Dear Reviewer#2,

Thank you so much for the feedback. These comments improved the quality of our manuscript. Below we provide detailed point-by-point responses to all comments. Reviewer comments are highlighted in boldface and italic. Our responses are in normal texts.

Sincerely,

Guofeng Zhu (on behalf of all authors)

We sincerely appreciate your detailed and insightful comments on this study. The issues you raised regarding the transparency of experimental design, precision in data presentation, and readability of figures are of significant value for refining this manuscript. We fully endorse your perspective that 'the study should provide substantive incremental contributions based on existing knowledge of irrigation in arid regions.'

Here is our detailed response to your feedback and improvement plan:

Specific comments:

1. The statement that there are few studies on irrigation water dynamics in arid areas is not true.

We appreciate your feedback. While global research on irrigation in arid regions is extensive, our study specifically examines the high-frequency isotopic monitoring of alfalfa (*Lupinus sativus*) throughout its growing season under sprinkler irrigation in the Jingdian Irrigation District of the Hexi Corridor—a high-head irrigation context where such research remains underdeveloped. In the revised manuscript, we will: (1) rephrase Line 60 to state: "Despite abundant research on arid zone irrigation, the precise characterization of sprinkler-induced rapid soil moisture mixing and renewal mechanisms in specific regions requires further investigation"; and (2) explicitly emphasize the "regional" nature of this study in the introduction, underscoring its practical implications for local high-head irrigation water resource management.

2. The recommendation on line 31 needs to be balanced against (especially fungal) pathogenicity and ensuring that plant diseases don't gain a foothold.

This is a critically important practical consideration. Although night irrigation can significantly reduce evaporation losses, high humidity conditions may indeed induce fungal diseases in alfalfa. We will include relevant discussions in the conclusions, recommending that the promotion of night irrigation should be combined with local plant protection monitoring and optimized sprinkler irrigation intensity to control leaf surface humidity.

3. There are a few minor usage issues like no space after the period on line 22. A quick check throughout the manuscript would go a long way to making improvements.

We sincerely appreciate the reviewers 'meticulous examination of the paper's details. The formatting issues did compromise the manuscript's professional quality and readability. We fully endorse your feedback and have implemented the following improvements: We conducted a thorough line-by-line review, correcting all missing spaces after periods and commas—including in line 22 (e.g., revising' subject.The 'to' subject. The'). Additionally, we refined the introduction and abstract to address long, complex sentences and punctuation errors, ensuring clear and coherent expression.

4.60: clarify earlier that the analysis is regional. There have been very many studies on irrigation and as written it states 'relatively few studies have explored the water dynamics in arid irrigated areas,', which isn't true! And if the study isn't regional (it's not yet apparent), this passage should be further re-written.

We fully endorse the reviewers' critique. The reviewers pointed out that there is an extensive body of research on irrigation in arid regions worldwide, a fact that is indisputable. Indeed, our phrasing in line 60 of the manuscript was overly generalized, failing to precisely delineate the incremental contribution of this study within the existing body of knowledge.

We will make the following in-depth revisions to the Introduction section:

We will remove the inaccurate assertion that "the study is relatively limited." Instead, we will emphasize the regional characteristics of this study: focusing on the rapid mixing and renewal mechanisms of soil moisture triggered by sprinkler irrigation pulses in the typical high-head, arid sprinkler irrigation farmland system of the Jingdian Irrigation District in Northwest China. We will cite a large number of existing irrigation studies in arid regions and explicitly state that this study aims to address the practical data gap in the refined management of water resources in this specific region. In the first half of the Introduction (before line 60), we will clearly indicate that this analysis is a regional experiment based on the specific hydrogeological background of Jingtai County. By monitoring the high-frequency isotopic composition of alfalfa during its growing season in this specific region, we aim to reveal the micro-regulatory role of sprinkler irrigation, a highly efficient water-saving method, on the regional water cycle under local climatic conditions. The revised paragraph will focus on the following discussion: Although the dynamics of irrigation water in arid regions are well-known, the use of isotopic techniques to quantitatively separate evaporation losses from deep percolation in composite systems like the Jingdian Irrigation District, which combine Yellow River water replenishment, sprinkler irrigation technology, and arid forage planting, still holds significant regional scientific and practical value.

5.93: this is too many significant digits for annual ET, it can't be measured nearly that accurately with flux measurements or other techniques.

We sincerely appreciate the reviewers' corrections regarding the rigor of data science. The reviewers pointed out that the annual evapotranspiration (2365.9 mm) contained an excessive number of significant figures, which indeed overlooked the inherent uncertainties in hydrological measurements.

We fully acknowledge that current observational techniques (e.g., meteorological station estimates or flux measurements) cannot support precision to one decimal place. In the revised draft, we will adhere to the conventions of hydrological studies in arid regions by rounding this value to a whole number without decimal places (i.e., 2366 mm). We will simultaneously verify all water balance-related items (precipitation, irrigation volume, storage changes) in the text to ensure their significant figures align with the precision of measuring instruments (e.g., rain gauges with 0.1 mm accuracy). We will avoid using false precision (exceeding physical measurement capabilities) in annual macro-scale summaries.

6. Fig. 1 upper left: font sizes too small to read.

We appreciate the reviewers' detailed feedback on the quality of the figures. We fully recognize the importance of figure clarity in enabling readers to understand the research context. Regarding the issues identified in the upper-left corner illustration of Figure 1 (the regional map section), we will implement the following improvements in the revised manuscript:

We will significantly enlarge the text in the sub-figure at the upper left corner of Figure 1 (including latitude/longitude annotations, place names, and legend text) to ensure clear readability in both standard print and electronic reading dimensions. The revised Figure 1 will be exported at higher resolution to enhance the distinctiveness of boundary lines and sampling station markers on the map. We will bold the guide line from the regional map to the Jingtai experimental field in the schematic diagram and optimize the layout between sub-figs (a) and (b) to help readers intuitively establish connections from macro-scale regions to micro-scale sections.

7.174: specify that this is the FAO Penman-Monteith equation. It's not what would be derived from the Penman-Monteith assumptions; it's adjusted to use commonly measured micrometeorological variables at a daily time step.

We sincerely appreciate the reviewers' corrections regarding the accuracy of formula definitions. The reviewers accurately identified the shortcomings in the original text when describing the potential evapotranspiration (PET) calculation method. We will make the following revisions in the revised manuscript as suggested:

In line with the reviewers' recommendations, we will explicitly state in line 174 that Equation (2) employs the FAO Penman-Monteith equation. We will further clarify that this equation represents a modified version with parameterized adjustments for daily time-step calculations. The equation is presented as a simplified form based on original physical assumptions, designed to accommodate data availability in engineering applications, thereby demonstrating a more rigorous academic understanding throughout the text.

8.203: why is the equation multiplied by 10?

We appreciate the reviewers 'attention to the formula details. In formula (4) $S = R \times W \times H \times 10$, the coefficient 10 is a unit conversion constant designed to standardize the calculation results into the commonly used millimeter (mm) unit in hydrology. The specific conversion logic is derived as follows: Input units: The unit of soil bulk density R is g/cm^3 (equivalent to the density ratio of water), the weight moisture content W is expressed as a decimal (g/g), and the soil layer thickness H is measured in centimeters (cm). Intermediate calculation: $R \times W \times H$ yields the equivalent height of water in the soil layer, measured in centimeters (cm). Unit conversion: Since 1 cm = 10 mm, the coefficient 10 must be multiplied to report soil water storage capacity S in millimeters (mm). In the revised manuscript, we will follow the reviewers' previous recommendations to perform dimensional normalization on formulas (4) and (5), and explicitly label the units of each variable and the physical meaning of the conversion coefficients in the text to ensure transparency and reproducibility in the storage capacity calculation process.

9.Figure 2 is hard to read, it's not immediately apparent why 2021 and 2023 are shown, and I was surprised that depth is going upward in the figure rather than using negative values for depth so that one doesn't have to interpret it standing on their head.

We sincerely appreciate the reviewers' constructive suggestions for Figure 2. Their critique regarding the orientation of the depth axis is highly pertinent. In soil science and isotope hydrology, the use of negative values or a downward-increasing depth axis aligns more intuitively with scientific logic. The current presentation format indeed causes unnecessary confusion for readers.

We will reconstruct Figure 2 as follows: We will completely invert the vertical axis of Figure 2 and adopt negative depth values consistent with hydrological conventions (i.e., extending downward from 0 cm to-100 cm). This will enable readers to intuitively observe the vertical dynamic evolution of isotopic signals and water from the surface to deeper layers without requiring mental switching. In our study, we present data from 2021 and 2023 (2022 data is not shown due to incomplete availability), aiming to enhance the robustness of conclusions through comparisons under different precipitation backgrounds. There are differences in precipitation and temperature distributions between 2021 and 2023 during the alfalfa growing season (see revised Figure 4). By comparing the heatmaps of these two years, we can demonstrate that the rapid isotopic response induced by sprinkler irrigation follows a consistent physical pattern under different climate variations. We will explicitly explain the rationale for the year selection at the beginning of the results section (Section 3.1) in the revised manuscript.

We will re-optimize the color bar of the heat map and add gridlines at different depths to better highlight the spatiotemporal variations of δ^2H, $\delta^{18}O$, and the lc-excess. By adjusting the resolution of the color blocks, we aim to make the downward movement of the infiltration front more clearly visible in the visualization.

10.240: was precipitation not measured?

We sincerely appreciate the reviewers 'thoughtful feedback. Our study has indeed conducted rigorous quantitative observations and sampling of precipitation. The initial draft's direct transition into isotope feature interpretation without adequately emphasizing meteorological monitoring data caused this misunderstanding. In the revised manuscript, we will provide the following clarifications and supplements:

A China standard rain gauge (CSPG) was installed in the experimental field to record the precipitation of each rainfall event in real time (with a precision of 0.1 mm). During the observation periods in 2021 and 2023 (May to September), we collected and analyzed a total of 110 precipitation samples.

We will add a detailed description of meteorological conditions during the observation period at the beginning of the results section, explicitly reporting monthly precipitation amounts and frequency. The revised Figure 4 will provide a detailed temporal distribution of these precipitation events, offering essential background information for understanding soil moisture dynamics. Although precipitation was measured, the observed results showed that the isotope signal of precipitation was not significant in soil water. This is because the intense surface evaporation in arid regions causes a small amount of precipitation to be lost before infiltration, and the strong signal from frequent sprinkler irrigation (using Yellow River water with lower isotopic values) masks the characteristics of precipitation input.

11. the eye can't discern the different colors for 10 different depths in figure 3. The results section should probably start with meteorological conditions during the study period in fig. 4.

We fully endorse the reviewers' observations. Figure 3 attempts to present the isotopic characteristics of 10 soil layers in a scatter plot, where excessive color categorization indeed caused visual overlap and reduced readability. Moreover, it is more logical to first introduce the meteorological background before discussing the hydrological response. We will implement the following improvements:

We will reorganize Section 3. The revised version will begin with Section 3.1, Meteorological Conditions During the Study Period (Original Figure 4), first reporting the distribution of temperature, relative humidity, and precipitation events to establish a physical background for subsequent analysis. Section 3.2 will then introduce the response of soil water storage and isotopic characteristics. Instead of assigning colors to the 10 depths individually, we will divide the 0–100 cm profile into three physically meaningful zones: surface layer (0–20 cm), middle layer (20–60 cm), and deep layer (60–100 cm). A more contrastive color scheme will be used, and different-shaped symbols (e.g., circles, triangles, squares) will be added to distinguish these depth zones. We will ensure that Figure 4 not only displays data but also more directly reflects the temporal nodes of extreme weather events or irrigation pulses during the sampling period.

12. Fig. 5: why is only one year shown? The study wasn't explained very well.

We sincerely appreciate the reviewers' feedback. We acknowledge that the initial draft inadequately explained the experimental cycle and data selection criteria for the charts, which caused confusion among readers. The manuscript will be revised as follows: Although this study covers two full growing seasons (2021 and 2023), Figure 5 was designed to demonstrate the seasonal dynamics of soil water storage under typical climatic conditions. This was because the sampling frequency and meteorological records for that year were the most complete and representative. To address this concern, we will supplement the revised manuscript with data from another year (2023) or clarify the compilation logic of the data (e.g., whether it represents a multi-year average or a representative year) in the legend to enhance the comprehensiveness of the results.

We will revise Section 2.2 (Plotting and Sample Collection) to include a detailed experimental design framework, clearly outlining the specific tasks, sampling frequency, and differences in meteorological background for the two observation years. The study explicitly adopts a dual observation strategy combining 'short-term intensive sampling' (for irrigation events) with 'long-term seasonal monitoring' (for the growing season scale).

In line with your suggestion, we will begin Section 3 by presenting the meteorological background during the study period (Figure 4), which provides the physical basis for interpreting changes in water storage (Figure 5) and isotopic composition (Figure 2/3). We will verify the data in Figure 5 to ensure logical consistency with the soil physical parameters reported in Table 1, including bulk density and corrected water content.

13. Why is Fig. 6 in the results and not the introduction as a conceptual figure?

We extend our sincere gratitude to the reviewers for their insightful observations and constructive feedback. We fully endorse their perspective that Figure 6 fundamentally serves as a conceptual schematic illustrating the physical mechanisms governing water storage, vertical transport, and potential loss pathways in irrigated pastures within arid regions. Placing this figure in the results section may mislead readers into believing it was entirely derived from the experimental observations, thereby obscuring its role as a conceptual framework. To address this, we will implement the following revisions in the revised manuscript:

We will explicitly label the figure as a conceptual diagram in the caption, emphasizing that it is based on existing arid zone hydrological theories and regional irrigation characteristics. This diagram aims to assist in interpreting the vertical migration and mixing processes observed through isotopic data.

14. I was expecting an analysis of plant water use through transpiration, which is conventionally understood to not discriminate against heavy isotopes but there are a few interesting studies and syntheses suggesting that it might happen a bit (https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.13461). My takeaway from the analysis presented here is that it's not really at the state of the science.

We are deeply grateful to the reviewers for sharing their cutting-edge perspectives and related literature (Barbeta et al., 2020). The reviewer's observation that' isotopic fractionation may occur during water uptake and transpiration in plant roots' represents one of the most challenging frontier topics in the field of stable isotope eco-hydrology.

We acknowledge that in the current draft, we adhered to the traditional "steady-state assumption," which posits that water uptake by plant roots does not undergo fractionation. This simplified approach indeed fails to adequately reflect the latest advancements in the field in the present analysis. In response to this criticism, we propose the following improvements in the revised draft:

（1）In Section 4.2, we will present a dedicated discussion on isotopic asymmetry or fractionation effects in plant water use. Drawing on reviewer-recommended literature and relevant reviews, we will examine how subtle isotopic discrimination during alfalfa water uptake may influence our estimation of soil water mixing ratios (Eq. 8) and E/ET allocation.

（2）As noted by the reviewers, neglecting this fractionation may lead to misjudgment of the contribution ratio to water sources. We will incorporate this "biological fractionation uncertainty" into the discussion of study limitations, explaining that it may result in a slight overestimation or underestimation of the infiltration contribution ratio of irrigation water.

（3）In the conclusion, we will add that although this study is based on physical mass balance, future research needs to combine plant physiological observations (e.g. comparing xylem water with in-situ soil water) to analyze the water cycle in arid farmland at a higher scientific frontier level.

（4）The core objective of this study is to use isotopes as tracers to delineate the dynamics of soil physical water induced by sprinkler irrigation, while the detailed fractionation mechanisms at the plant physiological level represent the next direction for further exploration.

15.376: were different irrigation practices really studied? I didn't see sufficient information in the figures to this effect.

We sincerely appreciate the reviewers 'inquiries regarding the rigor of experimental comparisons. This feedback has reminded us that the original manuscript's description of 'irrigation practices' may have caused confusion. In the revised manuscript, we will provide the following clarifications and improvements:

We acknowledge that the primary objective of this study was not to conduct parallel control experiments in the field comparing different irrigation methods (e.g., drip irrigation vs. sprinkler irrigation). The phrase 'the impact of different irrigation patterns' (line 376) in the text actually refers to the performance of sprinkler irrigation observed in this study under arid conditions, as well as theoretical discussions based on these observations regarding future improvement strategies (e.g., nighttime sprinkler irrigation, low-position multi-point sprinkler irrigation).

The reviewer's observation that' the chart lacks relevant information' is entirely accurate. To address this, we will supplement Section 2.2 with detailed operational parameters of the sprinkler system used in this experiment, including nozzle height, irrigation intensity, duration of each irrigation session, and irrigation quotas. We will ensure that Figure 4 (Meteorological and Water Input Chart) clearly displays the timing of each sprinkler event and the corresponding irrigation volume, enabling readers to verify the direct correlation between water dynamics and irrigation practices.

We will revise the discussion in lines 376-384, changing it from 'studied different irrigation practices' to 'evaluated the efficiency of current sprinkler practices and explored the feasibility of optimization strategies based on in-depth observations of sprinkler irrigation water dynamics.' We will explicitly state that the observation 'different irrigation patterns did not significantly affect soil moisture' is based on preliminary findings of specific sprinkler intensity variations, rather than large-scale cross-strategy comparisons. We will demonstrate how water is stored in the 0-40 cm soil layer and subsequently evaporates and migrates due to evaporation and transport under current sprinkler irrigation practices, using updated Figures 7 and 5, to provide empirical evidence for management recommendations.

16.381; this should be in the results section.

We are deeply grateful to the reviewers for their professional guidance on the logical structure of the paper. The reviewers pointed out that the descriptions of "water movement stabilizing 72 hours after irrigation" and "soil moisture and isotopic characteristics returning to pre-irrigation levels after 9 days" represent directly observed experimental phenomena rather than mechanistic discussions, and should therefore be categorized under the "Results" section. We will make the following adjustments:

We have fully relocated the description of the observed temporal nodes of water dynamics from lines 381-386 of the manuscript to Section 3.2 (Soil Water Storage Dynamics) or Section 3.3 (Vertical Transport Model) in the Results section. In the "Results" section, we will focus on describing the temporal variations observed in Figure 7, such as the active changes in water content within 24 hours and the subsequent flattening after 72 hours. In the "Discussion" section, we will retain only explanations of the underlying physical mechanisms (e.g., the balance between evaporation fractionation and capillary action), thereby clarifying the boundaries between "empirical" and "analytical" sections throughout the paper. Through this adjustment, the Results section will first present the meteorological background (Figure 4), followed by the evolution of water storage and isotopic characteristics (Figures 2, 5, 7), and finally summarize the typical cycles of water transport.