TYPE Original Research
PUBLISHED 19 November 2025
DOI 10.3389/fsufs.2025.1657011

OPEN ACCESS

EDITED BY
Alexandros Tataridas,
University of Coimbra, Portugal

REVIEWED BY
Guiro Jeudi TOPAN,
Université Thomas Sankara, Burkina Faso
Théodore NIKIEMA,
Institut de Mathématiques et de Sciences Physiques (IMSP), Benin

*CORRESPONDENCE
Boko Michel Orounladji
michel.orounladji@gmail.com

RECEIVED 11 July 2025
ACCEPTED 30 October 2025
PUBLISHED 19 November 2025

CITATION
Orounladji BM, Sib O, Kouakou PK, Darmaun M, Sanogo S and Vall E (2025) Dairy farms at an advanced stage in their agroecological transition show higher environmental and socio-economic performance.
Front. Sustain. Food Syst. 9:1657011.
doi: 10.3389/fsufs.2025.1657011

Dairy farms at an advanced stage in their agroecological transition show higher environmental and socio-economic performance

Boko Michel Orounladji[1]*, Ollo Sib[2,3], Patrice Koffi Kouakou[4,5], Maryline Darmaun[6], Souleymane Sanogo[1] and Eric Vall[3,7]

[1]CIRDES, Bobo-Dioulasso, Burkina Faso, [2]CIRAD, UMR SELMET, Dakar, Senegal, [3]SELMET, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier, France, [4]CIRAD, UPR AIDA, Dakar, Senegal, [5]AIDA, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier, France, [6]CIFOR-ICRAF, Transformative Partnership Platform on Agroecology (TPP), Nairobi, Kenya, [7]CIRAD, UMR SELMET, Montpellier, France

In Burkina Faso, the growing demand for milk prompts dairy farmers to pursue solutions that improve their production while maintaining profitability and sustainability. This study aimed to analyse the link between the level of agroecological transition achieved by dairy farms in the Bobo-Dioulasso milkshed area and their multidimensional performance. To address this issue, 204 dairy farms were assessed in the Bobo-Dioulasso milkshed area according to their level of progress in the agroecological (AE) transition, using the Holistic Localised Performance Assessment for Agroecology (HOLPA) tool. A typology of the dairy farms was produced according to their level of progress in the AE transition. Averaged scores for all questions in the HOLPA tool relating to the 13 principles of agroecology were used to rate each farm on a 5-point Likert scale, from 1 (Non-AE) to 5 (Very Strong AE). Performance was then compared according to these score levels. Results indicate that the dairy farms studied are mostly at the beginning (Non-AE: 7%, Weak AE: 54%, Moderate AE: 33%, and Strong AE: 6%) of their AE transition. Our findings suggest that dairy farms which have adopted more advanced AE practices demonstrate improved environmental, social and economic performance compared to conventional or less transitioned farms. The most AE dairy farms stand out on several key performance indicators. In terms of environmental performance, the most AE dairy farms achieve higher scores for crop diversity and natural resource and land management. In terms of social performance, the most AE dairy farmers share more knowledge about agroecology and natural resources, report higher levels of household satisfaction, and perceive trade associations as efficient. In terms of economic performance, the most AE dairy farms enjoy more stable and diversified income streams, which may reflect their greater resilience. With regard to agronomic performance, the most AE dairy farms perform better in terms of organic manure and fodder production. However, heavy reliance on labor and low crop productivity (e.g., for maize, sorghum, millet, rice, and cowpea) have been identified as key challenges to the AE transition and the sustainability of dairy farms. The findings of this study justify the implementation of several policy measures to support farmer training in AE on fodder and organic manure production, and natural resources management, to guaranty a better access to forages seeds and agricultural equipment to manage manure production, to increase the skills of farmers community in collective natural resources management in order to strengthen and accelerate the AE transition and enhance the resilience of the dairy sector in Burkina Faso. This study provides robust evidence to help improve public policy, guide dairy industry strategies, and support the agroecological transition in the Bobo-Dioulasso milkshed area.

KEYWORDS

agroecology, HOLPA, indicators, dairy farmers, performance, sustainability

1 Introduction

Agroecology is gradually emerging as an alternative paradigm for rethinking agricultural and food systems on a global scale (HLPE, 2019; Gliessman, 2020; Akanmu et al., 2023). It combines ecological and social principles such as biodiversity, recycling, co-creation of knowledge, and fairness with a view to achieving integrated sustainability (Wezel et al., 2020). In contrast to the standardised practices found in conventional agriculture, the implementation of these ecological principles is highly contextual and is based on the gradual transformation of systems along paths that reflect local realities (Gliessman, 2016; Anderson et al., 2019).

Agroecology is recognised for its benefits in terms of income and food security (Bezner Kerr et al., 2022), ecosystem sustainability (Madsen et al., 2021), climate change adaptation (Bezner Kerr et al., 2023), environmental factors that shape farmers' assessments of its value (Coe et al., 2025), and stakeholder empowerment, particularly women (Cetrone et al., 2021; Kansanga et al., 2024). However, it remains controversial, with some authors associating it with low productivity and farms at risk of being locked into low-profit farming practices (Mugwanya, 2019; Muhumuza, 2023). Empirical data is beginning to mitigate these criticisms: a recent review reveals that more than half of existing studies show positive socio-economic effects resulting from agroecological practices (Bezner Kerr et al., 2021, 2022; Lucantoni et al., 2023; Mouratiadou et al., 2024). However, such data remains limited with regard to Global South countries, and existing indicators are sometimes ill-suited to capture both socio-economic and environmental sustainability dimensions of alternative farming models (IPES-Food, 2016; Darmaun et al., 2023).

In Burkina Faso, and particularly in the Bobo-Dioulasso region, rainfed family farming remains the cornerstone of the local economy (Kouakou et al., 2023). This region is characterised by diversified agro-pastoral systems combining crops (cotton, cereals, legumes) and livestock. The dairy value chain is experiencing strong growth as a result of the growing demand for dairy products, with a sharp increase in the number of collection centers and mini-dairies (Vall et al., 2021; Kouakou et al., 2023). Some livestock farmers specialise in milk production by setting up mini-farms and introducing crop-livestock farming integration and crop and livestock co-product recycling practices designed to improve animal feed and soil fertility (Vall et al., 2021; Vall et al., 2023). These dynamics reflect an ongoing transition, the effects of which on farm sustainability remain poorly documented. Mini-farms are characterized by a relatively intensive production system, focused on crossbred zebu dairy cows kept mainly in stall-feeding systems with limited access to natural pastures. In contrast, agro-pastoral farms follow a relatively extensive production system, centered on local zebu females better adapted to the regional climate, with daily grazing on natural rangelands supplemented by forage and feed.

The challenge of ensuring the sustainability of these transitioning dairy farms calls for a better assessment of their performance and the contribution of agroecology. Several studies have shown that embracing agroecological principles promotes resilience, economic stability (Spicka et al., 2019; Leippert et al., 2020; Ulukan et al., 2022), natural resource conservation (Rivas et al., 2015), and social equity (Corson et al., 2022). According to Orounladji et al. (2024), these farms will be viable if and only if they are economically profitable (i.e., capable of generating sustainable profits to ensure their long-term viability), socially acceptable (i.e., aligned with local practices and mindful of individual integrity), and ecologically beneficial (i.e., preserving water resources, soil quality, plant and animal biodiversity, and air quality).

Assessing the performance of farming and food systems is now a key issue when it comes to supporting transitions toward more sustainable models (Müller and Sukhdev, 2018; Crossland et al., 2025). It is necessary to mobilise holistic assessment approaches capable of simultaneously addressing the agronomic, economic, social, and ecological dimensions of sustainability (Darmaun et al., 2023; Geck et al., 2023). However, existing tools struggle to assess farming systems undergoing such a transition, in particular because they sometimes insufficiently adapt to local contexts, engage end-users only superficially, and underrepresent multidimensional, multiscale, and temporal dynamics (Darmaun et al., 2023). Some methods, such as TAPE (Tool for Agroecology Performance and Evaluation), include preparatory steps to capture local socio-economic, cultural, and policy contexts, and allow translation and adaptation of indicators for local realities, thus enabling both local relevance and cross-context comparison. Nonetheless, limitations remain in the degree of adaptation and genuine stakeholder engagement during some applications. Other methods, such as MESMIS (Indicator-based Framework for Evaluation of Natural Resource Management Systems) emphasized context-specific indicator selection, strong involvement of local actors, adaptability across scales and timeframes, and a multidimensional framework allowing exploration of trade-offs; however, its high contextualization can hinder cross-site benchmarking. Few methods explores how environmental, social, and economic dimensions interact and trade off in agriculture (Binder et al., 2012; Wiget et al., 2020), and methodological advances are uneven across these three pillars (Lebacq et al., 2013; Côte et al., 2019). Most available tools foreground environmental concerns (Binder et al., 2010; Lebacq et al., 2013; Schader et al., 2014), while social and economic aspects are only sparsely integrated (Sachs et al., 2010; Affholder et al., 2018; Kanter et al., 2018). HOLPA (Holistic Localised Performance Assessment for Agroecology) addresses these gaps by combining comparability, local relevance, causal learning, and decision-usefulness in one modular design. It combines a holistic set of key performance indicators spanning18 themes, including often overlooked dimensions such as farmer agency and land tenure security, with explicit trade-off analysis. A dedicated Context module captures key socio-ecological variables, enabling rigorous scientific hypothesis testing by controlling for extraneous factors. Finally, a participatory Local Indicator Selection Process (LISP) engages local stakeholders to co-select and weight indicators, ensuring the evidence is tailored to local priorities while remaining decision-useful for planning and policy (Jones et al., 2024).

In light of this consideration, this study is being conducted, with the aim of analysing the link between the level of agroecological transition achieved by dairy farms in the Bobo-Dioulasso milkshed area and their multidimensional performance. It provides essential insights for guiding public policies, dairy value chain stakeholders' strategies, and development actions, with a view to improving the sustainability of farming and food systems. This study was carried out using the HOLPA methodology developed by the CGIAR Transformational Agroecology Initiative, which aims to collect data and evidence on the current state of agroecology and its performance (Jones et al., 2024).

The analysis was conducted as part of the Agroecological Living Landscape (ALL) around Bobo Dioulasso's dairy value chain. The ALL is defined as a space in which a variety of stakeholders—farmers, collectors, processors, consumers, and institutions—collectively engage in an agroecological transition based on a shared vision of a desirable future, with a view to co-designing and experimenting with new agroecological production practices and innovative business models, as well as fostering the development of a supportive institutional environment and the behavioral changes needed to achieve such desired future.

This paper contributes by providing evidence on the agroecological performance of dairy farms engaged in an agroecological transition in the Bobo-Dioulasso milkshed, applying the HOLPA tool to agro-pastoral systems for the first time, and linking levels of transition to multidimensional performance outcomes.

After this introduction, Section 2 presents the materials and methods. Section 3 reports the results, describing the agroecological status of the dairy farms and their classification according to the level of agroecological transition, as well as their multidimensional key performance. Section 4 discusses the findings, including the progress, challenges, and outlook of the agroecological transition, and highlights key levers to advance it through crop-livestock integration and strengthened support and training mechanisms. This section also examines the multidimensional benefits of adopting agroecological principles and discusses the limitations of the HOLPA tool in assessing agro-pastoral systems, despite its advantages over existing tools. Finally, the paper concludes with insights to guide public policies that aim to support and accelerate agroecological transitions in dairy farming systems.

2 Materials and methods

2.1 Description of the study area

Data was collected from dairy farmers in the Bobo Dioulasso Agroecological Living Landscape (ALL) intervention area, situated in the Hauts-Bassins region in Western Burkina Faso (Figure 1).

The Hauts-Bassins region lies within the Southern Sudanian savannah area, characterised by a sub-humid tropical climate with three distinct seasons: a rainy season from June to October, a cool dry season from November to February, and a hot dry season from March to May. Average daily temperatures are also subject to seasonal variations. In the middle of the rainy season, temperatures are low, averaging around 26 °C. During the dry season, temperatures rise, reaching a peak of around 32 to 33 °C.

Evapotranspiration is generally very high, exceeding rainfall from October to June, i.e., for more than 9 months, and leading to a significant drop in water resources which adversely affects livestock farming.

2.2 Dairy farm selection criteria

With regard to sampling, a non-probabilistic method was used to select farmer households for our data collection. Our survey targeted 204 farmers involved in local milk production systems. To ensure an agroecological gradient within each production system, farm selection was based on the following inclusion criteria:

- Farmers affiliated with the Bobo Dioulasso ALL who may or may not have already been involved in agroecology-related projects.
- Farmers planning to join the Bobo Dioulasso ALL and expressing a desire to transition to sustainable practices.

This selection strategy allowed for detailed data collection and comparison across different levels of agroecological adoption. We acknowledge that this approach excludes the majority of farms outside the ALL area, and therefore, the findings primarily reflect the situation within this network.

2.3 Data collection

Qualitative and quantitative data was collected during this study using a digital questionnaire deployed on KoboToolbox. Information was gathered by sequentially conducting household and farm surveys on each farmer. After gaining the respondent's consent to data being published without including any personal information, the questionnaire began with general information such as location and interviewer details. Four modules were covered in the household questionnaire: (i) Context module, (ii) Agroecology (Ae) integration module, (iii) Global key performance indicators module and (iv) Local key performance indicators module.

The Context module addressed various topics including the collection of demographic data, and involved the recording of respondent characteristics such as age, gender, involvement in farming activities, membership of farmers' associations, and participation in farming research or development projects. Farm household characteristics such as household structure, agricultural production system, end use of agricultural products, inputs (in particular fertilisers), farm size, and land tenure arrangements were also collected to assess socio-economic and environmental factors related to the evaluation unit. The contextual assessment also sought to explore motivations and attitudes toward agroecology by analysing individual perceptions of this approach.

The Agroecology integration module was designed to assess the current state of practices using questions covering the 13 agroecology principles, plus two additional questions to determine self-perceived adherence to these principles. Its purpose was to characterise the current uptake level of agroecology or the extent of the agroecological transition by assessing farming practices and

10.3389/fsufs.2025.1657011

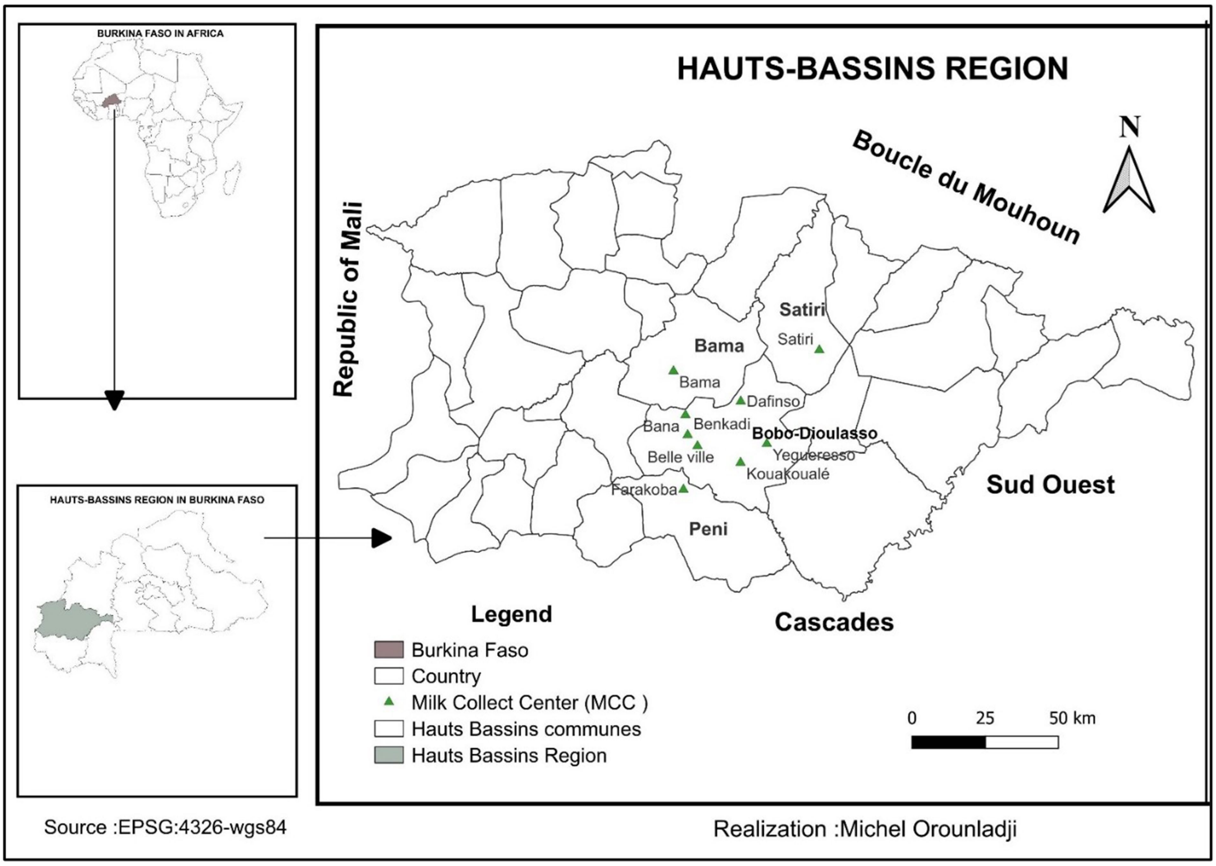

FIGURE 1
Administrative map of the Hauts-Bassins region.

the overall benefits gained from them. Most questions were multiple-choice using a five-point Likert scale, with all survey responses scored from 1 to 5. Based on a median score aggregated across all agroecology principles, a composite score ranging from 1 and 5 was generated to characterise the overall agroecological status. The cross-cutting theme of 'self-perceived adherence' was evaluated through questions designed to assess the respondent's opinion about the extent to which their field, farm or landscape was agroecological. Responses ranged from non-agroecological to very strongly agroecological. Self-perceived adherence does indeed provide an alternative way of assessing the level of transition to agroecology.

The Global indicators module was used to assess the farming system's agroecological performance at a selected scale through a set of survey questions and field measurements. The survey questionnaire and field measurement sections covered various elements of the four main areas: farming, economy, environment, and social issues. Data collected in this module was used to estimate agricultural, economic, environmental, and social performance when formulating the following questions: (1) What are the impacts of increased uptake of agroecology? (2) What are the trade-offs between the different sustainability dimensions?

The Local indicators module addressed issues relating to the four dimensions of farm performance assessment. It allowed for the specific features of dairy production in the geographical area of the Bobo-Dioulasso ALL to be fully integrated.

As part of the farm survey, data on biodiversity and soil health was collected for evaluation purposes. Soil samples were also taken for laboratory analysis in order to determine soil organic matter (SOM) and soil organic carbon (SOC) content. These samples were collected at three locations on each farm: (site 1) near buildings, (site 2) in the heart of cultivated land, and (site 3) near natural vegetation. A 10 × 10-meter square area was delineated at each site. Soil samples were then collected from five points corresponding to the centre and each corner of the square. A composite sample was made for each site on each farm. A total of 612 samples were analysed on the basis of 204 samples per site. SOC was determined using the Walkley and Black (1934) wet oxidation method. 0.5 g of air-dried soil was oxidized with 1 N potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid (H_2SO_4). The excess dichromate was back-titrated with ferrous ammonium sulfate using ferroin as an indicator. SOC content was calculated based on the amount of dichromate reduced, applying the conventional correction factor of 1.3 to account for incomplete oxidation. Conversion of % SOC to % SOM is done with the following empirical factor 1.724:

$$\%SOM = 1.724 \times \%SOC$$

2.4 Identification of key performance indicators

The assessment framework of HOLPA tool consists of three modules: (i) Context module, (ii) Agroecology module, and (iii) Performance module, all underpinned by a process of indicator contextualization. For this study, dairy farm performance in the Bobo-Dioulasso milkshed was assessed using key agronomic, economic, social, and environmental indicators derived from the Performance module (Table 1). These indicators include both (i) global measures applicable to all farming and food systems (Jones et al., 2024) and (ii) locally adapted indicators tailored to Bobo-Dioulasso milkshed area context (Orounladji et al., 2023). Local indicators were added to better contextualise the tool and make it truly relevant for assessing dairy farms' agroecological performance. The local indicator selection process is discussed further in Orounladji et al. (2023) and the overall HOLPA tool methodology is described by Jones et al. (2024).

2.5 Methods used to compare dairy farm performance

In order to study the possible link between the level of progress toward agroecology and farm performance levels, an overall agroecology score was calculated for each farmer. This score was derived from the individual scores achieved for each of the 13 principles of agroecology, namely: recycling, input reduction, soil health, animal health, biodiversity, synergy, economic diversification, co-creation of knowledge, social values and diets, fairness, connectivity, land and natural resource governance, and participation (HLPE, 2019; Wezel et al., 2020). Elementary scores were based on ratings assigned to the different levels of the Likert scale, as defined for each question in the HOLPA tool's Agroecology module (Supplementary Table S1). For each agroecological principle, the score was calculated using the arithmetic mean of all the scores recorded for the various indicators/questions related to that principle. It means that the scores of individual indicators/questions were summed and divided by the total number of indicators/questions for that principle, yielding a principle-specific score for each household. The overall household score was then obtained by averaging the scores of all 13 agroecological principles. To facilitate classification into groups, these values were rounded to the nearest integer. Since scores range from 1 to 5, this range was divided into 5 groups or levels of agroecological transition:

- Non-Agroecological: Agroecology score equal to 1; non-agroecological households
- Weak: Agroecology score equal to 2; households in the initial phase of agroecological transition
- Moderate: Agroecology score equal to 3; households showing moderate progress toward agroecological transition
- Strong: Agroecology score equal to 4; households showing strong progress toward agroecological transition
- Very Strong: Agroecology score equal to 5; households showing very strong progress toward agroecological transition.

Farmers were classified into these agroecology groups/levels based on their overall score.

2.6 Data analysis

Analyses were performed using R software version 4.4.1 (R Core Team, 2024). Data relating to factors that might influence households' agroecological transition (farm size, access to resources, technical support, etc.) were subjected to an analysis of variance (ANOVA). When ANOVA revealed significant differences between farm groups ($p < 0.05$), mean comparisons were conducted using the Student Newman–Keuls test. Outliers, which are sometimes observed in survey data on farming systems, were identified through exploratory data analysis. The normality of residuals was tested using the Shapiro–Wilk test and inspected via Q-Q plots, while the homogeneity of variances was assessed with Levene's test. The checks were carried out to ensure that the data were valid and that there were no entry errors. To preserve the ecological and agronomic diversity represented in the data, we chose not to perform data transformation or remove outliers, as such procedures could bias the results. Instead, we applied statistical methods robust to violations of ANOVA assumptions. Specifically, when residuals were not normally distributed or when there was heterogeneity of variances among groups, the non-parametric Kruskal-Wallis' test was used as an alternative.

The agroecology status across all farms in the Bobo-Dioulasso ALL was assessed and the results are presented as boxplots for all 13 agroecological principles along with the overall agroecological level of the farms.

Key performance indicators were calculated as described in Table 1. Cross-analysis of the agroecological transition level and the farms' (global and local) key performance indicators (Table 1) was carried out using an ANOVA test with mean structuring, and presented as boxplots.

3 Results

3.1 Implementation levels of agroecology principles in Bobo-Dioulasso dairy farms

Among the five implementation levels of the 13 agroecology principles, recycling ranks highest, with a high score (4.71 ± 0.7) reflecting its strong involvement in the agroecological transition (Figure 2). The principles of biodiversity (3.47 ± 1.03), animal health (4.10 ± 0.65), social values (4.00 ± 1.00), and participation (3.64 ± 1.30) come second, indicating their significant contribution to this transition. The principle of fairness, with a score of 3.41 ± 1.52, shows a moderate level of consideration.

By contrast, the principles of input reduction (2.44 ± 0.56), synergies (2.00 ± 1.00), co-creation of knowledge (2.20 ± 0.80), connectivity (2.30 ± 0.63), land and natural resource governance (2.12 ± 1.06), and economic diversification (1.73 ± 0.46) exhibit low scores, reflecting limited engagement at this stage of the AE transition.

The principle relating to soil health scores very low (1.00 ± 0.5), highlighting the major challenges that need to be addressed.

TABLE 1 Some of the parameters selected for dairy farm comparison.

Performance categories	Variables	Units	Indicator calculation principles	Indicator type
Agronomic				
	Maize yield	Kg/ha	Quantity of maize produced during the reference period/area sown to maize	Global
	Sorghum yield	Kg/ha	Quantity of sorghum produced during the reference period/area sown to sorghum	Global
	Millet yield	Kg/ha	Quantity of millet produced during the reference period/area sown to millet	Global
	Rice yield	Kg/ha	Quantity of rice produced during the reference period/area sown to rice	Global
	Cowpea yield	Kg/ha	Quantity of cowpea produced during the reference period/area sown to cowpea	Global
	Soil organic carbon	%	Mean of proportion of the three sites after laboratory determination	Global
	Organic matter	%	Mean of proportion of the three sites after laboratory determination	Global
	Quantity of organic manure produced	Kg	Quantity of organic manure reported by respondent	Local
	Quantity of organic manure used per hectare	Kg/ha	Quantity of organic manure spread/area covered	Local
	Quantity of stored quality fodder per cow	KgDM/ TLU	$\sum_{\text{quantity of quality fodder}}$ [Number per means of transport (U) x Conversion ratio (kgDM)]/ Total number of dairy cattle (TLU). Conversion ratios: Bales: 3; Rickshaw: 35; Motorbike: 20; Dumper: 100; Small flatbed cart: 170; Large flatbed cart: 250; Tricycle: 150; Trailer: 530	Local
	Quantity of stored coarse fodder per cow	KgDM/ TLU	$\sum_{\text{quantity of coarse fodder}}$ [Number per means of transport (U) x Conversion ratio (kgDM)]/ Total number of dairy cattle (TLU). Conversion ratios: Bales: 3; Rickshaw: 40; Motorbike: 30; Dumper: 100; Small flatbed cart: 170; Large flatbed cart: 250; Tricycle: 150; Trailer: 540	Local
	Amount of milk produced per cow during the cool dry season	l/c/d	∑Amount of milk produced during the cool dry season (November, December, January, February)/(Number of cows milked*number of days)	Local
	Amount of milk produced per cow during the hot dry season	l/c/d	∑Amount of milk produced during the hot dry season (March, April, May)/(Number of cows milked*number of days)	Local
	Amount of milk produced per cow during the rainy season	l/c/d	∑Amount of milk produced during the rainy season (June, July, August, September, October)/(Number of cows milked*number of days)	Local
	Agronomic acceptability	Likert scale	Respondent's score on their opinion about switching to sustainable farming practices	Global
Economic				
	Annual cost of fodder production	USD	Expenses reported by respondent	Local
	Revenue stream diversification	Likert scale	Respondent's score on revenue stream diversification	Global
	Crop production income	USD	∑ Crop production income reported by respondent	Global
	Income sufficiency	Likert scale	Respondent's score on household financial self-sufficiency	Global
	Income stability	Likert scale	Respondent's score on the stability of household revenue streams	Global
	Economic acceptability	Likert scale	Respondent's score on whether they believe switching to agroecology is a sound business decision	Global
	Income from milk sales	kUSD	∑ Income from milk sales reported by respondent	Local
	Income from livestock farming	kUSD	∑ Income from livestock activities reported by respondent	Global

(Continued)

TABLE 1 (Continued)

Performance categories	Variables	Units	Indicator calculation principles	Indicator type
Social				
	Livestock farmers' working conditions and access to land	Likert scale	Respondent's average score on household working conditions and access to land	Global
	Agroecological knowledge sharing	Likert scale	Respondent's score on the level of information sharing with peers, organisations, researchers, etc.	Global
	Relationships between farmers and local value chains	Likert scale	Respondent's score on their perceived level of collaboration with other farmers and local structures	Global
	Human well-being	Likert scale	Respondent's score on their perceived level of satisfaction with their standard of living	Global
	Social acceptability of the agroecological transition	Likert scale	Respondent's averaged scores on how they identify as an agroecological farmer, and how they perceive local consumerism or chemical-free food	Global
Environmental				
	Tree diversity	Likert scale	Respondent's score on tree diversity on their farm	Global
	Crop diversity	Likert scale	Respondent's score on crop diversity on their farm	Global
	Animal diversity	Likert scale	Respondent's score on the diversity of animals raised on their farm	Global
	Natural resource management (water, soil, pastures)	Likert scale	Respondent's score on the complexity of the landscape surrounding their household and farms	Global
	Use of renewable energy (solar, biodigesters, etc.)	Likert scale	Respondent's score on the sustainability of the energy sources used	Global
	Environmental acceptability of the agroecological transition	Likert scale	Respondent's averaged scores on their motivations for taking care of nature	Global

Key: ha, hectare; TLU, tropical livestock unit (1 TLU = one head of cattle with a body weight of 250 kg); kgDM, kilogram of dry matter; 1 USD = 605 CFA Francs; 1 kUSD = 1,000 USD.

Overall, dairy farms from the Bobo-Dioulasso milkshed area achieve an average agroecology score of 2.62 ± 1.06 out of 5.

3.2 Farm typology according to their level of agroecological transition

Dairy farms within the Bobo-Dioulasso ALL are distributed across the first four levels (out of five defined levels) of agroecological transition. Out of a total of 204 dairy farms, 15 (13 agro-pastoral farms and 2 mini-farms) are classified as non-agroecological based on data collected during the reference period (October 2022–September 2023—Table 2). The majority of farms (54%), including 105 agro-pastoral farms and 5 mini-farms, stand at a low level of agroecological transition. A total of 67 dairy farms, including one mini-farm, have achieved a medium level of agroecological transition. Farms with a high level of agroecological transition are mainly agro-pastoral (12 farms). These farms are characterised by a larger ($p < 0.05$) total area sown (3.8 ± 1.9 ha) for which they hold full land ownership rights. Additionally, farms showing a high level of agroecological transition boast larger cattle herds (33.1 ± 20.0 TLU) ($p < 0.05$) and the heads of these households are older (53 ± 12 years old), with most of them (67%) having received technical support.

Non-agroecological (conventional) farms are characterised by a smaller total land area (2.2 ± 1.6 ha), smaller cattle herds (14.7 ± 12.7 TLU), and the youngest household heads (41 ± 14 years old). Few (27%) of these non-agroecological farms receive technical support.

3.3 Agronomic key performance indicators

From an agronomic key performance indicator (KPI) perspective, dairy farms that are most advanced in the agroecological transition (AE) achieve better performance in terms of organic manure and fodder production. These farms produce an average of 4,833 kgDM of organic manure, 390 kgDM of quality fodder (cowpea, peanut, mucuna), and 806 kgDM of coarse fodder (maize, sorghum, millet). They are committed to changing their production practices toward sustainability by reducing the use of external inputs (feed concentrates, mineral fertilisers, pesticides, antibiotics). However, crop yields (maize, sorghum, millet, rice, and cowpea) remain low on these farms

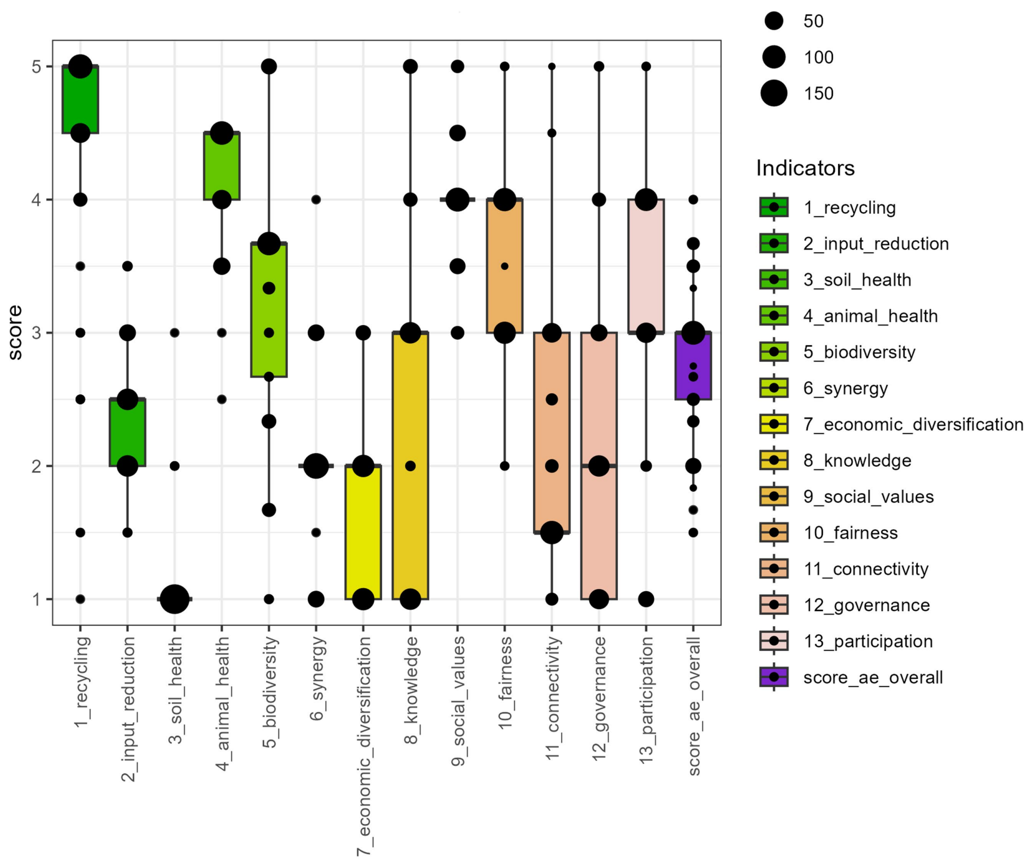

FIGURE 2
Scoring of the 13 agroecology principles on dairy farms from the Bobo-Dioulasso milkshed area.

(Figure 3). The reported grain yields are low compared to local averages (maize between 2,000 and 2,500 kg/ha, millet and sorghum between 800 and 1,000 kg/ha, rice between 1,500 and 2,000 kg/ha, peanuts and cowpeas between 500 and 1,000 kg/ha). The soil analysis results showed that there was no significant difference ($p > 0.05$) in soil fertility levels among the different groups or levels of agroecological transition, both for soil organic carbon (Non-AE: 0.87%; Weak AE: 0.89%; Moderate AE: 0.77%; Strong AE: 0.83%) and for organic matter (Non-AE: 1.50%; Weak AE: 1.53%; Moderate AE: 1.32%; Strong AE: 1.44%). Across all sites, the median soil organic carbon content is 0.85% and the median soil organic matter content is 1.46%. In terms of organic manure applied per hectare (averaging 3,185 kg/ha) and daily milk yield per cow (averaging 2.4 L/cow/day), there were no significant differences between the farm groups.

3.4 Economic key performance indicators

Dairy farms that are most advanced in the AE transition achieve the highest performance scores in terms of income diversification and stability (Figure 4). These farms also generate greater income from livestock activities compared to farms less advanced in the AE transition and conventional farms. Specifically, their income diversification (2.25 ± 0.45) is very close to Moderate AE (2.24 ± 0.43) and higher ($p < 0.05$) than Non-AE (1.60 ± 0.91) and Weak AE (1.57 ± 0.71). Their income stability is also the highest (3.58 ± 1.00), exceeding ($p < 0.05$) Non-AE (2.67 ± 0.72), and Weak AE (3.01 ± 0.67). This performance is closely tied to their orientation toward livestock, reflected in significantly higher ($p < 0.05$) livestock income (4,993 ± 2,385 USD) compared with Moderate AE (3,116 ± 2,316 USD), Non-AE (4,400 ± 3,335 USD), and Weak AE (3,481 ± 2,226 USD). However, in these livestock-oriented farms (Strong AE), agricultural income from crops is significantly lower ($p < 0.05$), at only 112 ± 56 USD, compared with Moderate AE (611 ± 642 USD), Non-AE (902 ± 987 USD), and Weak AE (1,118 ± 715 USD). In terms of the annual cost of fodder production (averaging 98 USD) and the income from milk sales (averaging 3,100 USD), there were no significant differences between the farm groups.

3.5 Social key performance indicators

Farms that are most advanced in the AE transition (Strong AE) achieve the highest performance scores ($p < 0.05$) in terms of knowledge sharing about AE and natural resources (3.58 ± 0.90), compared with Non-AE farms (1.60 ± 0.91), as well as household well-being (Figure 5). These farms award higher performance scores to the efficiency of trade associations. Social acceptability of the AE transition (such as identifying as an AE farmer, consuming local produce, and eating chemical-free food) is also highest ($p < 0.05$)

TABLE 2 Dairy farms' agroecological transition gradient and some of the factors affecting their transition.

Variables	Units	Mean	Median	Agroecological transition gradient				Total	p-value
				Non-AE	Weak AE	Moderate AE	Strong AE		
Agro-pastoral farms	U	–	–	13	105	66	12	196	–
Mini-farms	U	–	–	2	5	1	0	8	–
Total	U	–	–	15	110	67	12	204	–
Total area	ha	2.5	2.0	2.2 ± 1.6^{b}	2.4 ± 2.0^{b}	2.4 ± 1.6^{b}	3.8 ± 1.9^{a}	–	0.041*
Proportion of area with undisputed ownership	%	89	100	84^{b}	87^{ab}	90^{ab}	100^{a}	–	0.037*
Cattle herd size	TLU	16.7	12.3	14.7 ± 12.7^{b}	15.8 ± 12.3^{b}	15.6 ± 19.0^{b}	33.1 ± 20.0^{a}	–	0.003**
Number of cows milked	U	5	5	5 ± 2	6 ± 4	5 ± 1	5 ± 1	–	0.057
Proportion of stakeholders receiving technical support	%	38	0	27^{b}	40^{ab}	33^{b}	67^{a}	–	0.011*
Household size	U	12	11	13 ± 6	12 ± 6	11 ± 7	12 ± 6	–	0.851
Age of household head	Y	45	44	41 ± 14^{b}	44 ± 12^{b}	48 ± 13^{ab}	53 ± 12^{a}	–	0.026*
Agro-pastoral farm scoring	–	–	–	1.28	1.98	2.91	4.01	–	–
Mini-farm scoring	–	–	–	1.04	2.00	3.25	–	–	–

Key: ha, hectare; TLU, tropical livestock unit (1 TLU = one head of cattle with a body weight of 250 kg); U, unit; Y, year. a,b Values with different superscripts within the same row differ significantly at $p < 0.05$.

among the Strong AE farms (4.61 ± 0.13), and Moderate AE (4.43 ± 0.54), followed by Weak AE (4.05 ± 0.62), and Non-AE farms (4.04 ± 0.70). By contrast, conventional farms post the lowest performance scores for knowledge sharing, efficiency of trade associations, household well-being, and social acceptability. In terms of labour use, Strong AE (2.50 ± 1.00) and Moderate AE farms (2.54 ± 0.72) are more labour-intensive than Non-AE farms (2.30 ± 0.63) ($p < 0.05$).

3.6 Environmental key performance indicators

Dairy farms that are most advanced in the AE transition (Strong AE) achieve the highest performance scores in terms of crop diversity and management of natural resources (water, soil, pastures) and land (Figure 6). Crop diversity performance scores were 2.92 ± 0.29 for Strong AE, 2.27 ± 0.85 for Moderate AE, and 1.99 ± 0.96 for Weak AE, all higher than Non-AE (1.67 ± 0.90, $p < 0.05$) farms. Similarly, natural resource management performance scores reach 2.67 ± 0.78 in Strong AE, 1.66 ± 0.91 in Moderate AE, and 1.39 ± 0.73 in Weak AE, compared with only 1.20 ± 0.56 in Non-AE farms ($p < 0.05$). Environmental acceptability, i.e., caring for nature and enjoying its benefits, also follows the same trend, with AE farms scoring 4.47 ± 0.22 (Strong AE), 4.25 ± 0.31 (Moderate AE), and 4.07 ± 0.43 (Weak AE), all higher than Non-AE (4.24 ± 0.29, ($p < 0.05$). Conversely, conventional farms (Non-AE) record low performance scores in terms of managing cultivated or spontaneous plant biodiversity. The use of renewable energy sources (solar, biodigesters, etc.) allows no distinction to be made between dairy farms according to their level of AE transition.

4 Discussion

4.1 Agroecological transition on dairy farms: progress, challenges, and outlook

Our assessment of the agroecological level of dairy farms reveals that some agroecological principles are better integrated than others, reflecting differentiated dynamics among dairy farms' production, social, and environmental dimensions.

In terms of improving resource use efficiency within farms and agroecosystems, our findings show that the principle of recycling is particularly well integrated in dairy farms from the Bobo-Dioulasso milkshed area. The reason for this high level of integration is the interdependence between crops, livestock, and trees, a feature of African agro-sylvo-pastoral systems (Gliessman, 2014; Vall et al., 2023). Recycling crop and livestock co-products allows for optimum valorisation of local resources, contributing to soil fertilisation and waste reduction, thereby enhancing farm resilience (Francis et al.,

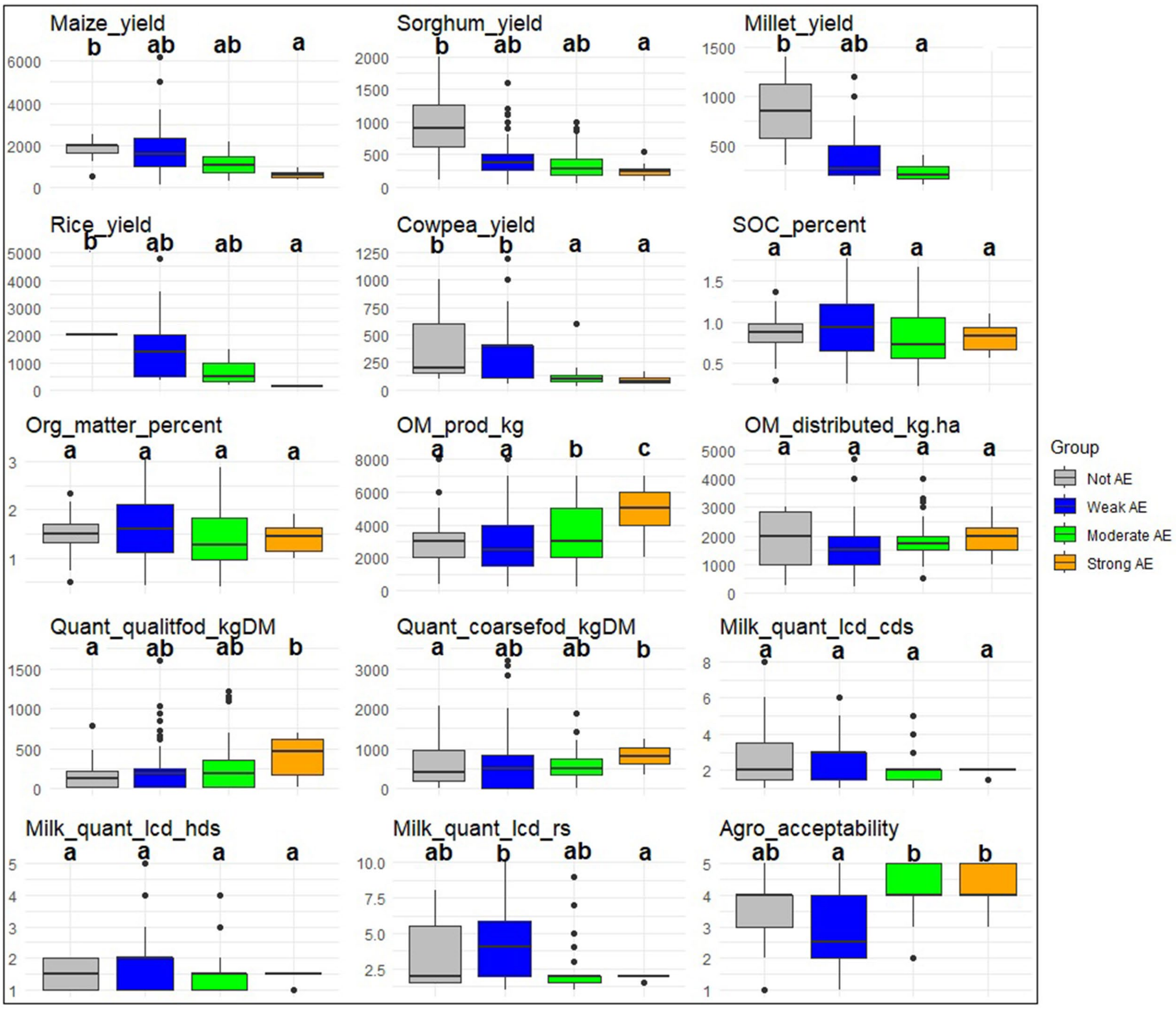

FIGURE 3
Dairy farms' agronomic key performance indicators according to their level of agroecological transition. Key: Maize_yield: Maize yield (Kg/ha); Sorghum_yield: Sorghum yield (Kg/ha); Millet_yield: Millet yield (Kg/ha); Rice_yield: Rice yield (Kg/ha); Cowpea_yield: Cowpea yield (Kg/ha); SOC_percent: Soil organic carbon (%); Org_matter_percent: Organic matter (%); OM_prod_kg: Amount of organic manure produced (Kg); OM_distributed_kg/ha: Amount of organic manure applied per hectare (Kg/ha); Quant_qualitfod_kgDM: Amount of stored quality fodder per cow (kgDM/TLU); Quant_coarsefod_kgDM: Amount of stored coarse fodder per cow (kgDM/TLU); Milk_quant_lcd_cds: Amount of milk produced per cow during the cool dry season (L/cow/day); Milk_quant_lcd_hds: Amount of milk produced per cow during the hot dry season (L/cow/day); Milk_quant_lcd_rs: Amount of milk produced per cow during the rainy season (L/cow/day); Agro_acceptability: Agronomic acceptability.

2003). By contrast, the practice of reducing chemical inputs remains poorly adopted, mainly due to the reliance on inputs to ensure short-term yields, a lack of accessible alternatives, and low awareness (Tittonell et al., 2012).

With regard to strengthening farm and agroecosystem resilience, farmers clearly prioritise animal health and welfare, given their direct impact on milk production and income (Dumont et al., 2013; FAO, 2018). This focus on animal health reflects an awareness of the close links between animal welfare and economic sustainability. Furthermore, despite pressures related to the use of chemical inputs, cultivated and spontaneous plant biodiversity shows relative enrichment, thus confirming that integrated systems can maintain or restore biological diversity (Perfecto and Vandermeer, 2010; Ulukan et al., 2022). Synergies between agroecosystem components remain largely untapped, revealing significant potential for improvement in optimising resource use. However, the fact that these synergies are low despite the high level of recycling cannot be ignored. Economic diversification remains low, with farmers mostly focusing on the sale of raw milk without local processing, despite processing having the potential to significantly improve the added value and economic sustainability of their farms. Soil and plant health score very low, despite being the cornerstone of any sustainable agroecological approach (Lal, 2015; Lehmann and Kleber, 2015). Organic matter is a prime source of nutrients (C, N, S, P, etc.) in highly weathered tropical soils with low mineral reserves. In the soils studied, organic matter contents (1.46%) are below reference thresholds (2 to 3%), indicating low soil fertility in terms of organic matter (Mulaji et al., 2016). These low organic matter levels in dairy farmers' soils would make them prone to acidification and fast degradation. Low organic content has a negative impact on soil fertility and leads to many soil deficiencies due to its physical, chemical, and biological effects. This leaves soils vulnerable to degradation by water erosion during heavy rainfall in

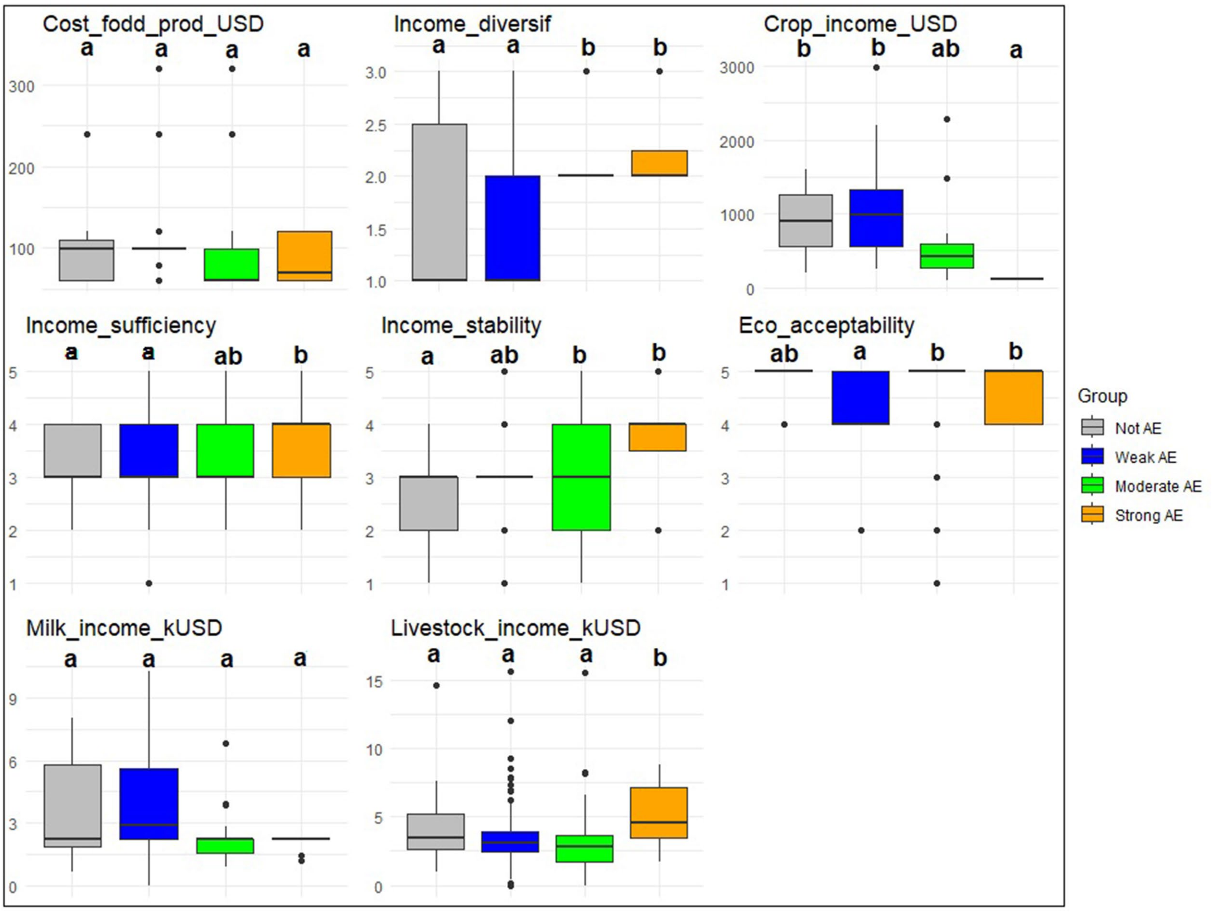

FIGURE 4
Dairy farms' economic key performance indicators according to their level of agroecological transition. Key: Cost_fodd_prod_USD: Annual cost of fodder production (USD); Income_diversif: Diversification of income sources; Crop_income_USD: Income from crop production (USD); Income_ sufficiency: Income sufficiency; Income_stability: Income stability; Eco_acceptability: Economic acceptability; Milk_income_kUSD: Income from milk sales (kUSD); Livestock_income_kUSD: Income from livestock farming (kUSD); kUSD = 1,000 USD; 1 USD = 605 CFA Francs.

humid tropical environments, especially on steep slopes (Mulaji et al., 2016). This study's findings raise questions about the perception and priority given to soil health by dairy farmers, despite its crucial role in resource use efficiency, agroecosystem resilience, and production system sustainability. This lack of attention can be attributed to the difficulty in perceiving its short-term benefits and the use of mineral fertilisers, which prioritise immediate productivity over soil sustainability, as well as labour constraints (Tittonell et al., 2012; Vanlauwe et al., 2014). As a result, sustainable practices such as composting are not being fully embraced, even though farmers are increasingly making efforts to produce quality organic manure. This finding is consistent with Vanlauwe et al. (2014), whose work highlights the socio-economic and technical constraints limiting sustainable soil management in sub-Saharan Africa. Other factors may also explain this situation: (i) the concept of soil health is often too abstract for farmers to directly apprehend, especially without targeted technical support and specific training (Tittonell et al., 2012); (ii) the priority given to other dimensions of the agroecosystem, such as animal health and welfare, or biodiversity, may draw farmers' attention away from specific soil management. This trend is exacerbated by livestock income, which tends to be more consistent than that from crop production.

To ensure fairness and social responsibility within the agroecosystem and the food system, fairness in value chains and active involvement of household members in the transition process, including women and young people, are well integrated, thereby promoting the dissemination of agroecological practices (Altieri and Toledo, 2011). Fairness in value chains, although present, needs to be strengthened to ensure fair benefit sharing and better inclusion of vulnerable stakeholders. However, key principles such as co-creation of knowledge, connectivity in value chains, land and natural resource governance, as well as social values and diets, remain underdeveloped. These weaknesses reflect the challenges associated with the structured collaboration between farmers and technical partners, which can be difficult for the Bobo-Dioulasso ALL stakeholders, particularly in view of agricultural expansion and residential development, combined with the effects of climate change (IPCC, 2022). These factors lead to a gradual reduction in grazing areas, forage and water availability, which sometimes gives rise to conflicts between crop and livestock farmers, highlighting the urgent need to improve management and access to those natural resources necessary for dairy farming (Orounladji et al., 2024).

The highest-scoring principles, such as recycling and animal health, stand out due to their direct link with farm productivity and

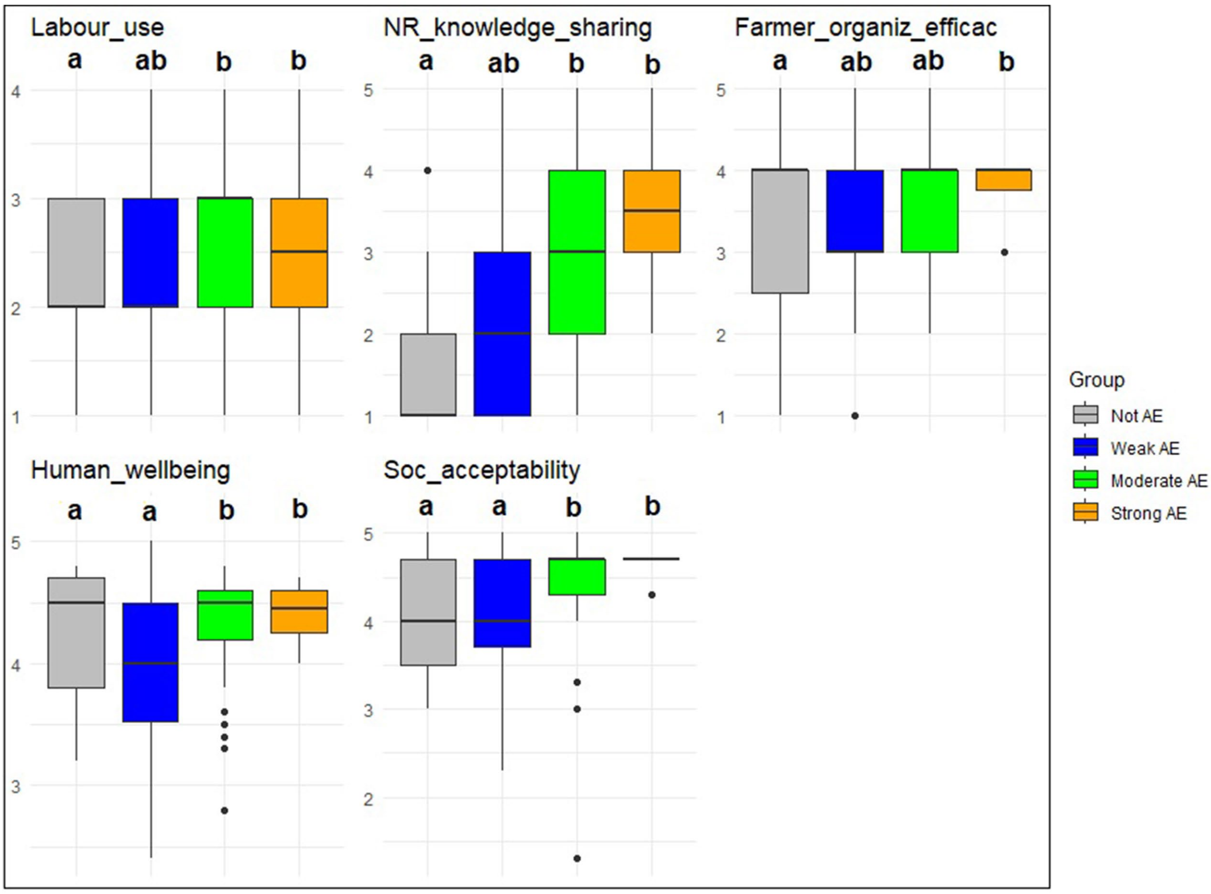

FIGURE 5
Dairy farms' social key performance indicators according to their level of agroecological transition. Key: Labour_use: Working conditions of livestock farmers and access to land; NR_knowledge_sharing: Sharing of agroecological knowledge; Farmer_organiz_efficac: Relationships between farmers and local value chains; Human_wellbeing: Human well-being; Soc_acceptability: Social acceptability of the agroecological transition.

economic resilience, while lagging principles, such as soil health and economic diversification, require resources and long-term support. This disparity underlines the importance of prioritising the immediate needs of farmers while planning strategic actions to integrate less developed agroecological principles in order to achieve a sustainable agroecological transition (Kremen and Miles, 2012; CGIAR, 2023). Regarding soil health, the findings point to the urgent need to step up awareness-raising, training and technical support efforts to help dairy farmers understand how crucially important this issue is. Participatory and locally adapted approaches, combining practical demonstrations and local expertise, could facilitate this process (Francis et al., 2003).

4.2 Crop-livestock farming integration and reinforced support and training mechanisms: key levers for driving the agroecological transition forward

This study reveals a highly heterogeneous level of progress in the agroecological transition of dairy farms in the Bobo-Dioulasso ALL. The majority of farms are at an early stage in their transition to agroecology, while only a minority are advanced, mainly among agro-pastoral farms. This shows that the agroecological transition is still in its infancy in the area covered by the Bobo-Dioulasso ALL, despite the sustainability and resilience challenges faced by dairy production systems.

Analysis of the characteristics of the different farm groups reveals that progress in the agroecological transition is strongly associated with resource availability, in particular a larger farmland area and a reasonable number of cattle, which provides greater flexibility for incorporating agroecological practices (Tittonell et al., 2012). Farms that are more advanced in the AE transition exhibit characteristics consistent with those of Livestock-oriented farms (2–10 ha; 30–100 TLU), as highlighted by several authors, where these farm types rank first in terms of agroecological status (Orounladji et al., 2024). This finding, showing that agroecological farms (Strong AE) are characterized by a significantly larger total land area (3.8 ± 1.9 ha) compared to non-AE farms (2.2 ± 1.6 ha), can be explained by the fact that, in extensive livestock systems in Burkina Faso that combine crop and livestock production, larger areas allow for greater fodder production and manure recycling, factors that can enhance agroecological practices. In contrast, larger areas are more difficult to manage for purely crop-based farms, which often lack sufficient manure, related ecosystem services, and animal traction for ploughing. However, care must be taken to ensure that the viability

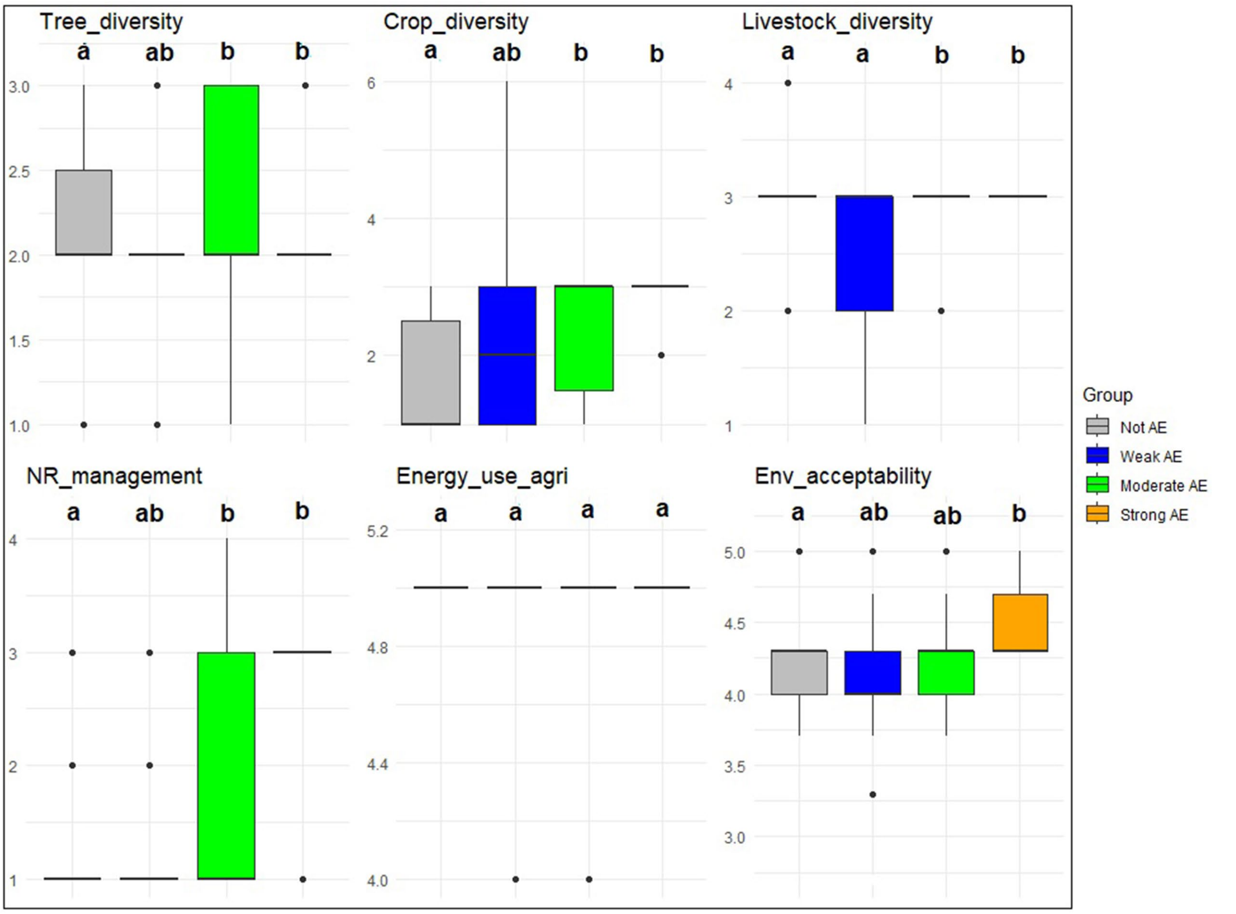

FIGURE 6
Dairy farms' environmental key performance indicators according to their level of agroecological transition. Key: Tree_diversity: Tree diversity; Crop_diversity: Crop diversity; Livestock_diversity: Animal diversity; NR_management: Natural resource management (water, soil, pastures); Energy_use_agri: Use of renewable energy sources (solar, biodigesters, etc.); Env_acceptability: Environmental acceptability of the agroecological transition.

of these livestock-oriented farms is not compromised due to difficulties in accessing pasture, intense agricultural pressure, and conflicts over collective pastoral resources (water points, forage resources), all of which make livestock-oriented farms less viable despite being more agroecological in these agro-sylvo-pastoral systems (Orounladji et al., 2024). For example, in Western Burkina Faso, the research team identified three groups of agroecological farming systems (Vall et al., 2023). The most agroecological farms (17%) feature a significant amount of livestock, which plays multiple roles in recycling and valorising crop and animal co-products into fodder, organic manure, and mulch. The least agroecological farms (25%) dedicate the largest land areas to cotton, use more mineral fertilisers than more agroecological farms, and grow fewer legumes. The findings suggest that crop/livestock synergies and co-product recycling are key factors in the agroecology of agro-sylvo-pastoral systems. Crop-livestock farming integration is also frequently identified as a strategy and pathway toward sustainable agriculture in West African crop-tree-livestock systems (CGIAR, 2023; Vall et al., 2023). In Tanzania, the integration of livestock into the farming system, which helped to increase biodiversity (Ulukan et al., 2022). Livestock farming and fertiliser use, combined with rainwater harvesting, can improve soil fertility and water use efficiency, thereby enhancing food security without compromising the environmental dimension of sustainability.

Farm managers' profiles are another point worthy of note. Farms that are most advanced in the agroecological transition are run by older, more experienced managers, and receive technical support more frequently. Several studies confirm the positive influence of age and experience on the uptake of agroecological practices, with older farmers often more inclined to embrace innovations due to their experience and ability to assess associated risks and benefits, as shown by Mwangi and Kariuki (2015). Older farmers might have gained a great deal of experience and assets or, by choice, have access to land or a large workforce given their age (Choudhury and Goswami, 2013). However, some studies nuance this effect, showing that the impact of age can vary depending on context and on the nature of innovations (Choudhury and Goswami, 2013). These results suggest that access to land, herd size, and farm manager experience are key drivers for the adoption of advanced agroecological practices.

Conversely, non-agroecological farms display more vulnerable profiles, with smaller landholdings and herds, younger household heads, and limited access to technical support. This structural vulnerability restricts their ability to engage in the agroecological transition, potentially exacerbating inequalities between farms

(Vanlauwe et al., 2014). Technical support thus emerges as an essential lever for guiding farmers toward more sustainable practices. Strengthening support and training systems, with particular emphasis on the least advanced farms, is therefore crucial to ensure a fair and inclusive transition (Francis et al., 2003).

4.3 Multidimensional benefits of adopting agroecological principles for dairy farms

Our assessment highlights positive results for dairy farms that are most advanced in their agroecological (AE) transition across a number of key performance indicators (KPIs). These results confirm that the gradual adoption of agroecological principles brings multidimensional benefits across environmental, social, economic, and agronomic spheres.

In environmental terms, these farms show greater crop diversity as well as more efficient natural resource and land management. The management of plant biodiversity, whether cultivated or spontaneous, is key to this increased performance, as shown by research highlighting the crucial role of biodiversity in the resilience of farming systems (Perfecto and Vandermeer, 2010). Farms that are most advanced in the AE transition better integrate biodiversity, both cultivated and spontaneous, which strengthens the ecological resilience of their production systems (Ulukan et al., 2022). Integrated vegetation and resource management promotes the sustainability of agricultural ecosystems, particularly in agro-sylvo-pastoral areas where interactions between trees, crops, and livestock play a central role (Vall et al., 2023). These results support the idea that biodiversity is a key pillar for the stability and productivity of sustainable farming systems.

From a social point of view, farms that are most advanced in the AE transition stand out for their greater sharing of knowledge about agroecology and natural resource management. This participatory dynamism is coupled with greater household satisfaction and increased confidence in the efficiency of trade associations. These elements confirm that co-creation of knowledge and collective management capacity building are key to the success of agroecology (Francis et al., 2003; CGIAR, 2023). They also highlight the importance of social and community dimensions in improving the performance of farming systems in the transition to agroecology.

From an economic perspective, farms that are most advanced in the AE transition enjoy more stable and diversified income streams, which means greater resilience to economic and climate risks. Income diversification, particularly through dairy products combined with associated crops, would help to compensate for potential drops in agricultural productivity. Such income diversification is widely recognised as a key factor for sustainability and economic security in farming systems (Kremen and Miles, 2012; Tittonell et al., 2012). In these livestock-oriented farms (Strong AE), where crop farming is also practiced, agricultural income is nevertheless significantly lower than in other farms (non-AE and low-AE). This may be explained by the large herd sizes of the fields of Strong AE farmers. Consequently, their priority is livestock (including milk production), and indeed, livestock income in these Strong AE farms is significantly higher than in the other groups.

The agronomic performance of dairy farms that are most advanced in the AE transition is reflected in increased organic manure and fodder production, which are essential for maintaining soil fertility and ensuring high-quality animal feed. However, this agroecological transition remains hindered by two major constraints: heavy reliance on labour and low productivity of main crops such as maize, sorghum, millet, rice, and cowpea. The low yields obtained may be related to the low fertility of the soils, as confirmed by the results of soil organic carbon (Non-AE: 0.87%; Weak AE: 0.89%; Moderate AE: 0.77%; Strong AE: 0.83%) analyses carried out in a specialised laboratory. However, this factor alone cannot explain the low crop yields recorded. The low crop yields can also be explained by the fact that dairy farmers show little interest in crop production, as it is considered a secondary activity. Most of the time, the cultivated plots are overrun by weeds. Dairy farmers also sell the manure they produce to crop farmers in order to generate income, rather than applying it directly to their own crop fields. These constraints are common in Sub-Saharan African farming systems, where labour shortage and low yields are major obstacles to adopting sustainable practices (Tittonell et al., 2012; Vanlauwe et al., 2014). Product diversification and gradual improvements in farming practices thus seem like appropriate strategies to compensate for yield declines and strengthen farms' overall resilience.

4.4 HOLPA tool's limitations in assessing agro-pastoral systems

Integrating local indicators into data collection via the HOLPA tool has undoubtedly helped to contextualise results, making them more relevant to local stakeholders. However, several significant limitations have been identified, particularly with regard to the evaluation of agroecological practices specific to agro-pastoral systems. As recently highlighted by Vall et al. (2023) in the agro-pastoral systems of Western Burkina Faso, key practices such as (i) crop co-product storage (straw, haulms) for fodder purposes, (ii) manure and compost production from livestock and crop co-products in night enclosures and manure pits, (iii) night penning of livestock in fields for fertilisation, (iv) sound management of field organic fertilisation, and (v) the use of animal energy for tillage and transport, play a major role in the agroecological characteristics and performance of these systems. Yet these practices are not taken into account in the overall HOLPA tool indicators. This omission is concerning as it leads to a significant underestimation of the agroecological dimensions of agro-pastoral systems, not only in Burkina Faso, but also in many parts of Africa, Asia and Latin America where these systems predominate (Herrero et al., 2016). The lack of specific indicators for these practices limits the tool's ability to accurately reflect the sustainability and complexity of agro-sylvo-pastoral systems.

Another limitation lies in the determination of the level of progress in the agroecological transition. The HOLPA approach assumes equal weighting for all 13 agroecological principles, implying, for example, that "connectivity" carries the same importance as "soil health" or "animal health." This assumption is debatable and lacks theoretical justification. Averaging across equally weighted scores may also mask trade-offs between principles.

Furthermore, the HOLPA tool does not factor in the doses of organic and mineral fertilisers applied per crop, thus preventing precise quantification of fertiliser inputs per unit area. This restricts detailed analysis of soil fertility management, which is key to understanding farms' agronomic sustainability (Vanlauwe et al., 2014;

Lal, 2015; Lehmann and Kleber, 2015). Integrating such quantitative data would considerably strengthen the tool's robustness.

The dual methodology used to assess soil fertility, which combines subjective statements from farmers and objective laboratory analysis, also reveals contradictions. For example, on the dairy farms studied, 89% of respondents consider their soils to be moderately fertile, whereas laboratory analyses show that soil fertility is low. This underlines the need to prioritise analytical data where available in order to avoid perception biases.

Finally, objective comparisons between ALLs are hampered by the qualitative nature of some of the questions used to assess agroecological indicators and performance. The use of proportions or percentages for assessment purposes can mask major quantitative differences, as seen in the example of self-produced manure versus purchased manure. This approach can lead to misinterpretations of the actual level of agroecological transition, thus affecting the decision-making process. To remedy this situation, some of the questionnaire items could be amended to include quantitative intervals (quantities, volumes, etc.) rather than percentages in order to obtain more accurate and comparable data.

5 Conclusion

This study aimed to analyse the relationship between the level of agroecological transition achieved by dairy farms in the Bobo-Dioulasso milkshed area and their multidimensional performance. To do so, 204 farms were assessed with the HOLPA tool, which allowed us to rate their progress across 13 agroecological principles on a 5-point Likert scale and to compare performance according to these levels. The results show that the majority of dairy farms in the Agroecological Living Landscape area of Bobo-Dioulasso are still in the early stages of their agroecological transition. Dairy farms that are most advanced in that transition achieve better environmental, social and economic performance. Crop diversity, sustainable management of natural resources and land, knowledge sharing, income stability, and increased production of organic manure and fodder all testify to the benefits of transitioning toward agroecology. However, heavy reliance on labour and low crop productivity remains major challenges for the sustainability of these systems. Product diversification and improved farming practices can be seen as relevant strategies for offsetting yield declines and boosting farm resilience.

In light of these findings, dairy farmers' technical support and guidance need to be stepped up in order to promote the widespread adoption of agroecological practices. The integration of suitable technologies could improve milk productivity, soil fertility, and farms' overall resilience. The insights gained from this study provide valuable guidance for public policy, dairy value chain stakeholders' strategies, and future action in support of a more sustainable and resilient dairy production. In particular, measures should:

- Support crop-livestock integration through financial incentives or subsidies for farmers who establish fodder production systems, adopt manure management practices, implement rotational grazing and integrated crop-pasture systems, and use organic fertilisers. This also includes facilitating access to quality fodder seeds and manure storage materials.
- Invest in farmer training and extension services to strengthen knowledge sharing and the adoption of agroecological practices. Actions may include organising regular training sessions and farmer field schools on manure management, fodder cultivation, and soil conservation; establishing demonstration farms to showcase successful crop-livestock integration models; using participatory approaches to involve farmers in knowledge exchange and co-creation of innovations; and providing tailored technical advice on feed ration balancing and manure technologies.
- Strengthen farmer organisations and cooperatives to enhance bargaining power and collective action. This can be achieved by facilitating the creation or consolidation of cooperatives, offering capacity-building on governance, financial management and negotiation skills, and supporting linkages between cooperatives, markets, and financial institutions.
- Promote appropriate technologies to improve productivity and soil fertility, such as covered manure pits or composting systems, improved fodder conservation methods, and simple feed ration balancing tools.

For a more in-depth analysis, a study of the performance of different types of dairy farms would be valuable, as would an assessment of the actual impact of some agroecological practices, such as fodder demonstration plots, livestock and crop co-product management, cow rationing, and the use of covered manure pits, on farms' overall performance. These perspectives will pave the way for a better understanding of the levers needed to step up the agroecological transition in the Bobo-Dioulasso milkshed area.

This study has discussed some limitations that, if addressed in an updated version, could strengthen the HOLPA framework. The tool omits key agro-pastoral practices such as fodder storage, composting, or the use of animal traction, leading to an underestimation of agro-sylvo-pastoral systems, the assumption of equal weighting across the 13 agroecological principles may simplify results and obscure trade-offs, and the lack of quantitative data on fertiliser doses and the reliance on partly qualitative indicators restrict the precision and comparability of results. In addition, discrepancies between farmers' perceptions and laboratory analyses of soil fertility highlight the need to prioritise objective measures where available.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by The Institutional Review Board (IRB) of the Alliance of Bioversity International and CIAT. Reference: Transformational Agroecology across Food, Land and Water Systems (AE-I): WP2 HOLPA survey (2023 – IRB39). The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because Verbal informed consent was obtained prior to the interview of the dairy farmers. The interviewed dairy farmers have consented to the submission of the results of this study to the journal.

Author contributions

BO: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing. OS: Validation, Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. PK: Validation, Conceptualization, Writing – review & editing, Investigation. MD: Methodology, Conceptualization, Writing – review & editing. SS: Writing – review & editing, Conceptualization, Methodology. EV: Validation, Resources, Funding acquisition, Supervision, Conceptualization, Writing – review & editing, Project administration, Methodology.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This work was supported and funded by the Consultative Group on International Agricultural Research (CGIAR) through the Agroecology Initiative: Transforming Food, Land, and Water Systems Across the Global South (Grant Number: CGIAR Initiative on Agroecology, INIT-31). Additional financial support for publication was provided by the CGIAR Fund–SP04; Multifunctional Landscapes.

Acknowledgments

All the authors would like to thank the Dairy Innovation Platform (PIL) of Bobo-Dioulasso, particularly the farmers, for their sincere collaboration during data collection. Gratitude is also extended to the partners of the ASAP platform (https://www.dp-asap.org/) for their collaboration throughout this study. Special thanks go to Raoul Zoundi and Amadou Barry for their outstanding dedication to data collection.

Conflict of interest

The authors declare that the research 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 authors declare that no Gen AI was 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.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1657011/full#supplementary-material

References

Affholder, F., Bessou, C., Lairez, J., and Feschet, P. (2018). Évaluation des compromis entre enjeux environnementaux et socio-économiques dans les systèmes agro-écologiques. In: La transition agro-écologique des agricultures du Sud. François-Xavier Côte (ed.), Emmanuelle Poirier-Magona (ed.), Sylvain Perret (ed.), Philippe Roudier (ed.), Bruno Rapidel (ed.), Marie-Cécile Thirion (ed.)., Quae. Versailles, pp. 313–345

Akanmu, A. O., Akol, A. M., Ndolo, D. O., Kutu, F. R., and Babalola, O. O. (2023). Agroecological techniques: adoption of safe and sustainable agricultural practices among the smallholder farmers in Africa. *Front. Sustain. Food Syst.* 7:1143061. doi: 10.3389/fsufs.2023.1143061

Altieri, M. A., and Toledo, V. M. (2011). The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants. *J. Peasant Stud.* 38, 587–612. doi: 10.1080/03066150.2011.582947

Anderson, C. R., Bruil, J., Chappell, M. J., Kiss, C., and Pimbert, M. P. (2019). From transition to domains of transformation: getting to sustainable and just food systems through agroecology. *Sustainability* 11:5272. doi: 10.3390/su11195272

Bezner Kerr, R., Liebert, J., Kansanga, M., and Kpienbaareh, D. (2022). Human and social values in agroecology: a review. *Elem. Sci. Anth.* 10:00090. doi: 10.1525/elementa.2021.00090

Bezner Kerr, R., Madsen, S., Stüber, M., Liebert, J., Enloe, S., Borghino, N., et al. (2021). Can agroecology improve food security and nutrition? A review. *Glob. Food Secur.* 29:100540. doi: 10.1016/j.gfs.2021.100540

Bezner Kerr, R., Postigo, J. C., Smith, P., Cowie, A., Singh, P. K., Rivera-Ferre, M., et al. (2023). Agroecology as a transformative approach to tackle climatic, food, and ecosystemic crises. *Curr. Opin. Environ. Sustain.* 62:101275. doi: 10.1016/j.cosust.2023.101275

Binder, C. R., Feola, G., and Steinberger, J. K. (2010). Considering the normative, systemic and procedural dimensions in indicator-based sustainability assessments in agriculture. *Environ. Impact Assess. Rev.* 30, 71–81. doi: 10.1016/j.eiar.2009.06.002

Binder, C. R., Schmid, A., and Steinberger, J. K. (2012). Sustainability solution space of the Swiss milk value added chain. *Ecol. Econ.* 83, 210–220. doi: 10.1016/j.ecolecon.2012.06.022

Cetrone, H. M., Santoso, M. V., Bezner Kerr, R., Petito, L., Blacker, L., Nonga, T., et al. (2021). Food security mediates the decrease in women's depressive symptoms in a participatory nutrition-sensitive agroecology intervention in rural Tanzania. *Public Health Nutr.* 24, 4682–4692. doi: 10.1017/s1368980021001014

CGIAR. (2023). The agroecology transition: different pathways to a single destination-eight country experiences. p. 32. CGIAR Initiative on Agroecology. Available online at: https://cgspace.cgiar.org/items/0607f5cd-82e0-4fcd-94ac-ad1d159911f0 (Accessed April 14, 2025).

Choudhury, H. K., and Goswami, K. (2013). Determinants of expansion of area under *jatropha* plantation in north East India: a Tobit analysis. *Forest Policy Econ.* 30, 46–52. doi: 10.1016/j.forpol.2013.02.006

Coe, R., Andrieu, N., Alary, V., Ky-Dembele, C., Magaju, C., Orounladji, B. M., et al. (2025). Environmental factors are an important part of farmers' assessments of the value of agroecology. *Front. Sustain. Food Syst.* 9:1618006. doi: 10.3389/fsufs.2025.1618006

Corson, M. S., Mondiere, A., Morel, L., and van der Werf, H. M. G. (2022). Beyond agroecology: agricultural rewilding, a prospect for livestock systems. *Agric. Syst.* 199:103410. doi: 10.1016/j.agsy.2022.103410

Côte, F. X., Poirier-Magona, E., Perret, S., Roudier, P., Rapidel, B., and Thirion, M.C. (2019). La transition agro-écologique des agricultures du Sud. In Libr. Quae. Available online at: https://www.quae.com/produit/1546/9782759228232/la-transition-agro-ecologique-des-agricultures-du-sud (Accessed September 30, 2025)

Crossland, M., Coe, R., Lamanna, C., Chiputwa, B., Orero, L., Adoyo, B., et al. (2025). Measuring the holistic performance of food and agricultural systems: a systematic review. *Front. Sustain. Food Syst.* 9:1472109. doi: 10.3389/fsufs.2025.1472109

Darmaun, M., Chevallier, T., Hossard, L., Lairez, J., Scopel, E., Chotte, J. L., et al. (2023). Multidimensional and multiscale assessment of agroecological transitions. a review. *Int. J. Agric. Sustain.* 21:2193028. doi: 10.1080/14735903.2023.2193028

Dumont, B., Fortun-Lamothe, L., Jouven, M., Thomas, M., and Tichit, M. (2013). Prospects from agroecology and industrial ecology for animal production in the 21st century. *Animal* 7, 1028–1043. doi: 10.1017/S1751731112002418

FAO (2018) Shaping the future of livestock: sustainably, responsibly, efficiently. The 10th global forum for food and agriculture (GFFA). 20p

Francis, C., Lieblein, G., Gliessman, S., Breland, T. A., Creamer, N., Harwood, R., et al. (2003). Agroecology: the ecology of food systems. *J. Sustain. Agric.* 22, 99–118. doi: 10.1300/J064v22n03_10

Geck, M. S., Crossland, M., and Lamanna, C. (2023). Measuring agroecology and its performance: an overview and critical discussion of existing tools and approaches. *Outlook Agric.* 52, 349–359. doi: 10.1177/00307270231196309

Gliessman, S. R. (2014). Agroecology: The ecology of sustainable food systems, third edition. *3rd* Edn: CRC Press, 405.

Gliessman, S. (2016). Transforming food systems with agroecology. *Agroecol. Sustain. Food Syst.* 40, 187–189. doi: 10.1080/21683565.2015.1130765

Gliessman, S. (2020). A voice for African agroecology. *Agroecol. Sustain. Food Syst.* 44, 825–826. doi: 10.1080/21683565.2020.1744851

Herrero, M., Wirsenius, S., Henderson, B., Rigolot, C., Thornton, P., Havlik, P., et al. (2016). Livestock and the environment: what have we learned in the past decade? *Annu. Rev. Environ. Resour.* 40, 177–202. doi: 10.1146/annurev-environ-031113-093503

HLPE. (2019). Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Available online at: https://openknowledge.fao.org/server/api/core/bitstreams/ff385e60-0693-40fe-9a6b-79bbef05202c/content

IPCC (2022). Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change. Cambridge, UK and New York, NY, USA: Cambridge University Press. Cambridge University Press, 3056.

IPES-Food (2016) From uniformity to diversity: A paradigm shift from industrial agriculture to diversified agroecological systems. International panel of experts on sustainable food systems Available online at: https://www.ipes-food.org/_img/upload/files/UniformityToDiversity_ExecSummary.pdf (Accessed May 6, 2025).

Jones, S. K., Sánchez Bogado, A. C., Lamanna, C., Dickens, C., Geck, M. S., Wickramaratne, C., et al. (2024). Holistic localized performance assessment (HOLPA) tool for collecting locally relevant and globally comparable evidence of agroecology's effects on nature and people. *Cell Press*:25. doi: 10.2139/ssrn.4891979

Kansanga, M. M., Bezner Kerr, R., Lupafya, E., Dakishoni, L., and Luginaah, I. (2024). Can gender transformative agroecological interventions improve women's autonomy? *Agric. Hum. Values* 41, 1161–1175. doi: 10.1007/s10460-024-10544-9

Kanter, D. R., Musumba, M., Wood, S. L. R., Palm, C., Antle, J., Balvanera, P., et al. (2018). Evaluating agricultural trade-offs in the age of sustainable development. *Agric. Syst.* 163, 73–88. doi: 10.1016/j.agsy.2016.09.010

Kouakou, P. K., Sib, O., Orounladji, B. M., Assouma, M. H., Ouédraogo, A., and Vall, E. (2023). Context document Burkina Faso. Agriculture and agroecology in the Hauts-Bassins region, an ALL intervention area in Burkina Faso. Montpellier: CGIAR Initiative on Agroecology, 50.

Kremen, C., and Miles, A. (2012). Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. *Ecol. Soc.* 17:25. doi: 10.5751/ES-05035-170440

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability* 7, 5875–5895. doi: 10.3390/su7055875

Lebacq, T., Baret, P. V., and Stilmant, D. (2013). Sustainability indicators for livestock farming. A review. *Agron. Sustain. Dev.* 33, 311–327. doi: 10.1007/s13593-012-0121-x

Lehmann, J., and Kleber, M. (2015). The contentious nature of soil organic matter. *Nature* 528, 60–68. doi: 10.1038/nature16069

Leippert, F., Darmaun, M., Bernoux, M., and Mpheshea, M. (2020). The potential of agroecology to build climate-resilient livelihoods and food systems. Rome: FAO and Biovision.

Lucantoni, D., Sy, M. R., Goïta, M., Veyret-Picot, M., Vicovaro, M., Bicksler, A., et al. (2023). Evidence on the multidimensional performance of agroecology in Mali using TAPE. *Agric. Syst.* 204:103499. doi: 10.1016/j.agsy.2022.103499

Madsen, S., Bezner Kerr, R., LaDue, N., Luginaah, I., Dzanja, C., Dakishoni, L., et al. (2021). Explaining the impact of agroecology on farm-level transitions to food security in Malawi. *Food Secur.* 13, 933–954. doi: 10.1007/s12571-021-01165-9

Mouratiadou, I., Wezel, A., Kamilia, K., Marchetti, A., Paracchini, M. L., and Bàrberi, P. (2024). The socio-economic performance of agroecology. A review. *Agron. Sustain. Dev.* 44:19. doi: 10.1007/s13593-024-00945-9

Mugwanya, N. (2019). Why agroecology is a dead end for Africa. *Outlook Agric.* 48, 113–116. doi: 10.1177/0030727019854761

Muhumuza, J. R. (2023). Why current agroecology rhetoric stands to protract farmer poverty in the developing world. *Outl. Agric.* 52, 303–310. doi: 10.1177/00307270231195381

Mulaji, C., Disa-Disa, P., Kibal, I., and Culot, M. (2016). Diagnostic de l'état agropédologique des sols acides de la province de Kinshasa en république démocratique du Congo (RDC). *C. R. Chim.* 19, 820–826. doi: 10.1016/j.crci.2015.08.010

Müller, A., and Sukhdev, P. (2018). The complex reality of eco-agri-food systems. In measuring what matters in agriculture and food systems: a synthesis (p. 84). Nairobi: TEEP, UNEP. Available online at: http://www.teebweb.org/agrifood/home/scientific-and-economic-foundations-report

Mwangi, M., and Kariuki, S. (2015). Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. *J. Econ. Sustain. Dev.* 6, 208–216.

Orounladji, B. M., Sanogo, S., Kouakou, P. K., Ouédraogo, A., Sib, O., and Assouma, M. H. (2023). "Work package 2" in Localized indicators for multi-criteria assessment of agroecological performance (Bobo-Dioulasso: CGIAR Initiative on Agroecology-CIRAD), 13.

Orounladji, B. M., Sib, O., Berre, D., Assouma, M. H., Dabiré, D., Sanogo, S., et al. (2024). Cross-examination of agroecology and viability in agro-sylvo-pastoral systems in Western Burkina Faso, *agroecology and sustainable food systems* 48, 581–609. doi: 10.1080/21683565.2024.2307902

Perfecto, I., and Vandermeer, J. (2010). The agroecological matrix as alternative to the land-sparing/agriculture intensification model. *Proc. Natl. Acad. Sci. USA* 107, 5786–5791. doi: 10.1073/pnas.0905455107

R Core Team (2024). R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online at: https://www.R-project.org/

Rivas, J., Perea, J., Angon, E., Barba, C., Morantes, M., Dios-Palomares, R., et al. (2015). Diversity in the dry land mixed system and viability of dairy sheep farming. *Ital. J. Anim. Sci.* 14, 179–186. doi: 10.4081/ijas.2015.3513

Sachs, J., Remans, R., Smukler, S., Winowiecki, L., Andelman, S. J., Cassman, K. G., et al. (2010). Monitoring the world's agriculture. *Nature* 466, 558–560. doi: 10.1038/466558a

Schader, C., Grenz, J., Meier, M. S., and Stolze, M. (2014). Scope and precision of sustainability assessment approaches to food systems. *Ecol. Soc.* 19:15. doi: 10.5751/ES-06866-190342

Spicka, J., Hlavsa, T., Soukupova, K., and Stolbov, M. (2019). Approaches to estimation the farm-level economic viability and sustainability in agriculture: a literature review. *Agric. Econ. Czech* 65, 289–297. doi: 10.17221/269/2018-AGRICECON

Tittonell, P., Scopel, E., Andrieu, N., Posthumus, H., Mapfumo, P., Corbeels, M., et al. (2012). Agroecology-based aggradation-conservation agriculture (ABACO): targeting innovations to combat soil degradation and food insecurity in semi-arid Africa. *Field Crop Res.* 132, 168–174. doi: 10.1016/j.fcr.2011.12.011

Ulukan, D., Bergkvist, G., Lana, M., Fasse, A., Mager, G., Öborn, I., et al. (2022). Combining sustainable livelihood and farm sustainability approaches to identify relevant intensification options: implications for households with crop-based and gathering-based livelihoods in Tanzania. *Ecol. Indic.* 144:109518. doi: 10.1016/j.ecolind.2022.109518

Vall, E., Orounladji, B. M., Berre, D., Assouma, M. H., Dabiré, D., Sanogo, S., et al. (2023). Crop-livestock synergies and by-products recycling: major factors for agroecology in west African agro-sylvo-pastoral systems. *Agron. Sustain. Dev.* 43. doi: 10.1007/s13593-023-00908-6

Vall, E., Sib, O., Vidal, A., and Delma, J. D. (2021). Dairy farming systems driven by the market and low-cost intensification in West Africa: the case of Burkina Faso. *Trop. Anim. Health Prod.* 53:288. doi: 10.1007/s11250-021-02725-z

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., et al. (2014). Sustainable intensification and the African smallholder farmer. *Curr. Opin. Environ. Sustain.* 8, 15–22. doi: 10.1016/j.cosust.2014.06.001

Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* 37, 29–38. doi: 10.1097/00010694-193401000-00003

Wezel, A., Gemmill Herren, B., Bezner Kerr, R., Barrios, E., Rodrigues Gonçalves, A. L., and Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agron. Sustain. Dev.* 40:40. doi: 10.1007/s13593-020-00646-z

Wiget, M., Muller, A., and Hilbeck, A. (2020). Main challenges and key features of indicator-based agroecological assessment frameworks in the context of international cooperation. *Ecol. Soc.* 25:25. doi: 10.5751/ES-11774-250325