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From soil to society: A transdisciplinary assessment of farmers' adoption of agroecology through the social-ecological systems framework in Algeria

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ABSTRACT

North African countries are increasingly facing climate change, natural resource degradation, and food crises. Algerian regions such as Laghouat are one of the hotspots where problems such as soil degradation, desertification, and water scarcity are experienced. Current agricultural production systems are not responding to future needs and are inadequate to address these problems. Agroecology emerges as a promising alternative that can respond to growing future needs by providing resilient and sustainable production systems. This study investigates the factors affecting farmers' adaptation to agroecology in Laghouat, Algeria, using Elinor Ostrom's Social Ecological Systems Framework (SESF). We apply our mixed-methods methodology in the field to systematically examine the complex relationships of the system, resource systems and, governance, and actors. Our findings suggest that the negative impacts of unsustainable agricultural practices, combined with climate change and misguided policies, are leading to a problematic trend that results in a system that is losing its resilience and sustainability and is becoming increasingly vulnerable. However, the study also highlights that farmer training, incentives to support the adoption of environmentally friendly practices, and strong social networks can significantly increase the transition to sustainable agroecology. These insights underline the need for integrated and collaborative strategies to achieve sustainable soil management, and hence more resilient agricultural system.

1. Introduction

In North African countries, agriculture is a key sector, underpinning food security, export revenues, and overall economic development (Abdelhedi and Zouari, 2020). However, these countries are increasingly challenged by climate change and the degradation of natural resources, which pose serious threats to environmental and socioeconomic sustainability (Lacirignola et al., 2014; Noureddine et al., 2020). In Algeria these issues are particularly pressing due to the predominance of arid lands (Hadj Henni, 2024). Most of the country lies within the Sahara Desert and suffers from limited water availability (Mohammed and Al-Amin, 2018). Consequently, Algeria is significantly affected by desertification, soil degradation and water scarcity (Hadj Henni, 2024). Despite these challenges, Algeria remains North Africa's leading producer of key crops such as wheat, potatoes and palm dates. Algeria, given its important role in the production of such strategically important crops, faces intensifying effects of climate change, and has become increasingly vulnerable due to continued reliance on conventional agricultural practices (Mohammed and Al-Amin, 2018; Omran and Negm, 2020).

As documented in the literature, conventional farming systems generate numerous negative externalities including soil degradation, erosion, and desertification (Kremen and Miles, 2012a). These processes compromise soil quality, contribute to the depletion of underground water reserves, lead to the loss of local crop varieties, and reduce biodiversity (Kremen and Miles, 2012b; Lal, 2012; Omran and Negm, 2020). Research has identified the heavy reliance on intensive chemical inputs and the mismanagement of natural resources as major drivers of this environmental degradation (Jhariya et al., 2021; Westhoek et al., 2016). In Algeria, the vulnerability of agricultural production is further intensified by the impacts of climate change – such as prolonged dry seasons, frequent droughts, erratic rainfall, and flooding – combined with ongoing natural resources depletion (Schilling et al., 2012). In light of these challenges, there is an urgent need to transition toward alternative agricultural systems that can support both environmental restoration and socio-economic resilience.

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Soil is a natural living resource that can fall under private, common or public ownership within agricultural landscapes (Hartemink, 2016). As a foundational element of agroecosystems, it serves not only as a medium for plant growth but also contributes to essential chemical and biological functions (Robbie and Strenger, 2003). Soil quality reflects the cumulative effects of past and present land management practices and, in turn, influences the productivity of future cultivation cycles (Grahmann et al., 2022). Intensive use of conventional agricultural practices has led to soil degradation which can result in declining crop yields, increased food insecurity, and heightened vulnerability to climate change (Vanwalleghem et al., 2017).

Beyond its physical role, soil is integral to ecological processes, such as nutrient cycling or microbial activity – functions that are vital for agricultural activities (Grover et al., 2024). Given the ecological interconnectedness of farm plots and the long-term environmental sustainability of soil functions, this research addresses current and emerging challenges in soil sustainability, emphasizing the need for long-term, sustainable soil management in agriculture.

We further argue that soil should be considered as a common pool resource due to its characteristics of rivalry and non-excludability (Cooper et al., 2009; Gerrard et al., 2012). Poor management by one stakeholder – for example, through pollution or overuse – can diminish soil quality and reduce access for others (Delelegn et al., 2017). While landowners may control access and immediate impacts on their land, they cannot fully govern the broader environmental consequences or future effects of their land-use decisions (France-Hudson, 2017; Tomalka et al., 2024).

Agroecology is increasingly recognized as one of the most promising alternatives for addressing soil degradation and other broader environmental issues (Altieri and Rosset, 1996; Wezel et al., 2014). Its holistic approach integrates ecological principles with the social realities of farming communities, offering economic benefits while preserving biodiversity and respecting environmental limits (Carlile et al., 2021). Rooted in ecological science, agroecology promotes sustainable farming practices that support ecosystem health (Wezel et al., 2009).

Agroecological production systems aim to enhance resilience and sustainability not only for the ecosystem, but also for farmers, consumers and other stakeholders, both socially and economically (Mouratiadou et al., 2024). In ecologically fragile and climate-vulnerable contexts such as Algeria, maintaining a balance among the three pillars of sustainability – social, environmental and economic – is crucial for building more resilient agricultural systems (Srinivasa Rao et al., 2019). However, a transition to agroecological production system presents significant challenges and is constrained by a range of structural and institutional limitations (Ewert et al., 2023).

The transition from a conventional to an agroecological farming system is a complex and multifaceted process, involving numerous challenges (Prost et al., 2023; Soini Coe and Coe, 2023). While agroecology offers significant ecological and social benefits, one of the key barrier to its advancement is the low rate of adoption among farmers (Alphonse et al., 2024). This reluctance is shaped by a range of factors, including systemic issues such as institutional and economic constraints, as well as cultural and traditional practices embedded in local farming communities (Dessart et al., 2019). A comprehensive and holistic understanding of these barriers is essential to promote sustainable land and farm management through the increased adoption of agroecological practices. In this article we examine the factors influencing farmers' adoption of agroecology in the peri-oasis farming system of Laghouat, Algeria, with the aim of reducing soil degradation while ensuring social, economic and ecological sustainability.

Given the inherent complexity of agricultural systems and the multiple, interrelated challenges that hinder the adoption of agroecology, a systematic and interdisciplinary research approach is essential to effectively address this research question. Approaches limited to a single disciplinary lens often fall short in capturing the complex, multilevel interactions between ecological processes and social dynamics. An adaptive interdisciplinary framework – encompassing disciplines such as soil science, ecology, agricultural economics and social sciences – is crucial for uncovering the interdependencies that shape farmers' decisions. In the Algerian context, where conventional agriculture practices converge with rapid environmental changes, a comprehensive and systemic analysis is particularly necessary to accurately identify the factors influencing agroecological adoption. Adopting such an interdisciplinary and systemic methodology not only enhances the analytical depth of the study, but also provides a more robust foundation for designing effective, context-sensitive agricultural policies. This integrative approach is vital to bridge the gap between theoretical frameworks and the real-world challenges faced by farmers on the ground in Algeria.

To gain a comprehensive understanding of the social, ecological and economic dimensions of sustainability, this study employs Ostrom's (2009) Social- Ecological System Framework (SESF). The SESF provides a structured approach for analyzing the complexity of agricultural systems, including their ecological and social components, and is particularly well suited for studying agroecology. It facilitates the identification of farmers' role within the broader system and their interactions with other components, such as natural resources, governance structures, and economic drivers. By applying the SESF, we aim to conceptualize and analyze the key factors influencing the adoption of agroecological practices in the region. Its detailed structure allows for a nuanced examination of the variables shaping farmers' decision-making processes. In the peri-oasis case study of Laghouat in Algeria, we use soil as an entry point into environmental management, positioning it as a common-pool resource within the SESF framework**.**

This study adopts a field-based approach developed within the framework of the NATAE European Horizon project in Algeria, utilizing an innovative *living lab* methodology to explore the transition to agroecological practices. This approach actively engages a range of local stakeholders through field observations, in-depth interviews, and participatory workshops. Iteratively and dynamically developed across multiple stages and involving various stakeholders, it integrates interdisciplinary perspectives to identify the main levers for both policy intervention and practical innovation. By incorporating new insights generated through field activities, this method offers a robust foundation for promoting sustainable agriculture in Algeria.

2. Methodology

2.1. Case study

The study is conducted within the Living Lab (LL) of Laghouat (in Algeria), located in two communes of the Wilaya (province) of Laghouat; namely Laghouat (*33°48'23"N 2°51'46"E)* and El-Assafia (*33°49'38"N 2°59'20"E)* which are approximately 15 kilometers apart. For the purposes of this study, we refer to this area collectively as the "LL of Laghouat". A Living Lab is an open innovation system where the research is conducted in real-world settings through active collaboration with diverse stakeholders, including farmers, local actors, and researchers (Cascone et al., 2024). To build a comprehensive and context-specific application of the SESF, the research was carried out in close collaboration with local farmers and other stakeholders within the LL of Laghouat. The establishment and facilitation of this LL were supported by the NATAE project funded under European Union's Horizon 2020 European program (NATAE, Field Labs, 2023).

The LL of Laghouat is geographically located between the steppes to the north, the edges of the Sahara Desert to the south, and the Atlas Mountains to the northwest as illustrated in Fig. 1. The region is characterized by arid and semi-arid climate conditions and is shaped by a distinctive peri-oasis farming system. The Oued Mz'i River, which flows intermittently following occasional heavy rainfalls, serves as the primary water source of the area. Traditionally, agriculture in the LL of Laghouat's peri-oasis region has been structured around a multi-layered

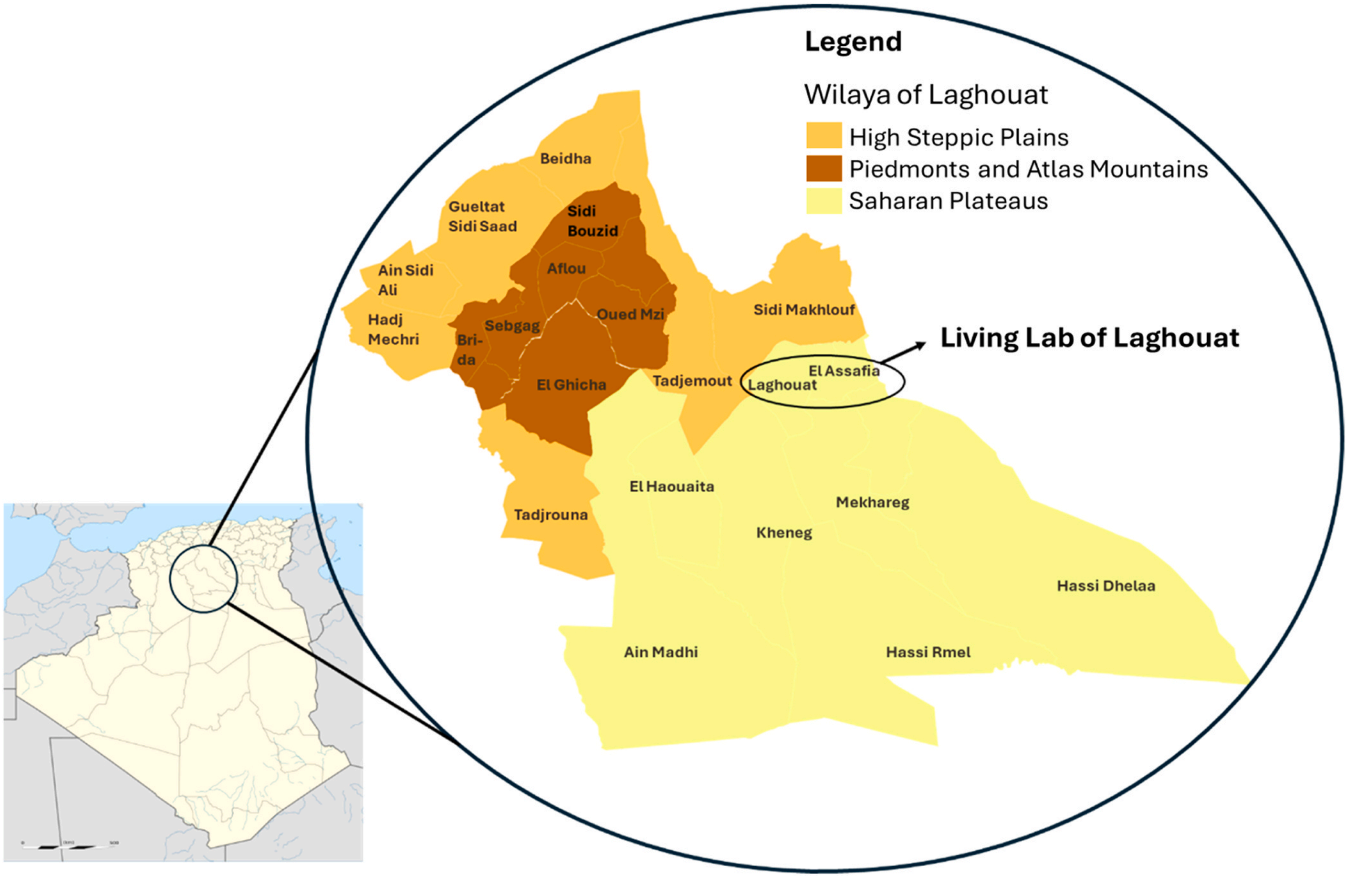

Fig. 1. Map of the Laghouat wilaya (Adapted from Belmecheri Benmoussa and Moulai, 2023).

canopy farming system. This system features characterized palm dates forming the upper layer, providing shade and microclimatic benefits; fruit trees such as figs occupying the middle layer; and a variety of ground-level crops suited to the region's climate cultivated on the lowest level. This agroforestry-based structure reflects an adaptation to the region's environmental constraints and exemplifies a historically sustainable approach to land use.

In the LL of Laghouat, traditional small-scale backyard gardening and sheep farming have gradually given way to larger farming systems that combine agroecology with conventional agricultural practices (with a limited access to inputs and mechanization). This shift has been driven by growing urban population pressure and evolving local market demands. There is a noticeable trend towards mixed farming systems that incorporate a variety of crops (such as vegetables, cereals and forage crops) and large ruminant livestock, with the aim of satisfying the growing need for diversified agricultural products. As a result, traditional backyard gardening has expanded beyond the city limits into larger farms. Currently, the LL of Laghouat is characterized by a range of varied farming systems that employs different irrigation techniques and include cereal cultivation, arboriculture or livestock-oriented practices. Despite this diversification, the unifying feature of all the farms within the living lab area is the cultivation of date palms – a crop of significant historical, cultural and economic importance in the region.

National agricultural policies in Algeria have played a significant role in shaping the agricultural structure of the Laghouat wilaya, where is located the LL of Laghouat. Since the Independence, a series of reforms – including the National Agricultural and Rural Development Program – have been implemented with the goals of enhancing agricultural productivity, increasing food security, and promoting rural development (Laoubi et al., 2017a). These reforms were supported by targeted programs, subsidies and modernization initiatives that encouraged the adoption of high-input, intensive practices, the cultivation of strategic crops and the introduction of new crop varieties. While these policies contributed to a diversification of the agricultural production in LL of Laghouat, they also accelerated environmental degradation, even with the limited access to chemical inputs (e.g., fertilizers and pesticides), particularly in the region's arid zones.

The transition towards the cultivation of new input-intensive crops has been accompanied by the increasing and often inappropriate use of chemical inputs, poor management of soil, and the over-exploitation of natural resources. As a result, the LL of Laghouat faces a range of negative externalities, including soil degradation and erosion, desertification, depletion of underground water reserves, the loss of traditional crop varieties, and a decline in biodiversity. These outcomes are largely driven by agricultural practices that are poorly adapted to the LL of Laghouat region's arid and semi-arid climatic conditions (Kremen and Miles, 2012b; Lal, 2012).

2.2. SES framework

Understanding complex social ecological systems (SES) requires a structured and holistic analytical approach. To address this need, this study employs the Social-Ecological Systems Framework (SESF), originally developed by Ostrom (2009), and later refined by McGinnis and Ostrom, (2014) as illustrated in Fig. 2. The SESF serves not only as a diagnostic tool for analyzing SES, but also provides a conceptual structure for building and testing new theories. (McGinnis and Ostrom, 2014; Ostrom, 2009). Developed through a multi-level approach, the SESF enables the examination of the interconnections between ecological and social components, thereby enhancing the analytical depth, inclusivity and contextual relevance of the analysis (McGinnis and Ostrom, 2014; Ostrom, 2009). This framework is particularly suited for complex

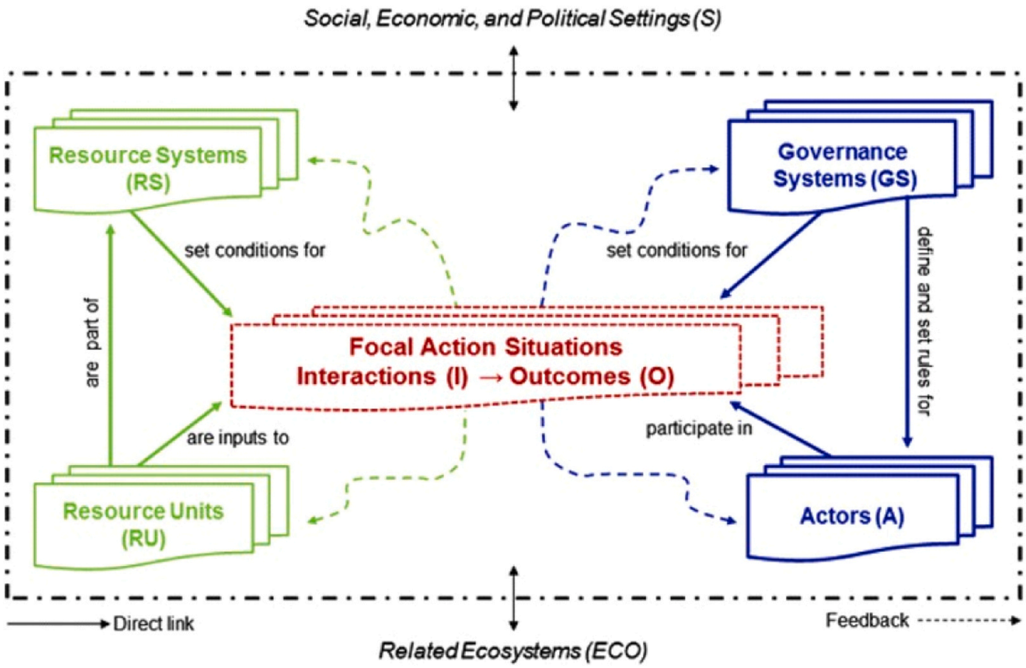

Fig. 2. Representation of SESF (McGinnis and Ostrom, 2014).

systems such as agriculture, where environmental, institutional, and human factors are deeply intertwined.

At the first tier, the SESF identifies the core subsystems of a SES: the resource system, resource units, governance systems, and actors (Ostrom, 2009; McGinnis and Ostrom, 2014). Each of these subsystems is further broken down into second-tier variables. For instance, the second-tier variables for *resource units* include characteristics such as the clarity of system boundaries, the size of the resource system or productivity. In the case of the *governance system,* second tier variables include the presence and role of government organizations, non-governmental organizations or network structures. Additionally, the framework allows for the development of the third tier variables which provide even greater specificity and contextual depth (McGinnis and Ostrom, 2014). Through its shared vocabulary and standardized approach, the SESF enables a systematic and interdisciplinary analysis of the interactions and interdependencies between ecological and social dynamics. This comprehensive approach supports detailed, case-specific inquiry while maintaining analytical coherence (Guiomarães et al., 2018).

The strength of Ostrom's approach in this study lies in its interdisciplinary and comprehensive nature as well as its anthropocentric orientation and balanced integration of both ecological and social dimensions in the LL of Laghouat (Binder et al., 2013). The SESF effectively encompasses the three pillars of sustainable agriculture – social, ecological and economic – which are foundational to agroecology. By taking into account the biophysical and ecological conditions that influence farmers' decision-making, the SESF provides a solid structure for analyzing environmental constraints. At the same time, it emphasizes the importance of social and institutional factors, which are essential for understanding the adoption of agroecological practices.

2.3. Study design

To build the SESF for the LL of Laghouat, we developed a methodology grounded in established recommendations for applying the framework to agroecological transitions. More specifically, we drew on Fleury et al. (2021) for identifying and analyzing the drivers of agroecological change, Hinkel et al. (2015) for systematically delineating SES subsystems and setting explicit criteria for selecting second-tier variables, and Nagel and Partelow (2022) for clearly defining system boundaries and case study parameters. While the literature offers numerous theoretical insights into the SESF, practical guidance for applying the framework – particularly in case studies involving field-based data collection such as questionnaires – remains limited. To bridge this gap and ensure the framework's appropriate application to our case study, we designed a cyclical and iterative methodology. This approach is characterized by non-linear steps in which all phases are interconnected, allowing for continuous refinement and adaptation as new insights emerge (Fig. 3).

2.3.1. Phase A – exploring the literature and defining the boundaries

Phase A involved a comprehensive review of both scientific and grey literature. On one hand, scientific literature provided a strong theoretical foundation on the SESF, including its conceptual development and application across different ecosystems. On the other hand, grey literature – such as project reports and deliverables - provided detailed contextual insights specific to the case study. Additionally, household farm surveys conducted within the scope of the NATAE project provided valuable empirical data on farming activities and household characteristics. This combined literature and data reviews allowed us to contextualize farmers' practices and socioeconomic conditions which in turn helped to define the system boundaries for our study. Based on this analysis, the boundaries of the resource system were identified as the two communes of Laghouat and El-Assafia both constituting the LL of Laghouat.

2.3.2. Phase B – selection of relevant variables from the SES framework, conceptualization of variables and identification of sources of information, and preparation of questionnaires

This phase focused on the structural development of the SESF tailored to our case study by selecting and conceptualizing the relevant second-tier variables and preparing for subsequent data collection. The aim was to adapt the framework in a way that accurately captures the specific dynamics of the LL of Laghouat. To ensure relevance and analytical coherence, we selected second-tier variables from the SESF based on two clear inclusion criteria: 1) the variable must be applicable and contextually appropriate for the case study area; and 2) It must align with the scope of our research question, particularly regarding the

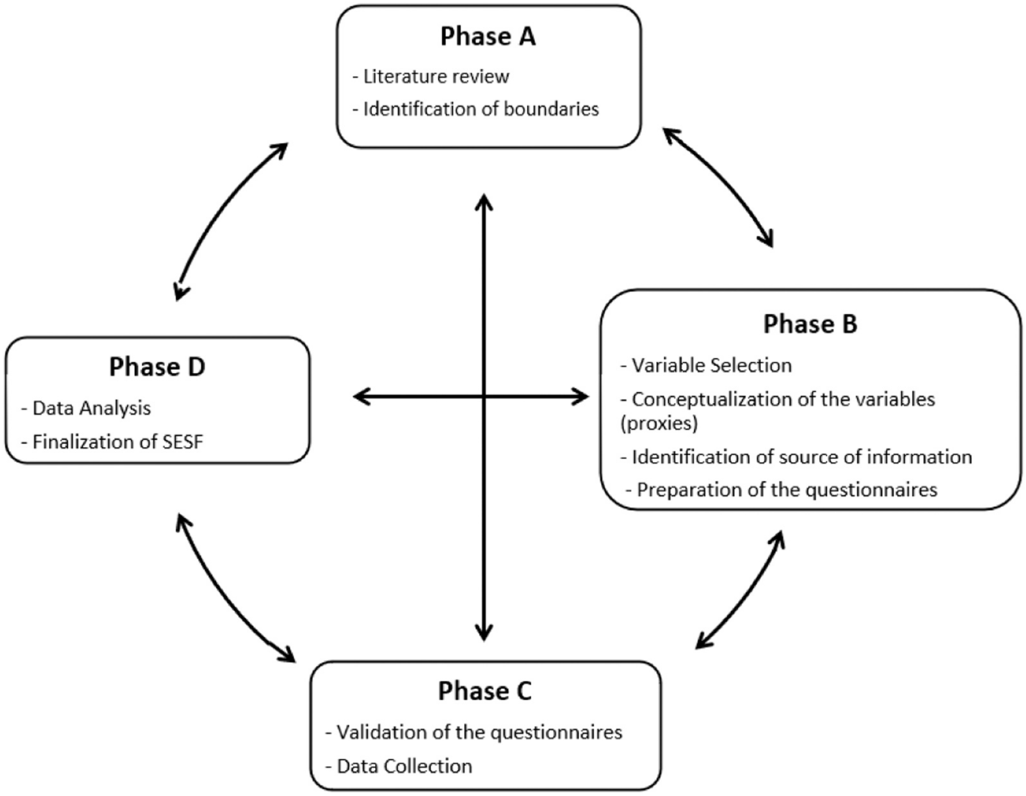

Fig. 3. Representation of the cyclical methodology developed.

drivers of agroecological adoption.

On the basis of the selected second-tier variables, we proceeded to conceptualize each variable by identifying appropriate proxies that would allow us to capture the relevant dimensions of the SES. For each second-tier variable and its corresponding proxy we also determined the source of information – whether it would be drawn from scientific or grey literature or directly from relevant field actors. Variables requiring empirical investigation were identified and selected for interviews. The questionnaires were then developed in alignment with the selected second-tier variables and proxies, and tailored to the profiles of different stakeholder groups. This design enabled the collection of context-specific data from multiple perspectives within the system (see appendixes for the questionnaires).

2.3.3. *Phase C –data collection*

In phase C, data collection was carried out using a combination of diverse sources and methods to ensure a comprehensive understanding of the system. This study employed a mixed-method approach including literature reviews, semi-structured interviews tailored to the SESF, household farm surveys, workshops, and farm site visits. During the farm site visits, information was collected through both direct observation and open-ended interviews with farmers, focusing on their agricultural practices and contextual challenges. Data collection occurred in multiple stages over different time periods. For instance, the same farmers who participated in the household farm survey – designed to gather information on farming activities and household socio demographics – were subsequently interviewed using SESF-specific questionnaires to explore deeper system-level insights. While the interviews, site visits, workshops and literature reviews were conducted directly by the research team, the household farm survey was implemented by the LL coordinators in the field, ensuring continuity and leveraging local knowledge.

The questionnaires developed for the SESF in Phase B were reviewed and validated by local experts to ensure the regional relevance of the content and the cultural sensitivity of the social questions. After validation, the questionnaires were administered on site between September 3rd and 22nd, 2024, in the form of semi-structured interviews, each session lasting 45–75 min (Table 1). Interviews were conducted with 14 farmers, carefully selected to represent the different farm types identified within the LL of Laghouat. Additionally, 11 interviews were carried out with diverse agricultural stakeholders in the region. These included: a representative from the Department of Agriculture, the head of an agricultural association, a farm shop owner, a hydraulic expert, a member of the agricultural chamber, a nursery owner, a retired agricultural engineer, two professors from the Department of Agriculture at the University of Laghouat, a soil expert and a representative from the Department of Forestry. Due to the limited number of soil experts in the Laghouat region/LL, only two interviews were conducted, one with a soil expert who runs his own agricultural consulting firm and the other with a soil researcher at the university.

The interviews were conducted primarily in Algerian Arabic, and French, with four interviews held in English, depending on the preferences and language proficiency of the participants.

2.3.4. *Phase D, data analysis*

In Phase D, data collected through the methods outlined in Table 1 were analyzed using a systematic content analysis approach. NVIVO software was employed to organize, code and interpret the qualitative data. The analytical process combined contextual and thematic analysis, enabling a comprehensive examination of the explicit and latent content of the dataset. The contextual analysis allowed for an understanding of the environmental and situational dynamics, while the thematic one identified recurring patterns and emergent themes relevant to the research objectives. This dual approach ensured a nuanced interpretation of the data, enhancing the depth, rigor, and reliability of the qualitative analysis. The findings from Phase D played a key role in informing and shaping the subsequent phases of the research framework, contributing to the overall validity and robustness of the study.

Table 1
The data collection methods and the source types.

Method	Participants	Number of Participants	Source Type
Interview	Farmers (14), Different actors: Department of Agriculture (1 actor), the head of the agricultural association (1 actor), farm shop owner (1 actor), hydraulic expert, an agricultural chamber (1 actor), nursery owner (1 actor), retired agricultural engineer (1 actor), Professors from the Department of Agriculture at the University of Laghouat (2 actors), soil expert (1 actor) and the Department of Forestry (1 actor)	25	Semi-structed, face to face in the field from 3 to 22 September 2024
Workshop	Representative community of the Living Lab	15 participants, 2 times in total	First, 17th of February 2024, regarding the farming systems in region and their activities, secondly, 19 September 2024, regarding the farming inputs and the output-yield of the farm types of the LL
Site visit	Farmers, Living Lab members, Guide from the Farmer's Association	7 farms in 15th of February 2024, 13 farms from 3rd to 22nd of September 2024	Observation, Open interviews
Household farm survey	Farmers	38	Structured Interviews for the NATAE project
Literature Review	Literature		Research articles, Project Reports

3. Results

The overall understanding of the SES and human-nature interactions in the agricultural context of Laghouat's LL is structured into three main analytical sections: (1) Resource System and Resource Units, (2) Actors and Governance Systems, and (3) Action Situations. These components reflect the core structure of the SESF and provide a holistic view of the interdependent ecological and social dynamics within the peri-oasis farming system. To unfold these components, we employed a multi-method approach, incorporating field observations, household farm surveys, semi-structured interviews, and stakeholder workshops. Table 2 provides a detailed overview of the selected second-tier variables, their conceptualization through proxies, and the corresponding data sources used in the case study analysis.

3.1. Resource system and resource unit

Agriculture ranks as the fourth most significant economic sector in the LL of Laghouat, following industry, administration, and services (Belmecheri Benmoussa and Moulai, 2023) (RS1). The agricultural system analyzed in this study is located in the LL, encompassing the communes of Laghouat and El-Assafia (RS2). The average farm size is approximately 12 ha (RS3). The LL of Laghouat is exposed to a range of environmental phenomena that challenge agricultural production, including drought, floods, sand winds and soil erosion, as reported by both farmers and other local stakeholders (RS7). During the rainy season, the river that runs through these two communes – which is the main source of groundwater– is prone to flash floods caused by irregular and intense rainfall events. These floods frequently inflict significant damage on farms located near the riverbed. Conversely, the region also experiences prolonged dry seasons which contribute to persistent drought conditions. This climatic variability compels farmers to rely heavily on irrigation in order to avoid yield losses. As one local researcher emphasized: "Sometimes it rains a lot, but the climate risk is very high, even when rainfall is good there can be significant losses. In the south, we rely on irrigation. We can't do agriculture without irrigation because there is only 150 mm per year. For instance, wheat is irrigated." This quote illustrates the critical dependence on irrigation in an area where annual precipitation averages only 150 mm, underscoring the vulnerability of local agriculture to climatic extremes.

The dominant soil texture in the LL of Laghouat is primarily sandy, characterized by a high limestone content (RU6). According to a local soil expert, there are two main types of soil in the LL zone of Laghouat: fertile soils (usually found in wadis or depressions) and non-fertile soils (predominant in the LL). Based on his local field experience, the expert estimates that fertile soils account for about 15 % of the total area, while non-fertile soils represent about 85 %. Moreover, fertile soils are characterized by a higher clay, sand and silt content, while infertile soils are very calcareous and poor in nutrients. This assessment is consistent with the findings of the scientific literature on Laghouat, where Demdoum et al. (2017) highlight the presence of calcareous sandy soils with high levels of CaCO3. Furthermore, a soil analysis in the LL of Laghouat indicates high pH levels (approximately pH 9,05), and low organic carbon content, which corresponds to the findings of Houyou et al. (2016), who reported an organic carbon content of less than 0.2 % in Laghouat. These characteristics contribute to reduced water retention and nutrient-holding capacity, exacerbating the challenges associated with agroecological practices in the LL of Laghouat.

In addition, soil's regenerative capacity in the region of LL of Laghouat is very limited, largely due to the arid climatic conditions, scarcity of organic matter, and low diversity of soil biota (RU2) (Moumni et al., 2023). These factors severely constrain pedogenetic processes, slowing down the natural recovery of soils following degradation. Moreover, connectivity and interactions between different plots, for instance soil erosion, or pollution of underground water resources, degrade overall soil health (RU3, RS6) (Khatteli et al., 2016). Over time, the inappropriate use of chemical fertilizers – urea and compound fertilizers such as NPK (nitrogen phosphorus potassium) and MAP (monoammonium phosphate) for cereals and fodder crops (approximately 2 quintals per hectare each), NPK for fruit trees, and both NPK and urea for vegetable production) combined with excessive irrigation (3000–6000 m^3/ha for vegetables; irrigation every 4 days for 6–8 h for cereals and fodder crops – has exacerbated these conditions. Such irrigation practices have contributed to an increased risk of desertification, which significantly damages soil quality and agricultural productivity (Mekki et al., 2007). As one respondent observed, "We have gypso-calcer soils, biological activity is low, humus is limited, therefore the pedogenesis is slow. So, after erosion, we have to wait long years for new soil to form. The soil is very rich in limestone and soluble salt, and the water is very hard."

The sustainable management of agricultural resources in the LL of Laghouat depends fundamentally on the complex and dynamic interactions between the RU – specifically land and farm plots and the RS or the surrounding environmental context. The region is subject to intense climatic stressors, particularly flash floods and prolonged droughts, which directly impact soil degradation combined with difficult parent rock. For example, flash floods lead to topsoil erosion stripping away the most fertile soil layer that is essential for plant growth and takes a very long time to regenerate – thereby severely undermining the already fragile regenerative capacity of soils (RU2;

Table 2
Representation of the selected second tier variables and their conceptualization in the case study with the data sources.

First tier Variable	Second Tier Variable	Related Proxy	Source of Information
S - Social, economic, and political settings	S3 – Political stability	Influence of governance systems	Literature (Colin et al., 2021; Daoudi and Colin, 2016)
	S5 – Markets	Scale of the market	Literature (Vlontzos et al., 2025), Field Visits, Expert Knowledge
RS - Resource systems	RS1 – Sector (e.g., water, forests, pasture, fish)	Agriculture (Agricultural sector)	
	RS2 – Clarity of system boundaries	Geographical boundary	Literature (Belmecheri Benmoussa and Moulai, 2023)
	RS3 – Size of resource system	Average area under farm management	Household Farm Survey
	RS4 – Human-constructed facilities	Types of facilities constructed for agricultural production	Household Farm Survey
	RS5 – Productivity of system	Soil efficiency	Surveys (with soil expert and researcher)
	RS6 – Equilibrium properties	Variation of soil health over the years	Surveys (with all actors)
	RS7 – Predictability of system dynamics	Types of environmental phenomena	Surveys (with all actors)
	RS9 – Location	Geographical location and climate properties	Surveys, Literature (Belmecheri Benmoussa and Moulai, 2023; Laoubi et al., 2017b)
RU - Resource units	RU2 – Growth or replacement rate	Soil ecosystem regenerative capacity	Literature (Moumni et al., 2023)
	RU3 – Interaction among resource units	Existence of unit's connectivity in the ecosystem, type of unit's connectivity in the ecosystem	Surveys (not farmers but the rest) and Literature (Khatteli et al., 2016)
	RU4 – Economic value	Economic value of plots	Surveys (Experts)
	RU5 – Number of units	Number of farms in the LL	Grey Literature (Belmecheri Benmoussa and Moulai, 2023)
	RU6 – Distinctive characteristics	Different types of soils in the region	Surveys (Soil Experts), Household farm survey
GS - Governance systems	GS1 – Government organizations	Number, type and objective of organizations related to agriculture, type of activities of these organizations	Surveys (with all actors)
	GS2 – Nongovernment organizations	Number, type and objective of organizations related to agriculture, type of activities of these organizations	Surveys (with all actors)
	GS3 – Network structure	Type of interactions between the different actors	Surveys (with all actors)
	GS4 – Property-rights systems	Land ownership types for Agriculture	Surveys (with all actors), Literature (Colin et al., 2021; Daoudi and Colin, 2016)
A - Actors	A1 – Number of relevant actors	Number of actors in the system and their roles	Surveys (with all actors)
	A2 – Socioeconomic attributes	Number of farmers above the retirement age, number of farmers that are younger than 35, number of farmers that graduated from high school, Number of farmers to which farming is the primary occupation	Household Farm Survey
	A3 – History or past experiences	Number of years of experience, Number of years of experience in the region	Household Farm Survey, Surveys (with experts)
	A5 – Leadership/entrepreneurship	Existence of leader farmers; Existence of leader organizations	Surveys (with all actors)
	A6 – Norms (trust-reciprocity)/social capital	Strength of trust within farmers; Strength of trust within organizations	Surveys (with all actors)
	A7 – Knowledge of SES/mental models	Knowledge of the impacts of agricultural, practices on soil, Quality of knowledge; Type of knowledge	Surveys (with all actors)
	A8 – Importance of resource (dependence)	Influence of soil on the agricultural activity	Surveys (with all actors)
	A9 – Technologies available	Presence of agricultural technologies and agroecology, existing agroecological practices	Site Visits
I - Interactions (Action situations I -> O)	I1 – Harvesting	Type of benefit from the natural resources in the ecosystem, intensity of it	Workshops
	I2 – Information sharing	Type of information shared between different actors (which actors?)	Surveys (with farmers)
	I4 – Conflicts	Conflicts on soil ownership	Surveys (with all actors)
	I5 – Investment activities	Number /length of soil preparation activities	Surveys (farmer and soil expert)
	I7 – Self-organizing activities	Presence of self-organizing activities between farmers in the LL area, Type of self-organizing activities between the farmers in the LL area	Surveys (with all actors)
	I8 – Networking activities	Type of network in the LL area between different actors	Surveys
O - Outcomes (Action situations I -> O)	O1 – Social performance measures (e.g., efficiency, equity, accountability, sustainability)	Economic measurement of the system, efficiency of the system, sustainability of the system	Workshops
	O2 – Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability)	The level of ecosystem health	Surveys with soil expert/researchers
	O3 – Externalities to other SESs	Type of other SES	Site Visit
ECO - Related ecosystems	ECO1 – Climate patterns	Drought pattern due to the climate change	Surveys
	ECO2 – Pollution patterns	Existing pollution to the other ecosystems	Site Visit

RS5; RS6). Conversely, drought conditions significantly delay soil biochemical processes and microbial activities both of which are crucial for the formation of organic matter and soil recovery (Qu et al., 2023). The degradation of one plot of land can lead to the degradation of soil health in neighboring plots. For instance, the loss of vegetation cover and topsoil due to flooding can increase wind and water erosion, intensify surface runoff, or transport agricultural chemical residues, thereby accelerating the degradation of soil health in neighboring land even in the absence of direct flooding (RS6). In response to these compounding threats, farmers in the LL of Laghouat have developed local agroecological strategies aimed at buffering degradation. One such practice is to plant barbarian figs (*Opuntia spp.)* as hedges against wind erosion. These hedges not only reduce wind erosion but also enhance the resilience of the RS by providing soil stabilization, improving microclimates, and offering economic benefits through the sale of their fruits. Similarly, to remedy poor soil fertility, farmers make extensive use of manure spreading which improves soil structure and increases organic matter content throughout the LL of Laghouat. However, farmers do not have strategies to prevent soil erosion caused by rain and flooding, which makes the system vulnerable to water-related erosion despite the protective measures taken against wind erosion. Thus, the interactions between RU and RS in the LL of Laghouat reveal critical socio-ecological feedback loops: while environmental challenges can intensify degradation processes, context-specific and ecologically informed management practices present viable pathways for restoring system balance and long-term sustainability.

3.2. Actors and governance systems

A wide range of governmental and non-governmental organizations is actively involved in agricultural governance in the LL of Laghouat, each contributing to different facets of the system (GS1, GS2). These include the Directorate of Agricultural Services, the General Directorate of Forests, the Chamber of Agriculture, the University of Laghouat, a local farmer's association (El Argoub), as well as agricultural input suppliers, a nursery, private sector actors, local markets, intermediaries, and consumers. These stakeholders and their roles are illustrated in Fig. 4 (A1).

Among the farming population, 50 % of farmers are above retirement age of 60 %, and 60 % rely on farming as their primary occupation (A2). On average, farmers have accumulated 30 years of experience in the field (A3).

Soil characteristics play a crucial role in shaping agricultural decisions. The specificity of soil types influences crop selection and farming practices, as certain crops are better suited to the Laghouat LL region's high-calcareous and sandy soils (A8). Traditional agroecological practices, such spreading manure as natural fertilizer and using prickly pear cactus (*Opuntia spp.*) to combat erosion, coexist with conventional practices. Despite limited access to modern agriculture and intensive mechanization, soil degradation is increasing in the LL region of Laghouat (due to the cultivation of water-intensive fodder crops and excessive extraction of groundwater for irrigation) on calcareous soils that are already poor in nutrients (A9). Another traditional agroecological practice in the LL of Laghouat is the implementation of three-level cropping system. This system consists of: 1) date palms forming the upper canopy, 2) fruit trees such as figs or olives occupying the intermediate layer, and 3) fodder or vegetable crops planted at the ground level. This multi-layered agroecosystem creates a micro-climatic environment that enhances resource use efficiency, promotes biodiversity, and contributes to the resilience of the farming system (A9).

Farmers in the LL of Laghouat demonstrate a high level of mutual trust and maintain trust-based relationships with certain organizations, as well as with informal digital platforms such as the internet and social media, which they frequently consult for technical guidance and problem-solving on their farms (A6). In addition to peer-to-peer knowledge sharing, the presence of farmers' leaders and centralized actors, notably the El Argoub farmers' association, plays an essential role in facilitating the exchange of knowledge and collective action. This association is widely recognized by farmers as one of the most reliable and influential sources of advice offering guidance on a range of topics including the use of agricultural inputs, palm dates, cultivation practices and technical production itineraries (A5).

The strength and adaptability of potential agroecological governance in the LL of Laghouat lie in the synergistic interactions between diverse actors and institutional frameworks that support both formal and informal governance mechanisms. Formal bodies such as the Directorates of Agricultural Services play a critical role in capacity building by offering technical training and guidance in response to farmers' evolving needs. These organizations also contribute to technological diffusion, as demonstrated by the adoption of drip irrigation systems facilitated by financial support and incentives. Furthermore, initiatives like the promotion and preservation of local palm tree varieties, represent institutional efforts to safeguard agrobiodiversity and sustain culturally embedded practices.

Farmers' associations are central to the informal governance landscape. They actively translate technical knowledge into relevant local practices and act as platforms for the intergenerational transfer of knowledge, bringing together older and younger farmers to ensure the continuity of traditional agricultural knowledge. Additionally, the use of digital tools (e.g., social media and online platforms) enhances both vertical and horizontal connectivity, allowing farmers to access new information, share experiences, and engage with experts and peers across geographic boundaries. All of the aforementioned formal and informal interactions are essential not only for the adaptation of agroecological practices in a climate-vulnerable context, but they also contribute to strengthen trust and legitimacy within the governance framework.

Since the Independence, Algeria has implemented a series of land use policies that can be broadly categorized into two major phases, as outlined by Colin et al., (2021); socialist land use initiatives followed by liberal land use reforms (S3). The first phase began with the nationalization of formerly colonized agricultural lands, culminating in the launch of the Agrarian Revolution in 1971 (Daoudi and Colin, 2016). During that period, tribal lands, ownerless lands, and rangelands were converted into state property and placed under the management of Agricultural Cooperatives for Rural Actions (ACRA) which were supported with significant technical assistance (Daoudi and Colin, 2016). However the initiative proved largely unsuccessful and some lands were eventually returned to private owners (Daoudi and Colin, 2016).

The second phase, beginning in the 1980s, marked a shift toward liberalization, during which state-owned lands were progressively opened to privatization (Colin et al., 2021; Daoudi and Colin, 2016). This transition culminated in the establishment of EAC (Exploitations Agricoles Collectives) and EAI (Exploitations Agricoles Individuelles). Under these mechanisms, collective or individual farms were granted perpetual use rights, while land ownership remained with the state. These reforms reflect a broader trend of transitioning from centralized state control toward greater privatization and decentralization of land governance in Algeria. Under the EAC (Exploitations Agricoles Collectives) model, the law required that members of each collective farm jointly and directly work the land. These initiatives were primarily aimed at veterans, unemployed and other social groups providing them with a means of livelihood through agricultural production (Daoudi and Colin, 2016). In 1983, Algeria introduced another mechanism to facilitate access to land and promote agricultural expansion, particularly in the Sahara and steppe regions: the AFPA (Accès à la propriété foncière agricole par la mise en Valeur) or access to land ownership through land development (Daoudi and Colin, 2016; Moulai and Bouammar, 2020). By the 2000s, the AFPA program was transformed into a concession system, allowing private actors to access public lands through 40-year leases (Daoudi and Colin, 2016; Moulai and Bouammar, 2020).

All LL farmers own the private land on which their farms are located. Additionally, 11 % of farmers benefit from land concession. These concessions are allocated by local administrative authorities through a formal selection process. Following allocation, the government provides technical support and monitors farm activities to ensure compliance and productivity. As one local actor described the process: "When the government allocates the land, they install the power line, give the permission to dig a hole for water, and access the road. And these are followed by a list of strategic required elements. They tell you what to do according to the nature of your soil. If it's a good soil, organic soil, they'll ask you to have wheat. If it's a rocky soil like here (referring to his farm in Laghouat) they'll ask you to cultivate trees like figs, etc."

Although the concession policy is supported by a strong theorical

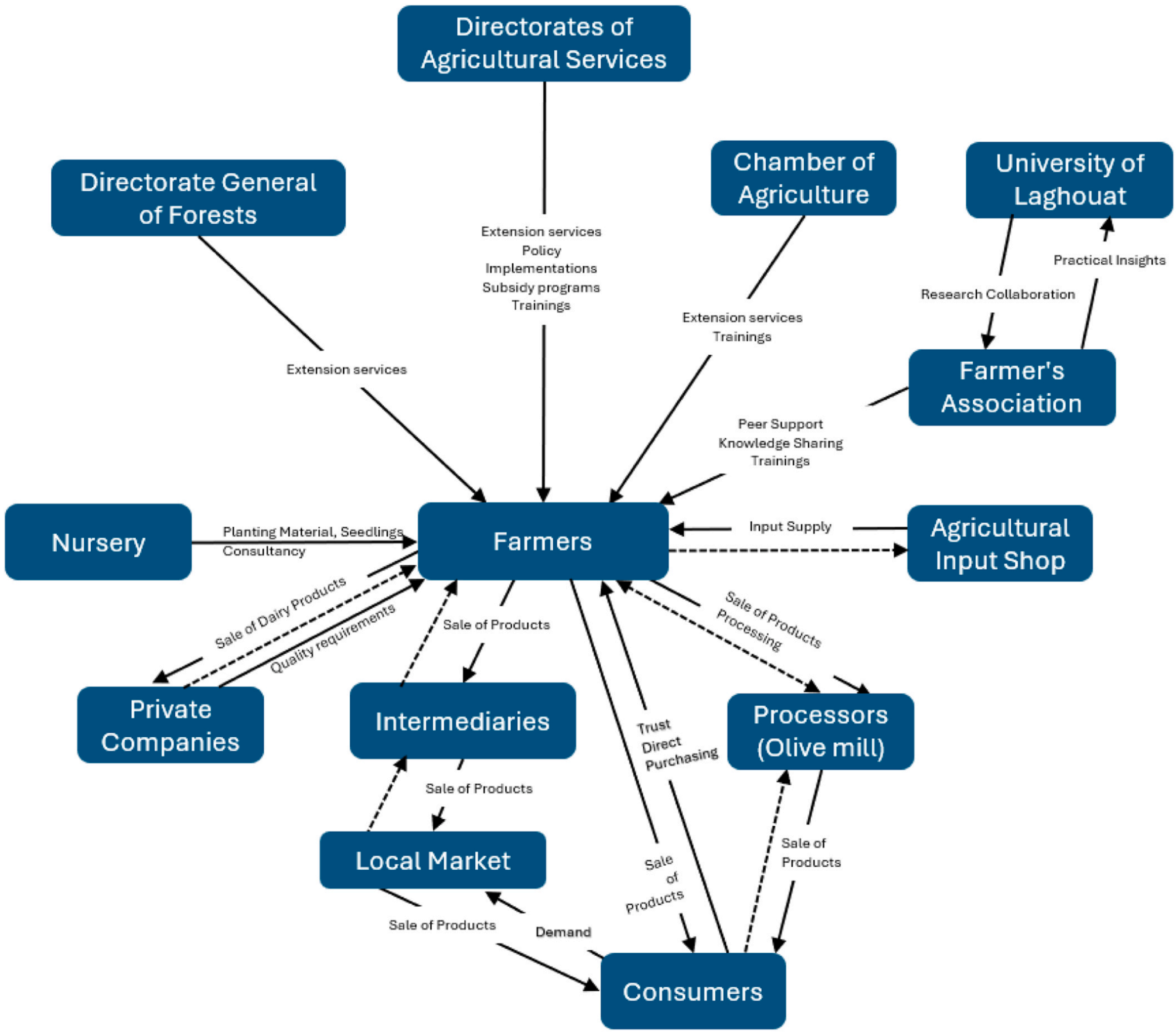

Fig. 4. Social Diagram of the Agriculture of Living Lab of Laghouat (Dashed lines stand for the "Payments").

framework, its implementation in practice has shown significant limitations. In many cases, concession lands are not consistently monitored by the state, leading to irregularities and unintended consequences. For example, it has been reported that some concession lands are abandoned by farmers, resulting in underutilized agricultural potential (Moulai and Bouammar, 2020). According to Moulai and Bouammar (2020), the main causes of such abandonments include ineffective candidate selection, poor enforcement of zoning regulations by local authorities, and the overexploitation of water resources which has led to declining water tables and a lack of reliable irrigation sources. Although it has not yet been reported in Laghouat LL, Daoudi and Colin, (2016) note additional challenges associated with land concessions. These include informal land markets, where concession lands are sometimes subject to unregulated leasing and sales and land conflicts with local tribes in areas opened up for agricultural expansion. As described by one local actor: "If farmers ask for a piece of land, they do the paperwork and the government gives the piece of land. The conflict starts when there is a tribe's land meeting with the government land.". Furthermore, they elaborate: "In Algeria, we have an issue which is a little complicated because we have tribe lands. And you have government land and the private land of people, individuals. This makes the situation really complex. Sometimes you find a piece of land that people say it belongs to a tribe but nobody has got a property paper on that. But usually around the city everything is clear."

Algerian agricultural policies have increasingly prioritized achieving self-sufficiency in key staple crops, particularly milk, potato and wheat – essential components of the Algerian diet. To support this objective, the state provides subsidies for strategic crops, aiming to reduce dependency on imports by an estimated $2.5 billion until 2024 (Rabita and Justina, 2021). The rapid population growth both nationally and in the Living Lab and the commune of Laghouat – where the population grew by 304.6 % between 1977 and 2012 (Othmani Merabout, 2023) – has contributed to surging demand for products. In response, farmers are encouraged to cultivate cereals, local palm date varieties, and to engage in cattle production for milk to benefit from state subsidies. These subsidies also result in preferential consumer prices in the markets, making basic foodstuffs more affordable. In addition, olive cultivation was introduced in Laghouat in the early 2000s through the National Olive Oil Plan (PNO) (Vlontzos et al., 2025). This initiative, supported by the expansion of irrigation infrastructure, has enabled olive farming to become increasingly common across the Laghouat LL demonstrating strong adaptability to the region's arid climate. Despite these successful efforts to promote olive production, the local value chain remains underdeveloped. Most of the olives are sold either directly from farmers to consumers or, through the local market. Moreover, olive oil processing remains limited, as the commune is currently served by only one olive mill, which limits the scale and effectiveness of local value-adding.

Farmers in the LL of Laghouat primarily sell their produce – mainly vegetables and arboricultural products – to the local market, through intermediaries (S5). Olive oil is often sold directly to consumers, either through social media networks, or on-site at the olive mill (Vlontzos et al., 2025). Some livestock-oriented farmers enter into formal agreements with large private companies to whom they supply their entire milk production under contract. The value chains for dates and olive oil in Laghouat are characterized by short supply chains, relatively low production volumes, and strong local demand. Similarly, vegetables and most arboricultural products are sold locally via short chains enabling farmers to maintain direct or semi-direct links with consumers. In particular, large-scale livestock breeders have set up on-farm processing ateliers where they transform their own production into artisanal dairy products which are then sold to restaurants and hotels in the capital. However, a major constraint facing most farmers is the lack of cold storage facilities, which limits their ability to store products. Consequently, they are often compelled to sell their harvests immediately after production, affecting their ability to time the market or reduce post-harvest losses.

In Algeria there is currently no certification or labelling system for organic agriculture, or the promotion of local varieties (Hadjou et al., 2013). This absence of formal certification significantly limits the potential expansion of agricultural value chains into international markets as European and global standards for organic and origin-based labeling are not met. Nevertheless, at the local level, consumers in Laghouat city highly value locally produced goods even in the absence of formal certification. These products are perceived as healthy and of high-quality, largely due to the direct relationships between producers and consumers, and the transparency of production practices (Vlontzos et al., 2025). This phenomenon is typical of short supply chains where proximity, trust, and the visibility of farming practices often serve as an informal assurance of quality, fostering consumer loyalty (Cruz et al., 2021).

El Argoub farmer's association is an active and influential organization in the region. However, not all farmers are members of the association. This lack of adherence is not attributed to geographic or spatial constraints, but rather to individual behavioral attitudes or cultural factors. Some farmers cite time constraints due to demanding work schedules as a reason for non-participation. More significantly, there are cultural and historical influences that impact farmers' willingness to engage in collective structures. As noted in the *NATAE project deliverable, Synthesis Report on Agroecological Value Chains in North Africa*, Algeria's socialist legacy, marked by a centralized state control and administrative bureaucracy, has fostered a level of skepticism or reluctance toward collective action and organizational involvement. This historical context continues to inhibit grassroots collective initiatives (Vlontzos et al., 2025). The head of the farmers' association offers further insight into this situation, stating: "And there are some associations which only have a president and a chairman assistant who can sign the papers. It's like this in the other regions and everywhere. We are the only association to have a group of 20–25 farmers with a group of six, seven or ten people who are always there."

3.3. Action situations

In the peri-oasis environment of LL of Laghouat, a high intensity of natural resource utilization is observed despite the various environmental constraints and limitations of the RS (I1). The region is characterized by a rocky soil surface, which has a direct and significant impact on land use and patterns, constraining the types of agricultural activities that can be undertaken. In areas where no initial investment is made, the rocky terrain primarily supports tree-based agriculture systems such as the cultivation of palm, olive trees and figs (I1). According to local actors and farmers, the rocky conditions severely restrict crop diversity, as most tree crops are selected for their resilience to these conditions. However, where farmers are able to invest in land improvement – specifically, clearing rocks from the surface – this enables the cultivation of cereals and market garden crops, which would otherwise be unfeasible. Farmers reported that such investments are typically made before initiating any agricultural activity (I5), although they are incurred with substantial financial costs. Following this initial land development, there is still a pressing need to enhance soil fertility as soils in the region are characterized by low nutrient and organic matter content. In response, many farmers resort to using manure as soil amendment, both because chemical fertilizers are often unaffordable and because manure serves as a cost-effective alternative that is more accessible under local conditions. However, the preference for manure with initial investment does not preclude the use of synthetic fertilizers in subsequent production stages. In practice, farmers apply both inputs, combining them in a hybrid strategy aimed at increasing short-term yields.

Another long- established agroecological practice employed to improve soil quality and enhance crop yields is the collection and application of nutrient-rich alluvial soils from the riverbed to the farms. The river that runs through the region flows intermittently, usually for only a few days after rainfall, after which it dries up and helps recharge the underlying aquifer. During these brief flow periods, the river transports fine sediments enriched with organic matter and nutrients, which settle along the riverbed. Once the riverbed has dried, farmers collect this fertile alluvial soil either through direct collection efforts or by purchasing it from nurseries, middlemen, or soil suppliers. The alluvial soil is then transported to their farms and applied to fields or tree basins, serving as a natural amendment to improve soil fertility, structure, and water retention capacity. As one local actor mentions: "What we call vegetal soil, that means good soil mixed up with clay, is of course less expensive than the organic manure" and they mention the benefits of this soil as "you enrich your own soil, the roots will go very deep very clearly, irrigation will be more helpful, it will reduce the water infiltration; you have such different things that you can benefit of"

For certain strategic crops – notably cereals such as wheat, barley, and corn – the Algerian government provides subsidies to help offset input costs including seeds and chemical fertilizers. This financial support enables farmers to access agricultural inputs at reduced prices through state-supported programs, and also offers market stability by guaranteeing the purchase of these crops by public agencies at fixed rates. In addition to cereal support, targeted subsidies are allocated for specific agroecological goals, such as the preservation of local palm date varieties or the implementation of drip irrigation now widely adopted across orchards and tree plantations, replacing the previously dominant submersion irrigation method.

The government provides training programs tailored to farmers, offering guidance on the cultivation of various crops and associated agricultural practices. These programs are crop-specific, delivering targeted information and technical support aligned with the production systems and needs of each farmer (I2). As the local actor describes "training is organized according to the demand of the farmers or according to the State program. For example, this year we have arboriculture plantations that will soon begin, and we will do training in arboriculture, shepherding, and maintenance, with the Institute of Forestry. If there is also a demand from farmers on any subject, we program and organize the training". A farmer who participated to one of these trainings gave his opinion: "Directorates of agriculture services and agricultural chamber sometimes organize trainings. Personally, I have been participating several times. I was there for breeding trainings. These trainings are for one-two days. It was good. We exchange the different experiences with other farmers, we exchange. It's good that there are a lot of farmers, so I could exchange a lot with other farmers."

In addition to government programs, the farmers' association also organizes training sessions and meetings focused on environmentally friendly solutions such as pest management, manure and compost use and yield improvement. These events also support intergenerational transfer, preserving traditional practices by connecting older and younger farmers (I7).

The interactions across variables in the SES, highlight key dynamics and outcomes as illustrated in Fig. 5. First, the interaction between actors (A) and the governance system (GS) underscores how education, training, and knowledge-sharing initiatives enable the adoption of improved agricultural practices. Second, the interaction between the governance system (GS) and the resource system (RS) reveals how state-led incentives (e.g., subsidies) and local market demand influence strategic decisions like crop selection, often pushing farmers toward higher-input activities such as corn cultivation or dairy farming. Lastly, the interaction among actors (A) reflects the high value of social capital in the dissemination of information and decision-making. Trust in farmer leaders and the farmers' association, as well as peer-to-peer knowledge sharing are key drivers of innovation and problem-solving processes within the farming community.

Understanding how local populations perceive and relate to their natural environment is crucial for designing effective transition strategies. In LL of Laghouat, most residents regard the natural environment as a fragile ecosystem, marked by increasing soil degradation and unpredictable rainfall patterns (see Fig. 6). This shared perception of environmental fragility – rooted in lived experience and local knowledge – can serve as a powerful catalyst for change. When this collective awareness is coupled with institutional frameworks that respond to local ecological needs and provide accessible resources, it can drive meaningful transformations within the agricultural system (A9, GS3).

To sum up, the action situations observed in LL of Laghouat reflect a dynamic interplay between physical and climatic constraints, traditional knowledge, and institutional support. Agricultural management practices –such as land investment to enable crop diversification, the use of organic fertilization to address soil limitations, and the adoption of drip irrigation technologies – illustrate how local communities continually negotiate with their natural environment.

4. Discussion

This study aims to explore the complex interactions among system components and understand how farmers adopt agroecological practices. Using the SESF, we conceptually model the system by focusing on soil and land management as the primary entry point, within the boundaries of the Laghouat peri-oasis living lab. A transdisciplinary approach is employed to assess and support the agroecological transition of farmers (Duru et al., 2015; Guiomarães et al., 2018). The research investigates the multifaceted factors influencing farmers' decision-making, considering the three pillars of sustainability – social, economic, and environmental. This framework enables the identification of key trends and context-specific dynamics, both current and emerging, that are essential for understanding and guiding the system transitions.

Improving soil health in complex agricultural systems requires comprehensive, systems-based approaches (Angst et al., 2023; Kibblewhite et al., 2007; Neuenkamp et al., 2024). Maintaining a healthy soil ecosystem does not rely solely on individual practices, as agricultural

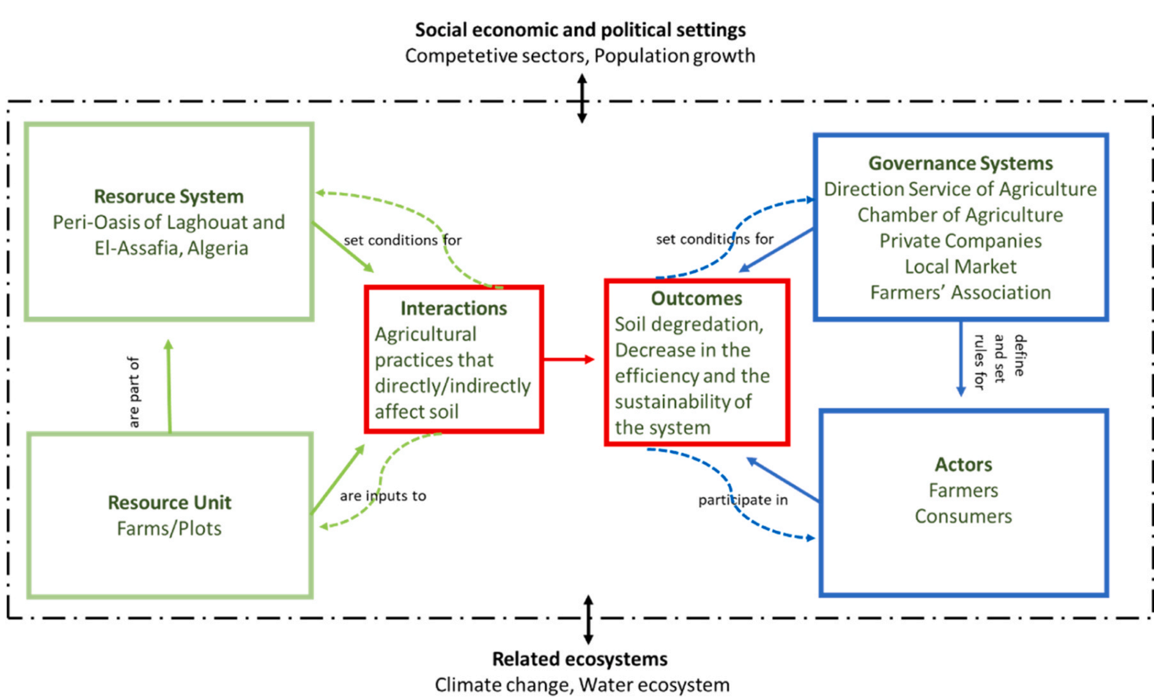

Fig. 5. Representation of the SESF with the details of the case study.

Fig. 6. Laghouat's Natural Environment According to Local Actors.

systems are inherently complex, and involve numerous biological, physical, and chemical interactions with both short- and long-term consequences (Davis et al., 2023; Mombrikotb et al., 2022; Turner and Kodali, 2020). In the LL of Laghouat, where traditional agriculture coexists with various agroecological practices, protecting soil health remains a significant challenge despite the presence of some individual agroecological practices. This situation results not only from harsh natural environmental conditions (arid climate, salinization, calcareous soil, intensive irrigation) but also from increasingly inappropriate agricultural practices. However, these inappropriate practices alone are not sufficient to explain soil degradation. Rather, it is the interaction between social dynamics and governance policies that collectively determines the trajectory of soil health (Amin et al., 2023; Hou et al., 2020). We address soil health issues by shifting our perspective to focus on the surface, examining the interactions between soil and society (Bouma and Montanarella, 2016). To achieve this, we examined a wide range of social and ecological system components to identify the key factors that hinder or encourage farmers, as direct managers of the soil, to adopt agroecology.

Our findings show that farmers in LL of Laghouat currently adopt a wide range of agroecological practices at the farm level that improves soil health. These include traditional methods such as multilevel agroforestry systems, use of "organic soil" from the riverbed, alongside state-promoted practices like drip irrigation and manure application – often driven by limited access to chemical inputs. Moreover, the use of organic soil sourced from the riverbed illustrates how economic constraints can serve as a catalyst for agroecological innovation to improve the soil health. These observations align with the findings of Boudedja et al., (2024), who noted that small family farms in Algeria tend to develop resilience strategies in response to resource limitations and insufficient advisory support.

Despite the existence of agroecological practices in the LL of Laghouat, our findings demonstrate that soil degradation remains a critical and unresolved issue that has not yet received sufficient attention. Although farmers have implemented practices such as wind erosion control and soil quality improvement, they have not been able to take action against serious problems such as soil salinity, high calcareous content, or erosion caused by heavy rainfall. Individual agroecological practices have not prevented soil health deterioration, which is linked to complex interdependent factors. are. For instance, the arid climate, and topography constraints such as difficult bedrock, excessive groundwater uses and excessive irrigation, when combined with other practices, accentuate soil degradation and exceed the capacity of current practices to improve soils. Furthermore, even if individual farmers take action and implement certain practices, the absence of collective, more policy-driven and coordinated practices reflects a lack of comprehensive action.

The observed social dynamics in LL of Laghouat reveal a general absence of active cooperatives or associations, with the notable exception of El Argoub. Farmers' limited engagement with such organizations is not attributable to the geographical isolation but rather to prevailing attitudes and a lack of interest, often stemming from the perception that these entities fail to provide meaningful technical or practical support. El Argoub, also modest in size and membership, plays a key role in addressing this gap. The association facilitates peer-to-peer knowledge exchange, supports the adoption of environmentally friendly practices, and serves as an important link between farmers and research institutions. Within this network, leader farmers – recognized for their expertise in specific domains – act as informal knowledge hubs, offering guidance and support to others facing challenges or considering new agricultural practices. The presence of such an association is crucial for the agroecological transition aimed at disseminating soil conservation practices, as it promotes collective action through peers' knowledge sharing - even at a small scale.

Strengthening collective action is essential for advancing the transition to agroecology (Cardona et al., 2021; Ruggieri et al., 2023). Expanding both the number and capacity of local farmers' associations can enhance peer-to-peer learning and facilitate the widespread adoption of agroecological practices (Lucas et al., 2019). These organizations also play a vital intermediary role, linking farmers with institutional actors and contributing to the formulation of policies that reflect local needs (Nimmo et al., 2023). As noted by David et al., (2022), a range of factors – including stakeholder interactions, individual beliefs, attitudes, and capabilities – shapes the effectiveness of agroecological transitions. In our study, social norms and community networks also emerged as critical drivers. Local social networks enable the exchange of information and practical knowledge, fostering trust and stimulating the collective action necessary for promoting and sustaining soil health by agroecological practices (Castella et al., 2022).

Governance in LL of Laghouat both enables and constrains the transition from conventional agriculture to agroecology. Certain policies – such as the promotion of drip irrigation systems and olive tree cultivation – have proven well adapted to the region's arid ecological conditions and have been widely adopted by farmers. Conversely, other state-supported initiatives, such as dairy farming, are poorly suited to the LL of Laghouat's fragile environment. These practices place additional pressure on already scarce water resources and exacerbate ecological vulnerabilities, particularly by encouraging the cultivation of water-intensive fodder crops that are not suitable for the environmental conditions. These policies ultimately accelerate soil degradation, leading to soil salinization and depletion of groundwater resources due to the intensive irrigation requirements of crops. As some farmers and other local actors have pointed out, a more effective measure would be to favor crop types that are ecologically suitable and adapted to local climate conditions, such as fruit trees like date palms or figs, in order to preserve the long-term health of soils and ecosystems. Although land concessions offer a theoretically sound opportunity for expanding agricultural activities, their practical implementation has fallen short. Reports of land abandonment suggest that promised state monitoring and technical support are not consistently delivered (Moulai and Bouammar, 2020). This misalignment reveals broader governance issues, including misaligned subsidy schemes, inadequate local institutional presence, and insufficient technical guidance, all of which hinder the broader adoption of agroecological practices. As Ostrom (2009) emphasizes, effective governance is a cornerstone for sustainable management of both natural resources and the SES that depend on them.

As documented in the literature, market forces have strongly influenced farmers' crop choices, while ecologically unsuitable agricultural policies have encouraged the adoption of unsustainable farming practices, leading to less sustainable agricultural systems in the province of Laghouat (Chao et al., 2024; Saad, 2024). At the local level, a successful transition to agroecology in order to restore soil health is easier to achieve when policies promote ecologically appropriate and resilient practices to both current and future climate conditions. In response to local experts' concerns about excessive water use and drought, regulatory mechanisms such as water use quotas or over-irrigation penalties could prevent water overuse and mitigate soil salinization. Moreover, the development of participatory certification schemes or regionally recognized labels could not only help consumers to differentiate agroecological products in the marketplace and farmers to better valorize their production, but also strengthen the existing trust between them. At the same time, market strategies must be designed carefully to avoid encouraging production intensification beyond ecological limits—thereby preserving the core principles of agroecology.

Consistent with findings in the broader literature, our study shows that farmer's adoption of more sustainable agricultural practices is shaped by a complex interplay of social, economic and ecological factors (Kanjanja et al., 2022; Nguyen-Thi-Kim et al., 2024). Among these, economic viability and profitability emerge as critical determinants in farmers' decision making processes (David et al., 2022; Kleftodimos et al., 2021; Owombo and Idumah, 2017). In the context of the Laghouat LL, our results highlight the important role of public subsidies and technical assistance in promoting the uptake of certain agroecological practices—most notably, the widespread adoption of drip irrigation.

Despite the application of a holistic and comprehensive approach through the SESF, several limitations of this study should be acknowledged. First, the research was conducted within a SESF to reflect social and ecological dynamics; however, at this stage this scope may not sufficiently assess the economic details of agriculture production which affects the farmers' decision. Second, while efforts were made to interview representatives from a diverse range of actors, the sample size for data collection remains relatively small. Third, the scarcity of existing literature specific to the study area posed challenges for both data collection and fieldwork design. Fourth, although the questionnaires gathered farmers' perceptions on various SESF indicators, they did not include questions on the potential impacts of agroecological practices on soil health, that could underestimate the contribution of agroecological practices to soil ecosystem services. Finally, the process of translating collected data may have led to a loss of nuanced meanings in the original responses, potentially affecting the depth of contextual interpretation during analysis.

Further research exploring the economic dimension of sustainability in greater depth would be valuable. This could involve the use of integrative tools such as bioeconomic models to simulate different scenarios and assess the viability and impact of agroecological practices (Andrieu et al., 2022; Komarek et al., 2020; Mkondiwa and Ngoma, 2024). Moreover, applying the SESF at broader scale could offer insights into how the system interactions differ across scales, thereby enhancing our understanding of transition mechanisms toward more sustainable agricultural production systems at multiple levels.

5. Conclusion

This study examines farmers' transition to agroecology in the LL of Laghouat using the SESF. Our findings show that farmers are currently implementing several agroecological practices to preserve soil health, including windbreaks to combat erosion, the application of "organic compost" from riverbeds, and drip irrigation. However, these agroecological practices have only limited success in improving soil health because they are applied in isolation in a context marked by stress factors such as the overexploitation of groundwater in the arid conditions of the Saharan oasis peripheries. Our results, obtained through the SES framework, indicate that limited interactions among actors beyond the El Argoub Association hinder collective soil management efforts. While governance policies enable adaptive elements through farmer training or subsidies for the preservation of local palm date varieties or the implementation of drip irrigation, which is widely adopted in orchards, subsidies for milk production exacerbate degradation by encouraging the cultivation of water-intensive fodder crops.

These concrete findings reveal the interaction between governance failures, social dynamics, and ecological pressures in the persistence of soil degradation despite farmers' limited efforts. They highlight the need for policy reforms and climate-resilient, ecologically balanced practices to achieve measurable soil restoration in arid peri-oasis systems. Future research should assess the results of the SESF, including economic modeling for applicable incentives, and encourage multi-actor collaboration to overcome these limitations and advance agroecology.

CRediT authorship contribution statement

Amélie Bourceret: Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Seyhan Sevde Cagiran:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Sophie Drogue:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Perplexity AI in order to improve the clarity and grammatical accuracy of the text. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Appendix A
First-tier and Second-tier variables of a social-ecological system. Source: Adapted from (McGinnis and Ostrom, 2014)

First-tier variable	Second-tier variables
Social, economic, and political settings (S)	S1 – Economic development
	S2 – Demographic trends
	S3 – Political stability
	S4 – Other governance systems
	S5 – Markets
	S6 – Media organizations
	S7 – Technology
Resource systems (RS)	**RS1 – Sector (e.g., water, forests, pasture, fish)**
	RS2 – Clarity of system boundaries
	RS3 – Size of resource system
	RS4 – Human-constructed facilities
	RS5 – Productivity of system
	RS6 – Equilibrium properties
	RS7 – Predictability of system dynamics
	RS8 – Storage characteristics
	RS9 – Location
Governance systems (GS)	**GS1 – Government organizations**
	GS2 – Nongovernment organizations
	GS3 – Network structure
	GS4 – Property-rights systems
	GS5 – Operational-choice rules
	GS6 – Collective-choice rules
	GS7 – Constitutional-choice rules
	GS8 – Monitoring and sanctioning rules
Resource units (RU)	RU1 – Resource unit mobility
	RU2 – Growth or replacement rate
	RU3 – Interaction among resource units
	RU4 – Economic value
	RU5 – Number of units
	RU6 – Distinctive characteristics
	RU7 – Spatial and temporal distribution
Actors (A)	**A1 – Number of relevant actors**
	A2 – Socioeconomic attributes
	A3 – History or past experiences
	A4 – Location
	A5 – Leadership/entrepreneurship
	A6 – Norms (trust-reciprocity)/social capital
	A7 – Knowledge of SES/mental models
	A8 – Importance of resource (dependence)
	A9 – Technologies available
Action situations: Interactions (I) → Outcomes (O)	**I1 – Harvesting**
	I2 – Information sharing
	I3 – Deliberation processes
	I4 – Conflicts
	I5 – Investment activities
	I6 – Lobbying activities
	I7 – Self-organizing activities
	I8 – Networking activities
	I9 – Monitoring activities
	I10 – Evaluative activities
	O1 – Social performance measures (e.g., efficiency, equity, accountability, sustainability)
	O2 – Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability)
	O3 – Externalities to other SESs
Related ecosystems (ECO)	**ECO1 – Climate patterns**
	ECO2 – Pollution patterns
	ECO3 – Flows into and out of focal SES

The second-tier variables selected for this study are highlighted in bold.

Appendix B. – Questionnaires

SESF Survey for Farmers

Date: Age: Gender: Years of Experience:

RS4 – Human-constructed facilities (Types of facilities constructed for agricultural production)

1. Do you have a well on your farm?
2. Do you have a reservoir on your farm?
3. What type of irrigation system do you use on your farm?

RS7 – Predictability of system dynamics (Types of environmental circumstance)

4. Have you ever experienced soil erosion on your farm (caused by water or wind)?

5. How did this soil erosion affect your land, and how frequently has it occurred over the past years?

A3 – History or past experiences (Number of years of experience, Number of years of experience in the region)

6. How long have you been engaged in agricultural activities on your current farm?

7. Has the land you are currently farming been used for agriculture before or did you start farming activities here for the first time?

8. If you are farming in a different place than before, what is the reason why you no longer use the farm/land for agricultural activities?

9. Would you like to farm on a different plot in the future, rather than the current one? If so, why?

10. Would you like to expand your farm by adding more land in the future? If so, why?

A6 – Norms (trust-reciprocity)/social capital (Strength of trust within farmers; Strength of trust within organizations) and A5 – Leadership/entrepreneurship (Existence of leader farmers, Existence of leader organizations)

11. Suppose you wanted to make a change in your production system. Who would you ask for advice?

(Please identify each person with a code/anonymized identifier, and provide the following information for up to 5 people/organizations:)

#	Identify the person with a code (anonymized) / organization	Since when do you know them?	Profession	Type of link (family,friend, colleague,other)	Frequency of communication
1					
2					
3					
4					
5					

12. If you had technical problems on your farm or with your agricultural production, who would you ask for advice?

(Please identify each person with a code/anonymized identifier, and provide the following information for up to 5 people/organizations:)

#	Identify the person with a code (anonymized)	Since when do you know them?	Profession	Type of link (family, friend, colleague, other)	Frequency of communication
1					
2					
3					
4					
5					

A7 – Knowledge of SES / Mental Models (Knowledge of the impacts of agricultural practices on soil, Quality of knowledge, Type of knowledge)

13. If you had 100 units of X fertilizer and your current crop needs only 50 units, what do you do with the rest (e.g., stocking, sharing, using)? Why?

A8 – Importance of resource (Influence of soil on the agricultural activity)

14. What are the main characteristics of the soil on your farm (e.g., fertile, rocky, saline, alkaline, dry, clay, loam, sandy, etc.)?

15. Did the soil type influence your decision on your crop choices? How did it affect your decision?

I5 – Investment activities (Number /length of soil preparation activities)

16. Did you carry out any soil preparation activities when you acquired the land (such as clearing rocks from the surface)?

I7 – Self-organizing activities (Presence of self-organizing activities between farmers in the LL area, Type of self-organizing activities between the farmers in the LL area)

17. Do you share manure or other inputs with your neighbors?

18. Do you decide on your crops together with your neighbors?

19. Do you share any material with your neighbors?

20. Do you share or exchange ideas with your neighbors?

21. Do you meet with other farmers? If so, where? (E.g., cooperative, association, café, etc.)

22. What type of information do you share during these meetings?

23. For the last 5 decisions you made about implementing an agricultural practice on your farm, how many were influenced by these meetings? If not, where did the ideas come from?

I8 – Networking Activities (Type of network in the LL area between different actors)

Between farmers:

24. Are there any organizations that are only between farmers?

25. Do you participate in any of the organization activities between farmers? If so, which ones?

With other actors:

26. Do you interact with any of the following actors during any stage of your agricultural production: Agricultural Chamber, Cooperative, Association, Private Companies or other?

27. What kind of interaction do you have? (e.g. information sharing, advisory, selling production) What type of information do you share?

28. Do you sell your products to the private sector? If you have livestock, do you sell your milk production to the private sector?

29. For each actor you work with, please complete the following table.

(Please identify each person with a code/anonymized identifier, and provide the following information for up to 5 people/organizations:)

#	Identify the person with a code (anonymized) / organization	Role of the organization in your agricultural practices	What do you think about its performance (from 1 to 5, 1 being poor and 5 very good)					Did it encourage you to implement a new practice/ innovation in your farm?
			1	2	3	4	5	
1								
2								
3								
4								
5								

Other Questions

30. How would you describe the nature/ecosystem of Laghouat?
31. Have you ever heard about agroecology?
32. What is agroecology? What do you think about it or what are your ideas about it?
33. Do you use soil from the riverbed on your farm? (If yes, please answer the following question)
34. How do you obtain soil from the riverbed- do you collect it yourself, or do you get it from a nursery?
35. Could you briefly describe how often you use this practice and how you implement it on your farm?

SESF Survey for Experts

Date: Age: Gender: Years of Experience:

1. Could you tell us about your organization, role of your organization in Laghouat and your work there?
   S1 – Economic development (Growth in competitive sectors)
2. What sectors in Laghouat are competitive with agriculture?
   RS4 – Human-constructed facilities (Types of facilities constructed for agricultural production)
3. What human constructed facilities are present on farms in Laghouat (such as wells)?
   RS5 – Productivity of system (Soil efficiency)
4. How would you describe the soil characteristics and the efficiency of agricultural systems in Laghouat?
   RS6 – Equilibrium properties (Variation of soil health over the years)
5. How would you describe the trends in agriculture of Laghouat over the last years (types of crops, access to technology)?
   RS7 – Predictability of system dynamics (Types of environmental circumstance)
6. What types of environmental circumstances are experienced in Laghoaut? (e.g., drought, soil erosion, flooding)
7. How frequently does it occur?
8. How have these circumstances affected agriculture in it the region?
9. Do you have any methods to predict these circumstances (traditional, technological, etc.)? If yes, please specify?
   RU3 – Interaction among resource units (Existence of resource units connectivity in the ecosystem, Type of resource units connectivity in the ecosystem)
10. Are farms in Laghouat affected by the practices of other farms practices (e.g., nitrogen leaching, pollution of water resources etc.)?
11. If so, by which practices?
    RU4 – Economic value (Economic value of plots)
12. What is the price of 1 ha of land in Laghouat (in different locations, such as next to a river etc.)?
13. How did the price change over last years?
    RU6 – Distinctive characteristics (Different types of soils in the region)
14. What are the different types of soil in the region? How would you classify these soil types in terms of fertility?
15. Does farmers' crop choice depend on soil type? If so, how?
    GS1 – Government organizations (Number, type and objective of organizations related to agriculture, type of activities of these organizations)
16. What governmental organizations are involved in agriculture in Laghouat?
17. How many are there in total?
18. What are the objectives and activities of these organizations?
    GS2 – Nongovernment organizations (Number, type and objective of organizations related to agriculture, type of activities of these organizations)
19. What non-governmental organizations are involved in agriculture in Laghouat?
20. How many are there in total?
21. What are the objectives and activities of these organizations?
    A5 – Leadership/Entrepreneurship (Existance of leader farmers, Existance of leader organizations)
22. Are there any farmers in Laghouat who are recognized as leaders by other farmers?
23. In which areas or for what reasons are they recognized as leaders?
24. Are there any organizations recognized as leaders in Laghouat? In which areas are they recognised as leaders?
    A6 – Norms (trust-reciprocity) / Social capital (Strength of trust within farmers, Strength of trust within organizations)
25. How would you describe the level of trust among farmers and between farmers and organizations in Laghouat? (For example, in situations where they face an issue in on their farm or need advice)

A7 – Knowledge of SES / Mental models (Knowledge of the impacts of agricultural practices on soil, Quality of knowledge, Type of knowledge)

26. Do farmers have knowledge of the impacts of agricultural practices on ecology and soil? If yes what kind of knowledge do they have, and what is the source of this knowledge (traditional knowledge, trainings, peer knowledge)?

A8 – Importance of resource dependence (Influence of soil on the agricultural activity)

27. What factors that affect farmers' crop decisions in Laghouat?
28. Does soil type affect farmers' crop decisions? If so how? Could you give some examples?

A9 – Technologies available (Presence of agricultural technologies and agroecology)

29. Are there any agroecologycal practices that farmers are implementing in Laghouat? (e.g., drip irrigation, barbarian fig hedges, traditional agroforestry system, etc.)

I4 – Conflicts (Type of conflict regarding the soil)

30. What kind of land conflicts exist in the region, and between whom?

Other Questions

31. What are the main difficulties encountered in Laghouat's soils and other ecosystems?
32. What are the main challenges posed to Laghouat's soils by human interaction?
33. How would you describe the nature/ecosystem of Laghouat?

A3 – History or past experiences (Number of years of experience, Number of years of experience in the region)

34. How long have you been doing expertise?

SESF Survey for Soil Experts

Date: Age: Gender: Years of Experience:

1. Could you tell us about your organization, its role in Laghouat and your objectives and services?
2. What is the cost of soil analysis in your office?
3. How often do farmers request soil analysis, and why do they want to analyze the soil on their farm?
4. What type of fertilizers do farmers use on their farms?
5. What are the main nutrient deficiencies in the soils of Laghouat?

S1 – Economic development (Growth in competitive sectors)

6. What are the sectors in Laghouat compete with agriculture for land and resources?
7. Which sectors are shifting land use away from agriculture?
8. Does this land use shift involve high quality, productive soils being removed from agriculture?
9. How do these sectors affect soil quality in the region (e.g. pollution, compaction, contamination etc.)?

RS4 – Human-constructed facilities (Types of facilities constructed for agricultural production)

10. What human constructed facilities are present on farms in Laghouat (e.g., wells, irrigation systems)?

RS5 – Productivity of system (Soil efficiency)

11. What is the typical soil composition?
12. What is the general level of soil fertility?
13. What is the average water holding capacity of the soils?
14. How rich is the soil biodiversity, and what types of organisms are present?
15. What elements are dominant in the soil?

RS6 – Equilibrium properties (Variation of soil health over the years)

16. How has the soil composition changed over time?
17. How has soil fertility change over time?
18. How has water holding capacity changed over time?
19. How has soil biodiversity and the presence of different organisms changed over time?
20. How have the dominant soil elements changed over time?
21. Do you have historical and current soil analysis for the same plot? If so, how do the results compare in terms of significant differences or similarities?

RS7 – Predictability of system dynamics (Types of environmental circumstance)

22. Have you observed soil erosion in Laghouat? If so, what are the main causes (e.g., wind, water)?
23. How has soil erosion affected the soil of the region?
24. How has soil affected agriculture in the region?
25. How frequent has soil erosion occurred over the past years?
26. Are there any other environmental circumstances that affect the region (e.g., drought, flooding, salinization)?
27. Do you use any methods to predict these circumstances (traditional, technological etc.)? If yes specify?

RU3 – Interaction among resource units (Existence of units' connectivity in the ecosystem, Type of units' connectivity in the ecosystem)

28. Are farms in Laghouat affected by the practices of neighbor farms?
29. By which specific practices (e.g., overuse of fertilizers, water extraction etc.)?
30. How do these practices affect soil properties (e.g., nitrogen leaching, salinity etc.)?

RU4 – Economic value (Economic value of plots)

31. What is the price of 1 ha of with good, normal, poor-quality soil in Laghouat (in different locations, such as near river etc.)?
32. Where are the areas with good, normal, poor-quality soils located in Laghouat?
33. How has the of agricultural land price change over the past years?

RU6 – Distinctive characteristics (Different types of soils in the region)

34. What are the main soil types in the region?
35. Which soil type is the most common in agricultural lands?
36. What is the soil typical soil structure?
37. How do you classify these soil types in terms of fertility?
38. Do farmers' crop choices depend on the soil type? If so, how?

GS1 – Government organizations (Number, type and objective of organizations related to agriculture, type of activities of these organizations)

39. What are the governmental agriculture organizations in Laghouat that focus on soil?
40. How many such organizations are there in total?
41. What are their objectives and activities?
42. What specific activities do they have regarding soil management?

GS2 – Nongovernment organizations (Number, type and objective of organizations related to agriculture, type of activities of these organizations)

43. What non-governmental agriculture organizations operate in Laghouat?
44. How many such organizations are there in total?
45. What are their objectives and activities?

A3 – History or past experiences (Number of years of experience, Number of years of experience in the region)

46. How long have you been doing expertise?

A5 – Leadership/entrepreneurship (Existence of leader farmers, Existence of leader organizations)

47. Are there any farmers in Laghouat who recognized as leaders by other farmers?
48. In which areas are they recognized as leaders?
49. Are there any organizations recognized as leaders in Laghouat? In which areas are they recognized as leaders?

A6 – Norms (trust-reciprocity)/social capital (Strength of trust within farmers, Strength of trust within organizations)

50. How would you describe the level of trust among farmers and between farmers and organizations in Laghouat (for example, when they face an issue on their farm or need advice)?

A7 – Knowledge of SES/mental models (Knowledge of the impacts of agricultural practices on soil, Quality of knowledge, Type of knowledge)

51. Do farmers have knowledge of the impacts of agricultural practices on soil or natural environment? If yes, what kind of knowledge they have?

A8 – Importance of resource dependence (Influence of soil on the agricultural activity)

52. Does soil type affect farmers' crop decisions? If so, how? Could you provide some examples?

A9 – Technologies available (Presence of agricultural technologies and agroecology)

53. Are there any agroecological soil management practices being implemented in Laghouat? (e.g. drip irrigation, barbarian fig hedges, traditional agroforestry system, etc.)

I4 – Conflicts (Type of conflict regarding the soil)

54. What kinds of land conflicts exist in the region, and between whom?

I5 – Investment activities (Number /length of soil preparation activities)

55. Do farmers carry out soil preparation activities when they acquire new land, before starting their agricultural activities, (such as removing rocks)? If so, how often and for how long these activities typically last?

Other Questions

56. What are the main natural challenges affecting soils in Laghouat?
57. What are the main challenges affecting soils in Laghouat that are caused by human activities?
58. How would you describe nature and ecosystem of Laghouat?

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