# Assessing sustainability in small dairy cattle farms: Pathways for improvement in northeastern Tunisia

NADIA OUNALLI*, MOHAMED ZIED DHRAIEF*, MONDHER BEN SALEM**, BOUBAKER DHEHIBI***, INES GHARBI*, MOURAD REKIK***, MUSTAPHA MANSOURI****, FERID RIAHI*****

DOI: 10.30682/nm2504h
JEL codes: Q12

***Abstract***

*In Tunisia, rising costs, low productivity, and climate change have reduced cattle numbers in the last decade. This study evaluates the sustainability of small dairy cattle farms in northeastern Tunisia and explores pathways for improvement. A sustainability assessment was conducted on 109 dairy farms in Bizerte, using IDEA method to evaluate agroecological, socioterritorial, and economic dimensions. At the regional level, sustainability was highest in agroecology, moderate in economics, and lowest in socioterritorial aspects. Cluster analysis identified four groups. The first supports employment and resource use but struggles with organic farming and waste management. The second practices agroforestry with moderate biodiversity but faces economic challenges. The third excels in biodiversity and manure management. The fourth benefits from diversification and self-sufficiency, enhancing performance. For long-term sustainability, the dairy sector must adopt resilient systems with mixed forage crops, improve funding and subsidies, and invest in infrastructure, training, and cooperatives to boost productivity, reduce environmental impact, and integrate farmers into the value chain.*

***Keywords***: *Sustainability, Dairy cattle farms, IDEA, Cluster analysis, Tunisia.*

## 1. Introduction

Dairy cattle farming plays a crucial role in the Tunisian economy, providing significant contributions both economically and socially (Dhraief *et al.*, 2019). This strategic sector represents an important part of the country's agro-food industry, contributing about 7% of its total value (Chebbi, 2019). Additionally, it accounts for approximately 25% of animal production and 11% of overall agricultural production. In 2015, it provided employment for over 112,100 farmers,

* Rural Economic Laboratory, National Institute of Agronomic Research of Tunisia (INRAT), Carthage University, Tunis, Tunisia.
** Animal and fodder production laboratory, National Institute of Agronomic Research of Tunisia (INRAT), Carthage University, Tunis, Tunisia.
*** Social, Economy and Policy (SEP) Team, International Center for Agricultural Research in the Dry Areas (ICARDA), Tunis, Tunisia.
**** North-West Sylvo-Pastoral Development Office (ODESYPANO), Béja, Tunisia.
***** Territorial Extension Unit (CTV), Sejnane, Tunisia.
Corresponding author: nediaounalli@gmail.com

which is more than 40% of all agricultural jobs in the country. The increase in demand for animal-based products in Tunisia over recent decades highlights the strategic importance for food security, the economy, and nutrition. This sector also requires particular attention regarding associated environmental and socioeconomic challenges (Soltani *et al.*, 2011).

The dairy value chain in Tunisia is sensitive and could be negatively affected by the opening of the Tunisian market to European milk and dairy products, which are considered more competitive. Within this value chain, small- and medium-sized farmers face numerous problems and threats that weigh on its present and could jeopardize its future in an already challenging global context associated with climate change and soil degradation (FAO, 2021). Therefore, the quest for competitiveness in local dairy farming in Tunisia is crucial to reducing the significant gap between domestic milk supply and demand (Steinfeld *et al*., 2006). It is important to consider the environmental and health concerns related to this expansion, such as soil biodiversity loss (Caplat *et al*., 2012) and greenhouse gas emissions, highlighting the urgency of adopting sustainable and environmentally friendly agricultural practices.

The low productivity observed in small- and medium-sized dairy farms can be explained by multiple constraints, including low nutritional values and poor technical management of dairy cows, especially in smaller farms (Sraïri *et al.*, 2007; M'Hamdi *et al.*, 2017; Attia *et al.*, 2022). In the field, strategies and practices for developing the local dairy sector primarily focus on improving farmers' incomes rather than seeking social balance, and even less on reducing environmental threats.

Dairy farms in Tunisia face increasingly warmer temperatures, exceeding cows' thermo-neutral zone for over five months each year, leading to reduced production efficiency and substantial economic losses (Bouraoui *et al*., 2002). Frequent droughts, often occurring for two consecutive years after no more than three years of normal rainfall, have diminished the quality and availability of fodder – a critical constraint for livestock farming (Kayouli, 2006). This has hindered the genetic potential of high-yielding breeds, raising concerns about their ability to adapt to these harsh conditions (Hammami *et al.*, 2008). Projected climate change scenarios are expected to exacerbate these challenges, further impacting natural resources, animal productivity, health, and the sustainability of livestock-based production systems (Ben Salem, 2011).

Reflecting on the performance and sustainability of small and medium dairy farms is important. The sustainability of these agricultural operations is crucial for ensuring food security, reducing poverty, and preserving natural resources, particularly in developing countries (Schindler *et al.*, 2015) Indeed, assessing agricultural sustainability is an essential step in building the knowledge necessary to improve management and evolve toward more sustainable practices and systems. Thus, this assessment contributes to the design of innovative solutions to enhance the sustainability of farms (Bockstaller *et al*., 2015). A decision-making support objective should accompany this assessment through public policy guidelines that encourage environmentally friendly agricultural practices.

Several methods, such as RISE (Häni *et al*., 2003), MOTIFS (Meul *et al*., 2008), SAFA (FAO, 2014), FoPIA (Bechir and Ounalli, 2020), DPSIR (Bechir *et al*., 2020), and SIAT (Corvo *et al*., 2021), have been developed to study agricultural farm sustainability, but mainly in developed countries and to a much lesser extent in developing countries (Fadul-Pacheco *et al.*, 2013). Among these methods, IDEA (Indicateurs de Durabilité des Exploitations Agricoles or Farm Sustainability Indicators) describes the overall performance of farms, taking into account the three dimensions of sustainability: agroecological, socioterritorial, and economic. This method enables an in-depth analysis of each aspect of sustainability, including all dimensions of the farm and is compatible with different contexts (Zahm *et al*., 2008). The IDEA method has been used in various studies assessing the sustainability of agricultural systems (Attia *et al.*, 2022; Baccar *et al.*, 2018; Gharbi *et al*., 2022; M'Hamdi *et al.*, 2017; Bekhouch-Guendouz, 2011).

This study aims to assess the sustainability of the small dairy cattle farms in northeastern Tunisia and explores pathways for improvement. A sustainability evaluation was undertaken with 109 smallholder dairy farms in the Bizerte region using the IDEA method in the agroecological, socioterritorial, and economic scales.

## 2. Methodological framework

### 2.1. *Study area*

The study area focused on the two regions of Sejnane-Joumine and Utique in Bizerte governorate (Figure 1). This region is located in the extreme northeast of the country and benefits from a privileged geographic position with a broad opening to the Mediterranean. Bizerte covers an area of 3,750 km² and in April 2014 had a population of 568,219. This area is characterized by a humid and semi-humid climate, receiving an average rainfall of over 600 mm, which promotes forage production.

The study region represents a dairy basin characterized by small- and medium-sized dairy cattle producers. The Utique region is an old dairy basin and the leading milk producer in the governorate. It ranks third in the number of producing female cattle. The Sejnane-Joumine region features an integrated cattle farming system. It ranks first in terms of the number of productive females (6,762) and third in milk production (18,205 liters per day).

Figure 1 - Study area (Authors' elaboration, 2024).


### 2.2. *Study design*

The study area was chosen due to the diversity of crops and the importance of dairy cattle farming activity. The survey was conducted among 109 selected dairy cattle farmers. The sample size was determined using the equation of Cochran WG (1977) with a confidence interval of less than 95% and a precision of 10%. The formula used is $n = N/(1 + (e^2)$, where n is the sample size, N is the population size, and e is the level of precision. Farmers were selected based on specific criteria to ensure representativeness of the sample.

### 2.3. *Data collection*

The data used were collected through field surveys of 109 farmers from Sejnane-Joumine (59 individuals) and Utique (50 individuals), who have small and medium sized farms, with an average herd size of six cows and an average area of 4.85 ha.

Various types of data were collected during the two-year period (2021-2023). The data included statistical information and specific data related to the IDEA method. This method consists of 122 questions. The specific guide for this method includes general information about the farm, livestock, management practices, biodiversity aspects, land use, management and farming practices, life quality, and economic aspects.

In addition to a literature review on farm sustainability assessment, and field surveys, six mini-workshops have been co-organized successively since 2021, including National Institute of Agronomic Research of Tunisia (INRAT), North-West Sylvo-Pastoral Development Office (ODESYPANO) Sejnane, Livestock and Pasture Office (OEP) Mateur, and territorial extension unit (CTV) Sejnane-Joumine and Utique (Table 1). These working meetings involved the main stakeholder groups concerned with dairy production.

Table 1 - Description of multi-stakeholder workshop organized in the study area.

| *Date* | *Location* | *Participants* | *Topics* |
|---|---|---|---|
| 24 March 2024 | Agricultural Investment Promotion Agency (APIA) Bizerte | 3 | Collection of statistical data on the dairy value chain in Bizerte (for sampling).<br>Discussion of the variables determining the sustainability of dairy cattle farming in Bizerte.<br>Presentation of the IDEA method.<br>Data collection for the IDEA exercise. |
| 12 September 2021 | INRAT Tunis | 28 | National workshop: "Diagnosis of the dairy value chain in Bizerte."<br>Discussion of the variables determining the viability of dairy cattle farming in Bizerte. |
| 25 March 2022 | ODESYPANO Sejnane | 11 | Sampling and fieldwork preparation.<br>Presentation of IDEA survey elements. |
| 16 April 2022 | OEP Mateur | 3 | Data collection for the IDEA method.<br>Discussion of the variables determining the viability of dairy cattle farming in Bizerte. |
| 5 May 2022 | CTV Sejnane | 4 | Sampling and fieldwork preparation.<br>Presentation of IDEA survey elements.<br>Discussion of IDEA sustainability indicators. |
| 23 May 2023 | ODESYPANO Beja | 16 | Regional workshop: "Sustainability indicators and methods for assessing the sustainability of cattle farming in the regions of Sejnane-Joumine and Utique."<br>Discussion and validation of IDEA method results. |

*Source: Authors' elaboration, 2024.*

### 2.4. *Data analysis*

The data analysis was based on the IDEA method, a tool based on 42 indicators developed by Vilain (2003), who identified three scales: agro-environmental with 18 indicators, socio-territorial with 18 indicators, and economic with six indicators. In this study, the method was adapted while retaining all components and initial thresholds. Each indicator provides information about the level of sustainability. The score from the lowest scale among the three mentioned scales reflects the level of sustainability of the farm (Zahm *et al.*, 2008). This analysis is combined with principal component analysis and ascending hierarchical classification—statistical analyses to classify the farms into groups according to the sustainability scores.

## 3. Results

### 3.1. *Descriptive analysis of the sustainability of dairy cattle farming systems*

Overall sustainability is rated at 151/300 points for Sejnane-Joumine and 134/300 points for Utique. The agroecological scale scores the highest with 56.37 points, followed by the economic scale at 55.7 points (Figure 2). The socioterritorial scale has the lowest score at 32.13 points, which is the main limiting factor for the sustainability of these farms. This limitation stems from weaknesses observed in the product and territorial quality, as well as the ethics and human development components. Enhancing the sustainability of these dairy farming systems requires addressing all three scales.

The component of *spatial organization* has a relatively high average of 14.17 points, driven by high parcelization (5.14/6 points) and effective management of organic materials, with farmers using manure on over 20% of the utilized agricultural area (UAA) to enhance soil fertility and reduce fertilization costs (2.75/5 points). The *farming practices* component also scores significantly with an average of 20.1/34 points, where the liquid organic waste indicator, assessing effluent management, achieved a perfect score since none of the visited farms used liquid organic waste (manure). The *in-*

Figure 2 - Representation of the sustainability scales of farms.

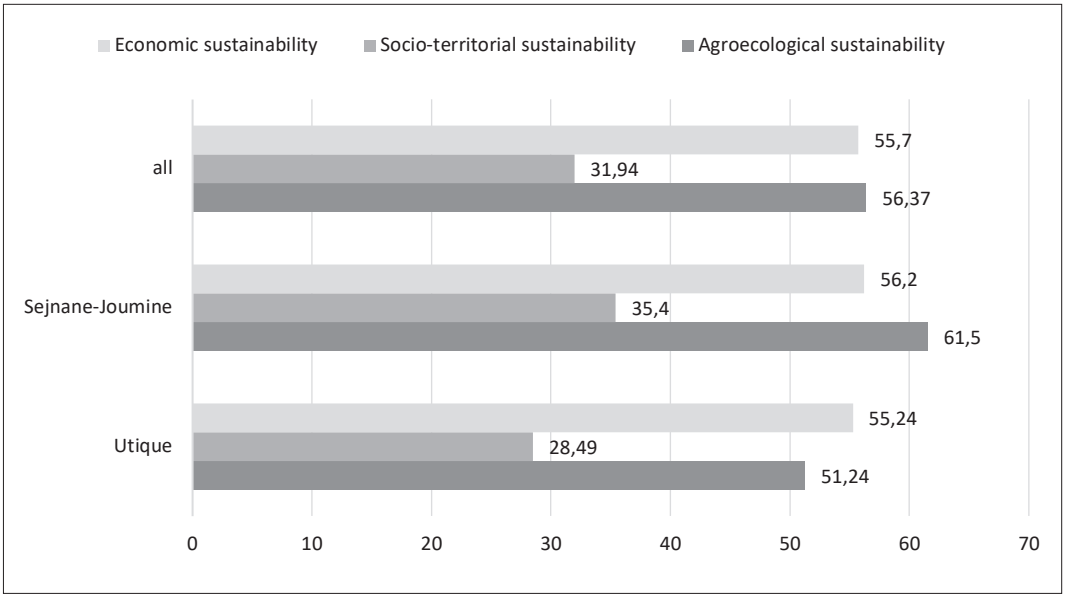
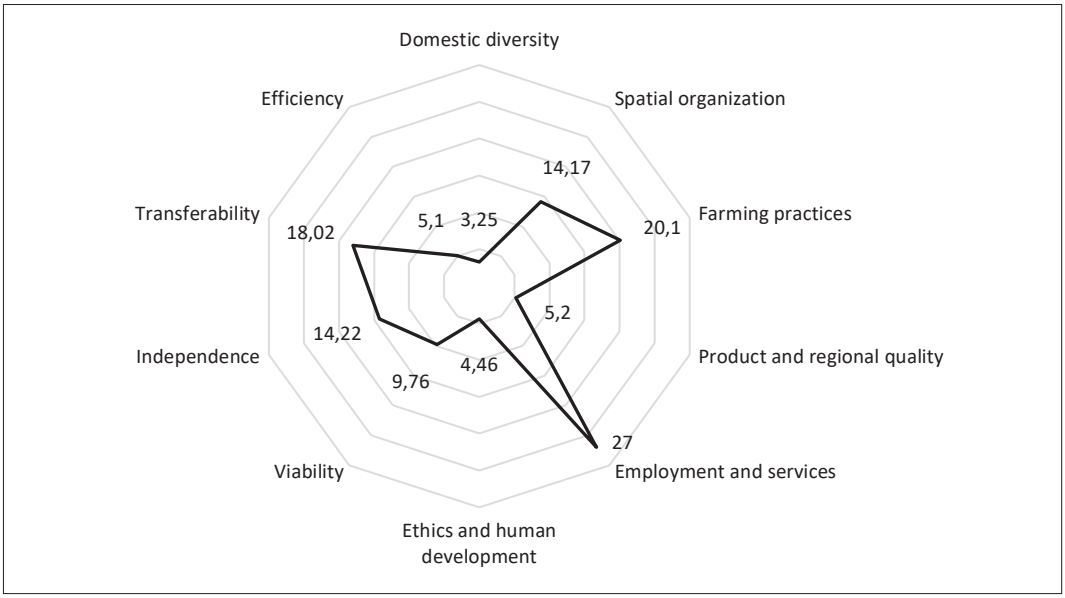



Figure 3 - Graphic representation of the sustainability components.




*dependence* component, with a score of 22.95 points, reflects financial autonomy, as farmers did not receive credit due to their land tenure status, which did not meet the requirements of funders. Lastly, the *transferability* component, which measures the ease of farm succession, scored highest in economic transmissibility due to the low capital levels of the farms relative to the full-time family agricultural workforce (Figure 3).

Table 2 - Indicator scores for the production diversity component (PDC).

| | *Diversity of annual and temporary crops* | *Diversity of perennial crops* | *Animal diversity* | *Enhancing genetic heritage* | *PDC* |
|---|---|---|---|---|---|
| All | 5.95 | 3.1 | 9.8 | 3.25 | 22.1 |
| Sejnane-Joumine | 6.2 | 4.6 | 10.6 | 3.4 | 24.8 |
| Utique | 6 | 1.6 | 9 | 3.1 | 19.4 |
| Theoretical maximum | 14 | 14 | 14 | 6 | 33 |

3.1.2. *Sustainability assessment of the agroecological scale*

The *diversity of annual and temporary crops* component averages 22.1/33 points, with Sejnane-Joumine scoring 24.8/33 and Utique 19.4/33 (Table 2). The *domestic plant biodiversity* indicator, which measures the variety of plants on farms, averages 5.95/14 points. The *diversity of perennial crops,* based on the presence of grasslands, arboriculture, agroforestry, and agro-silvopastoralism, averages 3.1/14 points across both areas. *Animal diversity*, determined by the number of productive animal species and breeds, scores 9.8/14 in Sejnane-Joumine and 10.6/14 in Utique, with the high score reflecting the combination of sheep and cattle farming in 78% of the farms. The indicator for *genetic heritage enhancement*, which supports local breeds and endangered species, shows low scores. Over the past 20 years, the local breed has been replaced by imported breeds (Holstein breed) that are more productive but less resilient to the climatic challenges in Tunisia.

The *spatial organization* component, with an overall average value of 14.17/33 points, includes several key indicators reflecting farming practices (Table 3). The *crop rotation* indicator scores low, at just 17% of the theoretical maximum, due to the limited plot size, which averages 5.37/6 points, restricting farmers' ability to grow enough forage and cereal crops to meet their livestock's food needs. The *organic matter management* indicator scores 2.75/5, as most farmers apply manure to over 20% of their Utilized Agricultural Area (UAA) to enhance soil fertility and reduce costs. The *space for enhancement* indicator is low (1.6/5), highlighting poorly managed forage areas affected by overgrazing and monoculture. Similarly, *forage area management* scores just 1/3 due to unplanned grazing and inadequate post-mowing care.

The *agricultural practices* component, which focuses on soil protection, treatment techniques, and the management of energy and non-renewable resources like irrigation water, is capped at 34 points and has an average score of 20.1 points. The *fertilization* indicator, which measures the ratio between imports (fertilizers, concentrated feed, and roughage) and exports (milk, animals, and plants), reveals nitrogen pollution from nitrate leaching, resulting in an

Table 3 - Scores of indicators for the component related to spatial organization (SOC).

| | *Crop rotation* | *Plot size* | *Organic matter management* | *Ecological regulation* | *Space enhancement* | *Management of forage areas* | *SOC* |
|---|---|---|---|---|---|---|---|
| All | 1.4 | 5.37 | 2.75 | 2.05 | 1.6 | 1 | 14.17 |
| Sejnane-Joumine | 1.4 | 5.6 | 2.8 | 2.6 | 2.1 | 1.2 | 15.7 |
| Utique | 1.4 | 5.14 | 2.7 | 1.5 | 1.1 | 0.8 | 12.64 |
| Theoretical maximum | 8 | 6 | 5 | 12 | 5 | 3 | 33 |

Table 4 - Indicator scores for the agricultural practices component (APC).

| | *Fertilization* | *Liquid organic effluents* | *Pesticides* | *Veterinary treatments* | *Water resource management* | *Protection of soil resources* | *Energy dependence* | *APC* |
|---|---|---|---|---|---|---|---|---|
| All | 1.75 | 3 | 6.25 | 1.35 | 3.2 | 0,55 | 4 | 20.1 |
| Sejnane-Joumine | 0.8 | 3 | 7.1 | 1.4 | 3.2 | 0,8 | 4.7 | 21 |
| Utique | 2.7 | 3 | 5.4 | 1.3 | 3.2 | 3,2 | 3.3 | 19.2 |
| Theoretical maximum | 8 | 3 | 13 | 3 | 4 | 5 | 10 | 34 |

unbalanced and polluted environment, with an average score of 1.75/8, ranging from 0.8/8 in Sejnane-Joumine to 2.7/8 in Utique (table 4). The *use of pesticides* indicator, which addresses threats to human health and ecosystems, scores modestly with Sejnane-Joumine at 6.25/13 and Utique at 7.1/13. The *veterinary treatments* indicator scores 1.35/3, revealing inadequate veterinary care in building-based farming systems. *Soil protection* is minimal, with a low score of 0.55/5, as most farmers neglect conservation practices. *Energy dependence* remains high, scoring 3.3/10 in Utique and 4.7/10 in Sejnane-Joumine, reflecting heavy reliance on fertilizers, fuel, and electricity.

### 3.1.3. *Sustainability assessment of the socioterritorial scale*

The quality of products and territories component, capped at 33 points, includes five indicators: *product quality, local and human development, non-organic waste management, space accessibility, and quality of life*. The *quality process* indicator, which covers all products from the studied territories such as milk, meat, honey, cow's cheese, and curdled milk, received a score of zero due to the lack of official labeling, organic certification, and traceability despite high consumer demand, reflecting a weak quality assurance approach. Additionally, the *social involvement indicator*, which reflects the dynamism and social vitality of the territories, scored poorly, with an average of 0.25/6, as Sejnane-Joumine recorded 0.1/6 and Utique 4/6, highlighting a significant disparity in the richness and diversity of the associative environment (Table 5).

The *employment and services* component, capped at 33 points, includes various indicators reflecting local economic practices. The short supply chains indicator scores relatively low, with Sejnane-Joumine at 0.28/7 and Utique at 0.12/7, as milk is sold directly to collection centers, and young bulls and lambs are sent to livestock markets, with only a small amount of honey sold directly to consumers (table 6). The *valorization of local resources*, reflecting dependence on suppliers, scores the highest within this component, with Sejnane-Joumine scoring 6.6 and Utique 6.2, averaging 6.4 points. The *services and pluriactivity* indicator, related to commercial services, agritourism, and social inclusion practices, shows

Table 5 - Indicator scores of the quality of products and territories component (QPTC).

| | *Quality process* | *Enhancing built heritage* | *Non-organic waste management* | *Space accessibility* | *Social involvement* | *QPTC* |
|---|---|---|---|---|---|---|
| All | 0 | 0.9 | 1.8 | 2.4 | 0.1 | 5.2 |
| Sejnane-Joumine | 0 | 2.9 | 1.9 | 2 | 0.4 | 7.2 |
| Utique | 0 | 1.9 | 1.85 | 2.2 | 0.25 | 6.2 |
| Theoretical maximum | 10 | 8 | 5 | 5 | 6 | 33 |

Table 6 - Indicators scores of the employment and services component (ESC).

| | *Short supply chains* | *Valorization of local resources* | *Services and pluriactivity* | *Contribution to employment* | *Collective work* | *Probable sustainability* | *ESC* |
|---|---|---|---|---|---|---|---|
| All | 0.12 | 6.2 | 0.6 | 5.1 | 0.1 | 1.5 | 27 |
| Sejnane-Joumine | 0.28 | 6.6 | 0.9 | 4.9 | 0.2 | 2 | 14.05 |
| Utique | 0.2 | 6.4 | 0.75 | 5 | 0.15 | 0.15 | 14.6 |
| Theoretical maximum | 7 | 10 | 5 | 6 | 5 | 5 | 33 |

Table 7 - Indicator scores of the ethics and human development component (EHDC).

| | *Contribution to global food balance* | *Animal welfare* | *Training* | *Work intensity* | *Quality of life* | *Isolation* | *Hygiene and safety* | *EHDC* |
|---|---|---|---|---|---|---|---|---|
| All | 3 | 1 | 0.4 | 0.06 | 2.8 | 1.9 | 0.6 | 4.46 |
| Sejnane-Joumine | 4 | 1.4 | 0.9 | 0.4 | 3.3 | 2.7 | 0.9 | 6.7 |
| Utique | 3.5 | 1.2 | 0.65 | 0.23 | 3.05 | 2.3 | 0.75 | 5.58 |
| Theoretical maximum | 10 | 3 | 6 | 7 | 6 | 3 | 4 | 34 |

poor results, with Sejnane-Joumine scoring 0.9 and Utique 0.6, averaging 0.75 points. Finally, the *contribution to employment* indicator scores 4.9/6 in Sejnane-Joumine and 5.1/6 in Utique, reflecting the employment of a few permanent workers for livestock farming and seasonal workers for crop production, leading to an overall average of 5.1/6.

The *ethics and human development* component, capped at 34 points, includes indicators such as *contribution to global food balance, animal welfare, training, work intensity, quality of life, isolation, and hygiene and safety* (Table 7). The contribution to global food balance indicator scores an average of 3.5/10, with Sejnane-Joumine at 4/10 and Utique at 3/10, reflecting relatively low farm profitability due to excessive reliance on purchased livestock feed. The animal welfare indicator scores poorly, with an average of 1.2/3 points. *Training,* which had a low average score of 0.65/6 points, is not prioritized by most farmers, as 90% do not participate in relevant training programs. The *quality-of-life* indicator, based on farmers' self-assessment, shows acceptable values with scores of 2.8/6 in Sejnane-Joumine and 3.3/6 in Utique, reflecting moderate feelings of isolation. *Hygiene and safety* scored an average of 0.75/4 points due to inadequate facilities for storing pesticides, as evidenced by the unsafe storage conditions in buildings used by occasional workers, resulting in scores of 0.9/4 for Sejnane-Joumine and 0.6/4 for Utique.

### 3.1.4. *Sustainability assessment of the economic scale*

*Viability* is assessed through two components: *economic viability* (C1) and the *rate of specialization* (C2). The overall average score for both regions is 8.35/30 points, with Sejnane-Joumine scoring 9/30 and Utique 7.7/30 (Table 8). These results stem from low specialization rates, mainly due to the dominance of breeding systems focused solely on milk production. This lack of diversification contributes to an average economic viability score of 5.65/20 points, with Sejnane-Joumine scoring 5.3/20 and Utique 6.0/20. The low score reflects farm unprofitability, exacerbated by rising input costs such as concentrated feed, roughage, plant seeds, and veterinary expenses. Similarly, the economic specialization indicator scores modestly, with

Table 8 - Indicator scores of the economic components (EC).

| | *Indicators of viability component* | | *Indicators of independence component* | | *Transmissibility* | *EC* |
|---|---|---|---|---|---|---|
| | *Economic viability* | *Rate of economic specialization* | *Financial autonomy* | *Sensitivity to aid* | | |
| All | 5.65 | 2.7 | 12.95 | 10 | 18.02 | 5.1 |
| Sejnane-Joumine | 6 | 3 | 12 | 10 | 18 | 5.2 |
| Utique | 5.3 | 2.4 | 13.1 | 10 | 18.04 | 5 |
| Theoretical maximum | 20 | 10 | 15 | 10 | 20 | 25 |

Sejnane-Joumine scoring 3.0/10 and Utique 2.4/10, averaging 2.7/10.

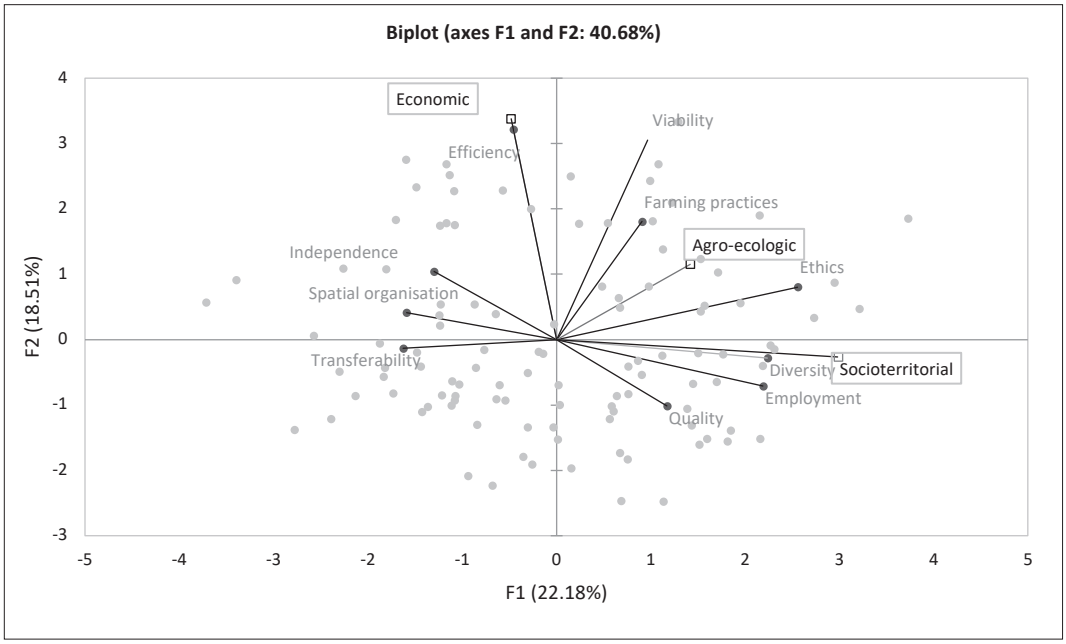
The *independence* component, which includes *financial autonomy* (C3) and *sensitivity to aid* (C4), scores an average of 22.95 points, with Sejnane-Joumine scoring 22.0 and Utique 23.1, indicating financial independence despite limited government support. *Financial autonomy* scores 12.95/15, with Sejnane-Joumine at 12/15 and Utique at 13.1/15. Small farmers, lacking access to formal credit, rely on peddlers and input suppliers for small loans. Sensitivity to aid scores 10/10, highlighting a strong dependence on support that remains unmet by the state. The *economic transmissibility* indicator scores highest at 18, driven by low farm capital and reliance on family labor. In contrast, *production efficiency* scores just 5.1/25, reflecting poor feeding management, high dependence on concentrated feed, and limited use of expert guidance for inputs.

### 3.2. *Typology of small farmers based on sustainability scales and components*

The principal component analysis (PCA) reveals a dominant first component (F1) that accounts for 22.176% of the total variability, with the first four axes (F1–F4) explaining nearly 65% of the variability. The first two axes (F1 and F2) contribute 40.682% to the cumulative variability and are used in the hierarchical ascending classification (HAS) to identify breeder groups (Figure 4). The agroecological and socioterritorial scales are strongly represented on axis F1, contributing 41% and 86%, respectively, while the economic scale is mainly represented on axis F2 with a 14% contribution. A positive correlation exists between the agroecological and socioterritorial scales (r = 0.257), whereas the agroecological and economic scales show a low correlation (r = 0.085), and the economic and socioterritorial scales are independent. The agroecological scale is positively correlated with all components except quality and independence, while the socioterritorial scale is negatively correlated with spatial organization, independence, transmissibility, and efficiency. The economic scale is highly correlated with viability and efficiency (r = 0.797 and 0.857, respectively) but negatively correlated with components of the socioterritorial scale, such as quality, jobs, ethics, and diversity.

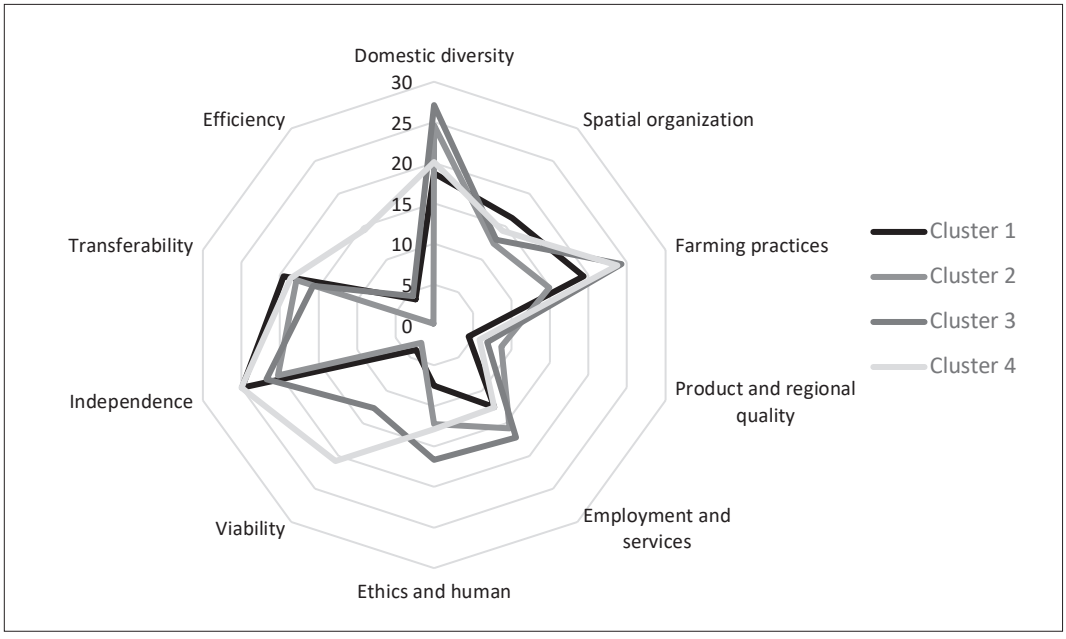
Based on the IDEA method indicators, the hierarchical ascending classification (HAS) results reveal four distinct breeder groups (Figure 5). The first group, representing 35% of the surveyed sample (mostly from Utique), is characterized by significant employment contribution (94%) and the use of local resources (61%). However, this group faces challenges related to the absence of labels, organic farming, and low involvement in professional organizations and human development. The second group (23.85% of the sample, mostly from Sejnane-Joumine) exhibits average racial and plant biodiversity, agroforestry practices, and fodder and fertilizer independence but struggles with poor livestock nutrition management, affecting economic performance. The third group (20% of farmers, primarily from Sejnane-Joumine) shows high livestock and

Figure 4 - Graphical representation of the principal component analysis of farm sustainability components and scales.




plant biodiversity, good manure management, and flood meadow presence but faces soil erosion and poor energy management, hindering economic growth. The fourth group (22.93% of the sample) consists of farms with diverse activities, including dairy cattle rearing and crop production, and demonstrates strong farm input use, leading to good performance.

Figure 5 - Clusters profiles according to their sustainability components.



## 4. Discussion

### 4.1. *The agro-ecological dimension*

Agricultural strategies across regions face significant challenges in land management and climate adaptation, with some areas prioritizing diversification and resilience, while others struggle with poor crop integration and resource overexploitation. In Tunisia, inefficient land use, exemplified by limited forage diversification and high reliance on industrial inputs, raises concerns about the sustainability of agriculture, negatively impacting productivity and environmental resilience. The Bizerte region, for example, suffers from prolonged droughts and irregular rainfall, which affect water availability for irrigation and livestock, further reducing farm performance (Mwadzingeni *et al*., 2022; Ahmed *et al*., 2023). Soil protection remains a critical issue, with a low adoption of anti-erosion techniques, which contributes to the region's vulnerability. In contrast, European approaches like crop rotation with legumes have proven to enhance farm resilience by 30%, and integrating mixed forage crops, especially legumes, could help restore soil fertility, increase productivity, and mitigate environmental impacts (Steinfeld *et al.*, 2006).

The limited diversification of forage crops and high dependence on concentrated feed undermine the food autonomy of farms in Tunisia, a challenge also observed in Europe's intensive agricultural systems, which are vulnerable to price fluctuations and environmental pressures. Agroecological strategies, such as multi-species pastures and crop rotation in Scandinavian countries, reduce dependence on external inputs and enhance soil fertility (Rasmussen *et al*., 2015). In Tunisia, the underutilization of local breeds and limited forage areas mirror the challenges faced in regions like Russia's Central Black Earth, in contrast to the Organic Valley model in the United States, where the use of indigenous breeds has improved farm resilience and profitability. Moreover, veterinary treatments remain limited (1.35/3), and artificial insemination usage is rising, albeit still lower than the scores reported by M'Hamdi *et al.* (2017) (1.7) and Attia *et al.* (2022) (2.3). The increased use of pesticides, a significant issue in Europe, also presents challenges in Tunisia and Algeria due to high costs (Yakhlef *et al*., 2005). While manure is widely used in both countries, livestock effluents are often discharged without specific pollution regulations, raising environmental concerns (Attia *et al*., 2022; Ghozlane *et al.,* 2006). Additionally, while agroecological farming can create employment opportunities, its adoption is hindered by the increased labor requirements (Aubron *et al.*, 2016).

*The socio-territorial dimension*

The study of Tunisian dairy systems reveals significant socio-territorial vulnerabilities, emphasizing the fragility of these systems in contrast to the environmental sustainability focus of the FAO and Dairy Sustainability Framework. The lack of collective organization and underdeveloped short supply chains are major obstacles to farm resilience, with integration into professional organizations and local valorization of products being notably weak in the Bizerte region (Attia *et al.*, 2022). These issues are echoed in international contexts such as Georgia (Al Sidawi *et al*., 2021) and Bangladesh (FAO, 2016), where similar challenges limit farm resilience. The absence of certifications and collective organizations restricts market access and income growth, a contrast to the benefits seen in Europe, where 62% of certified farms thrive (Bórawski *et al*., 2020).

Working and hygiene conditions on Tunisian dairy farms are inadequate, falling short of international standards, and the physically demanding nature of the work is discouraging younger generations from entering the field, exacerbating workforce aging (Nandi *et al*., 2022; Lursinsap *et al*., 2023). Cultural and religious factors further complicate farm succession and require deeper investigation (Gasmi *et al*., 2019). Social issues such as low wages and inadequate housing also contribute to poor conditions, with hygiene and safety standards scoring particularly low. Training participation remains limited, preventing the adoption of modern livestock practices and hindering sector growth (Okello *et al*., 2021). However, successful training programs in countries

like Colombia and Brazil demonstrate the potential for improving agricultural practices, offering a pathway for similar improvements in Tunisia (Gonzalez *et al*., 2024; Madalena, 2012).

While Tunisian dairy farms show some strengths in forage autonomy and local resource valorization, challenges remain with reliance on external seed supplies and inefficient crop management. The contribution of agriculture to local development is also underperforming, as seen in the low score for "Service and Pluriactivity" (0.75). In contrast, initiatives like educational farms in Poland and agritourism in Italy offer models for diversifying agriculture and promoting rural development (Kacprzak *et al*., 2019). The study also highlights the potential for improving animal welfare, which remains a concern, and farm profitability, which is hindered by inefficient feed use and poor ration management. International frameworks, such as the Feeding Performance Indicator (Lapierre *et al*., 2013), offer a basis for enhancing resource efficiency and improving farm profitability.

*The economic dimension*

The economic performance of dairy farms in Tunisia is characterized by low profitability, primarily due to high input costs, inefficient resource management, and limited income diversification. These challenges are exacerbated by a heavy reliance on external inputs and market fluctuations, a situation similar to that observed in Bangladesh and certain rural areas of India (Urak *et al*., 2022). Hemme and Otte (2010) argue that dairy farm profitability in developing countries is often hindered by disproportionate production costs relative to milk prices, as seen in Bangladesh where concentrated feed accounts for 60% of production costs. Strategies to improve profitability include income diversification, such as integrating high-value crops to reduce feed costs by 30% (Krupko *et al*., 2023). Additionally, microfinance models inspired by Tanzania and diversification strategies seen in Dutch, Indonesian, and Vietnamese farms offer pathways to improve both economic performance and sustainability by combining dairy production with renewable energy or capital investment (Sembada, 2018). The adoption of semi-extensive farming models, such as those in Argentina, could further enhance economic resilience and reduce feed costs in Tunisia (Naranjo *et al*., 2013).

The analysis also highlights the financial autonomy of Tunisian dairy farms, with an average score of 22.95 for financial independence, surpassing the 13.6 points reported by M'Hamdi *et al.* (2017). This suggests that, despite limited state support, Tunisian farms have achieved a relatively higher degree of financial autonomy. Chatellier (2010) emphasizes that the European Union's Common Agricultural Policy (CAP) provides aid mechanisms to reduce farm vulnerability to market fluctuations, underscoring the importance of managing reliance on subsidies to maintain sustainable economic independence.

## 5. Conclusion and policy implications

Although the Bizerte region has strong natural, human, and ecological potential, cattle farming remains economically inefficient, socially inequitable, and ecologically fragile, particularly for small and medium-sized farms. To ensure the sustainability of dairy farming systems, this study highlights the need for a transition toward more sustainable livestock systems, drawing inspiration from international experiences that have proven effective. Improving sustainability will inevitably require a concerted effort across social, economic, and agro-ecological dimensions to ensure the long-term viability of the dairy sector and its contribution to rural development.

The supervision of dairy farming has improved production through agricultural development programs and state intervention, particularly in market expansion. However, these advancements have not been sufficient to significantly increase local production. It is therefore crucial to include small and medium-scale farmers in the dairy value chain to foster the sector's sustainable growth.

From this perspective, promoting mixed forage crops that combine legumes and grasses presents a sustainable solution to enrich the soil with nitrogen, improve its organic matter content, reduce greenhouse gas emissions, and op-

timize production costs. This approach would enhance dairy productivity while minimizing environmental impact.

An effective restructuring of the sector requires several priority actions. It is essential to increase funding for technical modernization to enhance the competitiveness of farms. A better distribution of public subsidies is also crucial to include small-scale farmers and facilitate their integration into the market. Additionally, optimizing processing channels and diversifying commercial outlets are key to enhancing the value of local production. Finally, price adjustments should be considered to ensure adequate profitability for producers.

Investments in rural infrastructure, agricultural technologies, and farmer training are essential to support these efforts. The government must also implement policies to enhance pastoral farms, improve animal health, and reduce greenhouse gas emissions. The development of cooperatives could significantly increase the value of local milk, create stable jobs, and curb rural exodus by engaging more young people in agriculture. In this context, support measures should be introduced, including awareness of financing opportunities, widespread use of artificial insemination, continuous access to water, and the promotion of agricultural innovation.

### *Acknowledgements*

This work is part of the AIPEC project funded by IRESA (Institution of Agricultural Research and Higher Education). This research was also partially funded by the CGIAR Initiative on Sustainable Animal Productivity (SAPLING; grant number 200296). We would like to thank all funders who support the CGIAR through their contributions to the CGIAR Trust Fund.

## References

Ahmed Z., Gui D., Murtaza G., Yunfei L., Ali S., 2023. An overview of smart irrigation management for improving water productivity under climate change in drylands. *Agronomy*, 13(8): 2113.

Albouy V., Godefroy P., Lollivier S., 2010. Une mesure de la qualité de vie. *France, Portrait Social 2010*. Montrouge: INSEE, pp. 99-146.

Al Sidawi R., Urushadze T., Ploeger A., 2021. Factors and components affecting dairy smallholder farmers and the local value chain-kvemo kartli as an example. *Sustainability*, 13(10): 5749.

Amato F., 1998. L'agrotourisme, enjeu de développement des régions defavorisées de l'interieur de l'Italie. Le cas du Molise. In: *L'aménagement du territoire et le développement de l'économie de montagne en Méditerranée. Le cas du Maroc Méditerranéen*, pp. 109-130. Casablanca: Le Fennec-Germ.

Attia K., Darej C., M'Hamdi N., Zahm F., Moujahed N., 2022. Assessment of the sustainability of small dairy farms in the North of Tunisia. *BASE*, 26(3): 166-177.

Aubron C., Noël L., Lasseur J., 2016. Labor as a driver of changes in herd feeding patterns: evidence from a diachronic approach in Mediterranean France and lessons for agro ecology. *Ecological Economics*, 127(C): 68-79.

Baccar M., Dugue P., Bouaziz A., Gafsi M., 2018. The determining factors of farm sustainability in a context of growing agricultural intensification. *Agroecology and Sustainable Food Systems*, 43(4): 1-23.

Bechir R., Ounalli N., 2020. Participatory impact assessment of water and soil conservation policy in south-east of Tunisia Oum Zessar watershed. *International Journal of Advanced Research*, 8(7): 1650-1662.

Bechir R., Ounalli N., Jaoued M., Sghaier M., 2020. Disparités régionales et développement local au Sud tunisien. *New Medit*, 19(4): 35-50.

Bekhouch-Guendouz N., 2011. *Assessment of the sustainability of dairy cattle farms in the Mitidja and Annaba watersheds*. Doctoral thesis. National Polytechnic Institute of Lorraine.

Ben Salem H., 2011. Changes in sheep food systems in Tunisia and the role of alternative resources. Options Méditerranéennes : Série A. *Séminaires Méditerranéens*, 97: 29-39.

Bockstaller C., Feschet P., Angevin F., 2015. Issues in evaluating sustainability of farming systems with indicators. *OCL*, 22(1), https://doi.org/10.1051/ocl/2014052.

Bórawski P., Pawlewicz A., Mickiewicz B., Pawlewicz K., Bełdycka-Bórawska A., Holden L., Brelik A., 2020. Economic sustainability of dairy farms in the EU. *European Research Studies Journal*, 23(Special Issue 1): 955-978.

Bouraoui R., Lahmar M., Majdoub A., Djemali M., Belyea R., 2002. The relationship of temperature-humidity index with milk production of dairy

cows in a Mediterranean climate. *Animal Research*, 51(6): 479-491.

Broom D.M., 2010. Animal welfare: an aspect of care, sustainability, and food quality required by the public. *Journal of Veterinary Medical Education*, 37(1): 83-88.

Caplat J., 2012. *Organic farming to feed humanity: Demonstration*. Arles: Actes Sud, https://www.amazon.com/Lagriculture-biologique-pour-nourrir-lhumanit%C3%A9/dp/2330007507.

Chatellier V., 2010. La PAC et ses mécanismes actuels et futurs de régulation des marchés agricoles. *Notes et études socio-économiques*, 34: 7-35.

Chebbi H.E., Pelissier J.P., Rolland J.P., Kechimi W., 2019. *Summary report on agriculture in Tunisia* (Research report). CIHEAM-IAMM, pp. 99. ff-hal-02137636f.

Cochran W.G., 1977. *Sampling Techniques*. New York: Wiley & Sons.

Corvo L., Pastore L., Antonelli A., Petruzzella D., 2021. Social Impact and Sustainability in short food supply chains: an experimental assessment tool. *New Medit*, 20(3): 175-189.

Dhraief M.Z., Bedhiaf S., Dhehibi B., Oueslati-Zlaoui M., Jebali O., Ben-Youssef S., 2019. Factors affecting innovative technologies adoption by livestock holders in arid area of Tunisia. *New Medit*, 18(4): 28-35.

Fadul-Pacheco L., Wattiaux M., Espinoza-Ortega A., Sánchez-Vera E., Arriaga-Jordán C., 2013. Evaluation of sustainability of smallholder dairy production systems in the highlands of Mexico during the rainy season. *Agroecology and Sustainable Food Systems*, 37(8): 882-901.

FAO, 2014. *Sustainability Assessment of Food and Agriculture Systems Indicators. Guidelines Version*. Rome: FAO.

FAO, 2016. *Smallholder Dairy Development in Bangladesh, Myanmar and Thailand: Improving the Bargaining Power and Sustainable Livelihood of Smallholder Dairy Farmers, through the Enhancement of Productivity and Market*. *Technical report Bangladesh.* Rome: FAO.

FAO, 2021. *Analysis of food losses: causes and solutions – Case study of the milk value chain in Tunisia*. Tunis. https://doi.org/10.4060/ca7334fr.

Gasmi H., Morardet S., Younsi S., Burte J., 2019. Évaluation de la durabilité des exploitations agricoles familiales par la méthode IDEA à l'amont du bassin versant Merguellil Kairouan, Tunisie. *Journées de Recherches en Sciences Sociales*, 13.

Gharbi I., Elloumi M., Jamin J.E., 2002. Influence of land practices on the sustainability of irrigated farms in Tunisia: an analysis using the IDEA Method. *Journal of New Sciences, Agriculture and Biotechnology*, 88(3): 4972-4983.

Ghozlane F., Yakhlef H., Allane M., Bouzida S., 2006. Evaluation de la durabilité des exploitations bovines laitières de la Wilaya de Tizi Ouzou (Algérie). *New Medit*, 5(4): 48-52.

Gliessman S., 2006. *Agroecology: the ecology of sustainable food systems*, 2nd ed. Boca Raton (FL): CRC Press - Taylor and Francis Group. https://www.taylorfrancis.com/books/mono/10.1201/b17420.

Gonzalez R., García Elver H., Florez F., Burkart S., Arango J., 2024. A case study on enhancing dairy cattle sustainability: The impact of silvopastoral systems and improved pastures on milk carbon footprint and farm economics in Cauca department, Colombia. *Agroforestry Systems*, 98(8): 3001-3018.

Hammami H., Rekik B., Soyeurt H., Bastin C., Stoll J., Gengler N., 2008. Genotype, environment interaction for milk yield in Holsteins using Luxembourg and Tunisian populations. *Journal of Dairy Science*, 91: 3661-3671.

Häni F., Braga F., Stämpfli A., Keller T., Fischer M., Porsche H., 2003. RISE, a tool for holistic sustainability assessment at the farm level. *International food and agribusiness management review*, 6(4): 78-90.

Kacprzak M., Gralak K., Wielewska I., Maresova P., Jedlicka P., Soukal I., 2019. Educational activities of agritourism farms in Poland. *Hradec Economic Days*, DOI: 10.36689/uhk/hed/2019-01-037.

Kayouli C., 2006. *Country Pasture/Forage Resource Profiles: Tunisia*. Rome: FAO.

Krupko A.E., Rogozina R.E., Derevyagina M.V., Kulakovskiy E.S., 2023. The role of the dairy sector in the sustainable development of Central Black Earth region. *E3S Web of Conferences*, 460, 02004.

Lapierre A., Lapierre O., 2013. L'indicateur de performance nourricière de l'exploitation agricole. *OCL*, 20(5): A501.

Lursinsap S., Sirisunyaluck R., Sreshthaputra S., Chalermphol J., 2023. Factors influencing the chance of inheriting the family farming career among heirs in the upper northern region of Thailand in the crisis of farming labor decline. *Sustainability*, 15(2): 1709.

Malick M.A., 2021. Évaluation de la durabilité de la filière lait local dans les Niayes de Dakar. *Global Journal of Economics and Finance*, 5(1).

Meul M., Van Passel S., Nevens F., Dessein J., Rogge E., Mulier A., Van Hauwer A., 2008. MOTIFS: a monitoring tool for integrated farm sustainability.

*Agronomy for Sustainable Development*, 28: 321-332.

M'Hamdi N., Darej C., M'Hamdi H., Attia K., Lanouar L., Chouchen R., Sadkaoui G., Abbes A., 2017. Assessment of sustainability of small-holder beef cattle farms in the north of Tunisia. *Journal of Animal Research and Nutrition*, 2(3), 10.21767.

Mukson M., Setiyawan H., Handayani M., Setiadi A., 2017. Analysis of the local resource-based dairy cattle development in Central Java. *Journal of the Indonesian Tropical Animal Agriculture*, 42(1): 48-56.

Mwadzingeni L., Mugandani R., Mafongoya P., 2022. Risks of climate change on future water supply in smallholder irrigation schemes in Zimbabwe. *Water*, 14(11): 1682.

Nandi R., Pratheepa C.M., Nedumaran S., Rao N., Rengalakshmi R., 2022. Farm parent and youth aspirations on the generational succession of farming: Evidence from South India. *Frontiers in Sustainable Food Systems*, 5: 804581.

Okello D., Owuor G., Larochelle C., Gathungu E., Mshenga P., 2021. Determinants of utilization of agricultural technologies among smallholder dairy farmers in Kenya. *Journal of Agriculture and Food Research*, 6: 100213.

Schindler J., Graef F., König H.J., 2015. Methods to assess farming sustainability in developing countries. A review. *Agronomy for Sustainable Development*, 35(10): 43-57.

Sembada P., 2018. *Transformation des systèmes bovins laitiers en Indonésie : évaluation de la durabilité et des trajectoires des exploitations*. Doctoral dissertation. Montpellier: SupAgro.

Seuneke P., Lans T., Wiskerke J., 2013. Moving beyond entrepreneurial skills: Key factors driving entrepreneurial learning in multifunctional agriculture. *Journal of Rural Studies*, 32: 208-219.

Soltani E., Hammami M., Bouraqui R., 2011. Aboveground dairy farming in Tunisia: Current difficulties and uncertainties for the future (case of Boumerdes-the Tunisian-Sahel). *New Medit*, 10(1): pp. 58-64.

Sraïri M.T., Ben Salem M., Bourbouze A., Elloumi M., Faye B., Madani T., Yakhlef H., 2007. Comparative analysis of the dynamics of milk production in Maghreb countries. *Cahiers Agricultures*, 16: 251-257.

Steinfeld H., Gerber P., Wassenaar T., 2006. *Livestock's long shadow: environmental issues and options*. Rome: FAO.

Urak F., Bilgic A., Bozma G., Florkowski W., Efekan E., 2022. Volatility in live calf, live sheep, and feed wheat return markets: A threat to food price stability in Turkey. *Agriculture*, 12(4): 566.

Uzir N.Z.M., 2024. Best Practices and Challenges of Farm Tourism in Malaysia. *FFTC Journal of Agricultural Policy*, 6: 50-59.

Vilain L., 2003. *La méthode IDEA : indicateurs de durabilité des exploitations agricoles - guide d'utilisation*. Dijon: Educagri Ed., 2ème éd., 151 pp.

Yakhlef H., Ghozlane F., Bira A., Benidir M., 2005. Essai d'application de la méthode des indicateurs de la durabilité des exploitations agricoles (IDEA) dans le contexte de l'élevage bovin laitier de la zone semi-aride de Sétif. *Algerian Annals of Agronomy*, 26(1): 95-109.

Zahm F., Viaux P., Vilain L., Girardin P., Mouchet C., 2008. Assessing farm sustainability with the IDEA method - from the concept of agriculture sustainability to case studies on farms. *Sustainable Development*, 16(4): 271-281.