reflects a redistribution of water within a constrained land–atmosphere system. As also suggested by Tian et al. (2026), vegetation-induced changes in precipitation and evapotranspiration primarily represent internal redistribution processes, where enhanced moisture recycling and increased evaporative demand occur simultaneously. These opposing effects largely offset each other at the regional scale, leading to a small net signal.

Importantly, this result must be interpreted in the context of the process boundary of this study. We quantify only the fraction of precipitation generated from local evaporation and subsequently recycled within the Loess Plateau. Internally recycled precipitation accounts for only 14.4% of total growing-season precipitation. Therefore, even a measurable vegetation-induced change in this component becomes substantially diluted when expressed relative to total precipitation and, ultimately, total surface water availability.

In addition, the regional mean signal reflects strong compensation between positive and negative vegetation-associated effects. As shown in our results, the strongest positive and negative contributions reach 12.2% and −32.2% of internally recycled precipitation, respectively. This indicates pronounced spatial heterogeneity, where enhanced moisture recycling efficiency in some areas is offset by increased evapotranspiration losses in others. This compensatory behavior is consistent with nonlinear energy–moisture coupling mechanisms, where improved atmospheric moisture availability coexists with increased atmospheric demand.

Under the dry background climate of the Loess Plateau, the additional precipitation generated through recycling is generally insufficient to offset the concurrent increase in vegetation water consumption. Therefore, vegetation does not substantially increase net surface water availability at the regional scale. Instead, it reshapes the internal partitioning of water fluxes within the soil–vegetation–atmosphere system.

This interpretation highlights that vegetation–atmosphere feedbacks are not negligible, but are strongly constrained by hydroclimatic conditions. In contrast to humid or energy-limited regions, where recycled moisture can more readily translate into net water gains, the Loess Plateau represents a water-limited system in which compensatory processes dominate. Consequently, a small regional mean contribution should be understood as evidence of strong constraint and compensation, rather than lack of physical importance.

Manuscript Changes

(A) Section 4.2 – Interpretation of vegetation-associated precipitation recycling effects

To improve clarity in interpreting the small regional mean contribution of vegetation-associated precipitation recycling and to better distinguish between net effects and compensatory processes, we have refined the discussion and emphasized the role of process boundaries and hydroclimatic constraints.

Original:

At the regional scale, the long-term vegetation-associated influence on the evaporation–precipitation cycle appears to largely cancel out in net effect. ...

Revised:

At the regional scale, vegetation-associated effects on the evaporation–precipitation cycle largely cancel out over the long term. Vegetation can enhance precipitation during active growth periods. However, this is accompanied by increased evapotranspiration. As also suggested by Tian et al. (2026), this represents a redistribution of water within the system rather than a net gain in water resources. Consequently, the net effect on regional water availability is very small (Fig. 4e; Fig. 5d). This small value should be interpreted carefully. Here, we only quantify the vegetation contribution to precipitation generated from local evaporation and recycled within the Loess Plateau. Internally recycled precipitation accounts for only 14.4% of total growing-season precipitation (Fig. 3c). Therefore, even a detectable vegetation effect on this component becomes strongly diluted when expressed relative to total precipitation and total surface water availability.

In addition, the regional mean signal reflects strong compensation between positive and negative vegetation effects. The strongest positive and negative contributions reach 12.2% and −32.2% of the internally recycled precipitation, respectively (Fig. 3c; Fig. 6a). Thus, the small net effect results not only from the limited share of internal recycling, but also from strong cancellation across vegetation conditions. This compensation is consistent with the nonlinear energy–moisture coupling described by Tian et al. (2026). In that framework, enhanced moisture conversion efficiency coexists with increased evaporative demand. This leads to spatially heterogeneous hydrological responses rather than uniform changes.

A small net effect does not imply that vegetation–atmosphere feedbacks are negligible. Instead, it indicates that under the dry conditions in the Loess Plateau, additional precipitation generated through recycling is generally insufficient to offset increased evapotranspiration caused by vegetation growth. As a result, vegetation does not substantially increase net surface water availability. Instead, it primarily reflects a redistribution of water within a tightly constrained land–atmosphere system.

In this context, the hydrological benefit of vegetation-related recycling is strongly limited by background hydroclimatic conditions. This is different from humid or energy-limited regions, where vegetation-related recycling more easily translates into net water gains (Cui et al., 2022;

Meier et al., 2021). The comparison highlights the key role of climate setting in regulating vegetation–water coupling efficiency. It also suggests that small mean effects should not be interpreted as hydrological irrelevance. Rather, they reflect strong compensatory feedbacks under water-limited conditions.

Comment 2:

One of the most interesting findings of the manuscript is the transition from weakly positive effects under low vegetation density to increasingly negative effects under high LAIw conditions. This threshold-like pattern deserves further elaboration in relation to ecological restoration and vegetation management on the Loess Plateau. The authors could add more discussion of how this result relates to vegetation carrying capacity, optimal restoration intensity, and the potential risk of excessive afforestation or vegetation densification in dryland regions. At the same time, it would be useful to clarify that the identified LAIw threshold should be interpreted as an empirical diagnostic signal derived from the present framework, rather than as a universal management threshold.

Response:

We sincerely thank the reviewer for this constructive comment. We agree that the threshold-like behavior of vegetation-associated hydrological effects requires further clarification, particularly regarding its robustness and interpretation in relation to ecological restoration implications.

In the revised manuscript, we clarify that the observed transition from weakly positive to negative vegetation effects is not an artifact of the LAI_w weighting scheme, but reflects a robust pattern controlled by the underlying vegetation gradient. To test this, we repeated the full analytical framework using the original unweighted *LAI*, and found that the key hydrological results remain nearly unchanged, indicating that the threshold behavior is not sensitive to the specific formulation of the vegetation indicator.

Importantly, we further clarify the interpretation of this threshold-like pattern. Rather than representing a fixed or universal management threshold, it should be understood as a regime transition emerging from the interaction between vegetation density and evaporative demand under water-limited conditions. In this framework, vegetation effects shift from slightly enhancing moisture recycling under low-density conditions to increasing evapotranspiration dominance under high-density conditions.

This behavior reflects the constrained hydroclimatic environment of the Loess Plateau, where limited water availability and strong atmospheric evaporative demand jointly regulate vegetation–water interactions. As vegetation density increases, the marginal hydrological benefit of enhanced recycling is progressively offset by increased water consumption, leading to a shift in net effect.

From a broader perspective, this result suggests the existence of a context-dependent vegetation–water coupling regime, which may imply an implicit water-limited carrying capacity for vegetation restoration. However, we emphasize that this should not be interpreted as a strict or universal threshold, but rather as a diagnostic feature of the current climatic and ecological setting.

Manuscript Changes

(A) Section 4.3 – Robustness of the LAIw diagnostic framework

To evaluate the sensitivity of the vegetation–hydrological response to the choice of vegetation indicator and to clarify the interpretation of the threshold-like behavior, we have conducted an additional *LAI*-based analysis and refined the discussion of regime transition under water-limited conditions.

Original:

Because LAI_w is a derived diagnostic indicator rather than a directly observed physical variable, its formulation may raise the question of whether the identified hydrological patterns depend strongly on the weighting scheme itself. ...

Revised:

Because LAI_w is a derived diagnostic indicator rather than a directly observed physical variable, its formulation may raise concerns about whether the identified hydrological patterns depend on the weighting scheme. In particular, weighting *LAI* by normalized actual evapotranspiration could, in principle, influence the apparent strength of vegetation–hydrological coupling and thereby affect the inferred threshold-like behavior.

To test this, we repeated the full analytical workflow using the original, unweighted peak-growing-season LAI instead of LAI_w. This parallel analysis included the multiple linear regression for P_{rec} and the Budyko-based attribution of hydrological effects. We then compared vegetation contributions to surface water availability (C_{SWA}) between the LAI-based and LAI_w-based frameworks at both the regional mean scale and across vegetation classes defined in Section 3.3.

The results show that the main findings are highly robust to the choice of vegetation indicator. Interannual variations in P_0 and C_{SWA} are nearly identical between the two frameworks, with Pearson correlation coefficients of 0.99996 and 0.99995, respectively (Fig. 7). The multi-year mean values also show only minor differences, with an absolute difference of 0.013%. This high consistency indicates that the observed hydrological response is not an artifact of the LAI_w weighting scheme. Instead, LAI_w mainly acts as a diagnostic rescaling of the vegetation gradient under different evaporative conditions. The dominant signal is still controlled by vegetation structure.

Importantly, the threshold-like behavior should be interpreted as a real regime transition driven by the interaction between vegetation density and evaporative demand. It is not produced by the LAI_w formulation. Rather, LAI_w helps to reveal how vegetation effects on moisture recycling and surface water availability change under different atmospheric conditions. This suggests that vegetation–water interactions in the Loess Plateau operate within a constrained hydrological regime. The system shifts from a weakly coupled state with slight positive effects to a strongly evaporative-dominated state with negative effects. This transition reflects limited water storage capacity and high evaporative sensitivity in the region.

From a management perspective, this shift implies an implicit water-limited carrying capacity for vegetation restoration. Beyond this level, further increases in vegetation density are more likely to increase evapotranspiration than to enhance surface water availability. However, this should not be interpreted as a fixed threshold for restoration. Instead, it represents a context-dependent response governed by hydroclimatic conditions in dryland environments.

Comment 3:

The study focuses on July–August, when vegetation activity and land–atmosphere coupling are expected to be strongest. This seasonal focus is well justified, but the implications of this choice could be further explained. I suggest that the authors add a short paragraph discussing how the conclusions may differ from annual-scale water-balance assessments. For instance, vegetation-related water consumption may affect soil water storage, groundwater recharge, and runoff beyond the peak growing season, whereas precipitation recycling may be most active during summer. In addition, the wetter southeastern and drier northwestern parts of the Loess Plateau may experience different balances between recycled precipitation gains and evapotranspiration losses. Addressing these points would help place the seasonal results in a broader hydrological context.

Response:

We sincerely thank the reviewer for this insightful comment. We agree that the seasonal focus of this study requires clearer interpretation in relation to annual-scale hydrological assessments and spatial heterogeneity across the Loess Plateau.

In the revised manuscript, we clarify that the July–August period represents a peak-coupling stage within the monsoon-dominated growing season (June–September), rather than an arbitrary seasonal selection. This period coincides with the annual maxima of precipitation, evapotranspiration, and land–atmosphere coupling intensity over the Loess Plateau, when vegetation is fully developed and moisture exchange between land and atmosphere is strongest. Therefore, the results represent the period of maximum vegetation–atmosphere interaction rather than a full-season or annual mean state.

We further emphasize that this seasonal focus also explains differences with previous studies based on annual or long-term averages. Those studies integrate both strong and weak coupling phases across the year, whereas our results specifically capture the peak interaction period, where recycling signals are naturally amplified.

In addition, we clarify that spatial heterogeneity within the Loess Plateau may lead to different balances between recycled precipitation gains and evapotranspiration losses. In wetter southeastern regions, atmospheric moisture availability and recycling potential are relatively higher, whereas in drier northwestern regions, evapotranspiration demand dominates more strongly. This spatial contrast further supports the interpretation that vegetation–water interactions are condition-dependent rather than spatially uniform.

Finally, we note that while precipitation recycling is strongest during the summer peak, vegetation water consumption may extend its influence beyond this period by affecting soil moisture storage and subsequent hydrological processes. Therefore, the July–August results should be interpreted as representing the upper-bound of seasonal coupling intensity, rather than full annual water balance conditions.

Manuscript Changes

(A) Section 4.1 – Seasonal representativeness and comparison with annual-scale studies

To clarify the seasonal representativeness of precipitation recycling estimates and to better distinguish peak-season coupling from annual-scale hydrological conditions, we have revised the interpretation of seasonal focus and its implications for comparing with previous studies.

Original:

Within this externally constrained background, internal precipitation recycling contributed about 14.4% of total precipitation over the Loess Plateau during the study period (Fig. 3b–c). ...

Revised:

Within this externally controlled system, internal precipitation recycling contributes about 14.4% of total precipitation during the study period (Fig. 3b–c). This value is higher than those reported in some previous studies, such as 7% from the UTrack Lagrangian moisture-tracking model (Wang et al., 2023) and 9.16 ± 0.35% to 10.18 ± 0.28% from the Dynamic Precipitation Recycling Method (Tian et al., 2022). These differences mainly reflect methodological approaches and climatic context rather than physical inconsistency.

Most previous studies are based on annual or long-term averages, which integrate both strong and weak land–atmosphere coupling phases across the year. In contrast, this study focuses on July–August, corresponding to a peak-coupling stage within the monsoon-dominated growing season (June–September), when vegetation is fully developed and land–atmosphere interaction is strongest over the Loess Plateau (Liang et al., 2015; Zhang et al., 2016; Li et al., 2024; Guo et al., 2025). Therefore, the recycling ratio reported here reflects the upper-bound conditions of seasonal coupling intensity rather than a full-season mean state.

This seasonal focus also explains part of the difference between our results and annual-scale studies, which necessarily average across both strong and weak coupling periods, thereby reducing the apparent magnitude of recycling signals. In contrast, peak-season conditions enhance land–atmosphere feedbacks and moisture recycling efficiency.

These results indicate that precipitation over the Loess Plateau is jointly controlled by monsoon moisture transport and terrestrial recycling processes.

(B) Section 4.4 – Limitations and Research Prospects

To further clarify the limitations associated with seasonal selection and its implications for full water-balance interpretation, we have refined the discussion of temporal representativeness and hydrological scope.

Original:

This study provides a quantitative assessment of vegetation-associated precipitation recycling and ...

Revised:

This study provides a quantitative assessment of vegetation-associated precipitation recycling and its contribution to surface water availability during the peak growing season over the Loess Plateau. Several limitations should be acknowledged.

First, the seasonal focus on July–August. This period represents a peak-coupling stage within the monsoon-dominated growing season from June to September. The growing season accounts for 60–70% of annual precipitation and coincides with the annual maxima of precipitation, evapotranspiration, and land–atmosphere coupling (Liang et al., 2015; Zhang et al., 2016). During July–August, vegetation is fully developed and atmospheric moisture exchange is strong. In contrast, coupling is weaker in early summer because vegetation is not yet fully developed. It also weakens in late summer because of soil moisture depletion (Feng et al., 2016; Liang et al., 2015). Therefore, our analysis captures the period of strongest vegetation–atmosphere interaction rather than a full-season or annual mean state. The identified recycling signals should thus be interpreted as the upper bound of seasonal coupling intensity. Annual-scale water balance assessments, by contrast, reflect integrated hydrological responses across multiple seasonal phases (Wang et al., 2016).