



OPEN ACCESS

EDITED BY

Taiyi He,
Southwestern University of Finance and
Economics, China

REVIEWED BY

Zhaoxin Huo,
Capital University of Economics and
Business, China
Marcela Guerrero,
Centro de Investigaciones y estudios
Ambientales (CINEA), Argentina
Yaxin Zhang,
Henan Finance University, China

*CORRESPONDENCE

Yuexiao Zhai
✉ ruc_zyx@163.com

RECEIVED 11 December 2025

REVISED 10 February 2026

ACCEPTED 10 February 2026

PUBLISHED 27 February 2026

CITATION

Zhang Y and Zhai Y (2026) Beyond
policy fatigue: how environmental
literacy shapes sustainable grazing in
China's pastoral regions.
Front. Sustain. Food Syst. 10:1765434.
doi: 10.3389/fsufs.2026.1765434

COPYRIGHT

© 2026 Zhang and Zhai. This is an
open-access article distributed under
the terms of the [Creative Commons
Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use,
distribution or reproduction in other
forums is permitted, provided the
original author(s) and the copyright
owner(s) are credited and that the
original publication in this journal is
cited, in accordance with accepted
academic practice. No use, distribution
or reproduction is permitted which does
not comply with these terms.

Beyond policy fatigue: how environmental literacy shapes sustainable grazing in China's pastoral regions

Yitong Zhang¹ and Yuexiao Zhai^{2*}

¹School of Economics and Management, Fujian Agriculture and Forestry University, Fuzhou, China,

²School of Agricultural Economics and Rural Development, Renmin University of China, Beijing, China

Grassland degradation poses severe ecological and socio-economic risks in China's pastoral regions. The effectiveness of top-down policies is often constrained by high enforcement costs, low compliance, and a lack of intrinsic motivation among stakeholders. To address this research gap, this study introduces a novel behavioral perspective by examining environmental literacy as a complementary, bottom-up mechanism for sustainable grassland management. Using unique micro-level survey data from 273 herder households in Gansu and Qinghai provinces, we construct a composite index for environmental literacy. Empirically, we employ instrumental variable (IV) regression to establish causality and mediation analysis to unpack the underlying pathways. The empirical results demonstrate that higher environmental literacy significantly reduces grazing intensity and the likelihood of overgrazing. These effects operate primarily through these two mediating channels: enhancing ecological cognition and improving environmental information-processing capacity. Furthermore, we identify a disconnect between attitude and action, where pro-environmental attitudes alone rarely translate into sustainable practices without the requisite knowledge and skills. This study provides one of the empirical assessments of the role of environmental literacy in pastoral systems, highlighting its potential to complement formal institutions and foster more adaptive, self-regulated grazing behaviors. The findings offer important insights for designing integrated policies that promote ecological sustainability and livelihood resilience in China's pastoral regions.

KEYWORDS

cognitive engagement, environmental literacy, grassland management, grazing behavior, herder

1 Introduction

Grassland degradation presents a severe and escalating ecological crisis across China's pastoral regions, threatening both environmental stability and local livelihoods. Driven by climate change and intensive anthropogenic pressures, over 50% of grasslands in arid and semi-arid zones have undergone significant degradation (Julia Ihli et al., 2022; Lü et al., 2025), manifesting in biodiversity loss, widespread soil erosion, and advancing desertification (Feng et al., 2021; Su et al., 2021). This deterioration not only undermines the ecological services, including carbon sequestration and climate regulation (Bardgett et al., 2021; Huang et al., 2024), but also jeopardizes the socioeconomic sustainability of pastoral communities dependent on these

ecosystems.

Despite sustained policy efforts, governance outcomes have remained inconsistent and often unsatisfactory. Since the 1990s, top-down programs like the Grain to Green Program (GGP) and the Grassland Ecological Compensation Policy (GECGP) have relied chiefly on administrative mandates and economic incentives—such as grazing bans and subsidies—to alleviate pasture pressure (Lu et al., 2018; Qiu et al., 2022). While localized ecological improvements have been documented (Allington et al., 2017; Wang et al., 2018; Liu et al., 2023; Dong et al., 2024), these interventions have frequently failed to induce lasting behavioral change among herders. In some cases, grazing intensity has even increased following policy implementation, reflecting a disconnect between regulatory design and on-the-ground practices (Hu et al., 2019; Ding et al., 2022; Runa et al., 2025). Scholars attribute these limitations to a persistent institutional gap: an overreliance on centralized control that neglects the agency, knowledge, and intrinsic motivations of local stakeholders (Qiu et al., 2020; Ran, 2013; Zhou et al., 2022). As a result, policy fatigue has emerged, characterized by diminishing returns from repeated, externally imposed interventions.

This governance impasse raises a pivotal question: Can sustainability be more effectively advanced through micro-level cognitive engagement rather than solely through top-down enforcement? Shifting the focus to herders' internal drivers, this study introduces environmental literacy as a critical cognitive governance mechanism capable of complementing formal institutions. Environmental literacy, understood as a multidimensional construct encompassing ecological knowledge, pro-environmental values, and behavioral competencies, provides individuals with the cognitive foundation to understand, value, and respond to environmental challenges (Blasch et al., 2017). Originating from the concept of basic literacy, the term has been extended to various domains such as energy, health, and climate, denoting the knowledge and skills necessary for informed decision-making in specific fields (Howell, 2018; He et al., 2022; Hu et al., 2025). In environmental contexts, it has been shown to significantly promote pro-environmental behaviors across diverse settings, including energy conservation (Schleich et al., 2024), sustainable consumption (Tan et al., 2017), and eco-friendly farming practices (Lin et al., 2025; Yu et al., 2022). By fostering intrinsic motivation and enhancing self-regulated decision-making, environmental literacy may enable herders to adopt and sustain adaptive grazing practices even in settings where external policy enforcement is weak or inconsistent.

However, research on environmental literacy remains notably scarce within pastoral systems. Existing studies have predominantly focused on crop-based agricultural contexts, while the unique socio-ecological dynamics of grazing systems. In these systems, herders often operate with significant autonomy within flexible policy frameworks, a dimension that has been overlooked. Conversely, research on grassland management has heavily emphasized external determinants of grazing behavior, such as policy instruments (Su et al., 2022), market access (Cao et al., 2025), social capital (Shi et al., 2026), and climate stressors (Feng et al., 2023), with limited attention to herders' own cognitive and psychological processes. This dual gap underscores the need to examine whether and how environmental literacy operates as an endogenous catalyst for sustainable grazing in China's pastoral regions. Accordingly, this study seeks to explore the role of environmental literacy in bridging the cognitive and behavioral divide between top-down policy design and on-the-ground pastoral practice,

thereby offering a pathway from policy fatigue to sustained, self-motivated stewardship.

Based on micro-level survey data from 273 pastoral households in Gansu and Qinghai provinces, this study constructs a multidimensional index of environmental literacy encompassing ecological knowledge, environmental values, and related behavioral capacities. Using instrumental variable estimation and mediation analysis, we empirically examine the effects of environmental literacy on grazing intensity and overgrazing, and explicitly investigate the cognitive and informational mechanisms through which these effects operate. We further explore heterogeneity in these relationships across households with different resource endowments. This study makes four main contributions. First, it introduces a cognition-oriented perspective to the study of grassland governance by considering environmental literacy as a potential micro-level factor influencing grazing decisions alongside formal institutions. Second, it develops a systematic and operational measurement framework for environmental literacy, offering a practical tool for quantitative analysis in pastoral and other resource-dependent settings. Third, it conceptualizes and empirically examines two possible channels—ecological cognition and information processing—through which environmental literacy may relate to grazing behavior. Fourth, it identifies substantial heterogeneity in the effects of environmental literacy across herders with differing resource endowments, providing empirical evidence to support the design of more targeted and inclusive grassland management policies. This study offers both theoretical insights and practical implications for promoting sustainable development in pastoral areas through micro-level behavioral mechanisms.

The subsequent sections are arranged as follows. Section 2 introduces the study's theoretical foundation. Section 3 elaborates on the research design, including data sources, measurement construction, and descriptive statistics. Section 4 reports the empirical results. Section 5 summarizes the main conclusions and explores related policy implications.

2 Theoretical framework

2.1 Conceptual definition of environmental literacy

Drawing on existing research, this study conceptualizes environmental literacy as a multidimensional capability that supports individuals in understanding environmental systems and making informed decisions in contexts involving ecological trade-offs. In pastoral settings, herders' environmental literacy refers to their capacity to interpret ecological information, evaluate resource-use choices, and consider potential environmental consequences when managing grassland resources.

Literacy involves a systemic understanding of an issue, and scholars have proposed various frameworks for categorizing individual literacy dimensions. We adopt the classification system of Maurer and Bogner (2020), which conceptualizes environmental literacy as an integration of knowledge, values, and behavior. Environmental knowledge provides the cognitive basis for recognizing ecological processes and constraints, including concepts such as biodiversity, carrying capacity, and climate variability. Such

knowledge can influence how individuals perceive environmental change and assess the implications of resource-use decisions. Environmental values refer to an individual's moral, ethical, and emotional orientations toward environmental issues. These values influence how people prioritize environmental goals relative to other considerations such as income generation or cultural traditions. Environmental behaviors encompass actions that actively promote environmental protection, ranging from daily habits such as waste sorting and energy conservation to deliberate adaptive strategies such as livestock reduction during droughts and avoidance of overgrazing.

Importantly, these three dimensions of environmental literacy are interrelated and operate in a mutually reinforcing manner. Environmental knowledge serves as a foundation for the formation of pro-environmental values, which in turn drive the adoption of environmentally responsible behaviors. In pastoral regions such as Qinghai and Gansu, where ecological fragility intersects with strong livelihood dependence on natural resources, this perspective highlights environmental literacy as a potential micro-level factor in grazing governance.

2.2 Theoretical model

Building on the conceptual foundation of environmental literacy established in Section 2.1, this section develops a formal theoretical model to explicate its influence on herders' grazing decisions. The model posits that herders, as rational economic agents, make grazing choices aimed at maximizing their utility, which comprises both short-term economic returns and long-term ecological benefits. Drawing on the work of Le Coent et al. (2021), we construct a utility maximization model that explicitly incorporates grazing intensity (G) and environmental literacy (EL). The model assumes that herders derive utility from two main sources: First, economic returns from livestock production, which are positively related to grazing intensity due to increased output, but subject to diminishing marginal returns. Second, ecological utility, which reflects the long-term benefits of maintaining grassland health. This component declines as grazing intensity rises, because overgrazing degrades the ecosystem, but its weight in the herder's utility function depends positively on environmental literacy. The utility of herder reducing grazing intensity is denoted as μ , and the utility maximization function can be expressed as:

$$\mu(EL, G) = a(G) + b(EL) \cdot h(G)$$

where $a'(G) > 0$, $a''(G) < 0$ capture the concave economic return function; $h'(G) < 0$, $h''(G) \leq 0$ describe the ecological health function, and $b'(EL) > 0$ indicates that higher environmental literacy increases the relative importance herders assign to ecological well-being in their overall utility.

The herder chooses G to maximize $\mu(EL, G)$. The first-order condition is:

$$a'(G) + b(EL) \cdot h'(G) = 0$$

Given $h'(G) < 0$, an increase in EL raises $b(EL)$, which magnifies the marginal disutility from additional grazing. To satisfy the first-order condition, $a'(G)$ must increase, which requires a reduction in G .

Applying comparative statics yields:

$$\frac{\partial G^*}{\partial EL} = -\frac{b'(EL) \cdot h'(G)}{a''(G)} < 0$$

Since $b'(EL) > 0$, $h'(G) < 0$, and $a''(G) < 0$. This unambiguously implies that an increase in environmental literacy leads to a lower optimal grazing intensity, in other word, EL is negatively associated with G .

Substituting the optimal grazing intensity into the utility function reveals two reinforcing effects of environmental literacy:

$$\mu^*(EL) = \mu(EL, G^*(EL))$$

The total derivative with respect to EL is:

$$\frac{d\mu^*}{dEL} = \mu_E + \mu_G \cdot \frac{\partial G^*}{\partial EL} < 0$$

At the optimum, the FOC ensures $\mu_G = 0$, so the expression simplifies to:

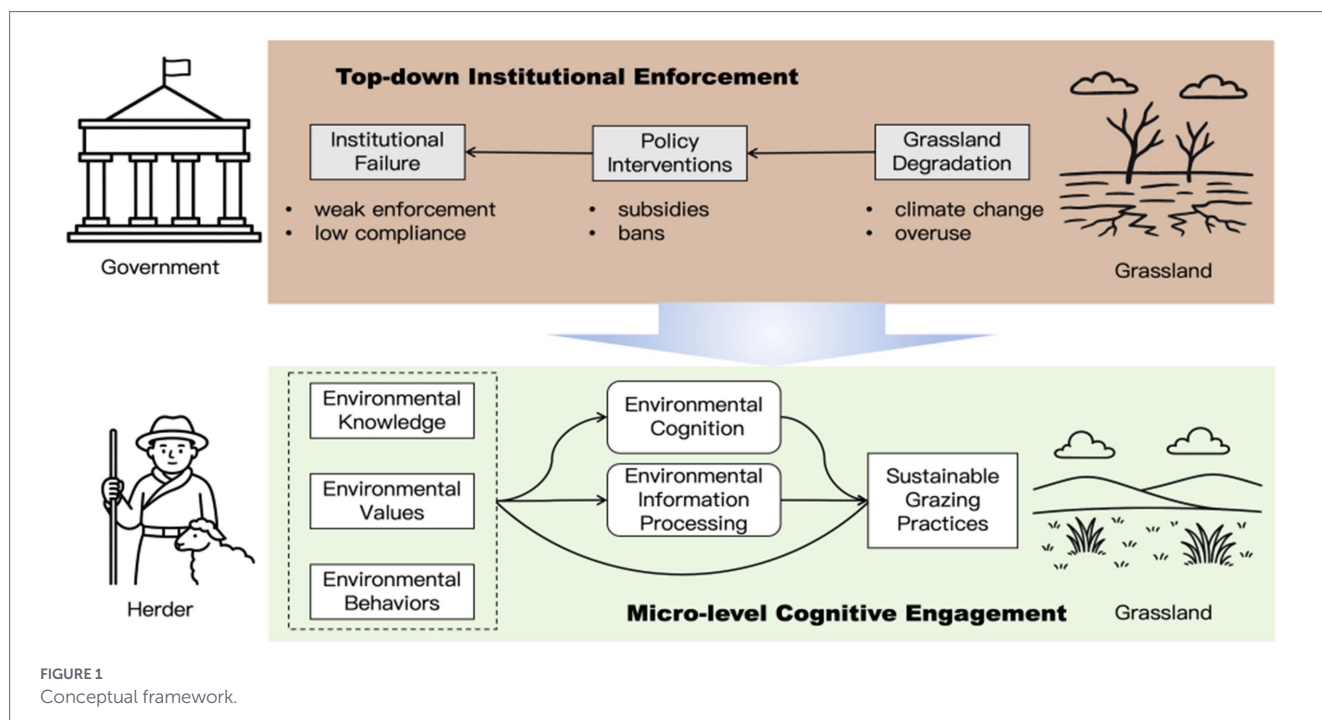
$$\frac{d\mu^*}{dEL} = \mu_E$$

Where $\mu_E > 0$ captures the direct effect of environmental literacy on utility. This result demonstrates that environmental literacy increases the weight placed on ecological well-being within the utility function, thereby enhancing overall utility even in the absence of changes in production output. Moreover, through its influence on optimal grazing intensity, higher environmental literacy reduces ecosystem degradation, sustaining elevated ecological utility over the long term.

2.3 Theoretical analysis

Building on the utility maximization framework, we incorporate the Theory of Planned Behavior (TPB) to capture the psychological and social drivers that may not be fully reflected in the economic model. According to TPB, behavior is guided by three key components: attitudes, perceived social norms, and perceived behavioral control (Ajzen, 2011). Variations in herders' environmental literacy levels lead to significant differences in their attitudes toward sustainable versus unsustainable grazing behaviors. This integrated approach enables us to investigate both the direct and indirect pathways through which environmental literacy influences grazing behavior (Figure 1), providing a behavioral science lens for interpreting the statistical relationships revealed in the empirical analysis.

From an indirect perspective, environmental literacy is expected to operate primarily through two interrelated dimensions: ecological cognition and information processing capacity. First, environmental literacy may enhance herders' ecological cognition. This involves not only the accumulation of ecological knowledge and practical experience but also the gradual formation and internalization of pro-environmental values (Yu et al., 2022). With stronger ecological cognition, herders may place greater importance on the long-term productivity and sustainability of



local rangelands, which in turn can influence how they evaluate grazing intensity, seasonal timing, and resource use strategies. In this sense, environmental literacy contributes to reshaping attitudes toward the relationship between livelihoods and ecological conditions. Second, environmental literacy may improve herders' ability to acquire, interpret, and utilize environmental and policy-related information. Herders with higher literacy are more likely to understand forage growth cycles, climate variability, and early signals of pasture degradation, and to connect these factors with production outcomes. They may also be more capable of interpreting policy guidelines, technical recommendations, and institutional incentives related to grassland management (Yang et al., 2021). Through this enhanced information-processing capacity, environmental literacy can influence how herders assess risks, anticipate environmental change, and adjust grazing arrangements. These cognitive and informational processes are mutually reinforcing: stronger ecological awareness can motivate further information acquisition, while accumulated information may deepen ecological understanding.

From a direct perspective, environmental literacy may strengthen herders' decision-making capacity and facilitate the integration of ecological considerations into everyday production practices (Li et al., 2022). More environmentally literate herders may be better positioned to evaluate trade-offs between short-term economic returns and long-term ecological sustainability, and to explore adaptive management strategies such as adjusting stocking rates, adopting improved forage varieties, or modifying feeding structures during ecologically sensitive periods. Environmental literacy may also influence how herders interpret and respond to policy instruments. A clearer understanding of ecological principles and regulatory objectives can enhance policy comprehension and perceived legitimacy, thereby affecting the likelihood of voluntary compliance and participation in grassland conservation initiatives.

These mechanisms suggest that environmental literacy may influence grazing governance along multiple dimensions: by

shaping attitudes toward ecological protection, strengthening the capacity to process environmental and policy information, and enhancing decision-making under ecological constraints. This framework highlights a set of theoretically grounded pathways through which environmental literacy can be translated into behavioral adjustments in grazing practices. The subsequent empirical analysis is designed to examine whether and to what extent these pathways are supported by the data. Building upon the conceptual framework and theoretical discussion above, this study proposes the following two testable hypotheses:

H1: Herders with higher levels of environmental literacy exhibit significantly lower grazing intensity and a reduced likelihood of overgrazing.

H2: Environmental literacy influences grazing behavior through two primary mechanisms: increased ecological cognition and improved attentiveness to ecological information.

3 Data collection

3.1 Data

Gansu and Qinghai provinces are situated in the arid and semi-arid ecological zone of northwest China, where grassland covers approximately 13.5% of the country's usable grassland area and supports 12% of the national livestock population, highlighting their critical ecological role. In recent years, under the combined pressures of climate change and intensified human activities, over 45% of the grassland in these two provinces has experienced degradation, characterized by vegetation decline, the spread of toxic weeds, and soil desertification, posing a threat to ecological security at both regional and broader scales. Qinghai and Gansu

were selected as study areas due to their typicality and representativeness: both are located in the transition zone between the Tibetan Plateau and the northern grasslands, encompassing major grassland types such as alpine meadow and temperate steppe. These regions exhibit pronounced ecological vulnerability, deep-rooted pastoral traditions, and a long history of implementing grassland ecological compensation policies, making them well-suited to reflect the common governance challenges faced in China's pastoral regions. Through scientifically designed stratified sampling and in-depth interviews, the sample obtained in this study demonstrates strong representativeness in terms of both grassland types and socio-ecological processes, thereby providing a solid basis for the research conclusions.

A multi-stage sampling approach was employed to gather household-level data from these areas, in 2020. In the initial stage, 2–3 counties with extensive grassland coverage and 2–3 with limited coverage were randomly selected from each province. Subsequent stages included: (1) random town selection within counties, ensuring proportional grassland type representation; (2) random village selection within towns; and (3) random selection of 5–8 herder households per village. Structured interviews were conducted with household heads using detailed questionnaires, which gathered comprehensive data on household demographics, livestock production, grassland management practices, income sources, and other relevant socioeconomic and ecological variables. After excluding entries with missing values or serious logical inconsistencies, the final dataset comprises 273 herder households from 10 counties, 30 towns, and 59 villages (Figure 2).

3.2 Method

To investigate the relationship between herders' environmental literacy and their grazing practices, we implement the following regression model:

$$Y_i = \alpha_0 + \alpha_1 Env_literacy_i + \alpha_2 Controls_i + \varepsilon_i$$

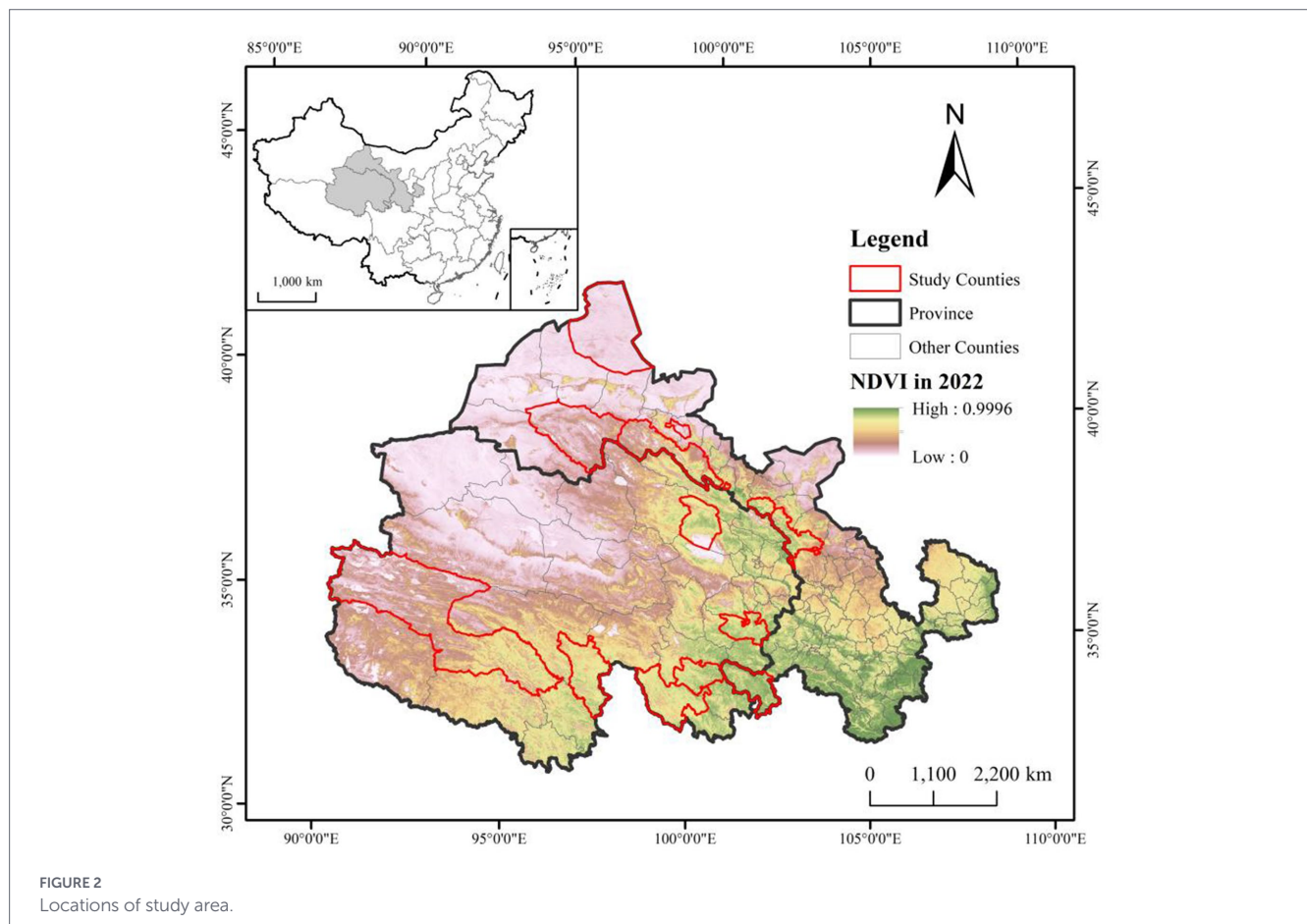
Where Y_i denotes either grazing intensity (*Grazing intensity*) or overgrazing behavior (*Overgrazing*) of household i , $Env_literacy_i$ represents herders' environmental literacy. $Controls_i$ includes control variables at the individual and household level. ε_i is an error term. α_0 , α_1 and α_2 are (vectors of) coefficients to be estimated.

The OLS estimation may cause biased results due to potential endogeneity between environmental literacy and grazing intensity, as unobserved confounding factors may simultaneously affect both through the error term. To address this issue and achieve unbiased identification of the causal effect, we employ an instrumental variable (IV) approach using two-stage regression methods. Specifically, we apply 2SLS and LIML estimators.

3.3 Key variables measurement and sample characteristics

3.3.1 Dependent variable

Following standard practices in the literature (Su et al., 2021; Tóth et al., 2018), grazing intensity at the household-level (*Grazing*



intensity) is defined as the total number of livestock—converted into standardized sheep-equivalent units—divided by the household's total managed grassland area (measured in mu). When calculating the total livestock, we also excluded the livestock animals primarily raised with supplemental feed to focus on ecologically impactful grazing (Qiu et al., 2020). An additional dependent variable, *Overgrazing*, represents the degree to which actual grazing intensity exceed sustainable thresholds, calculated as observed grazing intensity relative to the grassland's livestock carrying capacity (LCC), which represents the ecologically optimal stocking level for ensuring the long-term sustainability and productivity of grassland resources (Qiu et al., 2020). LCC data were collected through surveys in which herders were asked to report the official stocking limits set by higher-level authorities. If a herder was uncertain about these official figures, the village-level carrying capacity reported by the village head was used. In cases where village-level data were unavailable, we referred to the county-level LCC standards provided in the National Agricultural Industry Standard No. NY/T635-2015 (Ministry of Agriculture, 2015). *Overgrazing* thus captures the extent to which actual stocking exceeds sustainable thresholds, with higher values indicating greater ecological pressure. Specifically, when the value of *overgrazing* exceeds 1, it implies that the grazing intensity has surpassed the land's ecological capacity, indicating a state of ecological overexploitation.

3.3.2 Key independent variable

To capture the three dimensions of environmental literacy outlined in Section 2.1, we employ nine survey questions, as detailed in Table 1. Factor analysis is utilized to construct a composite environmental literacy index at the household level, serving to reduce the dimensionality of interrelated indicators into a set of latent constructs. This method enhances analytical clarity and efficiency by addressing multicollinearity and preserving the underlying structure of the data. Compared to alternative index construction approaches, factor analysis offers several key advantages: it eliminates the need for arbitrary weighting of indicators, is grounded in a solid theoretical framework, and explicitly accounts for inter-variable correlations. These features contribute to a more reliable and theoretically consistent measure of environmental literacy.

In line with existing literature, we also include a set of control variables that may influence herders' grazing behaviors. These are grouped into two categories: (1) characteristics of the household head, including age and education level, and (2) household-level attributes,

such as household size, total income, distance to township center, and total grassland area managed.

3.3.3 Instrumental variables

This study employs two instrumental variables (IVs) to address potential endogeneity in environmental literacy. The first IV is the village-level average environmental literacy, excluding the respondent's own household (*Env_literacy_village*). This variable captures peer-level cognitive exposure and shared informational contexts, reflecting how an individual herder's literacy is shaped by the local knowledge environment. By excluding the respondent's own value, it also reduces concerns related to individual-specific unobservables such as personal experiences or attitudes. The second IV is a dummy variable indicating whether the village has customary regulations for grassland protection and grazing management (*Informal*). Rather than functioning as binding enforcement mechanisms, such regulations are conceptualized as informal normative settings that influence herders' awareness, discussion, and interpretation of environmental issues. In many pastoral areas, these rules are weakly enforced and operate mainly through social communication and normative signaling. Thus, their effect on grazing behavior is hypothesized to be mediated through cognitive and perceptual channels rather than through direct coercion. Since both instruments are determined at the village level and are unlikely to be influenced by unobserved individual-level factors, they satisfy the relevance and plausibly satisfy the exogeneity conditions required for IV estimation.

3.3.4 Sample characteristics

Descriptive statistics for all study variables, drawn from 273 surveyed herder households in Gansu and Qinghai, are summarized in Table 2. *Grazing intensity* is 0.36, indicating that, on average, herders graze 0.36 sheep-equivalent units per mu (1 ha = 15 mu) of grassland. Regarding *Overgrazing*, the average value is 2.78, implying that, on average, actual grazing exceeds the livestock carrying capacity by more than twice, with some households facing severe overgrazing (up to 53.46). *Env_literacy*, representing the composite environmental literacy score constructed via factor analysis, is normalized with a mean of zero and a standard deviation of 0.62. The average age of household heads is approximately 50 years, with most having received only limited formal education (2.85 years on average). Households consist of

TABLE 1 Components and survey indicators of environmental literacy.

Component	Survey question	Mean	S.D
Knowledge	1 if herder has perception to local climate change, and 0 otherwise	0.908	0.289
	1 if herder has heard of the term "Ecological Environment," and 0 otherwise	0.725	0.447
	1 if herder has heard of the term "Grassland Ecosystem," and 0 otherwise	0.579	0.495
	1 if herder agrees that reduce livestock can protect grassland, and 0 otherwise	0.810	0.393
Values	1 if a herder agrees that grassland provides forage for livestock, and 0 otherwise	0.949	0.221
	1 if a herder agrees that grassland regulates the climate, and 0 otherwise	0.791	0.407
	1 if a herder agrees that grassland can be used for recreation and tourism, and 0 otherwise	0.846	0.361
Behavior	1 if a herder adopts rotational grazing, and 0 otherwise	0.322	0.468
	1 if a herder adopts supplementary feeding, and 0 otherwise	0.322	0.468

TABLE 2 Descriptive statistics of key variables (N = 273).

Variables	Descriptions	Mean	S.D	Min	Max
Dependent variables					
<i>Grazing intensity</i>	Grazing intensity at the household-level	0.355	0.811	0	8.224
<i>Overgrazing</i>	Deviation of grazing intensity from ecological carrying capacity	2.780	5.284	0	53.459
Exploratory variables					
<i>Env_literacy</i>	Herders' environmental literacy calculated by factor analysis method	0	0.623	-1.705	0.888
<i>Knowledge</i>	Factor score of ecological knowledge	0	1	-2.762	0.983
<i>Values</i>	Factor score of ecological values	0	1	-4.004	0.901
<i>Behavior</i>	Factor score of ecological behavior	0	1	-1.777	2.670
<i>Age</i>	Age of household head	50.274	10.994	25	96
<i>Education</i>	Schooling years of household head	2.846	3.949	0	16
<i>Household income</i>	Household income in the previous year ($\times 10^4$ yuan)	11.313	11.698	0	77.850
<i>Household size</i>	Total persons per household	4.670	1.827	1	12
<i>Grassland area</i>	Household grassland holding area ($\times 10^4$ mu)	0.990	2.967	0.002	31.2
Instrumental variables					
<i>Env_literacy_village</i>	Average environmental literacy of household within the same village after excluding the respondent	0	0.367	-1.397	0.840
<i>Informal</i>	1 if the village has customary rules and informal institutions for grassland protection and grazing management, and 0 otherwise	0.553	0.498	0	1
Mechanism variables					
<i>Env_importance</i>	Herder's evaluation of village environmental importance (1 = Not important, 2 = Moderate, 3 = Important)	1.243	0.470	1	3
<i>Policy attention</i>	Frequency of herders' attention to national agricultural/pastoral and ecological policy information (1 = Rarely, 2 = Occasionally, 3 = Weekly, 4 = Several times/week, 5 = Daily)	1.806	1.101	1	5

6.9 yuan = 1 \$; 15 mu = 1 ha.

around 4.67 members, and the average income in the previous year is 113,100 yuan (6.9 yuan = 1 \$). Notably, the surveyed herders manage relatively large grassland areas, averaging 9,900 mu (approximately

660 hectares). Approximately 55.3% of households report that their villages have customary rules and informal institutions for grassland protection and grazing management.

4 Empirical results

4.1 The effects of environmental literacy on herders' behaviors

The OLS regression results reported in Table 3 explore how environmental literacy among herders influences their grazing practices, with particular attention to grazing intensity and overgrazing. Model 1–3 show that *Env_literacy* has a significantly negative effect on grazing intensity across all specifications. In the full model (Column 2), each one-unit rise in environmental literacy corresponds to a 0.123-unit decrease in *Grazing intensity*, statistically significant at the 5% level. When regional dummies are aggregated to the province level in Model 3, the estimated effect remains stable ($-0.182, p < 0.01$). Similarly, Model 4–6 demonstrate a significant negative relationship between *Env_literacy* and *Overgrazing*. Coefficient estimates range from -1.259 to -0.740 and are statistically significant at conventional levels, specifically the 5 and 1% thresholds. The analysis reveals that improved environmental literacy among herders is associated with reduced grazing intensity and a lower likelihood of exceeding the sustainable carrying capacity of grassland ecosystems. Among the control variables, evidence from Models 2 and 5 indicates that *Education* is significantly and positively correlated with *Grazing intensity* and *Overgrazing*, with coefficients of 0.036 ($p < 0.10$) and 0.229 ($p < 0.10$), respectively. This finding indicates that better-educated herders may intentionally intensify livestock production due to enhanced capacity to access commercial livestock markets, and adopt productivity-enhancing technologies. *Grassland area*, by contrast, shows a

significant negative effect on both outcome variables ($-0.008, p < 0.01$; $-0.123, p < 0.01$). The potential explanation for this is that larger grazing areas provide greater spatial flexibility, which facilitates the implementation of rotational grazing systems and allows adequate vegetation recovery between grazing cycles.

The initial OLS findings suggest a favorable influence of environmental literacy; however, these estimates may suffer from endogeneity concerns, stemming from unobserved heterogeneity or potential reverse causation. To address this concern, Table 4 presents the results of IV regressions using both 2SLS and LIML estimators. In the first stage, both instruments—*Env_literacy_village* and *Informal*—are strong predictors of individual environmental literacy. The results show positive and statistically significant coefficients—at the 10 and 1% levels—which provide empirical support for the validity of the instruments employed. This result is further supported by the Kleibergen-Paap rk LM statistics (66.344 and 75.923, $p < 0.01$), which provide strong evidence against the null hypothesis that the instrumental variables are exogenous to the endogenous regressor. The second-stage estimates (columns 2–5) corroborate and strengthen the initial OLS findings. The Durbin and Wu–Hausman tests ($p < 0.10$) reject the null hypothesis, supporting the use of an IV estimation for consistency. Furthermore, The Cragg-Donald Wald F-statistic (50.274) exceeds conventional thresholds, alleviating concerns over weak instruments. And the Hansen J-statistics do not reject the overidentifying restrictions, supporting the validity of the instruments. After addressing endogeneity concerns, environmental literacy persists as a statistically significant negative determinant of both grazing intensity and overgrazing. After instrumenting for endogeneity, the magnitude

TABLE 3 Results of OLS regression.

Variables	Grazing intensity			Overgrazing		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
<i>Env_literacy</i>	-0.101^{**} (0.047)	-0.123^{**} (0.049)	-0.182^{***} (0.066)	-0.740^{**} (0.336)	-0.928^{***} (0.349)	-1.259^{***} (0.437)
<i>Age</i>		0.004 (0.003)	0.000 (0.002)		0.025 (0.022)	0.004 (0.016)
<i>Education</i>		0.036* (0.019)	0.034* (0.017)		0.229* (0.125)	0.224* (0.135)
<i>Household income</i>		0.001 (0.004)	-0.008^{**} (0.004)		0.016 (0.026)	-0.037 (0.027)
<i>Household size</i>		-0.025 (0.037)	-0.002 (0.031)		-0.171 (0.244)	-0.089 (0.200)
<i>Distance</i>		-0.001 (0.002)	-0.002 (0.002)		0.005 (0.018)	-0.004 (0.016)
<i>Grassland area</i>		-0.008^{**} (0.004)	-0.047^{***} (0.018)		-0.123^{***} (0.035)	-0.326^{***} (0.118)
Region dummies	County-level	County-level	Province-level	County-level	County-level	Province-level
Constant	0.165*** (0.027)	-0.180 (0.244)	0.545* (0.300)	1.726*** (0.250)	-0.578 (1.654)	3.900** (1.948)
Observations	273	273	273	273	273	273
R ²	0.241	0.264	0.117	0.197	0.224	0.113

The figures in parentheses are standard errors. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

TABLE 4 Results of IV regression.

Variables	Env_literacy	Model 7	Model 8	Model 9	Model 10
	1st stage	2nd stage 2SLS	LIML	2nd stage 2SLS	LIML
<i>Env_literacy_village</i>	0.175* (0.092)				
<i>Informal</i>	0.627*** (0.068)				
<i>Env_literacy</i>		-0.415*** (0.134)	-0.429** (0.182)	-2.654*** (0.977)	-2.725** (1.173)
<i>Age</i>	0.007** (0.003)	0.001 (0.003)	0.002 (0.003)	0.011 (0.030)	0.011 (0.019)
<i>Education</i>	0.013 (0.010)	0.039* (0.022)	0.039* (0.022)	0.254** (0.099)	0.255* (0.141)
<i>Household income</i>	0.009*** (0.003)	-0.005 (0.004)	-0.005 (0.004)	-0.020 (0.033)	-0.019 (0.025)
<i>Household size</i>	0.005 (0.016)	-0.001 (0.030)	-0.001 (0.030)	-0.082 (0.174)	-0.082 (0.195)
<i>Distance</i>	0.000 (0.002)	-0.002 (0.002)	-0.002 (0.002)	-0.001 (0.023)	-0.001 (0.016)
<i>Grassland area</i>	-0.005 (0.007)	-0.051*** (0.019)	-0.051*** (0.019)	-0.350*** (0.108)	-0.351*** (0.125)
Region dummies	Province-level	Province-level	Province-level	Province-level	Province-level
Constant	-1.016*** (0.226)	0.384 (0.298)	0.375 (0.299)	2.940 (2.226)	2.890 (1.924)
Observations	273	273	273	273	273
Kleibergen-Paap rk LM statistic	66.344***		-	75.923***	-
Cragg-Donald Wald F statistic	50.274			50.274	
Durbin	3.460*			2.897*	
Wu-Hausman	3.350*			2.799*	
Hansen J statistic	3.070*			3.712*	

The figures in parentheses are standard errors. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

of the estimated effects grows considerably. Specifically, a one-point increase in environmental literacy leads to a reduction of 0.415–0.429 units in grazing intensity and 2.654–2.725 units in overgrazing, reaching statistical significance at the 5 and 1% thresholds. The pronounced amplification of these coefficients suggests that the original OLS estimates may have been downwardly biased, potentially due to attenuation caused by measurement error or omitted variable bias. This discrepancy highlights the importance of addressing endogeneity to obtain more accurate and reliable estimates of the true effect of environmental literacy on grazing practices.

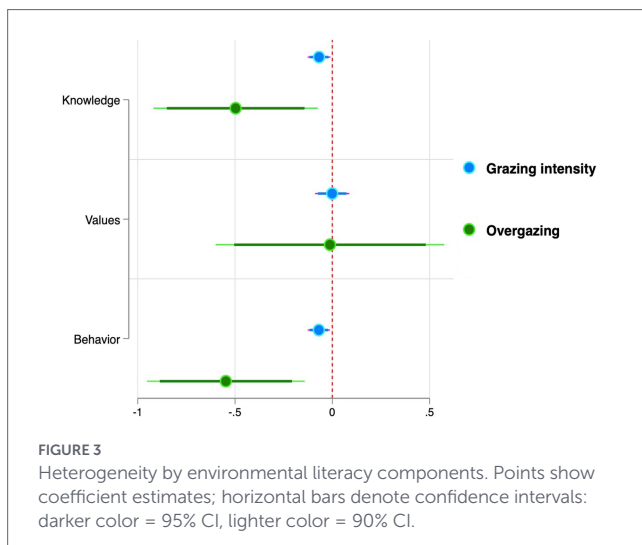
To conclude, evidence from both OLS and IV estimations consistently highlights the significant role of environmental literacy in facilitating the sustainable use of grassland resources. The IV estimates further highlight that failing to account for endogeneity would

underestimate the true impact of environmental literacy on grazing practices.

4.2 Heterogeneous effects

4.2.1 Effects of environmental literacy dimensions on grazing behaviors

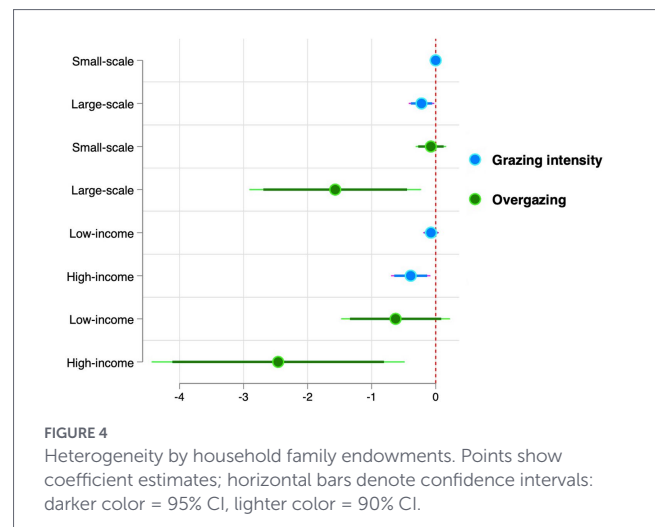
To further elucidate the underlying drivers of the observed effects, we use the three dimensions of environmental literacy, and analyze their respective effects on both grazing intensity and overgrazing. The results, reported in Figure 3, reveal notable heterogeneity among these dimensions. Specifically, both environmental knowledge and behavior show significant negative effects on



herders' grazing intensity and overgrazing. A one-unit rise in the knowledge score results in a 0.068-unit reduction in grazing intensity and a 0.497-unit decrease in overgrazing, both significant at the 5% level. Similarly, environmental behavior is associated with a 0.069-unit ($p < 0.01$) and 0.547-unit ($p < 0.01$) decrease in grazing intensity and overgrazing, respectively. These findings imply that herders' environmental literacy affects grazing behavior primarily through cognitive understanding and practical implementation rather than value-oriented attitudes. This suggests that policy interventions focusing on knowledge dissemination and skill-based behavioral guidance may be more effective in fostering sustainable grassland management than approaches that rely solely on promoting environmental values or awareness. Strengthening practical education and training programs could therefore play a pivotal role in improving ecological outcomes in pastoral regions.

By contrast, the coefficients for environmental values are not statistically significant in either specification. Rather than indicating that values are unimportant, this result may reflect the inherent difficulty of measuring value orientations and their indirect relationship with behavioral outcomes. In particular, value-related influences may operate through knowledge acquisition and behavioral capacities, whose estimated effects absorb part of the marginal contribution of values in the regression framework. From this perspective, the findings are consistent with the idea that capability-related factors mediate how value orientations translate into action.

Accordingly, the results should not be interpreted as evidence that environmental values are ineffective. Instead, they suggest that values alone may be insufficient to generate behavioral change in the presence of practical constraints, institutional conditions, and livelihood pressures. This interpretation aligns with prior research indicating that pro-environmental attitudes do not automatically translate into behavioral adjustments when individuals face capability or resource limitations (Chai et al., 2015). In pastoral contexts, where production decisions are strongly shaped by ecological variability and economic risk, the translation of values into practice is likely to depend on the availability of knowledge, skills, and feasible management options. These findings therefore highlight the importance of strengthening capability-related dimensions, such as practical training, information access, and adaptive management support, while recognizing the foundational role of environmental values in shaping long-term orientations toward resource stewardship.



4.2.2 Effects of environmental literacy on grazing behaviors of herders with different family endowments

Next, we explore whether the effects of environmental literacy vary across different household endowment levels. Figure 4 presents regression results stratified by grassland area (large vs. small) and household income (high vs. low). Among herders managing smaller grassland areas, environmental literacy shows no significant effect on either *Grazing intensity* and *Overgrazing*. In contrast, herders with larger grassland holdings demonstrate significant reductions in both *Grazing intensity* (-0.222 , $p < 0.05$) and *Overgrazing* (-1.569 , $p < 0.05$) associated with environmental literacy. These results suggest that when herders have sufficient land resources, environmental literacy becomes a more influential factor in grazing decisions. The greater spatial flexibility afforded by larger holdings likely enables these herders to translate their ecological knowledge into concrete sustainable practices, such as implementing rotational grazing systems or adjusting stocking rates according to pasture conditions. However, small-scale herders face more immediate livelihood pressures that constrain their ability to implement sustainable practices, regardless of their environmental knowledge.

Regarding income heterogeneity, the effect of environmental literacy is more prominent among high-income households. For this group, environmental literacy is associated with a 0.390-unit reduction in grazing intensity and a 2.460-unit reduction in overgrazing, both significant at the 5% level. However, no significant effects are observed among low-income households. This pattern aligns with the behavioral capacity hypothesis: wealthier herders can better implement environmental knowledge by affording sustainable technologies such as rotational grazing infrastructure, tolerating short-term income losses from stocking reductions, and accessing policy incentives like eco-subsidies that require initial investments. Conversely, poverty constraints may prevent low-income herders from applying environmentally literate practices despite their greater vulnerability to ecological risks.

The above visualization results indicate that the impact of environmental literacy on grazing intensity and overgrazing severity varies across herder groups with different household endowments. To precisely test this difference and present complete estimation results, Table 5 further reports the regression coefficients, standard errors,

TABLE 5 Results of inter-group coefficient heterogeneity tests.

Variables	Grassland area				Income level			
	Small		Large		High		Low	
	Grazing intensity		Overgrazing		Grazing intensity		Overgrazing	
<i>Env_literacy</i>	-0.000	-0.222**	-0.075	-1.569**	-0.390**	-0.073	-2.460**	-0.626
	(0.015)	(0.101)	(0.120)	(0.677)	(0.155)	(0.061)	(0.993)	(0.431)
T-test	-0.221*		-1.494*		0.317**		1.833**	
Observations	137	136	137	136	94	179	94	179

(1) The figures in parentheses are standard errors. * $p < 0.10$, ** $p < 0.05$. (2) T-test is used to examine the significance of coefficient differences between groups. This study employs Fisher's Permutation Test, which is implemented through 1,000 bootstrap resampling.

and statistical tests for inter-group coefficient differences for both groups.

4.3 Mechanism analysis

To investigate the pathways through which environmental literacy influences herders' grazing behavior, we examine two potential mediating factors: (1) herders' recognition of environmental importance, and (2) their frequency of seeking and processing ecological information. As shown in Table 6 (Models 11–12), environmental literacy significantly enhances both mediators. Specifically, a one-unit rise in environmental literacy is linked to a 0.166-unit increase in environmental importance assessment ($p < 0.01$), and a 0.370-unit increase in ecological information attention frequency ($p < 0.01$). These findings indicate that environmentally literate herders demonstrate greater appreciation of grasslands' ecological and productive value, while exhibiting more proactive information-seeking behaviors through channels like village announcements, technical workshops, and peer networks. This dual enhancement of environmental awareness and knowledge acquisition facilitates the adoption of sustainable grazing practices, including strategic supplemental feeding and rotational grazing systems. Our results therefore identify environmental cognition and information engagement as critical transmission channels through which literacy translates into improved grazing management.

4.4 Robustness checks

4.4.1 Treatment effect model

To mitigate potential sample selection bias and reinforce the robustness of our results, we employ a set of treatment effect models, including Inverse Probability Weighted Regression Adjustment (IPWRA), Augmented Inverse Probability Weighting (AIPW), and standard Inverse Probability Weighting (IPW). These methods jointly account for both treatment assignment and outcome modeling, offering doubly robust estimates even in the presence of model misspecification. As shown in Table 7, across all models, environmental literacy consistently exerts a statistically significant effect on both dependent variables. For instance, in the IPWRA model, the ATT for grazing intensity is -0.127 ($p < 0.05$), while that for overgrazing is -0.991 ($p < 0.05$). The direction, magnitude, and significance of these effects are reaffirmed under AIPW

TABLE 6 Mechanism analysis.

Variables	Model 11	Model 12
	Environmental importance assessment	Information attention frequency
<i>Env_literacy</i>	0.166***	0.370***
	(0.047)	(0.096)
Control variables	Yes	Yes
Region dummies	Yes	Yes
Constant	2.605***	1.088***
	(0.222)	(0.407)
Observations	273	273
R ²	0.072	0.214

The figures in parentheses are standard errors. *** $p < 0.01$.

and IPW approaches, lending further support to the validity and stability of our main empirical findings.

4.4.2 CMP estimation

To strengthen the identification strategy, the Conditional Mixed Process (CMP) estimator, as developed by Roodman (2011), is also employed to address endogeneity. CMP jointly estimates the system of equations using full-information maximum likelihood, allowing for correlation in unobservables across equations. In the first stage, the endogenous variable—environmental literacy—is modeled using IVs to isolate exogenous variation. In the second stage, the fitted values from the first equation, along with other relevant control variables, are used to estimate the main outcome variables, namely *Grazing intensity* and *Overgrazing*. By jointly modeling the system, CMP improves estimation efficiency and provides consistent results even in the presence of endogenous regressors and non-independent error terms.

As shown in Table 8 (Model 13–14), both instrumental variables—*Env_literacy_village* and *Informal*—are strong predictors of individual environmental literacy. In the second stage, the estimated effects of environmental literacy on *Grazing intensity* (-0.429 , $p < 0.01$) and *Overgrazing* (-2.725 , $p < 0.01$) remain statistically significant and consistent with IV and OLS results. Moreover, the significant correlation between the error terms of the two stages

TABLE 7 Robustness check using PSM, IPWRA, AIPW, and IPW models.

Estimate	Grazing intensity			Overgrazing		
	IPWRA	AIPW	IPW	IPWRA	AIPW	IPW
ATT	-0.127**	-0.173***	-0.135*	-0.991**	-1.327***	-1.052**
Robust standard	0.072	0.053	0.071	0.496	0.357	0.484

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

TABLE 8 CMP estimation results.

Variables	Model 13		Model 14	
	1st stage	2nd stage	1st stage	2nd stage
	Env_literacy	Grazing intensity	Env_literacy	Overgrazing
<i>Env_literacy_village</i>	0.175*		0.209**	
	(0.091)		(0.089)	
<i>Informal</i>	0.627***		0.620***	
	(0.064)		(0.064)	
<i>Env_literacy</i>		-0.429***		-2.725***
		(0.154)		(0.996)
Control variables	Yes	Yes	Yes	Yes
Region dummies	Yes	Yes	Yes	Yes
Constant	-1.004***	0.375	-1.01***	2.890
	(0.216)	(0.343)	(0.216)	(2.233)
Observations	273		273	
<i>atanrho_12</i>	0.226*		0.205*	
	(0.118)		(0.118)	
Wald chi2	194.90***		189.36***	

The figures in parentheses are standard errors. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

(*atanrho_12* = 0.226, $p < 0.10$) supports the presence of endogeneity, further justifying the use of CMP.

Overall, the robustness checks corroborate the main conclusion: environmental literacy plays a substantial and statistically significant role in mitigating excessive grazing intensity and reducing grassland degradation risk, even after correcting for potential biases.

5 Discussion and conclusions

Grassland degradation remains a critical ecological and socio-economic challenge in China's pastoral regions, where the overstocking of livestock has placed unsustainable pressure on fragile ecosystems. While top-down policy instruments have attempted to curb grazing intensity through subsidies and regulatory controls, their effectiveness has been constrained by high enforcement costs, limited compliance, and insufficient motivation among stakeholders. This study proposes that enhancing herders' environmental literacy could offer a complementary, bottom-up governance mechanism. Based on survey data from

273 households in Gansu and Qinghai, our analysis indicates that higher levels of environmental literacy are associated with a significant reduction in grazing intensity and overgrazing. This association is primarily linked to the knowledge and behavioral capacity dimensions of environmental literacy. By contrast, pro-environmental values do not exhibit a statistically significant direct association once these capability-related dimensions are taken into account. Rather than implying that values are unimportant, this pattern suggests that the influence of values is likely mediated through herders' ecological understanding and their ability to implement adaptive practices. Furthermore, environmental literacy likely influences grazing behavior through two interrelated pathways: by deepening ecological cognition and by strengthening information-processing capacity. These effects, however, are moderated by household endowments, being more pronounced among herders with larger grassland holdings and higher incomes, suggesting that resource availability conditions the translation of literacy into sustainable practice.

This study contributes to two distinct but interconnected strands of literature. First, it refines the theoretical understanding of environmental literacy within resource-dependent communities. While the tripartite model of knowledge, values, and behavior

is well established (Maurer and Bogner, 2020), the results suggest that these dimensions may operate in a conditional and interdependent manner in pastoral systems. The significant roles of knowledge and behavioral capacity, alongside the non-significant direct association of pro-environmental values in the regression models, indicate that value orientations may exert their influence indirectly through cognitive understanding and the ability to implement adaptive practices, rather than through immediate behavioral responses. This interpretation is consistent with discussions in the literature emphasizing the complexity of translating environmental concern into action (Chai et al., 2015). In contexts where livelihood pressures are immediate and resource constraints are binding, actionable knowledge and practical competencies appear to play a more immediate role in shaping behavioral adjustment, while values help orient longer-term attitudes and learning processes. These findings suggest that interventions focusing solely on awareness-raising or value promotion may have limited effects unless accompanied by efforts to strengthen herders' practical capabilities and access to adaptive strategies. Second, this study initiates a dialogue between cognition-oriented perspectives and traditional institutional approaches to pastoral management. Existing research has extensively documented the impacts of policy instruments such as the Grassland Ecological Compensation Policy (Hu et al., 2019) and market forces (Cao et al., 2025). The present findings do not contradict these institutional explanations but point to a complementary micro-level mechanism. Environmental literacy can be understood as an endogenous cognitive framework through which herders interpret and respond to external signals, including policy incentives and ecological information. The heterogeneity analysis further highlights the boundary conditions of this mechanism, showing that its influence is moderated by household endowments. This pattern aligns with studies emphasizing the role of capital and assets in shaping adaptive capacity (Li et al., 2023; Tong et al., 2024), while adding a cognitive dimension by indicating that knowledge and skills are more likely to translate into practice when supported by sufficient resources and opportunities. Taken together, these findings underscore the importance of integrating herders' endogenous capabilities with supportive institutional arrangements, rather than viewing top-down and bottom-up approaches as substitutes.

While this study offers meaningful insights, several limitations call for cautious interpretation and contextualized application of the findings. The relatively modest sample size and the geographic restriction of the data to pastoral areas in Qinghai and Gansu may affect the external validity of the results. Given the substantial heterogeneity in ecological conditions, institutional arrangements, and livelihood structures across China's pastoral regions, the conclusions presented here should be regarded as context-specific rather than universally generalizable. Accordingly, the policy implications derived from this study are intended as indicative and exploratory, providing possible directions for integrating environmental literacy into grassland governance rather than offering prescriptive, one-size-fits-all recommendations.

Against this background, and in line with the empirical evidence, this study supports a shift from an exclusively top-down regulatory approach toward a more integrated model of cognitive-structural co-governance. With due regard to the

forementioned limitations, we propose the following four adaptive and actionable policy directions:

First, design and implement targeted environmental education programs aimed at enhancing herders' ecological cognition. Specifically, policymakers should develop structured training modules focused on deepening understanding of grassland ecosystem functions, grazing-carrying dynamics, and the long-term ecological and socio-economic consequences of overgrazing. These programs should be systematically integrated into existing extension services, herder cooperatives, and community-based conservation initiatives. To ensure effectiveness, educational content should advance beyond general awareness and deliver practical, locally relevant knowledge. This includes skills such as visualizing vegetation recovery cycles, interpreting indicators of grassland health, and estimating sustainable stocking rates. Delivery methods should be participatory and culturally resonant, incorporating local ecological knowledge, employing visual tools, and involving respected community figures to facilitate trust and practical comprehension.

Second, develop and deploy decision-support tools and training to strengthen herders' capacity to process and act on ecological information. This involves creating and disseminating user-friendly, localized resources that assist herders in accurately interpreting environmental signals. Examples include simple pasture health assessment guides, weather and forage forecasting apps, and visual aids for grazing rotation decision-making. Training should focus on practical skills in monitoring grassland conditions, assessing carrying capacity in real time, and adapting management plans in response to seasonal or climatic variability. To ensure these tools are effectively adopted, policy should support the establishment of community-based information hubs, perhaps within herder cooperatives or local extension stations, where herders can regularly access updated data, share observations, and collectively refine grazing strategies. Empowering local facilitators or "ecological liaisons" to demonstrate and coach these skills can further bridge the gap between information awareness and informed action.

Third, focus on herders with low household endowments to facilitate the translation of cognition into action. Multiple constraints in resources, technology, and information prevent herders with limited endowments from translating environmental literacy into sustainable practices. Policies should provide a targeted support system: lower the threshold for technology adoption through microcredit, material subsidies, and skills training; establish community mutual-aid mechanisms to promote equipment sharing and experience exchange, thereby enhancing collective action capacity. This approach ensures the effective linkage between ecological awareness and grazing behavior under conditions of limited endowments.

Fourth, establish an intelligent and collaborative information governance system. The government should integrate data such as meteorological warnings and forage supply and demand to develop a smart pastoral platform, while establishing government-certified diversified information channels to accurately disseminate scientific grazing guidelines, climate forecasts, and policy updates, thereby reaching herder groups with varying levels of cognitive understanding and technological capabilities. At the same time, it is essential to actively expand both online and offline

collaborative networks. By organizing collective activities such as technical training and joint facility development and utilizing communication mechanisms like WeChat groups and village meetings, the exchange of experiences, mutual assistance in resources, and feedback on ecological information among herders can be effectively promoted.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YiZ: Data curation, Writing – original draft, Investigation, Conceptualization, Writing – review & editing. YuZ: Writing – original draft, Formal analysis, Writing – review & editing, Conceptualization, Data curation, Validation.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This research was supported by the National Natural Science Foundation of China (Young Scientists Fund, Category C)(Grant No.72503042), the State Key Program of National Natural Science Foundation of China

References

- Ajzen, I. (2011). The theory of planned behaviour: reactions and reflections. *Psychol. Health* 26, 1113–1127. doi: 10.1080/08870446.2011.613995
- Allington, G. R. H., Li, W., and Brown, D. G. (2017). Urbanization and environmental policy effects on the future availability of grazing resources on the Mongolian plateau: modeling socio-environmental system dynamics. *Environ. Sci. Pol.* 68, 35–46. doi: 10.1016/j.envsci.2016.11.005
- Bardgett, R. D., Bullock, J. M., Lavorel, Y., Manning, P., Schaffner, U., Ostle, N., et al. (2021). Combatting global grassland degradation. *Nature Rev Earth Environ.* 2, 720–735. doi: 10.1038/s43017-021-00207-2
- Blasch, J., Boogen, N., Filippini, M., and Kumar, N. (2017). Explaining electricity demand and the role of energy and investment literacy on end-use efficiency of Swiss households. *Energy Econ.* 68, 89–102. doi: 10.1016/j.eneco.2017.12.004
- Cao, F., Liu, L., Rong, Y., Jiang, N., Zhao, L., Zhang, Q., et al. (2025). Climate change enhances greening while human activities accelerate degradation in northern China's grasslands. *Sci. Total Environ.* 966:178570. doi: 10.1016/j.scitotenv.2025.178570
- Chai, A., Bradley, G., Lo, A., and Reser, J. (2015). What time to adapt? The role of discretionary time in sustaining the climate change value–action gap. *Ecol. Econ.* 116, 95–107. doi: 10.1016/j.ecolecon.2015.04.013
- Craig, C. A., and Allen, M. W. (2015). The impact of curriculum-based learning on environmental literacy and energy consumption with implications for policy. *Util. Policy* 35, 41–49. doi: 10.1016/j.jup.2015.06.011
- Ding, W., Jimoh, S. O., Hou, X., Shu, X., Dong, H., Bolormaa, D., et al. (2022). Grassland ecological subsidy policy and livestock reduction behavior: a case study of herders in northern China. *Rangel. Ecol. Manag.* 81, 78–85. doi: 10.1016/j.rama.2022.01.002
- Dong, S., Xu, Y., Li, S., Shen, H., Yang, M., and Xiao, J. (2024). Restoration actions associated with payment for ecosystem services promote the economic returns of alpine grasslands in China. *J. Clean. Prod.* 458:142439. doi: 10.1016/j.jclepro.2024.142439
- Feng, X., Tang, J., and Qiu, H. (2021). The effect of grassland transfer on herders' livestock production and grazing intensity in Inner Mongolia and Gansu, China. *China Agric. Econ. Rev.* 14, 242–258. doi: 10.1108/CAER-09-2020-0221
- Feng, X., Zhao, Q., Li, J., and Qiu, H. (2023). The impact of political status and social capital on herders' overgrazing behaviors in the pastoral areas of China. *J. Environ. Manag.* 327:116861. doi: 10.1016/j.jenvman.2022.116861
- He, S., Blasch, J., van Beukering, P., and Wang, J. (2022). Energy labels and heuristic decision-making: the role of cognition and energy literacy. *Energy Econ.* 114:106279. doi: 10.1016/j.eneco.2022.106279
- Howell, R. A. (2018). Carbon management at the household level: a definition of carbon literacy and three mechanisms that increase it. *Carbon Manag.* 9, 25–35. doi: 10.1080/17583004.2017.1409045
- Hu, Y., Huang, J., and Hou, L. (2019). Impacts of the grassland ecological compensation policy on household livestock production in China: an empirical study in Inner Mongolia. *Ecol. Econ.* 161, 248–256. doi: 10.1016/j.ecolecon.2019.03.014
- Hu, C., Pan, W., Wen, L., and Pan, W. (2025). Can climate literacy decrease the gap between pro-environmental intention and behaviour? *J. Environ. Manag.* 373:123929. doi: 10.1016/j.jenvman.2024.123929
- Hua, L., and Squires, V. R. (2015). Managing China's pastoral lands: current problems and future prospects. *Land Use Policy* 43, 129–137. doi: 10.1016/j.landusepol.2014.11.004
- Huang, J., Liu, K., Dou, P., Gao, Q., Liu, C., Du, J., et al. (2024). Different responses of soil water to warming controlled by evapotranspiration during grassland degradation: a case study in the typical steppe of China. *Ecol. Indic.* 167:112718. doi: 10.1016/j.ecolind.2024.112718
- Julia Ihli, H., Chiputwa, B., Winter, E., and Gassner, A. (2022). Risk and time preferences for participating in forest landscape restoration: the case of coffee farmers in Uganda. *World Dev.* 150:105713. doi: 10.1016/j.worlddev.2021.105713

(Grant No. 72141307), and the Chinese Academy of Engineering (2022-HZ-09).

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that Generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

- Le Coent, P., Préget, R., and Thoyer, S. S. (2021). Farmers follow the herd: a theoretical model on social norms and payments for environmental services. *Environ. Resour. Econ.* 78, 287–306. doi: 10.1007/s10640-020-00532-y
- Li, L., Jin, J., Zhang, C., Qiu, X., and Liu, D. (2023). How do livelihood capital affect farmers' energy-saving behaviors: evidence from China. *J. Clean. Prod.* 414:137769. doi: 10.1016/j.jclepro.2023.137769
- Li, Z., Su, B., and Liu, M. (2022). Research progress on the theory and practice of grassland eco-compensation in China. *Agriculture* 12:721. doi: 10.3390/agriculture12050721
- Lin, F., Li, J., and Wu, C. (2025). Social networks, environmental literacy, and farmers' clean low-carbon farming behaviors: evidence from villages in China. *Ecol. Econ.* 228:108439. doi: 10.1016/j.ecolecon.2024.108439
- Liu, M., Wu, W., and Li, H. (2023). The influence of grassland ecological compensation policy on grassland quality: evidence from the perspective of grassland ecosystem vulnerability. *Agriculture* 13:1841. doi: 10.3390/agriculture13091841
- Lü, Y., An, B., Pan, Q., Liu, W., Sun, J., Wang, J., et al. (2025). Nutrient amendment promotes vegetation restoration and improves ecosystem carbon uptake capacity in a degraded grassland. *Agric. Ecosyst. Environ.* 388:109666. doi: 10.1016/j.agee.2025.109666
- Lu, F., Hu, H., Sun, W., Zhu, J., Liu, G., Zhou, W., et al. (2018). Effects of National Ecological Restoration Projects on carbon sequestration in China from 2001 to 2010. *Proc. Natl. Acad. Sci.* 115, 4039–4044. doi: 10.1073/pnas.1700294115
- Maurer, M., and Bogner, F. X. (2020). Modelling environmental literacy with environmental knowledge, values and (reported) behaviour. *Stud. Educ. Eval.* 65:100863. doi: 10.1016/j.stueduc.2020.100863
- Ministry of Agriculture (2015). *Calculation of rangeland carrying capacity (NY/T635-2015)*. Beijing: China Standards Press.
- Qiu, H., Su, L., Feng, X., and Tang, J. (2020). Role of monitoring in environmental regulation: an empirical analysis of grazing restrictions in pastoral China. *Environ. Sci. Pol.* 114, 295–304. doi: 10.1016/j.envsci.2020.08.023
- Qiu, H., Su, L., and Tang, J. (2022). Effects of environmental regulation on rural livelihood diversification: evidence from pastoral China. *J. Rural. Stud.* 95, 26–39. doi: 10.1016/j.jrurstud.2022.07.008
- Ran, R. (2013). Perverse incentive structure and policy implementation gap in China's local environmental politics. *J. Environ. Policy Plann.* 15, 17–39. doi: 10.1080/1523908X.2012.752186
- Roodman, D. (2011). Fitting fully observed recursive mixed-process models with *cmp*. *Stata J.* 11, 159–206. doi: 10.1177/1536867X1101100202
- Runa, S., Baskaran, A., and Ishak, N. A. B. (2025). Towards cleaner and responsible herding: can ecological compensation ensure sustainable grassland management in Alxa league, Inner Mongolia? *Cleaner Responsible Consump.* 100370. doi: 10.1016/j.crc.2025.100370
- Schleich, J., Dütschke, E., Kanberger, E., and Ziegler, A. (2024). On the relationship between individual carbon literacy and carbon footprint components. *Ecol. Econ.* 218:108100. doi: 10.1016/j.ecolecon.2023.108100
- Shi, C., Li, P., and Guo, J. (2026). Balancing grassland ecology and herders' economic benefits: the impact of grassland ecological compensation policy in Inner Mongolia. *Land Use Policy* 162:107904. doi: 10.1016/j.landusepol.2025.107904
- Su, L., Tang, J., and Qiu, H. (2021). Intended and unintended environmental consequences of grassland rental in pastoral China. *J. Environ. Manag.* 285:112126. doi: 10.1016/j.jenvman.2021.112126
- Tan, C. S., Ooi, H. Y., and Goh, Y. N. (2017). A moral extension of the theory of planned behavior to predict consumers' purchase intention for energy-efficient household appliances in Malaysia. *Energy Policy* 107, 459–471. doi: 10.1016/j.enpol.2017.05.027
- Tong, Q., Yuan, X., Zhang, L., Zhang, J., Li, W. (2024). The impact of livelihood capitals on farmers' adoption of climate-smart agriculture practices: evidence from rice production in the Jiangnan plain, China. *Clim. Risk Manag.* 43:100583. doi: 10.1016/j.crm.2023.100583
- Tóth, E., Deák, B., Valkó, O., Kelemen, A., Miglécz, T., Tóthmérész, B., et al. (2018). Livestock type is more crucial than grazing intensity: traditional cattle and sheep grazing in short-grass steppes. *Land Degrad. Dev.* 29, 231–239. doi: 10.1002/ldr.2514
- Wang, L., Gan, Y., Wiesmeier, M., Zhao, G., Zhang, R., Han, G., et al. (2018). Grazing exclusion—an effective approach for naturally restoring degraded grasslands in northern China. *Land Degrad. Dev.* 29, 4439–4456. doi: 10.1002/ldr.3191
- Yang, S., Yu, L., Leng, G., and Qiu, H. (2021). Livestock farmers' perception and adaptation to climate change: panel evidence from pastoral areas in China. *Clim. Chang.* 164:21. doi: 10.1007/s10584-021-02992-7
- Yu, L., Liu, W., Yang, S., Kong, R., and He, X. (2022). Impact of environmental literacy on farmers' agricultural green production behavior: evidence from rural China. *Front. Environ. Sci.* 10:990981. doi: 10.3389/fenvs.2022.990981
- Zhou, K., Zheng, X., Long, Y., Wu, J., and Li, J. (2022). Environmental regulation, rural residents' health investment, and agricultural eco-efficiency: An empirical analysis based on 31 Chinese provinces. *Int. J. Environ. Res. Public Health* 19:3125. doi: 10.3390/ijerph19053125