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A Multi-Criteria Sustainability Assessment of Mediterranean Rainfed Farming Systems using the IDEA Method: A Moroccan Case Study

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Abstract

Sustainable agriculture in arid and semi-arid regions faces unique challenges that require targeted assessment and intervention. Addressing the knowledge gap in this context, the current study evaluates the sustainability performance of 50 rainfed farms in the Zaër Region of northwestern Morocco using the innovative *Indicateurs de Durabilité des Exploitations Agricoles*/IDEA method (indicators of farming systems sustainability), which encompasses agro-ecological, social and economic criteria to assess the three pillars of sustainability. Customized assessment criteria and a tailored scoring system, specific to the region's context, are employed, resulting in a comprehensive grid with 18 indicators across nine components. Data analysis and visualization were facilitated using statistical methods and an Excel macro. The findings reveal limitations in the sustainability of the surveyed farms. Socio-territorial factors, including issues with product quality, insufficient farmer training, limited workforce mobilization and low social involvement, contribute to the overall sustainability challenges. Agroecologically, low crop diversification, inadequate space management, and excessive reliance on chemical inputs are identified as areas of concern. On the economic scale, low specialization levels hinder economic viability despite some financial autonomy. The study emphasizes the need for interventions to enhance sustainability in rainfed agrosystems. Recommendations are provided to address socio-territorial constraints, improve agricultural practices, and promote economic viability. The findings have implications for policymakers, farmers and stakeholders, offering valuable insights for prioritizing strategies and actions to achieve sustainable agriculture in arid and semi-arid regions.

Keywords: agrosystem; Morocco; multi-criteria evaluation; rainfed agriculture; sustainability

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INTRODUCTION

After the end of the Second World War, the agricultural sector witnessed a transformative technological revolution known as the Green Revolution. This revolution brought about significant advancements in agriculture through the development of new technologies, mechanization, and increased chemical usage, leading to faster land clearance, cultivation and increased productivity (Swaminathan, 2017; Hamdan et al., 2022). These new capacities appeared as a blessing for humanity, which used them to the maximum during the twentieth century, without worrying about unintended consequences (Evenson and Gollin, 2003; Harwood, 2020). However, this prosperity has come at the expense of natural resources and the environment (Rahman, 2015; Llewellyn, 2018; von der Goltz et al., 2020). Over time, the costs have been significant, including soil degradation and contamination of water

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resources by fertilizer and pesticide residues, the decline of agro-biodiversity at the same rate as agriculture has industrialized, the decline of family farms, the continued deterioration of the living and working conditions of agricultural workers, the increase in production costs, and the disintegration of the economic and social conditions of rural communities (Sebby, 2010; Koopman, 2012; Ioris, 2016; Hurt, 2020). The adverse effects of conventional agricultural practices have highlighted the urgent need for sustainable agriculture, which takes into account economic, social and ecological dimensions while defining a global framework (Pingali, 2012; Sala and Bocchi, 2014). Sustainable agriculture aims to maintain food production while mitigating environmental harm, protecting natural resources, and eradicating poverty, hunger, and malnutrition (Umesha et al., 2018). It achieves this by reducing the use of synthetic inputs, optimizing resource utilization, and implementing practices that promote soil health, water conservation and biodiversity preservation (Umesha et al., 2018; Jhariya et al., 2021).

Furthermore, sustainable agriculture recognizes the importance of addressing social challenges such as poverty, hunger and malnutrition. It prioritizes the fair distribution of resources and opportunities, ensuring that everyone has access to nutritious food. By fostering inclusive and resilient food systems, sustainable agriculture contributes to the eradication of hunger and the enhancement of community well-being (Adenle et al., 2018; Umesha et al., 2018).

Achieving these goals necessitates a holistic approach that involves various stakeholders, including farmers, policymakers, researchers, and consumers. Sustainable agriculture calls for the adoption of innovative and context-specific practices that are economically viable, socially acceptable, and environmentally friendly (Adenle et al., 2019; Trigo et al., 2021). By considering the economic, social, and ecological dimensions of agriculture, sustainable agriculture offers a comprehensive framework for tackling the complex issues confronting the food systems (Umesha et al., 2018). Through the integration of sustainable practices and the implementation of responsible management strategies, researchers can transition toward a more resilient, inclusive, and sustainable agricultural system that meets the needs of present and future generations (Galli et al., 2018; Šūmane et al., 2018).

To achieve sustainability, it is crucial to implement assessment methods that comprehensively evaluate farming systems. These methods should go beyond purely economic considerations and incorporate social well-being and environmental stewardship aspects (Bockstaller et al., 2015; De Olde et al., 2017; Streimikis and Baležentis, 2020). By adopting such robust assessment methods, policymakers, researchers, and stakeholders can obtain a holistic understanding of the sustainability performance of farming systems. Evaluating multiple dimensions of sustainability, including economic viability, social well-being, and environmental stewardship, allows for a more accurate and comprehensive assessment. It enables the identification of strengths and weaknesses within farming systems and facilitates targeted interventions to improve sustainability (Latruffe et al., 2016; Janker and Mann, 2020; Çakmakçı et al., 2023). Such assessment methods provide valuable insights into the interconnections between agricultural practices’ economic, social and environmental aspects (Sala, 2020; Chopin et al., 2021). This integrated understanding allows policymakers to develop effective strategies that promote sustainable agriculture (Rivera-Ferre et al., 2013; Dizdaroglu, 2017). Researchers can use these assessment methods to generate evidence-based recommendations and innovations for improving sustainability in farming systems. Stakeholders, including farmers and industry representatives, can gain insights into the specific areas where improvements can be made and actively participate in the transition towards more sustainable agricultural practices (Janker and Mann, 2020). By embracing comprehensive assessment methods, the agricultural sector can move towards a more sustainable future (Talukder et al., 2020). This approach not only safeguards the long-term productivity and resilience of farming systems but also contributes to the preservation of natural resources, the enhancement of rural livelihoods and the mitigation of environmental impacts (Coteur et al., 2016; Chopin et al., 2021).

In this context, the present study focuses on rainfed farming in northwestern Morocco and aims to assess the sustainability of 50 farms using the *Indicateurs de Durabilité des Exploitations Agricoles*/IDEA method (indicators of farming systems sustainability). This method enables the evaluation of agro-ecological, social and economic conditions, providing a holistic understanding of sustainability (Zahm et al., 2019). This integration of multiple criteria makes the IDEA method highly advantageous in assessing sustainability, ensuring a more complete and nuanced perspective of the systems' performance. Customization to specific regional contexts enhances its relevance and applicability. The use of statistical methods and an Excel macro streamlines data analysis, saving time and resources. However, data collection may be extensive, and subjective indicators could introduce biases in evaluations. Despite these limitations, the IDEA method remains a valuable tool for sustainability assessment due to its multidimensional evaluation and efficiency in data analysis. The study will develop specific assessment criteria and a tailored scoring system aligning with the region's context, encompassing 18 indicators across nine components of sustainability to analyze and evaluate the sustainability of the farms under investigation. By doing so, it aims to identify the specific strengths and weaknesses present within these agricultural systems. The main objective is to pinpoint areas where improvements can be made in order to enhance the economic viability, social well-being, and ecological resilience of rainfed agrosystems. The findings will be disseminated to policymakers, farmers, and stakeholders, allowing for a broader understanding of the significance of sustainable agriculture. This dissemination of information is expected to foster a deeper appreciation for sustainable practices and inform decision-making processes regarding agricultural development.

Overall, the study seeks to contribute to the broader understanding of sustainable agriculture, with a particular emphasis on its applicability in arid and semi-arid regions. The Zaër Region in northwestern Morocco is highlighted as a case study, underscoring its importance in showcasing sustainable agricultural practices. By focusing on a rainfed region, the study aims to actively contribute to the ongoing discourse surrounding the challenges and opportunities associated with sustainable agriculture. Furthermore, it strives to promote the adoption of holistic approaches that carefully balance economic, social, and ecological considerations, ultimately supporting long-term agricultural development (Adenle et al., 2019; Trigo et al., 2021).

MATERIALS AND METHOD

Study area and sampling

The study was carried out in the region of Zaër, in the northwest of Morocco. It concerned 11 zones, where 6 zones are parts of Khémisset Province and 5 belong to the prefecture of Skhirate-Témara (Figure 1). The inclusion of 11 zones within the study region, comprising both the Khémisset Province and the Skhirate-Témara Prefecture, allowed for a diverse representation of agricultural practices and conditions. This geographical variation offered

Figure 1. Geographical location of the 11 selected study areas in Zaër Region (Morocco)

insights into the specific challenges and opportunities faced by farmers in different areas of the Zaër Region.

To ensure a representative sample, a careful and systematic selection process was employed in selecting farmers for the survey. The research aimed to capture a diverse group of participants with varied perspectives and experiences, enhancing the validity and reliability of the study's findings. Eligible participants were identified based on criteria such as farm size, crop diversity, production methods and socio-economic factors. The survey included 50 farmers, a sample size considered sufficient to explain the economic, social and environmental bio-physical diversity of agrosystems in the study area. This selected group covers the entire study region, ensuring a comprehensive representation of agricultural practices and conditions, allowing for meaningful analysis and inference, instilling confidence in the study's results and contributing to a holistic understanding of the region's agrosystem diversity (Paracchini et al., 2015).

The study utilized a combination of qualitative and quantitative data collection methods to gather a comprehensive set of information about the farms in the region. For the qualitative data analysis, thematic analysis was employed, involving careful review and categorization of data from interviews, observations, and questionnaires to identify recurring patterns and themes related to farmers' experiences and challenges. This approach provided a deeper understanding of the farmers' perspectives. The findings from the qualitative analysis were then integrated with the quantitative data, which offered measurable indicators of various aspects of farm operations, such as land size, crop yields, and income levels. This combined analysis provided a comprehensive understanding of the sustainability and diversity of rainfed farms in the Zaër Region of northwestern Morocco (De Olde et al., 2016; Coteur et al., 2020). This data-driven approach allowed for a thorough analysis of the general situation of the surveyed farms. By examining key indicators, the study aimed to identify common patterns, as well as unique characteristics and circumstances, among the farmers. Such insights were essential for gaining a holistic understanding of the region's agricultural landscape and informing recommendations for improvement and sustainable development (Roy et al., 2014; Hatanaka et al., 2022).

Data collection tools

To achieve the study objectives, a descriptive research approach was adopted, aiming to identify and analyze the various characteristics of the farms under investigation. This involved conducting a comprehensive diagnosis of farm operations at technical, socio-economic and environmental levels through a combination of quantitative and qualitative methods. Fieldwork, including meetings, interviews and surveys, was conducted in the study area to gather the necessary data (Gaviglio et al., 2017; Chopin et al., 2021). The collected data were then organized and analyzed to identify the strengths and weaknesses in farm operations. Thematic analysis was employed for the qualitative socio-economic and agro-environmental data. The results of the diagnosis provided insights into the strengths and weaknesses of farm operations, highlighting areas that needed improvement and guiding the formulation of targeted recommendations for enhancing sustainability in the region's agriculture.

Fieldwork was crucial for complementing the quantitative data with qualitative information, providing deeper insights into the functioning of the farms. Through face-to-face interactions with farmers, valuable context-specific knowledge and experiences were captured, enriching the overall understanding of the agricultural systems in question.

In order to effectively collect the required information during the fieldwork, a questionnaire was carefully developed. This questionnaire encompassed a range of relevant topics, including the profile of the farmers, farm structure, production equipment, cropping systems, technical and economic data of the farm, as well as the farms' relationships with their economic and institutional environment.

The survey guide and questionnaire were tailored to align with the IDEA assessment tool, ensuring consistency and compatibility with the overall research framework. Additionally, the questionnaire's format was redesigned to streamline the interview process and facilitate effective communication with the participating farmers (Bir, 2008; Khaldi and Hettiri, 2023).

By combining quantitative data analysis with qualitative insights gathered through fieldwork, the study aimed to obtain a comprehensive understanding of the farms' characteristics and functioning. This approach allowed for a thorough assessment of the technical, socio-economic, and environmental aspects, ultimately providing valuable insights into the overall sustainability of the agricultural systems under study (Roy et al., 2014; Hatanaka et al., 2022).

Methodology

The IDEA method was specifically designed to quantitatively assess sustainability in agricultural systems. It provides an analytical framework for evaluating the strengths and weaknesses of farm-level production systems without imposing any value judgments. The method utilizes a set of indicators that characterize the fundamental concepts derived from the definition of sustainable agriculture (Zahm et al., 2008; Zahm et al., 2019).

The objectives of the IDEA method are diverse and encompass several key aspects of sustainable agriculture. Firstly, the method aims to provide a tangible and practical understanding of sustainable agriculture by translating the abstract concept into concrete actions and practices. This objective is crucial in helping farmers and stakeholders grasp the essence of sustainability and its application in agricultural systems. Another important goal of the IDEA method is to assess the sustainability of a farm at a specific point in time. By evaluating various indicators and components, the method enables a comprehensive analysis of the farm's performance in relation to sustainability criteria. This assessment provides valuable insights into the current state of the farm and serves as a benchmark for gauging its progress toward sustainability (Vilain, 2008; Zahm et al., 2019).

Furthermore, the IDEA method seeks to identify and highlight potential avenues for improving sustainability on the farm. Through the assessment process, it pinpoints the strengths and weaknesses of the production system, enabling farmers and stakeholders to identify areas where changes and enhancements can be made. This objective promotes continuous improvement and encourages the adoption of sustainable practices.

In summary, the IDEA method aims to concretely appropriate the concept of sustainable agriculture, assess farm sustainability, identify improvement opportunities, measure progress and facilitate discussions on sustainable agriculture (Vilain, 2008; Zahm et al., 2008; Zahm et al., 2019).

It is important to note that the IDEA method was initially developed in France and tailored to the specific context of French agriculture. Consequently, the scale and the rating system for each of the criteria making up the various indicators have been revised according to the national agricultural context. The resulting framework encompasses 18 indicators grouped into nine components, capturing a comprehensive range of factors relevant to assessing sustainability (Table 1).

Indeed, each of the three sustainability components groups a certain number of indicators, totaling 18 sustainability indicators, themselves composed of one or more elementary items, characterizing a practice (or a characteristic) and contributing to the final value of the indicator. The number of points or units of sustainability assigned to each indicator is therefore between the lower bound of zero (even if the sum of elementary items is negative) and an upper value that is specific to each indicator (even if the sum of its elementary items is higher). Each component is also limited, in the same manner, to an upper value that weighs its relative importance and allows a large number of technical combinations to achieve it. The main assumption of the method is based on the idea that it is possible to quantify the various components of an agricultural system by assigning them a numerical score and then weighting and aggregating the obtained information to obtain a score for the operation for each of the three sustainability-qualifying scales: the agro-environmental scale, the socio-territorial scale and the economic scale.

Hence, the calculation method was based on a scoring system determined by a maximum score varying for each criterion based on its importance on the sustainability scale. The three sustainability scales, each with the same weight, have a score ranging from 0 to 100 points. The farm's score for each of the three sustainability scales is the cumulative number of points. It should be noted that the scales are independent and cannot be added together (Zahm et al., 2008; Zahm et al., 2019).

Table 1. The IDEA evaluation grid adapted to the Moroccan context

Components	Indicators	Max values	
	Agro-environmental scale		
Diversity	Crop diversity	18	28
	Animal diversity	10	
Space organization	Plot management	12	22
	Animal load and fodder management	10	
Agricultural practices	Fertilization and organic matter management	18	50
	Use of pesticides and veterinary products	10	
	Soil and water management	16	
	Energy dependence	6	
	Socio-territorial scale		
Quality of products and territories	Product quality	20	35
	Valuation by short circuits	15	
Employment and services	Contribution to employment	20	35
	Social implication	15	
Ethics and human development	Training and pluriactivity	10	30
	Hospitality, hygiene and safety	20	
	Economic scale		
Viability	Economic viability	20	50
	Commercial vulnerability	30	
Independence	Financial autonomy	20	20
Efficiency	Efficiency of the production process	30	30

The assessment of the agro-environmental sustainability scale relied on eight indicators divided into three components (diversity, spatial organization and agricultural practices). This scale evaluates to what extent the production system can develop long-term productive potential while protecting the environment. The criteria aim to guide the farmer towards performance that is less dependent on natural resources, favoring plant and animal biodiversity and protecting soils and their fertility.

The socio-territorial sustainability scale is based on six indicators divided into three components (product quality and local valorization, employment and services, ethics and human development). It characterizes the farmer's degree of commitment and contribution to local societal issues, including job creation and improvement of living conditions. It takes into account the management of ethics and human development.

For the economic sustainability scale, four indicators divided into three components (viability, independence and efficiency) assessed the farm's economic results beyond the short term.

Regarding the overall sustainability score, it corresponds to the score of the scale with the lowest score to encourage the farmer to prioritize efforts there. The higher the score, the more sustainable the operation is considered (Zahm et al., 2019).

By utilizing the IDEA method and a specific grid of indicators, this study aimed to systematically evaluate the sustainability of farms in the given context, shedding light on their performance across various components and indicators. This approach provided a robust and structured framework for analyzing and discussing the sustainability of the agricultural systems under examination.

Statistical analysis

The primary findings obtained from the IDEA evaluation method were subjected to a comprehensive analysis employing various statistical techniques. Descriptive analysis was conducted to calculate key parameters such as means, standard deviations, maximum and minimum values. Principal component analysis (PCA) was utilized to explore the underlying patterns and structure within the data. Hierarchical ascendant classification (HAC) was employed to group farms based on their sustainability scores across different scales. Multiple correspondence analysis (MCA) was conducted to examine the discriminative power of different variables, and the boxplot method was applied as a part of exploratory data analysis (Bekhouche-Guendouz, 2011; Biret et al., 2019).

To conduct these analyses, the IBM SPSS statistical program was used. By employing a combination of these statistical techniques, the study aimed to gain deeper insights into the relationships and patterns within the collected data. These analyses provided a comprehensive understanding of the various parameters and dimensions of sustainability within the studied farms.

RESULTS AND DISCUSSION

Overall sustainability analysis

Figure 2 showcases the outcomes of the sustainability assessment conducted on the farms under study. As highlighted by Valentin and Spangenberg (2000), sustainable agriculture encompasses the integration of social, economic and environmental dimensions. Among the three scales considered, the global sustainability score, with a mean value, emerges as the lowest. This finding aligns with previous research by Vilain (2008) and M'hamdi et al. (2017).

Notably, the results reveal that the socio-territorial scale significantly constrains the overall sustainability of the examined farms, as evidenced by its relatively lower score of 28.02. In contrast, the economic scale demonstrates the highest average sustainability score of 45.8 across all farms. This indicates that economic factors are relatively more robust in contributing to the overall sustainability of the agricultural systems. The agro-environmental scale follows closely behind, with a slightly lower score of 38.1, indicating the substantial attention given to environmental considerations.

In Figure 3, the dispersion of individuals represented by four different variables within the same unit is organized into four vertical blocks. The box plot provides information on the range of values, including the maximum and minimum values, as well as the median and average values (Ferreira et al., 2016).

The results highlight interesting patterns. Firstly, for the agro-ecological scale, the majority of the sustainability scores are concentrated within a small interval and close to the median. This suggests a relatively consistent performance across farms in terms of agro-ecological practices and their impact on sustainability. This clustering aligns with the observations made by Gara et al. (2021) and Ouakli et al. (2018) and emphasizes the consistent commitment of the examined Tunisian farms to agro-ecological practices. It indicates a narrower range of variation compared to the economic scale, implying a more consistent approach to agro-ecological sustainability among the studied farms.

On the other hand, within the socio-territorial scale, the amplitude of the sustainability scores falls within an average range. This indicates a moderate level of variation among the farms in terms of their socio-territorial sustainability, suggesting that some farms may be performing better in this aspect while others are lagging behind. This resonates with the conclusions of previous studies, signifying a congruence in the observed results (Ouakli et al., 2018; Gara et al., 2021; Attia et al., 2022). It is worth noting, as highlighted by Viaux (2004), that the

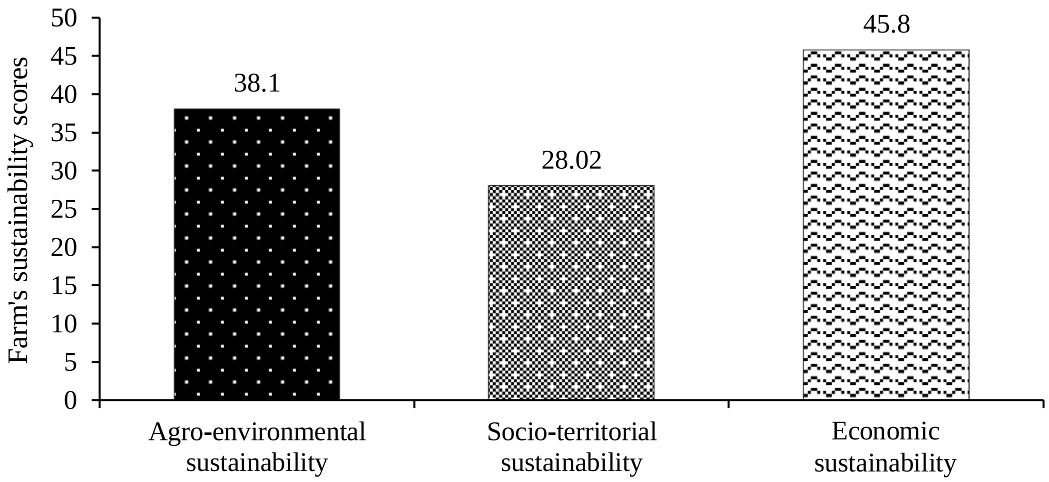

Figure 2. Global sustainability score of the studied farms

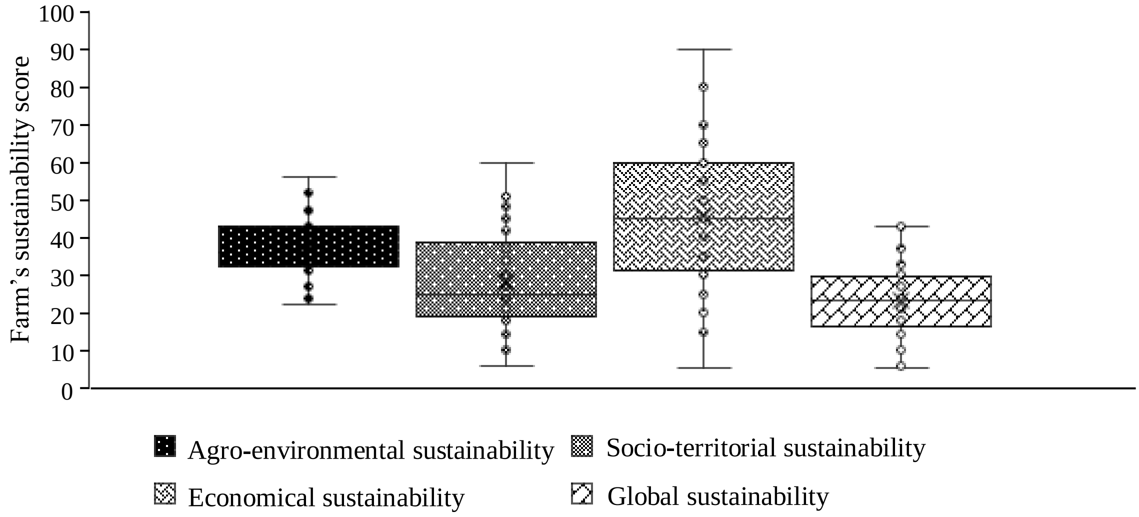

Figure 3. Dispersion of scores on the three sustainability scales and overall sustainability

components and objectives of socio-territorial sustainability are not precisely defined by science. Unlike certain scientific parameters, there is no universally accepted definition or standardized criteria for socio-territorial sustainability. Instead, it is a concept that depends on societal perspectives and opinions, making it more subjective and open to interpretation.

Regarding the economic scale, the sustainability scores exhibit a significant amplitude, indicating a wide variation among the farms in terms of their economic performance and contribution to sustainability. This suggests that some farms are achieving high levels of economic sustainability, while others may be facing challenges in this aspect. These findings correspond with earlier studies conducted by M’hamdi et al. (2017) and Gara et al. (2021).

Overall, the dispersion observed in Figure 3 reflects the varying degrees of performance and achievement across different sustainability scales. It emphasizes the need for further exploration and consensus-building regarding the socio-territorial dimension to establish clearer objectives and criteria for assessing and promoting socio-territorial sustainability in agricultural systems (Hayati et al., 2011; Bartzas and Komnitsas, 2020; Gara et al., 2021).

The PCA illustrated in Figure 4 unravels compelling insights into the diverse landscape of farm sustainability. By reducing the complex multidimensional data into two principal components, namely axis 1 and axis 2, PCA effectively captures the most significant variations in the overall sustainability scores of the farms (Gaviglio et al., 2017).

The PCA analysis delves into the interrelationships and patterns among multiple sustainability indicators, positioning the farms in a two-dimensional space based on their overall sustainability scores. This visual representation aids in the identification of clusters or distinct groups of farms exhibiting similar sustainability characteristics. Farms located in close proximity on the PCA plot share commonalities in their overall sustainability performance, while those situated farther apart demonstrate distinct and contrasting sustainability profiles (Dong et al., 2015).

Within this PCA-driven framework, two primary groups emerge: Group A (represented in red) and Group B (represented in blue). Group A consists of farms that are scattered both above and below axis 2, but all farms in this group are positioned above axis 1. Axis 1, as determined by the PCA analysis, is explained by the variables of plot management; use of pesticides and veterinary products; hospitality, hygiene, and safety; training and pluriactivity; efficiency of the production process; and economic viability. Meanwhile, axis 2 is explained by the variables of soil and water management; fertilization and organic matter management; social implication; valuation by short circuits; and financial autonomy.

The sustainability scores of Group A fall within a range of 24 to 43. This suggests that farms in this group exhibit a relatively higher level of overall sustainability compared to Group B. It is important to highlight that the farmers from both Group A and Group B are geographically scattered randomly across the study zone. The absence of any discernible spatial pattern or clustering indicates that the sustainability performance of farms in these groups is not influenced by their geographical proximity within the study area (Nunes et al., 2014). The distribution of scores within Group A indicates some variability, with certain farms performing better than others in terms of sustainability. It is worth noting that farms in this group demonstrate a generally favorable position in terms of sustainability, as they are situated above axis 1.

On the other hand, Group B comprises farms that are mainly clustered below both axis 1 and axis 2. The sustainability scores of farms in this group range from 5 to 30. This indicates a lower level of overall sustainability compared to Group A. The concentration of farms below both axes suggests that farms in Group B face greater challenges in achieving sustainability across multiple dimensions. It is important to note that the farms in this group exhibit a wider range of scores, indicating more variability in terms of sustainability performance.

The distinct separation of farms into these two groups based on overall sustainability scores highlights the presence of different levels of sustainability within the studied population (Brunori et al., 2016). It suggests that there are farms that have achieved a relatively higher degree of overall sustainability (Group A) and others that still have room for improvement (Group B).

The dendrogram of the ascending hierarchical classification reveals the existence of two classes of farms according to the scores of the three sustainability scales (Figure 5). According to the results, class 1 has an agro-environmental sustainability of 38.8, a socio-territorial sustainability of 26.25 and an economic sustainability of 46.023. Meanwhile, class 2 has a lower agro-environmental sustainability of 33.17, a higher socio-territorial sustainability of 41 and an economic sustainability of 44.17. This shows that the socio-territorial scale limits the sustainability of class 1 farms, while the agro-environmental scale limits that of class 2 farms.

As stated in the research conducted by Attia et al. (2022), the HAC dendrogram depicted in Figure 5 provides insights into the grouping of farms based on their sustainability scores across the three scales. The analysis reveals the presence of two distinct classes of farms.

Class 1 is characterized by an agro-environmental sustainability score of 38.8, a socio-territorial sustainability score of 26.25,

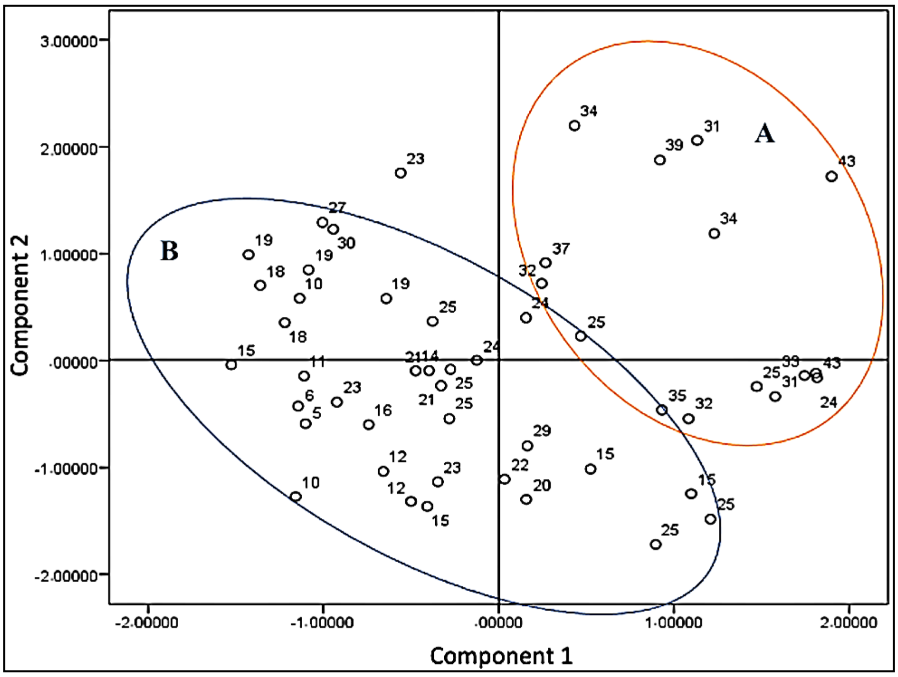

Figure 4. PCA on the three sustainability scales

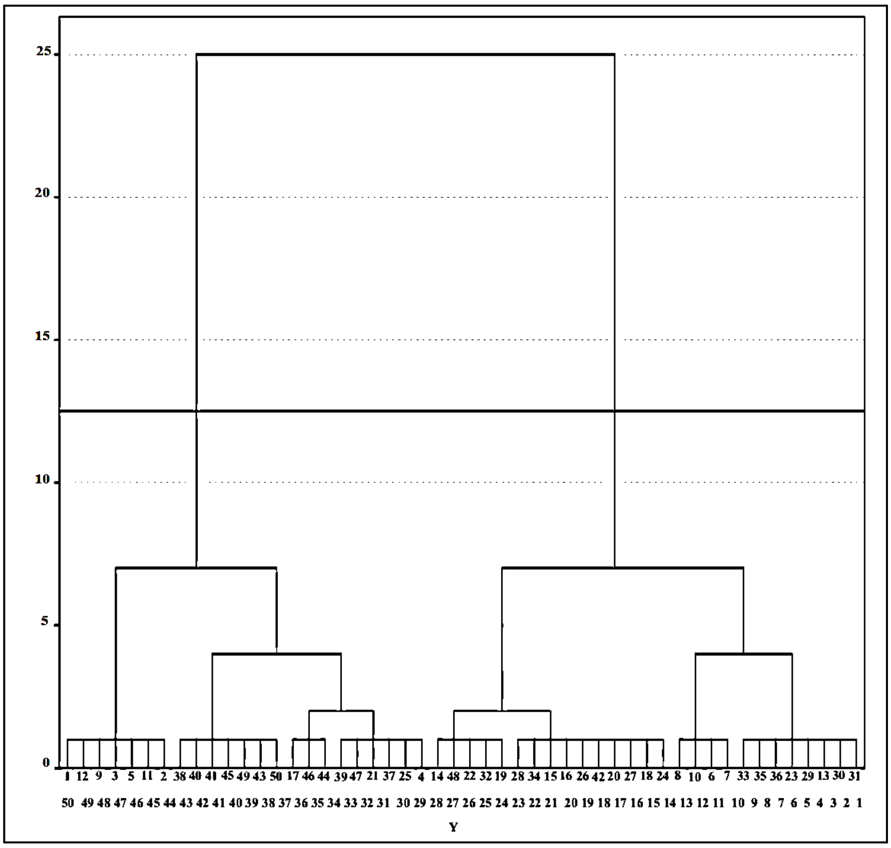

Figure 5. Dendrogram of ascending hierarchical classification on the three sustainability scales

and an economic sustainability score of 46.023. This class exhibits relatively higher economic sustainability compared to the other two scales. However, it is evident that the socio-territorial scale is a limiting factor for sustainability within class 1 farms, as indicated by the lower score in that dimension. As for Tunisian farms studied by M'hamdi et al. (2017) and Attia et al. (2022), the current findings suggest that there are challenges related to the socio-territorial aspects of sustainability that need to be addressed in class 1 farms to achieve a more balanced and comprehensive sustainability profile.

In contrast, class 2 farms display a slightly lower agro-environmental sustainability score of 33.17. However, these farms demonstrate a higher socio-territorial sustainability score of 41 and a comparable economic sustainability score of 44.17. This implies that the agro-environmental scale presents a limitation for sustainability within class 2 farms, while the socio-territorial scale appears to be relatively stronger. Addressing the agro-environmental dimension and improving practices related to environmental sustainability may be crucial for enhancing the overall sustainability of class 2 farms (Bachev and Terziev, 2017; Silalertruksa et al., 2017; DeBoe, 2020).

These findings emphasize the importance of considering multiple dimensions of sustainability and their interplay in agricultural systems as reported by Talukder et al. (2018) and Smith et al. (2022). The results suggest that the challenges and strengths associated with sustainability may differ across classes, emphasizing the need for tailored approaches and targeted interventions. Understanding the specific factors contributing to the limitations in each class can guide the development of strategies to improve sustainability in the respective areas. Moreover, exploring the characteristics and practices of farms within each class can facilitate knowledge sharing and peer learning, promoting sustainable agricultural practices across the broader farming community.

Figure 6 provides an overview of the overall performance of farms in the studied region, specifically in terms of the components of each of the three sustainability scales. It reveals that the socio-territorial scale exhibits the lowest results compared to the other scales.

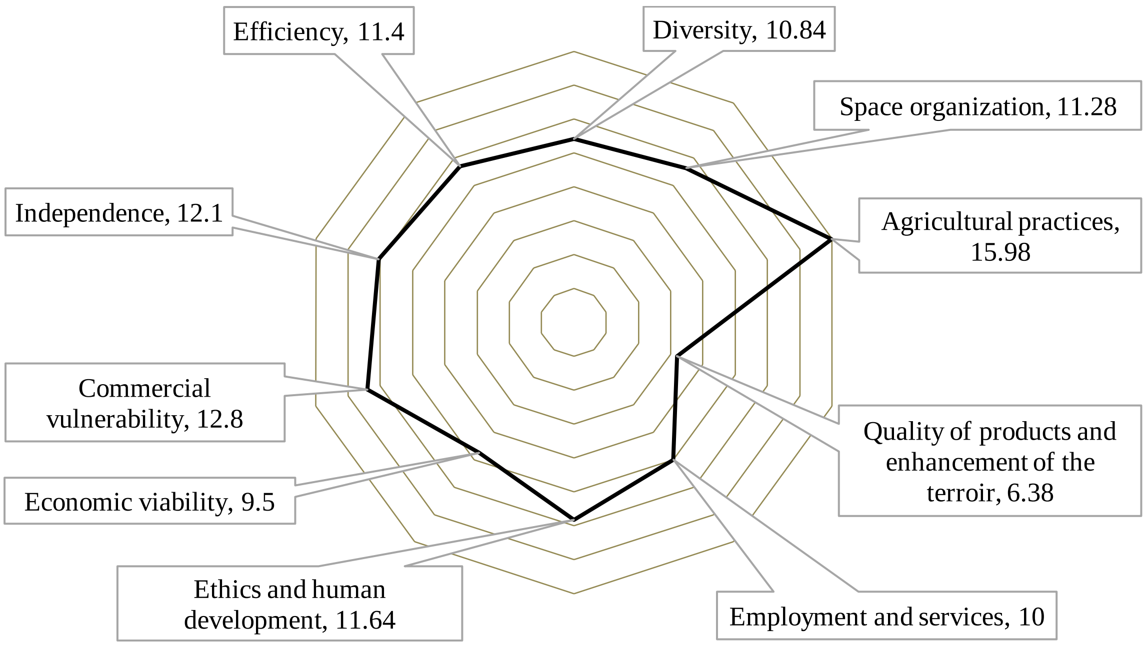

Figure 6. Graphical representation of the sustainability components of the studied farms

By assessing sustainability through the scores of different components, it becomes possible to identify the strengths and weaknesses of farms at an individual level. The surface area covered by the line connecting the component scores compared to the surface area covered by the outside perimeter offers a visual representation of sustainability (M’hamdi et al., 2017).

Analyzing the results in Figure 6, this study can observe that several components of the socio-territorial scale have relatively low scores. These findings are aligned with those recorded by Bir et al. (2019) in Algeria and Attia et al. (2022) in Tunisia. The components of “quality of products and territories,” “viability,” “employment and services” and “diversity” have the lowest values, namely 6.38, 9.5, 10 and 10.84, respectively. These results suggest areas where improvements can be made to enhance the socio-territorial sustainability of farms in the region.

On the other hand, the components of the other scales demonstrate higher scores. The components of “efficiency,” “ethics and human development,” “independence,” “commercial vulnerability” and “farming practices” exhibit the highest scores, specifically 11.4, 11.64, 12.1, 12.8 and 15.98, respectively. This indicates relatively stronger performance in these areas, highlighting the positive aspects of sustainability within the economic and agro-environmental dimensions.

Identifying the strengths and weaknesses of specific sustainability components is valuable for developing targeted strategies and interventions (Baskent, 2021). For example, addressing the low-scoring components within the socio-territorial scale, such as enhancing the quality of products and territories, improving viability, promoting employment and services, and fostering diversity, can contribute to a more comprehensive and balanced sustainability profile for farms in the Zaër Region.

It is important to note that these results are specific to the context and data of the farms in the studied region. Further research and analysis are needed to validate and expand upon these findings. Additionally, engaging stakeholders and farmers in the interpretation and application of these results can provide valuable insights and contribute to the development of more effective sustainability strategies in these agrosystems (Richardson et al., 2022). Overall, the assessment of individual component scores provides valuable insights for farm-level decision-making, policy development, and resource allocation aimed at promoting sustainable agriculture and fostering a more resilient and balanced farming system in the Zaër Region.

Analysis of the three scales of sustainability

Agro-environmental scale

This scale analyses the propensity of the technical system to make efficient use of the environment at the lowest possible ecological cost via different indicators from three components of equal importance (Zahm et al., 2008; Attia et al., 2021).

The results of the agro-environmental scale indicators provide valuable insights into various components of sustainability within the studied farms (Table 2). In terms of local diversity, both crop diversity and animal diversity scored reasonably well, with scores of 5.76 and 5.08, respectively, out of their respective norms of 0 to 18 and 0 to 10. This suggests a relatively diverse range of crops and animals present on these farms.

Regarding the organization of space, the indicator scores indicate a decent plot organization with a score of 6.08 out of a possible 12, while animal load and fodder management received a score of 5.20 out of 10. These scores suggest a moderate level of organization in terms of spatial arrangement and animal management practices. These results are similar to those recorded by Gara et al. (2021) and Attia et al. (2022) in Tunisia.

In farming practices, and contrary to the finding of Attia et al. (2022), fertilization and organic matter management received a relatively high score of 6.44 out of 18, indicating a positive approach toward enhancing soil fertility and organic content. However, the use of pesticides and veterinary products scored 5.08 out of 10, pointing to a relatively moderate level of usage.

Notably, the indicators related to soil and water management and energy dependence scored lower, with 1.30 and 3.16 respectively, out of their respective norms of 0 to 16 and 0 to 6. This might suggest areas for improvement in terms of efficient resource utilization and energy management.

Overall, the agro-environmental scale obtained a total score of 38.10 out of 100, indicating a moderate performance in terms of agro-environmental sustainability across the studied farms. The findings revealed that the agro-environmental sustainability is medium, as indicated by the average agro-environmental sustainability score obtained from the studied farms (38.1). Thus, constituting a limiting factor for some studied farms. This is justified by a lack of development and management of space; farms are especially characterized by monoculture, mainly cereals. The study also revealed a strong dependence of visited farms on chemical inputs and fuels, and an absence of sustainable production techniques such as direct seeding. Nevertheless, the region is characterized by diversified polyculture-livestock agro-systems (Hakimi and Brech, 2021). The exorbitant prices of inputs have prevented many farmers from providing them, but this has indirectly influenced the level of agro-ecological sustainability, which recorded a slightly high score of 38.1 (Table 2). In Tunisia, Bouzaida and Doukali (2019) confirmed that Tunisian production systems are characterized by a high agro-ecological sustainability attributed to their gradual conversion to organic farming, and this, by promoting organic fertilization rather than the use of chemical fertilizers and the limitation of phytosanitary treatments. Similarly, for dairy farms in Tunisia, M'Hamdi et al. (2009) asserted that they have a balanced rotation based on various annual and perennial crops associated with livestock, and farmers practice more organic fertilization. As for Cameroon's agro-systems (Sotamenou and Soh Fogwa Pogha, 2018), farmers have converted to

Table 2. Sum of agro-environmental sustainability indicators and components

Agro-environmental scale			
Components	Indicators	Scores	Norms
Local diversity	Crops diversity	5.76	0-18
	Animal diversity	5.08	0-10
Organization of space	Plot organization	6.08	0-12
	Animal load and fodder management	5.20	0-10
Farming practices	Fertilization and organic matter management	6.44	0-18
	Use of pesticides and veterinary products	5.08	0-10
	Soil and water management	1.30	0-16
	Energy dependence	3.16	0-6
	Total	38.10	0-100

more sustainable farming systems to be more competitive on national markets, which has increased the agro-environmental sustainability of their holdings.

Socio-territorial scale

The social dimension is related to three components: product quality and local development, employment and services, and ethics and human development. This scale aims to assess the quality of life of the farmers, their contribution to the mobilization of the workforce, social involvement, contribution to the services ensuring the quality of production, as well as behavior and responsibility towards production system (Zahm et al., 2019; Attia et al., 2022).

The results of the socio-territorial scale indicators shed light on various dimensions of sustainability related to the societal and territorial aspects of the studied farms (Table 3). In terms of the quality of products and territories, the score of 0 indicates a potential area for improvement, perhaps highlighting challenges in maintaining consistent product quality and enhancing the perception of local territories.

On the positive side, the indicator for valuation by short circuits received a notable score of 6.38 out of a possible 15, indicating a relatively strong emphasis on local distribution channels that promote regional products. This implies, as noted in prior research by of Tilman et al. (2011) and Mutyasira et al. (2018), a potential for supporting local economies and reducing the environmental impact of long-distance distribution.

In terms of employment and services, the contribution to employment scored 4.68 out of 20, and social implication received a score of 5.32 out of 15. While there is room for improvement in terms of job creation and social involvement, the scores suggest a certain level of contribution to employment and local societal issues.

The indicators related to ethics and human development reveal mixed results. Training and pluriactivity received a score of 3.16 out of 10. The results of present study are similar to those of Attia et al. (2022), indicating potential room for enhancing training and diversification of activities. On the other hand, hospitality, hygiene and safety scored relatively well with a score of 8.48 out of 20, suggesting a positive approach to ensuring safe and hygienic practices.

In summary, the socio-territorial scale obtained a total score of 28.02 out of 100, reflecting a modest performance in terms of societal and territorial sustainability aspects across the studied farms. This subdued socio-territorial sustainability score is consistent with the findings of M'Hamdi et al. (2009) and Attia et al. (2022).

The low score of the socio-territorial level is explained mainly by the absence of quality and traceability procedures, the weak social involvement of farmers through the associative structures, as well as by the absence of training and orientations by the local authorities. The results also show the low contribution of farms to employment (72% of farms employ less than 4 workers per ha), the mediocre quality of infrastructure, the lack of equipment and production storage premises, the lack of compliance with hygiene and quality standards in agricultural practices, and the absence of any form of recovery of non-organic waste. However, the strengths of the region lie in its proximity to local markets, which brings producers closer to consumers, promotes local production, and reduces transport costs (Specht et al., 2014) (the "valuation by short supply chains" indicator recorded an average score of

Table 3. Sum of socio-territorial sustainability indicators and components

Socio-territorial scale			
Components	Indicators	Scores	Norms
Quality of products and territories	Product quality	0	0-20
	Valuation by short circuits	6.38	0-15
Employment and services	Contribution to employment	4.68	0-20
	Social implication	5.32	0-15
Ethics and human development	Training and pluriactivity	3.16	0-10
	Hospitality, hygiene and safety	8.48	0-20
	Total	28.02	0-100

6.38 corresponding to 45% of the theoretical maximum score) (Table 3).

The socio-territorial sustainability level reported in Tunisia by Bouzaida and Doukali (2019) turns out to be higher than the result of the current study (48%), yet it is thus a limiting factor in the sustainability of irrigated perimeters in Tunisia. According to the study, this is explained by the lack of quality approaches, the absence of collective work given the absence of cooperatives, the small size of farms, the seasonal nature of crops and especially the lack of interest of young people in agricultural activity. Likewise, for Tunisian dairy farms, M'Hamdi et al. (2009) reported that the socio-territorial scale is a limiting factor following the low score recorded for the "employment and services" component.

In contrast, a study conducted in Cameroon by Sotamenou and Soh Fogwa Pogha (2018) found that pineapple agro-poles demonstrate a high level of socio-territorial sustainability. This can be attributed to better integration of farms into their environment, as well as the certification and traceability of their productions. The positive results from Cameroon indicate the potential for achieving higher socio-territorial sustainability through targeted interventions and improved practices.

Although there are regional variations in the socio-territorial sustainability levels, it is important to acknowledge that efforts are needed to improve all indicators of the socio-territorial scale across different contexts. Enhancing the quality approaches, promoting collective work and cooperation, addressing farm size limitations, diversifying agricultural activities and generating interest among young people can contribute to improving socio-territorial sustainability (M'Hamdi et al., 2009; Bir et al., 2019; Attia et al., 2022).

These comparative insights highlight the importance of context-specific analysis and the need for tailored strategies to address the socio-territorial challenges faced by agricultural systems. By learning from experiences in different regions (De Olde et al., 2016; Goswami et al., 2017; Zulfiqar and Thapa, 2017; Biret et al., 2019; Alary et al., 2020) and implementing best practices, it is possible to develop effective solutions and advance socio-territorial sustainability in the Zaër Region and beyond.

Economic scale

The indicators related to the economic scale provide insights into the financial performance and sustainability of the studied farms. The economic viability indicator received a score of 9.50 out of a possible 20, indicating a moderate level of economic sustainability. These findings are consistent with those of Attia et al. (2022), who documented a value of 12.8 for the same indicator, suggesting that the farms may have room for improvement in terms of maximizing profitability and economic stability.

The commercial vulnerability indicator scored relatively high with 12.80 out of 30, highlighting potential challenges in terms of market fluctuations and external economic pressures. This could suggest a need for strategies to mitigate risks and enhance market resilience (Buitenhuis et al., 2020; Shikwambana and Malaza, 2020; Cradock-Henry, 2021).

Financial autonomy, which assesses the farms' independence in managing their finances, received a score of 12.10 out of 20. The same results were recorded by Attia et al. (2022), suggesting that the farms have a reasonable level of financial self-sufficiency, but there may still be opportunities to further enhance their financial independence.

The efficiency of the production process, an indicator of how well resources are utilized in farming operations, received a score of 11.40 out of 30. This indicates a significant reliance on external inputs. The findings of the present study align with the outcomes of Benidir et al. (2013) and Bir et al. (2019), who reported similar results with 7.98 and 7.71 respectively. The importance of inputs, coupled with the escalating costs of concentrates, fertilizers, phytosanitary products, and energy, contributes to a diminished efficiency in the production process, consequently impacting economic viability (Bir et al., 2019). The obtained low score suggests that there could be potential for optimizing production processes to improve resource efficiency and reduce costs.

Economic sustainability scored high on the other scales (45.8). This scale has been impacted by both external and internal factors. On the one hand, the soaring prices of chemical inputs, diesel, seeds, and livestock feed have considerably increased production costs, reducing farm viability. On the other hand,

Table 4. Sum of economic sustainability indicators and components

Economic scale			
Components	Indicators	Scores	Norms
Viability	Economic viability	9.50	0-20
	Commercial vulnerability	12.80	0-30
Independence	Financial autonomy	12.10	0-20
Efficiency	Efficiency of the production process	11.40	0-30
	Total	45.80	0-100

the delay in the rains greatly reduced production. The results also demonstrated that the independence of farms is a strong point that has contributed to increasing their economic sustainability (Table 4). The independence component provides information on financial autonomy and sensitivity to subsidies and aid (M'hamdi et al., 2017). Indeed, the high dependence on external inputs drastically reduces economic efficiency (Van Passel et al., 2007). In contrast, when the dependence on external inputs is lower, the farms take advantage of their available resources, and then the production efficiency increases (Attia et al., 2021).

A similar study carried out in Tunisia by Bouzaida and Doukali (2019) showed that the studied farms had low viability and that it was financial autonomy that favored their sustainability. In Cameroon, Sotamenou and Soh Fogwa Pogha (2018) report that, in their study, economic sustainability is a limiting factor because of the heavy dependence of farms on state subsidies and bank credit. As for the Tunisian family farms studied by Gasmi et al. (2019), the results show that they are more autonomous by limiting their external borrowing as much as possible, the other hand the low scores of their economic sustainability are explained by monoculture, which makes them significantly vulnerable commercially. Alary et al. (2020) confirmed the same results in their multi-criteria study of the sustainability of farming systems in the reclaimed desert lands of Egypt.

CONCLUSIONS

The study assessed the sustainability of rainfed agro-systems in the Zaër Region of Morocco using the IDEA method, comprehensively evaluating agro-environmental, socio-territorial and economic dimensions. While diversity and agricultural practices positively impact the agro-environmental scale, space organization presents limitations. Weaknesses in socio-territorial aspects were evident due to lacking quality procedures, infrastructure and social engagement, despite the advantages of short food distribution circuits. At the economic level, farms displayed independence from external borrowing, but commercial vulnerability, high production costs and low profitability hindered viability and efficiency. The study's findings provide valuable insights for future research and policy discussions, emphasizing the importance of improving soil quality, adopting renewable energy and conserving biodiversity.

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