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Master of Science

Sustainable Agroecosystems and Resilience

Challenges, barriers, and determinants of farmers' adoption of agro-ecological practices in Tunisia: A case study of Hamam biadha and Elles, Tunisia

KHADER Amina
(Tunisia)

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KHADER Amina (Tunisia)

Challenges, barriers, and determinants of farmers' adoption of agro-ecological practices in Tunisia: A Case study of Hamam biadha and Elles Tunisia

Abstract

Agriculture in Tunisia is associated with unsustainable farm practices in an environment highly vulnerable to climate change, along with a general lack of political support. Agroecology is considered as a potential solution. Therefore, there is an urgent need for investigating Tunisian agricultural environment and farming practices. This study aims to assess the challenges and barriers and to identify the key determinants of farmers' adoption of agroecological practices in Hamam Biadha and Elles areas. Data were collected through interviews to 40 farmers and 16 key informants (KII's), and 2 focus group discussions (FGD's) targeting stakeholders. Based on the data processing, and their findings, a SWOT analysis was performed. Structured interviews, informed by surveys, delved into farmers' agricultural practices, barriers to adoption, and motivations for embracing agroecological techniques, while open and semi-structured interviews captured stakeholders' perspectives on benefits, barriers, and adoption influencers. In the empirical analysis, qualitative and quantitative approaches were used, including factor and bivariate analysis (i.e., Kendall's test). Farm typologies, predominantly mixed systems combining cereal-tree-small ruminant components, were identified. Most of the agroecological practices found were traditional: rotation accounted for the highest percentage (65%), followed by manure (35%), and lastly, biochar (3%). Results reveal that farmers are facing several barriers. Drought emerged as the primary barrier to the adoption of agroecological practices (100%), followed by resources access constraints (e.g. organic inputs and local seeds) (60%) and market-related factors, such as trails and roads (25%). Future initiatives should prioritize cooperative support to facilitate the transition toward agroecological practices, and bolstering food system resilience. The study concludes that the adoption of agroecological practices has economic, political, social, and institutional components. To enhance the adoption of such practices, empirical findings suggest the need for greater investment (capacity building, incentives, building farmer's organizations, etc.) to remove these barriers and institutional shortcomings. In addition, further research is required to understand farmers' needs, social dynamics, and perceptions, which are vital components for establishing better farmer organizations, considered as accelerators and facilitators for wider adoption of agroecological practices.

Keywords: *agroecological practices, agroecology transition, barriers, farmers' adoption, Tunisia*

KHADER Amina (Tunisie)

Défis, barrières et déterminants de l'adoption par les agriculteurs de pratiques agroécologiques en Tunisie : l'étude de cas de Hamam Biadha et Elles

Résumé

L'agriculture en Tunisie est associée à des pratiques agricoles non durables dans un environnement très vulnérable au changement climatique, ainsi qu'à un manque général de soutien politique. L'agroécologie est considérée comme une solution potentielle. Il est donc urgent d'étudier l'environnement agricole tunisien et les pratiques agricoles. Cette étude vise à évaluer les défis et les obstacles et à identifier les principaux déterminants de l'adoption par les agriculteurs de pratiques agroécologiques dans les régions de Hamam Biadha et d'Elles. Les données ont été collectées par le biais d'entretiens avec 40 agriculteurs et 16 informateurs clés (KII), et de deux groupes de discussion (FGD) ciblant les parties prenantes. Sur la base du traitement des données et de leurs résultats, une analyse SWOT a été réalisée. Les entretiens structurés, basés sur des enquêtes, ont permis d'approfondir les pratiques agricoles des agriculteurs, les obstacles à l'adoption et les motivations pour adopter des techniques agroécologiques, tandis que les entretiens ouverts et semi-structurés ont permis de recueillir les points de vue des parties prenantes sur les avantages, les obstacles et les facteurs influençant l'adoption. Dans l'analyse empirique, des approches qualitatives et quantitatives ont été utilisées, y compris des analyses factorielles et bivariées (c'est-à-dire le test de Kendall). Des typologies d'exploitations, principalement des systèmes mixtes associant céréales, arbres et petits ruminants, ont été identifiées. La plupart des pratiques agroécologiques recensées étaient traditionnelles : la rotation représentait le pourcentage le plus élevé (65 %), suivie par le fumier (35 %) et, enfin, par le biochar (3 %). Les résultats révèlent que les agriculteurs sont confrontés à plusieurs obstacles. La sécheresse est apparue comme le principal obstacle à l'adoption de pratiques agroécologiques (100 %), suivie par les contraintes d'accès aux ressources (par exemple les intrants biologiques et les semences locales) (60 %) et les facteurs liés au marché, tels que les pistes et les routes (25 %). Les initiatives futures devraient donner la priorité au soutien des coopératives pour faciliter la transition vers des pratiques agroécologiques et renforcer la résilience du système alimentaire. L'étude conclut que l'adoption de pratiques agroécologiques a des composantes économiques, politiques, sociales et institutionnelles. Pour favoriser l'adoption de ces pratiques, les résultats empiriques suggèrent la nécessité d'investir davantage (renforcement des capacités, incitations, création d'organisations d'agriculteurs, etc.) pour lever ces obstacles et combler les lacunes institutionnelles. En outre, des recherches supplémentaires sont nécessaires pour comprendre les besoins, la dynamique sociale et les perceptions des agriculteurs, des éléments essentiels pour établir de meilleures organisations d'agriculteurs, considérées comme des accélérateurs et des facilitateurs pour une adoption plus large des pratiques agroécologiques.

Mots-clés : *Pratiques agroécologiques, transition agroécologique, obstacles, adoption par les agriculteurs, Tunisie*

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Abbreviations

ATAE	Tunisian association for environmental agriculture
ATLAS	Tunisian Association for Leadership, Self-development and Solidarity
CIRAD	Center for international cooperation in agricultural research for development
CRDA	Regional Agricultural Development Commission
CSA	Community supported agriculture
CTAB	Technical Center for Organic Agriculture
DGACTA	The General Directorate of Planning and Conservation of agricultural lands
GDA	Agricultural development group
INAT	The National Agronomic Institute of Tunisia
INGREF	National Institute for Research in Rural Engineering, Water and Forests
INRAT	National Institute of Agronomic Research of Tunisia
MARHP	Ministry of Agriculture, Water Resources and Fisheries
SMSA	Mutual agricultural service society
OEP	Breeding and grazing office
ODESYPANO	North-West Sylvo-Pastoral Development Office
ODNO	North West Development Office

Introduction

Agriculture is confronted with substantial challenges, notably the imperative to ensure global food security (OCDE, 2013). The social, environmental and economic crisis the world is facing call for a profound change in the way we organize our food systems (FAO, 2018a). Moreover climate change makes this change essential, even urgent (CIDSE, 2018). Besides, the impacts of climate change on crop production are irreversible in the absence of large-scale adaptation methods, policies, and support measures (Ben nasr *et al.*, 2021).

That can challenge farmers more than ever to manage increasing complexity, adapt ecological and social production conditions, and reorganize their agricultural activities (Ghali *et al.*, 2022). An inventory of agroecology-related initiatives implemented in Tunisia since 1999 has been conducted. This inventory includes a total of 26 different initiatives (Lestrelin and Jaouadi, 2023), These changes prompt farmers to adopt technical improvements in their methods and, more broadly, to align themselves with society's standards for employing low-impact farming practices (Ghali *et al.*, 2022). This holistic approach sees itself as one of the main levers for achieving food sovereignty and climate justice, manifested in four dimensions of sustainability: environmental, socio-cultural, economic and political. These dimensions help to define the complexity and multidimensionality of agroecology. It will also be a step towards a better understanding of agricultural ecosystems and food systems (CIDSE, 2018).

The transition towards agroecology requires the involvement and coordination of various stakeholders, as well as the exploitation of Tunisia's territorial resources and genetic diversity. Research and actions are being conducted to develop agro ecological models that address local challenges, such as aridity and land tenure issues. In terms of livestock, Tunisia faces significant risks of vegetation and soil degradation due to the pressure from livestock. The Agrimonde-Terra scenarios include the hypothesis of conventional intensive livestock farming with imported resources, which leads to dependence on "virtual land" and competition with agricultural land (de Lattre-Gasquet *et al.*, 2017).

Nevertheless, the transition process remains challenging due to the obstacles and barriers outlined at the outset that can have significant effects on its progression. These difficulties can impede the adoption of sustainable farming practices, delay the realization of environmental benefits, and hinder the transformation of agricultural systems towards more ecologically conscious methods. In addition, they might lead to increased reliance on conventional and less environmentally friendly approaches, potentially undermining the goals of agroecology, such as improved soil health, biodiversity conservation, creation of knowledge and synergy (Lestrelin and Jaouadi, 2023).

In this regard, a literature will highlight the issue related to the drivers and barriers that influence farmers' perceptions and adoption of agroecological practices in the Tunisian living land-scapes (Ghali *et al.*, 2022) by using some tools to analyze to go beyond a description of the development of agroecology in the two regions. We uncover elements that support or hinder the agro ecological transition, as well as interactions between factors that produce vicious cycles, further impeding the spread of agroecology. The following section offers the theoretical foundation as well as some views on implementing these tools in the context of agroecology. Section 1 presents the methodology framework and the data collection tools. Section 2 presents the outcomes of the analysis data. Section 3 presents results and discussion that focuses on the efficacy of these techniques in increasing our understanding of agroecological transition and Section 4 includes conclusions and recommondations. This study is part of the agroecology initiative project and aims to provide an overview of agriculture in the Tunisian transect Siliana-El Kef, specifically focusing on the areas of Hamam Biadha and Elles while considering past influences. The study identified past and current driving forces and constraints that shape agriculture in the transect, as well as existing agroecological practices within production systems and opportunities for new practices. This comprehensive analysis served as a basis for exploring potential pathways towards an agroecological transition involving various stakeholders and considering potential combinations of agroecological practices. The study seeks to address the following research question:

What are the challenges and barriers of the adoption of agroecological practices?
What are the factors driving the use of agroecological practices by the farmers?
What factors influence farmers' decisions to adopt or dis-adopt agroecological practices in the Tunisian context?
What strategies can be developed to overcome the identified challenges and barriers to enhance the adoption of agro-ecological practices among farmers in Tunisia?

Following this work, we will be able to develop an action plan that aims to improve farmer's practices to better adapt to the external and internal factors and then try to propose economic, technical and institutional solutions to improve their capacity of adaptation. By addressing these critical components, we can pave the way for a successful and sustainable transition to agroecology.

Chapter 1. Literature Review

This chapter aim to provide a foundational understanding of agro ecology by covering key aspects such as definitions, principles, global perspectives, and a specific focus on the application of agro ecology in Tunisia. In doing so, it aims to set the stage for the subsequent exploration of agroecological concepts and practices.

1.1. Agroecology

1.1.1. Definition

Agro ecology is an applied science that utilizes ecological concepts and principles to build and manage sustainable agroecosystems (FAO, 2018a). It aims to minimize reliance on external inputs and instead focuses on natural processes like biological control and natural soil fertility. Agro ecology has gained attention globally over the past 20 years due to its potential to increase food production and improve the lives of the poorest (Chappell *et al.*, 2018). It is considered a reliable route to achieving sustainable development in the face of current and expected future climatic, energy, and economic conditions. The agro ecology is characterized by principles such as diversity, efficiency, natural regulation, synergies, and attention to the contributory roles of biotic and abiotic influences on ecological services and agroecosystem functions (Akanmu *et al.*, 2023).

1.1.2. Agroecology concepts

Agro ecology is an approach to food and agriculture systems that seeks to address the root causes of problems and provide holistic and long-term solutions. It aims to transform food systems by placing food producers, such as family farmers, indigenous peoples, fishers, rural women, and youth, at its heart. By combining scientific evidence with local wisdom and shortening the market chain, agro ecology can contribute to satisfying present and future food needs while ensuring that no one is left behind (Chappell *et al.*, 2018). Today's food and agricultural systems face major challenges such as deforestation, water scarcity, biodiversity loss, soil depletion, and high levels of greenhouse gas emissions. These challenges have been identified in the targets and goals of the 2030 Agenda for Sustainable Development. Agro ecology offers a way to address these challenges by promoting sustainable practices that enhance ecological and socio-economic resilience. It imitates natural ecosystems, supports the recycling of nutrients and biomass, and enhances resource-use efficiency, thereby reducing costs and negative environmental impacts (Gliessman, 2004). Agro ecology is a pathway for a sustainable livelihoods and inclusive food systems. It places a strong emphasis on human and social values, such as dignity, equity, inclusion, and justice. It seeks to address inequalities by creating opportunities for women and youth and values local food heritage and culture. By supporting healthy, diversified, and culturally appropriate diets, agroecology contributes to food security and nutrition while maintaining the health of ecosystems. It also promotes responsible governance, transparent and inclusive mechanisms, and equitable access to land and natural resources. It is not just a concept but a living practice that is gaining interest worldwide. Many successful agroecological approaches are being scaled up through the support of public policies, knowledge exchange networks, and the strengthening of rural institutions.

FAO, as a key partner, works with countries to develop policies and promote agro ecology. By fostering knowledge exchange, collaboration, and innovation, FAO aims to realize the full potential of agroecology and contribute to a better world. To promote agroecology, it is important to redirect agricultural policies towards sustainable approaches that consider the external costs and benefits of food systems. Plural market models that emphasize local and regional production and consumption can support diversified agroecological production. Public procurement programs can be used to promote agroecology and guarantee market access for agroecological products. Investments, credit, and insurance schemes can also support agroecological production and help overcome barriers faced by food producers. Additionally, strengthening research, education, and rural extension programs, as well as ensuring land tenure and access to natural resources, are crucial for the success of agroecology. Coordination and collaboration in policy and governance are essential to achieve coherence and integration among sectors, disciplines, and actors, and to create an enabling environment for agroecology (FAO, 2018a).

1.1.3. Agroecological principles

The various principles are allocated across the four sustainability dimensions: environmental, socio cultural, economic, and political (CIDSE, 2018).

1.1.3.1. The environmental dimension

Agroecology fosters favorable interaction, synergy, integration, and complementarity among the components of agricultural ecosystems (including plants, animals, trees, soil, water, etc.) and food systems, encompassing elements like water, renewable energy, and the dynamics arising from the reconfiguration of food chains. With this perspective, its objective is to establish and safeguard life in the soil, creating conditions conducive to plant cultivation. Through the optimization of natural processes, particularly the recycling of existing nutrients and biomass within agricultural and food systems, agroecology endeavors to sustain biodiversity both above and within the soil. This biodiversity spans various species, genetic resources, and locally adapted varieties/breeds, manifesting across different spatio-temporal scales such as plots, farms, and landscapes (Yadav *et al.*, 2021).Additionally, it endeavors to eradicate the reliance on external synthetic inputs, empowering farmers to combat diseases, pests, and weeds, while concurrently enhancing soil fertility through ecological processes. This holistic approach also champions adaptation and resilience in the face of climate change, simultaneously contributing to the mitigation of greenhouse gas emissions by advocating for judicious fossil fuel consumption and heightened carbon sequestration in the soil. In essence, agroecology assumes a comprehensive role as a solution that encourages sustainable agricultural practices in symbiosis with ecosystems, effectively addressing challenges associated with climate change.

1.1.3.2. The social and cultural dimension

Agroecology, deeply grounded in the culture, identity, tradition, innovation, and knowledge of local communities, assumes a vital role in fostering a wholesome and diverse diet that aligns with seasonal variations and cultural norms. This approach necessitates a broad array of knowledge and expertise, fostering horizontal relationships, particularly among farmers, to facilitate the exchange of knowledge, skills, and innovations.

It promotes fair collaborations between farmers and researchers, fostering solidarity and discussions within diverse cultures, including between different ethnic groups sharing common values but adhering to distinct practices. It also advocates for inclusivity by honoring diversity among populations in terms of gender, race, sexual orientation, and religion. It generates opportunities for young people and women, concurrently supporting female leadership and gender equality (Bezner Kerr *et al.*, 2022).

Notably, agroecology distinguishes itself through its adaptable stance on certification, often circumventing the elevated costs associated with external certifications. Preferring trust-based producer-consumer relationships, it advocates for alternatives such as the Participatory Guarantee System (PGS) and Community Supported Agriculture (CSA). Ultimately, by safeguarding the spiritual and material connections of individuals and communities to the land and the environment, agroecology emerges as a holistic model, promoting a harmonious equilibrium between agricultural practices and cultural values (FAO, 2018a).

1.1.3.3. The economic dimension

Agroecology advocates for brief and equitable distribution networks, abandoning linear chains, and intricately establishes transparent relationships between producers and consumers, often unnoticed in the official economy. Its fundamental role centers on providing sustenance to farming families, thus contributing to the fortification of markets, local economies, and job creation. Rooted in a vision of a social and solidarity economy, agroecology promotes the broadening of agricultural income streams, providing farmers with increased financial autonomy. It enhances resilience by diversifying sources of production and subsistence, fosters independence from external inputs, and mitigates the risk of poor harvests through its diversified system. Moreover, this approach enhances the influence of local markets, empowering producers to vend their products at equitable prices and actively cater to local market demands. This strategy diminishes reliance on humanitarian and developmental aid, consequently nurturing community self-sufficiency through the advancement of sustainable and dignified livelihoods (Ploeg *et al.*, 2019).

1.1.3.4. The political dimension

Agroecology places a clear emphasis on addressing the needs and interests of small-scale producers, who play a pivotal role in supplying the majority of the world's food, while concurrently mitigating the dominance of large-scale industrial food and agricultural systems. Through the empowerment of food system actors with control over seeds, biodiversity, land and territories, water, knowledge, and common resources, it ensures a holistic approach to integrated resource management.

Serving as a transformative force, that holds the promise of recalibrating dynamics to

facilitate greater involvement of both producers and consumers in decision-making processes pertaining to food systems, accompanied by the introduction of novel governance structures. At its core, agroecology necessitates a suite of complementary public policies. The alignment of these policies in support of agroecology, coupled with the backing of political decision-makers and institutions, alongside strategic public investments, is imperative for enabling the full realization of agroecology's potential. Moreover, agroecology fosters the emergence of social structures tailored to decentralized governance and localized administration of food and agricultural systems.
By instigating self-organization and collective management across various levels, spanning from local to global contexts, encompassing entities like farmer organizations, consumers, research bodies, and academic institutions, agroecology champions an inclusive and participatory approach (Molina *et al.*, 2019).

1.1.4. Key elements of agroecology

The HLPE created a succinct list of thirteen agroecological principles after compiling and reformulating concepts from three major sources (Nicholls and Altieri, 2016; CIDSE, 2018; FAO, 2018a) These revolve around the three operational principles that support sustainable food systems: Enhancing resource use efficiency, developing resilience, and ensuring equity/social responsibility (Nicholls and Altieri, 2016; CIDSE, 2018; FAO, 2018a).

- Recycling: Prioritize local renewable resources and, where possible, close the nutrient and biomass resource cycles.
  Input reduction: Reduce or eliminate reliance on commercial inputs while increasing self-sufficiency.
- Soil health: Ensuring and improving soil health and function in order to encourage plant growth, particularly through organic matter management and increased soil biological activity.
- Animal health: The improvement of animals' health and well-being.
- Biodiversity: The preservation and expansion of species diversity, functional diversity, and genetic resources to preserve the total biodiversity of agro ecosystems over time and place at the field, farm, and landscape levels.
- Synergies: Encourage good ecological interactions, integration, and complementarity among agroecosystem components (animals, crops, trees, soil, and water).
- Economic diversification: Ensure that small farmers have greater financial freedom and can add value while meeting consumer demand.
- Co-creation of knowledge: Strengthen the co-creation and horizontal sharing of knowledge, including local and scientific innovation, in particular through farmer-to-farmer contacts.
- Social values and types of food: Create food systems that are based on the culture, identity, tradition, social equity and gender equality of local communities, and that guarantee a healthy, diversified diet adapted to the seasons and culture.
- Fairness: Ensuring dignified and sustainable livelihoods for all stakeholders in food systems, particularly small farmers, through fair trade, just working conditions, and equal treatment of intellectual property rights.

- Connectivity: Fostering proximity and trust between farmers and consumers by establishing fair and short distribution networks and reintegrating food systems into local economies.
- Governance of land and natural resources: Strengthen institutional structures to improve recognition and support for family farms, small-scale farmers and food producers who ensure sustainable management of natural and genetic resources.
- Participation: Encourage social organization and increased engagement of food producers and consumers in decision-making to promote decentralized governance and local adaptive management of agricultural and food systems.

These 13 elements are interlinked and interdependent, forming the foundation of agroecology and guiding the transition to sustainable food and agricultural systems.

1.1.5. Agroecology's Role in Advancing Sustainable Development Goals (SDGs)

Agroecology is a holistic approach that tackles the root causes of hunger, poverty, and inequality by facilitating and strengthening the contributions of family farmers, indigenous communities, fishers, rural women, and youth. Agroecology is vital for building sustainable food systems that are based on an integrated vision that includes social, economic and environmental dimensions to achieve food security and adequate nutrition for all. It promotes biodiversity. It provides ecosystem services and conserves the natural resources that agriculture critically relies upon. It builds climate resilience. Indeed, we are convinced that agroecology can be adapted to and be effective in various climates, local conditions, cultures, traditions, and production systems. It contributes to adaptation, it contributes to mitigation, and it also enables inclusive economic development, including new opportunities for employment and income that can be particularly attractive to unemployed youth in rural areas. It promotes knowledge exchange, leading to new ways of thinking, new ways of doing, and new ways of organizing in rural and urban areas alike. Agroecology, most of all, provides the opportunity to support the dialogue between knowledge holders and experts. It offers a transformative and inclusive pathway to realize the Sustainable Development Goals worldwide. In short, we need this systemic approach to address the systemic challenges we face (Akanmu *et al.*, 2023; FAO, 2018b).

1.2. Agroecology in Tunisia

In Tunisia, a lot of organizations are extremely active in promoting the agroecological model throughout the country. The Association for Sustainable Agriculture (APAD) and the Tunisian Association for Environmental Agriculture (ATAE) are one of these institutions (CGIAR, 2023; Dhifallah, 1970).The adoption of agroecological practices in Tunisia involves initiatives such as the identification and valorization of local species through a gene bank, partnerships with neighboring countries for gene exchange, and the establishment of local initiatives for seed production and exchange.

The government encourages these initiatives and redirects subsidies towards production and farms that restore soil fertility, use wastewater, combine agriculture and livestock, and provide employment opportunities for young people (de Lattre-Gasquet *et al.*, 2017).

- ***The state of agroecology in Tunisia: focusing on the Agroecological Living Landscape (ALL) in the northwest region***

According to Alary et al. (2023) the framework of this ALL is the "Agro ecology Initiative" that aim to implement actions that facilitate ecological transformation within ecosystems. The project focuses on the promotion and popularization of agro ecological practices with the overarching goal of ensuring food sovereignty.

- Location of the Agroecological Living Landscapes (ALL): The Tunisian ALL, known as the 'Tunisian transect El Kef-Siliana,' is located in the semi-arid zone of the northwest of Tunisia. It is characterized by a gradient of partnerships and agroecological technical packages, allowing testing of how fairness, connectivity, and participation influence agroecological transitions.
- Environmental Context: The topography, soil, and agricultural land use in the Tunisian Agroecological Living Landscapes (ALL) are influenced by soil erosion, the effects of climate change, and the impact of drought and water scarcity on agricultural yields.
- Economic Context: The key farming systems, major agricultural commodities, livestock, market information, agricultural financing, and supportive infrastructure exist within the Agroecological Living Landscapes (ALL).
- Social Context: The household structure, rural employment, poverty, community leadership, and migration are considered within the context of the Agroecological Living Landscapes (ALL).
- Political Context: It reviews national policies over the last 15 years, focusing on policies related to climate change adaptation, regional development, organic agriculture, water and soil conservation, and sustainable development.
- Current State of Agroecological Principles: The current state of agroecological principles in the Tunisian Agroecological Living Landscapes (ALL) is being implemented and monitored to facilitate the transition towards agroecological practices and sustainable agricultural systems.

1.3. Agroecological practices

1.3.1. Definition

Agroecological practices refer to agricultural methods and techniques that are designed to integrate ecological principles and processes into farming systems. These practices aim to enhance agricultural sustainability by promoting the efficient use of natural resources, reducing reliance on external inputs such as synthetic fertilizers and pesticides, and fostering ecological balance within agroecosystems (Wezel *et al.*, 2014).

According to the Context Assessment for Agroecology Transformation in the Tunisian Living Landscape many practices were identified as Agricultural Environmental (AE) practices, as detailed below (Alary *et al.*, 2023).

- Recycling: The focus is on enhancing the use and valorization of local renewable resources (nutrients and biomass) while respecting resource cycles. This involves exploring plant species and agronomic practices to produce food and feed nutrients, and recycling crop and tree residues through machines to create nutritive feed rations for animals.

- Input reduction: The principle aims to reduce the use of chemical inputs that negatively impact human, animal, and soil health, and to increase self-sufficiency and resilience by decreasing dependency on purchased inputs.
- Economic diversification: This principle addresses the diversification of economic activities at the farm and off-farm level to cover the multiple nature of domestic and agricultural expenses at short, medium, and long term.
- Co-creation of knowledge: The aim is to enhance and valorize traditional and scientific knowledge at the local level by improving horizontal exchanges, such as farmer-to-farmer exchanges, to support people living in harsh and uncertain environments.
- Soil health: Practices to improve organic matter management and soil biological activity to favor vegetation growth. This includes crop-livestock integration and diversification to enhance soil health through organic matter and soil conservation practices.
- Biodiversity: The use of multi-species in the crop, tree, and livestock systems and their association or integration at the plot/farm level to promote soil biodiversity.

These practices are being implemented and monitored in the Tunisian ALL to facilitate the transition towards agroecological practices and sustainable agricultural systems.

1.3.2 Concepts of agroecological practices

Agroecological practices are based on several key concepts that integrate ecological principles into agricultural systems. Some of these concepts include:

- Biodiversity: Agroecological practices emphasize the importance of biodiversity in agricultural landscapes. This includes promoting diverse crop rotations, intercropping, and the integration of natural habitats to support beneficial insects and other wildlife.
- Resource Efficiency: Agroecology focuses on optimizing the use of natural resources such as water, soil, and nutrients. Practices like drip irrigation, reduced tillage, and organic fertilization aim to enhance resource efficiency.
- Ecological Balance: These practices seek to maintain ecological balance within agroecosystems by minimizing the use of synthetic chemicals and promoting natural pest control through the conservation of beneficial organisms.
- Resilience: Agroecological systems are designed to be resilient in the face of environmental challenges such as climate change. Diversification of crops and landscapes, as well as the use of locally adapted cultivars, contribute to system resilience.
- Sustainability: The overarching goal of agroecological practices is to foster sustainable agricultural production that meets the needs of the present without compromising the ability of future generations to meet their own needs.

These concepts underpin the implementation of agroecological practices and guide the development of farming systems that are environmentally sound, economically viable, and socially responsible (Wezel *et al.*, 2014).

1.3.3. Mechanisms for Transitioning to Agro ecological Systems

Agroecology consists of a variety of mechanisms and strategies that aim to support sustainable agricultural practices that are also environmentally friendly. Some examples include restructuring agricultural systems in response to variability and pressure from society such as land reform, food sovereignty, and poverty reduction. For example, in successful agroecological systems, management is based on sustainability principles that prioritize increased production efficiency, enhanced resilience and risk reduction, biodiversity conservation, social justice, economic prosperity, use of renewable resources only and environmental protection.

Also emphasized within agroecology is food sovereignty which calls for universal access to safe adequate nutritious culturally appropriate food and energy as well as technical sovereignty for effectively dealing with rising input costs. Hence it employs transdisciplinary approach through diversification, poly-cropping, agroforestry and integrated farming systems while minimizing water use pollution enhancing farming system resilience. These systems are inclusive of indigenous knowledge; encourage community involvement; empower small scale farmers thus offering a holistic path way to address issues such as food security production/sustainability and livelihood improvements (Akanmu *et al.*, 2023).

1.4. Determinants and Factors Influencing Adoption of Agro-ecological Practices

There are several factors that influence farmers' adoption of agroecological practices. One determinant is the availability of technical knowledge and training. Farmers need to be adequately trained in agroecological techniques in order to understand and implement them effectively. Another determinant is the economic viability of agroecological practices. Farmers need to see the potential benefits and profitability of adopting these practices in order to be motivated to make the switch. This includes considerations such as improved soil quality, higher productivity, and enhanced resilience to climate change. The social and cultural context also plays a role in farmers' adoption of agro ecological practices. Farmers may be more likely to adopt these practices if they are supported by their communities and if there is a strong social movement advocating for sustainable agriculture and food sovereignty (Mekuria *et al.*, 2022).

Additionally, policy and institutional support are important determinants of farmers' adoption of agroecological practices. Governments and institutions need to create an enabling environment that promotes and supports the implementation of these practices. This includes reforms in policies, institutions, and research and development agendas

(Akanmu *et al.*, (2023); Polonio and Rahmani, (2021)).

Schoonhoven and Runhaar (2018) indicated that personal motivation and personal access to information and awareness of sustainable alternatives, knowledge and experience are primary factors that determine farmers' willingness to adopt agroecology. In addition, population-specific factors such as gender and age as well as personal and educational background may have an impact on the perceptions of agroecology.
To a lesser extent, partners, family, children, social networks, government vision, market demand, availability of knowledge, specific implementation skills have also been found to influence the decision to adopt agroecology. Trust among farmers, voluntary or supportive networks, reciprocal trust, knowledge sharing based on peer experiences, and local networks have been found to contribute to the willingness to adopt agroecological practices. Farmers who perceive that they will have more access to financial dimensions and an innovative context and who are better informed participate more in advisory committees and other policy-forming bodies and have various social networks affect the decision of other farmers to accept agroecology by influencing their motivations, access to information and other personal factors that lead to the adoption of agroecology.

Ability dimensions related to financial resources and the market, peer influence, farming techniques and research access are factors that lead to the farmer's capacity to adopt agroecological practices and hence, indirectly affect the willingness to adopt them. Legitimacy dimensions associated with contracts and legislation and social norms and cultural context and policy frameworks affect the degree to which farmers are encouraged to adopt agroecology in their farming and horticultural practices.

1.5. Case Studies

1.5.1. The case study in the Central-North region of Burkina Faso

The study revealed significant influences of three perception variables on the adoption and intensification of agroecological techniques, notably showing that perceiving agroecology as useful increased the likelihood of adoption and intensification by 0.24 at the 5% significance level, with a greater increase of 0.38 for non-adopters. Control variables like gender, marital status, experience in agroecology, and access to credit were considered. Moreover the study focused on the intensity of technology use, measured by the fraction of land using agroecological practices, employing the maximum likelihood method for estimation (Tankoano and Sawadogo, 2022).

1.5.2. Agroecological Practices Adoption in the Sudano-Sahelian Zone

The study conducted in the Sudano-Sahelian zone revealed a gradual shift from traditional millet-bean cultural practices to agroecological techniques, with approximately 60% of producers adopting methods like superficial plowing, stone-rows, zaï, and composting. These practices have resulted in increased crop yields and enhanced incomes for producers, particularly evident in the improved grain and straw yields of sorghum post-adoption. On the other hand, the key determinants facilitating the adoption of agroecological practices include enhanced yields, increased incomes, access to resources and training. Variables like training and access to agricultural equipment were positively associated with adoption, while illiteracy negatively impacted adoption rates. Challenges hindering adoption included the labor-intensive nature of combined work, lack of material and labor support, and inadequate training and retraining opportunities for stakeholders (Coulibaly *et al.*, 2019).

1.5.3. Agro ecological Practices Adoption in Rural Laos

The study's findings highlight that potential barriers to the adoption of agro-ecology primarily stem from socio-cultural and political factors, with institutional and physical factors also playing significant roles. It underscores the urgent need for social, cultural, governmental, and institutional changes to facilitate a sustainable transition towards agro-ecology in rural areas. Specifically focusing on the Thongmang organic farming group, the study notes a considerable increase in membership, now comprising 43 members, including 35 women and 13 youth volunteers. The group's success is attributed to effective management, evident in its well-structured organization and clear delineation of roles among members. Additionally, environmental factors such as the utilization of EM fertilizer, mulching practices, and integrated pest management were identified as crucial components of their approach (ALiSEA, 2018).

1.6. Challenges affecting the adoption of agroecological practices

1.6.1. Challenges in agriculture practices

In the context of agroecological practices adoption, there are several challenges that farmers face. These challenges can be categorized into two main factors: observable factors and unobservable factors. Observable factors include socioeconomic factors such as age, gender, education, literacy, experience, social capital, access to credit, and household size. On the other hand, unobservable factors include the perception of utility, risk, necessity, entourage, and coverage of needs that farmers associate with agro ecological practices (Tankoano and Sawadogo, 2022).

The challenges affecting the adoption of agroecological practices include inadequate policy and institutional support, lack of access to credit and markets, limited extension services, weak land tenure systems (Sinyangwe *et al.*, 2023). Additionally, factors such as limited access to water, shortages of money, climate change adaptation (Amoak *et al.*, 2022), land, and labor hinder the implementation and sustainability of agroecological practices in certain regions (Adedibu, 2023). Moreover, resistance to transitioning from conventional agricultural models, economic barriers, and issues related to technology transmission are significant challenges faced in the adoption of sustainable agricultural practices, including agroecology (Mekuria *et al.*, (2022); Sinaga *et al.*, (2022)). These challenges highlight the complex socio-economic, institutional, and environmental barriers that need to be addressed to promote the widespread adoption of agroecological practices in different agricultural settings.

1.6.1.1. Regional and local challenges

In this regard, these are some obstacles faced by farmers in adopting agroecological practices in the Tunisian transect of “Siliana-Al Kaf”: The Fodder Crops domain grapples with the detrimental effects of drought and the consequential unavailability of seeds, particularly the vital legume forage seeds, attributing these issues to the pervasive climate change. A mere dozen women are engaged in seed collection, further accentuating the scarcity of legume seeds.

Within the Breeding sphere, encompassing small ruminant and cattle breeding, the high cost of animal feed, coupled with overgrazing and the intrusion of spine cactus, presents significant challenges. Dust contamination, arising from the inadequacy of feeding resources and their elevated costs, poses additional obstacles. Limited grazing areas and the unwieldy nature of the grinder restrict its usage to only some members of the GDA (Groupement de Développement Agricole). Moreover, the breed 'Queue fine de l'ouest' is found to be non-milk producing, posing limitations.

In the Transformation sector, including cheese production and the crafting of artisanal food products like cereal-based items, eggs, spices, mint, garlic, and dried tomatoes, commercialization issues take center stage. Despite having the capacity to transform up to 500 liters, a mere 50 liters are being processed owing to the village's small size and the absence of market access beyond the region. Challenges arise from the perishable nature of milk and cheese, hampering storage, and the deficient cooling chain from farm to processing unit. Recognition and competition issues also compound the situation.

The Beekeeping initiative faces dire circumstances with the majority of hives perishing due to the drought conditions. This is attributed to the lack of bee plants, resulting in inadequate food for the bees.

Finally, the Poultry undertaking experiences significant disease outbreaks and elevated summer mortality rates due to an inability to identify diseases for timely and accurate treatment.
These multifaceted challenges and barriers collectively underscore the complex landscape of the ALL in the Tunisian Transect, necessitating comprehensive solutions and interventions (Alary *et al.*, 2023).

Chapter 2. Materials and methods

2.1 Research methods

2.1.1. Description of the study area

The study took place in Hamam biadha and Elles located in the 'Tunisian transect El Kef-Siliana' (figure2) in the semi-arid northwest of Tunisia (figure1) known as The Tunisian agroecological living landscape (ALL) which was identified as a priority zone by the national partners during the national inception workshop of the agro ecology (AE) initiative, and where the mixed cereal-tree-small ruminant systems predominated. Besides, the transect connects two governorates with rough terrain divided into mountain ranges, high and medium plateaus, and alluvial plains.

The Tunisian ALL is composed of four farmers' organizations (FOs): SMSA "Chouarnia", GDA "Sers", SMSA "El Rhahla" and SMSA "Kouzira") in the targeted zone which have been selected along a gradient of partnerships (with international, national, and local partners) and agroecological (AE) technical packages (Alary et al., 2023). The agroecology initiative project aims to integrate Hamam Biadha and Elles into the Tunisian ALL by fostering the development of other farmers' organizations.

Figure 1. Aerial view of Hammam biadha and Elles (Source: Adapted from Google Maps, (n.d.))

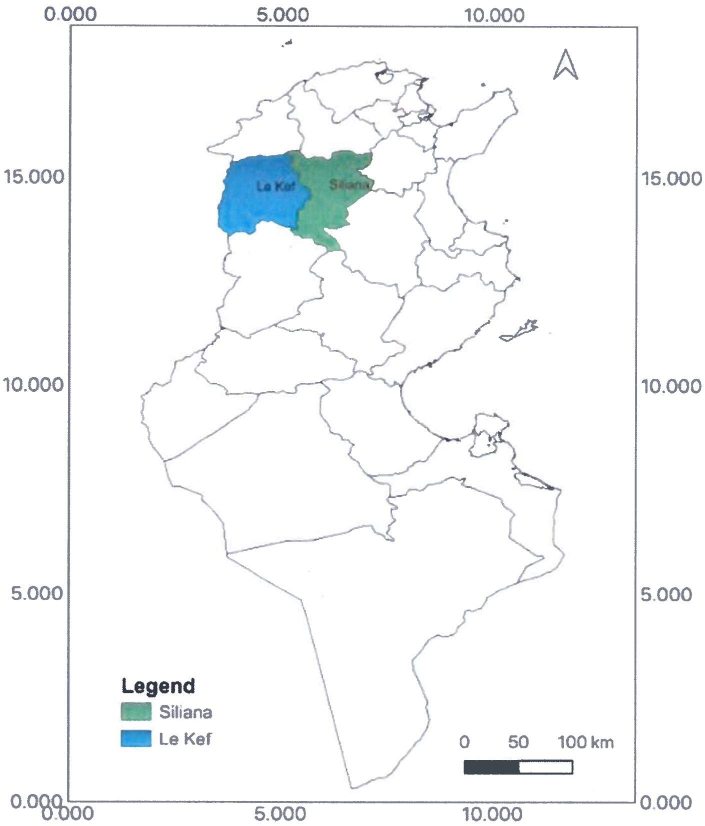


***Figure 2. The Tunisian Transect el Kef-Siliana localization in the Northwest of Tunisia (Source:* Alary *et al.*, 2023).**

***Figure 3. Localization of four FOs with three old ones (Where ICARDA is already engaged with national partners) and one new one (identified as potential new FO) (Source:* Alary *et al.*, 2023).**

The governorate of Siliana has a continental climate, with average annual rainfall ranging from 350 mm to 550 mm for the 2017-18 season. The lowest average temperatures in Siliana over the same season range from 3.2° to 13.0°, while the highest are recorded between 17.9° and 35.7°(ODNO, 2022). The climate stage in Siliana is highly contrasted due to precipitation and temperature variability, which is explained by the influence of relief. The steep massifs of the governorate's northern half are classified as semiarid, as are the mountainous sectors in the south. In between, the remaining governorates have an arid climate, which is more pronounced in the far south, where the lowest rainfall and greatest temperatures are recorded (ATLAS, 2013).

In the governorate of Kef, the average annual rainfall was between 350 mm and 450 mm during the 2017-2018 season. The lowest mean temperature recorded at Kef during the same season is 7.3° (January), and the highest is 26.5° (July) (ODNO, 2022).
This governorate is primarily classified as semi-arid in terms of bioclimate. However, some places in the governorate's southwest are in the desert bioclimatic stage, while others in the north are in the subhumid stage. Overall, the climate is continental, with cold and harsh winters and some of Tunisia's lowest minimum temperatures (ATLAS, 2013).

However, due to its geographical location in the northwest of Tunisia this “Tunisian transect el Kef-Siliana” was characterized by a diverse spectrum of agricultural production systems has thrived, showcasing the region's multifaceted agricultural landscape. Firstly, dry cereal-based systems have been prevalent, marked by a structured rotation of cereal crops. However, the integration of fodder crops has been relatively limited in these systems, with a primary focus on sheep rearing. Additionally, a modest number of dairy cows have been observed on household farms within this category.

Secondly, the agrosylvopastoral farms have taken center stage, characterized by their extensive management of sheep and goats. These farms derive their sustenance primarily from pastoral resources, showcasing a strong reliance on the area's natural grazing lands.

Lastly, in specific pockets of the region, irrigated systems have emerged, illustrating a fusion of market gardening and arboriculture. Despite this integration, these systems have not witnessed a significant intensification of crop rotation practices or the establishment of substantial dairy cow operations. Overall, these three distinct production systems collectively paint a vivid picture of the agricultural diversity and resource utilization patterns within the Kef-Siliana transect. In addition, the interplay of various value chains in agriculture forms a complex web, encompassing diverse sectors. One of these complex networks involves animal products, starting with the initial stages like seed multiplication and fodder production. This process encompasses the generation of raw materials from crops and tree residues, ultimately leading to the commercialization of dairy and meat products. This comprehensive system demonstrates the interdependence of the animal feed continuum. Moreover, the olive value chain integrates seamlessly with a range of agricultural activities, including livestock and grain production. This synergy illustrates the convergence of multiple agricultural activities in a coherent framework, where olive trees intertwine with animal husbandry and the cultivation of cereals.

Furthermore, the honey value chain presents a unique trajectory, starting with honey plants and leading to direct sales to consumers, often through short circuits. This journey highlights the direct link between natural resources and end consumers, highlighting the potential of localized distribution networks. Essentially, these value chains illustrate the complex relationships and interdependencies within agriculture, showcasing the various pathways from raw materials to final products in different sectors (Alary et al., 2023). Because of the efforts made by the State through the various programs and projects of agricultural development and improvement of the living conditions of the population (Table 1) across a considerable diversification beginning in the mid-2010s, there has been a concerted push to strengthen the value chains (Lestrelin and Jaouadi, 2023). These regions have known a deep mutation at the level of the production system and the way of life of the local population (Figure3).

Table 1. Initiatives in the Tunisia ALL (Source: Lestrelin and Jaouadi, 2023).

Name of initiative	Type of initiative	Project activities were conducted to address AE principle(s)?	Intervention logic
Prosol	Project	Reinforcement of adoption of soil and water conservation practices at local level	Innovations for farmers
PROFITS	Project	The development of agricultural and forestry sectors as a lever for the socioeconomic development of vulnerable areas, to strengthen and energize inclusive territorial development processes	Value chains
PACTE	Project	Territorial management of AE practices	Multi-stakeholders platforms
IAAA	Project	Innovations in the agriculture and agri-food sectors have contributed to sustainable rural development in some rural areas; scaling up, capitalization, anchoring and sustainability of promoted innovations	Value chains

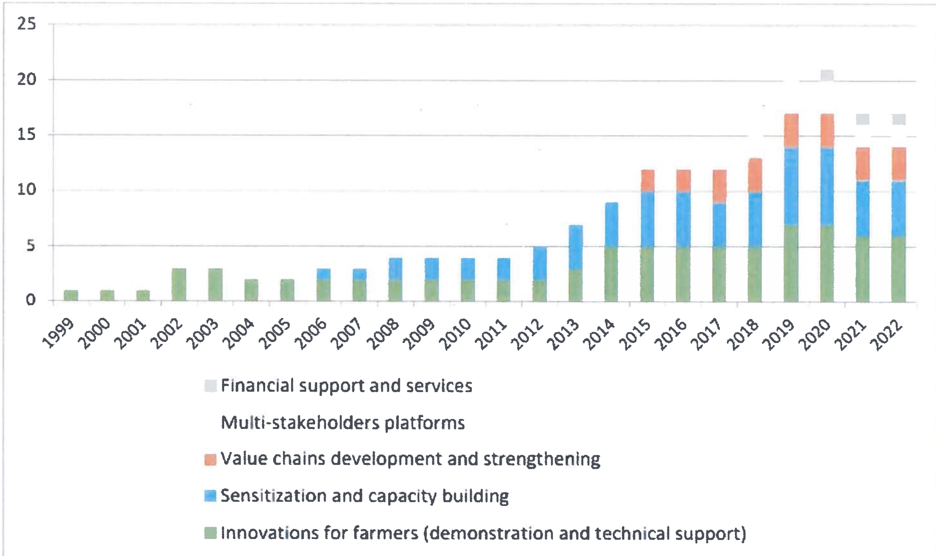


Figure 4. Number of active initiatives, per year and primary intervention domain (Source: Lestrelin and Jaouadi, 2023).

2.2 Research methodology

Methodological steps are categorized according to data collection, data processing and data analysis. The methodology adopted in this study involved a combination of qualitative and quantitative research techniques using: Focus group discussion, farmers surveys, key informant interview and SWOT analysis. Fieldwork was conducted in October, November and December 2023, January and February 2024. Interviews were performed with stakeholders and with farmers. Focus group discussion were carried out as open discussions or semi-structured discussions based on topics to address. A pilot survey was executed based on farm surveys developed beforehand and followed a structured setting. For the KII, the stakeholders were used to answer to five open questions and based on the findings from these three tools, the SWOT analysis is developed.

2.2.1 Choice of data:

The data used in this research was collected from farmers in the Northwestern region of Tunisia, within the framework of the implementation of a research and development project called "Agroecology initiative" at the ICARDA organization.

Various actors helped with data collection at the starting phase, such as the Directorate-General for the Development and Conservation of Agricultural Land (DG ACTA), the Regional Commissioner for Agricultural Development (CRDA Kef and Siliana), Agricultural Development Group (GDA), Mutual agricultural service company (SMSA), Farmers, the professional structures, Scientists and the Non-Governmental-Organizations.

Secondary data

To supplement our research, we harness a diverse array of sources. These sources will include but are not limited to official reports, scholarly articles, documentation from development projects, and other relevant data repositories. By drawing upon this comprehensive range of secondary sources, we aim to enrich our research and provide a better-rounded and substantiated analysis.

Primary data

To gather essential data, we can employ a variety of methodologies, including focus group discussions, key informant interviews, and questionnaires. Based on the outcomes of these methods, a SWOT analysis emerges as a pivotal tool in our data collection arsenal. These techniques play distinct yet complementary roles in our research, offering valuable insights and facilitating a comprehensive understanding of the subject matter. Let's delve into each of these methods and explore their purposes and target groups (Table 2).

Table 2. Data collection tools (Source: Author own elaboration).

Data collection tool	Target groups	Type of data (Qualitative/Quantitative)	Purpose	Expected output
Focus Group Discussion (FGD's)	Stakeholders	Qualitative	Exploring and gaining a deeper understanding of people's thoughts, perceptions, attitudes, opinions, and behaviors.	Current and future perceptions in the farming system/ Overview about the challenges and opportunities in the farming system
Surveys Questionnaires	Farmers	Quantitative	Gather a quantifiable information from a large number of respondents to perform statistical analyses	The survey questionnaires tool/ Data set/ Determinants/ barriers/challenges
Key Informant Interviews (KII's)	Researchers/ Developper/ scientists/ Head of farmers' associations	Qualitative	Gather ideas and insights that would inform the development of the questionnaire	Demographic Information/ Comparative Analysis / Narrative Summaries/Determinants factors/ barriers/ challenges
SWOT	Stakeholders / policymakers	Qualitative	To identify the internal and external factors (Strengths, Weaknesses, Opportunities and threats)	Strategies and initiatives to leverage strengths and opportunities, while mitigating weaknesses and threats.

2.2.2 Methodology outline

Our methodology consists of two main steps:

- The first step consists of harmonizing the Data collected
- The second step is Data analysis by applying methods under a set of approaches, concepts, and terms we already defined in the bibliography section. Three methods are applied depending on the four research questions' objectives.

Each question represents one or two sub-objectives and requires a specific database and analysis method. Figure 5 illustrates the study methodology within the conceptual framework.

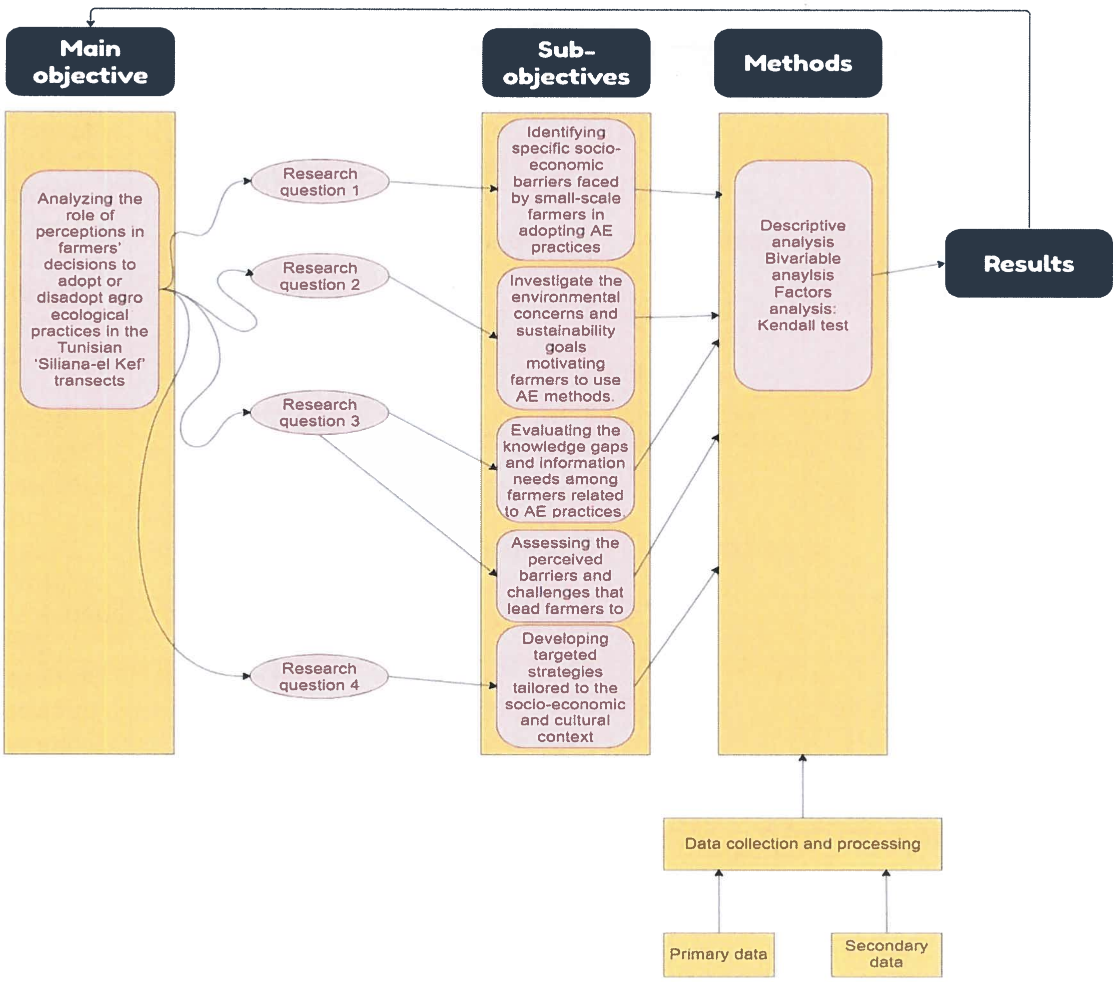


Figure 5. Research conceptual framework (Source: own elaboration).

2.3 Data collection methods

2.3.1 Focus group discussion

A focus group is a qualitative research method where a small group of people are brought together to discuss and share their opinions, attitudes, and experiences on a specific topic (Claude, 2019). In this regard, the FGD was made to explore and gain a deeper understanding of farmers' thoughts, perceptions, attitudes, opinions, and behaviors regarding the agroecology practices. This took place over two days during a workshop focused on work package 3, specifically addressing the olive oil business model was proposed to encourage the olive producers of SMSA to produce a labeled olive oil to improve their revenues, enhance livelihoods and create a system of values that includes land (terroir) and to facilitate the agroecological transition through potential value chains.

2.3.2 Farmers surveys

A survey was developed prior to structured interviews conducted with the farmers (Annex 1; Annex 2).

The aim was to characterize the farm systems based on their resources, identify agroecological practices, drivers and constraints of practices.

Agroecological practices were chosen based on studies conducted by Wezel et al. (2014) and Nicolétis *et al.*, (2019), as well as those commonly used in the Tunisian context within the framework of the agroecology initiative project (Alary *et al.*, 2023). The questions were formulated to assess the presence of such practices in the farms and identify potential new ones. The topics discussed covered the households' characteristics, crops and livestock types, familiarity with AE practices, barriers, motivations, limitations and their awareness towards these selected AE practices. The survey was tested in two trials among the ICARDA team prior to the start of the data collection. Farmers were reached via a contact person local to the areas or via the local authorities. Some farmers were encountered spontaneously via visits to the fields or based on a neighbour recommendation. In total, 40 farmers were interviewed based on the survey. The interviews followed a structured setting and duration varied between one hour to two hours. An intake preceded the interviews, clarifying the purpose of the survey along with the topics that would be covered. The answers were noted down during the meeting. Permission was asked for audio recordings when assessed as necessary and ethical concerns were clarified based on a consent form according to the data management policy of the agroecology initiative project. The interviews were transcribed digitally after each meeting. Answers providing data for the analysis were entered via SPSS statistical program.

This questionnaire was designed based on brainstorming sessions with the various team members of ICARDA (Annex1) It is structured in eight sections defined as follows:

Section 1: "Socio-demographic data".

This group describes the sociodemographic characteristics of the individuals interviewed (questions 1 to 10). The questions used are single-answer questions, to collect information on gender, socio-professional category, age, monthly income, etc.

Section 2: "agricultural production".

This group describes the occupation of the farmer, including their yield, personal consumption, sales, and whether the area is irrigated or rainfed.

Section 3: "Variety of olive tree".

Section 4: "Familiarity with AE practices".

Section 5: "The different AE practices".

The project has selected these agroecological (AE) practices based on studies that are widely utilized in the Tunisian context.

Section 6: "The barriers that hinder you from using AE practices".

This group exclusively comprises factors influencing acceptance, measured on a 5-point Likert scale to evaluate the significance of each barrier in influencing the adoption of agroecological practices.

Section 7: "Technology awareness and its assimilation"

Each question is assigned a code measured on a 5-point Likert scale ranging from 1

(Strongly agree) to 5 (Strongly disagree).
Section 8: "Motivations and limitations of adopting AE practices".

2.3.3 Key informant interview

To enhance the dataset, a questionnaire was crafted to interview 16 researchers (Table 3).

The aim was to collect insights on farmers' awareness and inclination toward adopting agroecological practices. The questionnaire delved into their perceptions of the benefits, identified barriers, and factors they believe influence adoption. Additionally, it probed into the presence or number of government aid and the potential impacts of agroecological practices in Tunisia across environmental, economic, and social dimensions. The questionnaire was administered partly through face-to-face interactions and partly via the "Google Forms" platform, which included 5 open-ended questions.

Table 3. Stakeholders met during the data collection (Source: Author own elaboration).

Participants	Stakeholder name	Organization/ Affiliation/ Institution
1	project coordinator	ksar jedid development association / National agronomic institute of tunis (INAT)
2	Economic researcher	FranceAgriMer
3	Researcher	Olive institute of Tunisia
4	Engineer	National agricultural research institute of tunis (INRAT)
5	Researcher	National agricultural research institute of tunis (INRAT)
6	Director	National Institute of Major Crops of Tunisia
7	Agriculture Innovation specialist	The International Center for Agricultural Research in the Dry Areas (ICARDA)
8	Researcher	The International Center for Agricultural Research in the Dry Areas (ICARDA)
9	Phd Student	The International Center for Agricultural Research in the Dry Areas (ICARDA)
10	Researcher	Centre de coopération internationale en recherche agronomique pour le développement (CIRAD)/ The International Center for Agricultural Research in the Dry Areas (ICARDA)
11	Postdoctorate	National agronomic institute of tunis (INAT)
12	Researcher	National agricultural research institute of tunis (INRAT)
13	Researcher/ National Coordinator for the CGIAR Agroecology Initiative project.	National agricultural research institute of tunis (INRAT)
14	Deputy Director of Training	Technical Center for Organic Agriculture (CTAB), Ministry of Agriculture, Water Resources, and Fisheries, Tunisia
15	Researcher	Institut national de recherché du génie rural, eaux et forêts (INGREF)
16	Engineer/ deputy director	Livestock and Pasture Office (OEP)

2.3.4 SWOT analysis

The SWOT analysis was carried out to identify internal and external factors (Strengths, Weaknesses, Opportunities, and Threats) relevant to the adoption and implementation of agroecological practices. Employing an interactive approach, the study undertook a thorough SWOT analysis concerning the transition to agroecology.This analytical process thoroughly explored various aspects of farmer engagement, encompassing their perceptions, experiences, skills, and overall awareness of agroecological practices, gathered from extensive focus group discussions. Additionally, the survey phase of the study played a pivotal role in the SWOT analysis, directly soliciting input from farmers. Participants rated their levels of agreement, satisfaction, and provided opinions using a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree).

The survey also included several dichotomous questions to obtain more nuanced insights. Moreover, outcomes from key informant interviews were integrated into the SWOT analysis, enhancing the overall assessment with valuable perspectives and real-world insights.

Chapter 3. Results and discussion

3.1. Descriptive analysis

3.1.1. Sociodemographic characteristics of the sample studied

SPSS was used to analyze means, frequencies and percentages of sociodemographic variables, and the results were graphically represented in Excel.

3.1.1.1. Age, gender, and education level

The average age of questionnaire respondents is 50 years old. Women's average age is about 39 years old, while men's average age is 53 years old. The sample studied comprises 85% men and 15% women, indicating a notable gender disparity in agricultural involvement (Figure 6). These outcomes are confirmed by Raney *et al.*, (2011) which show that despite the undeniable significance of women's roles in agriculture globally, their participation appears limited in the study area. Traditionally, men have been more prominently visible in agricultural activities; however, there is an increasing recognition of women's contributions. Women play crucial roles in various aspects of agriculture, contributing significantly to agricultural output.

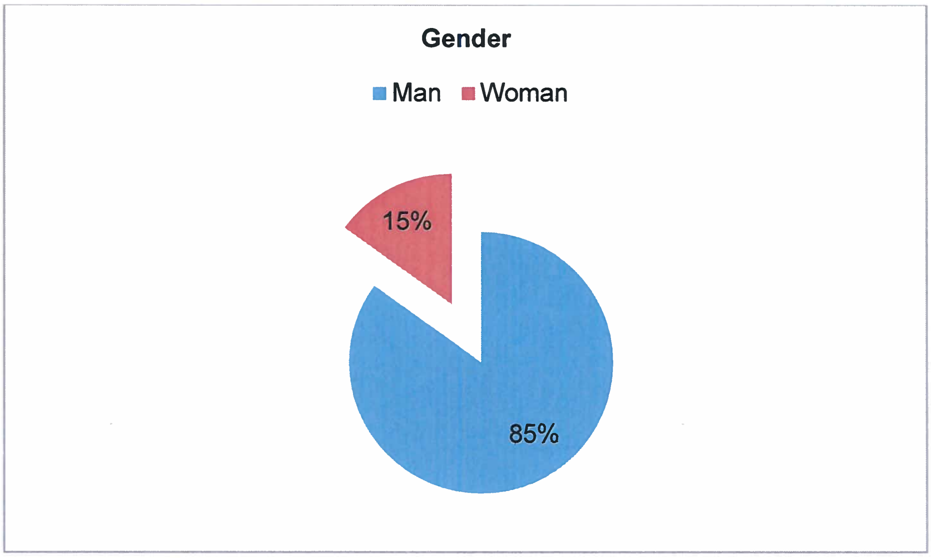


Figure 6. Gender distribution of the sample (n=40) (source: Author's elaboration from analysis of field data, 2024).

Regarding the education level, professional training represents 3% of the respondents while the predominant level of education is the primary school representing 47% of the participants (Figure 7). This disparity in educational attainment among farmers in Tunisia reflects the pervasive poverty in these areas, exacerbated by inadequate transportation and a notable unemployment. Tunisia encounters challenges primarily associated with rural living and insufficient infrastructure, particularly in education and healthcare (Arfa and Elgazzar, 2013). The population, predominantly composed of young individuals, confronts significant obstacles such as high illiteracy rates and limited educational opportunities (Shimi, 2014).

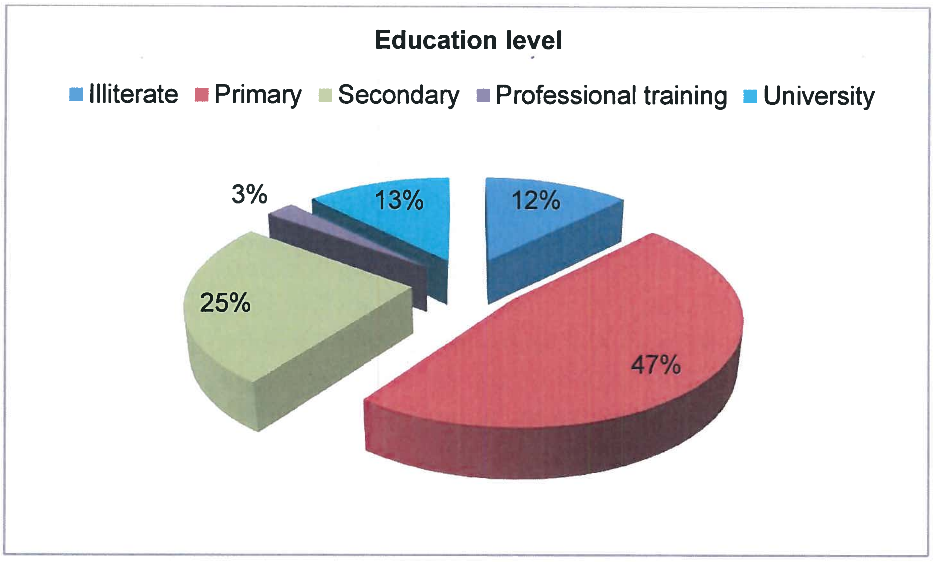


Figure 7. Distribution of Education Levels (Source: Author's elaboration from analysis of field data, 2024).

3.1.2. Household size

In the studied sample, the household size varies (Figure 8). The majority, constituting 30%, comprises households with 5 people. Additionally, 22.5% of respondents reported a household size of 4 people. A minority, accounting for 4.5% of the population studied, are either transitioning to living alone or sharing a household with one other person. Further distributions include 20% living in households with 6 people, 7% in households with 7 people, 2.5% in households with 8 people, and 12.5% in households with 3 people. In this context a study report that in Tunisia, the typical rural household size declined from an average of 5.7 individuals per household in 1975 to 4.3 individuals per household by 2014 (Marzin *et al.*, 2016).

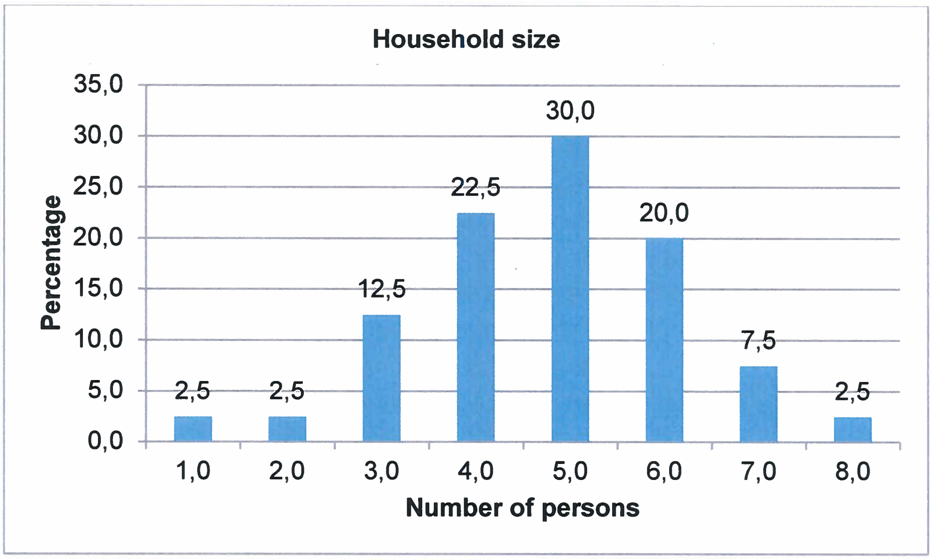


Figure 8. Percentage of household size (source: Author's elaboration from analysis of field

data, 2024).

3.1.3. Average monthly household income

The average monthly household income of the individuals surveyed varies from less than 600 DT per month to more than 3000 DT per month (Figure 9). In fact, 55% of the sample declared income of less than 600 DT which places this income category in first place followed by the category [601 DT to 1200 DT], comprising 32.5% of respondents, then 10% for [1201-2000], and finally 2.5% for [2001-3000]. In this context a study shows that a significant number of farmers experience diminished income levels. This phenomenon stems from notable migration trends among major regions. Individuals frequently depart from the western and southern regions, dubbed as "repellent poles," in favor of settling in the District of Tunis or the northeastern and central-eastern regions, labeled as "attractive poles." These migration patterns are shaped by factors like declining agricultural productivity, reduced earnings from farming endeavors, and the division of agricultural land (Chebbi *et al.*, 2019).

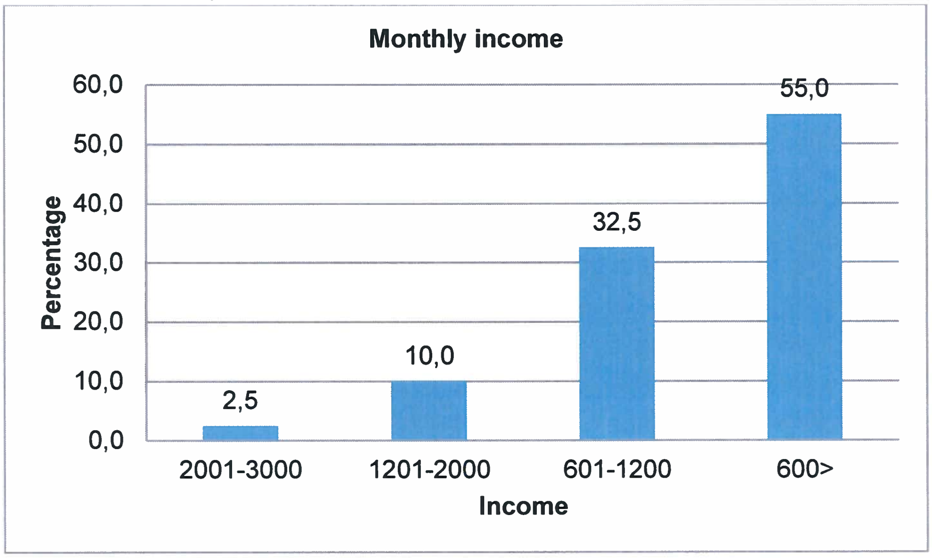


Figure 9. Monthly income distribution (Source: Author's elaboration from analysis of field data, 2024).

3.1.4. Operating characteristics of the sample studied

3.1.4.1. Occupation

In Elles, a significant proportion of farmers opt for irrigated areas for vegetable cultivation, (37.5%). In Hammam Biadha, only one farmer uses rainfed vegetable cultivation. Similarly, representing 6.3%, engage in irrigated fruit tree cultivation in Elles, whereas in Hammam Biadha, a mere 4.2% adopt this practice. For forage crops and cereals, in Elles leans heavily towards irrigated areas, with 87.5% of farmers utilizing them there, in contrast to only 6.3% in rainfed areas. However, in Hammam Biadha, despite the smaller percentage, 66.7% of farmers cultivate forage crops and cereals in rainfed areas. The cultivation of olive trees portrays a notable difference, with 62.5% of farmers in Elles choosing irrigated areas for planting, while in Hammam Biadha, all 24 farmers, constituting 100%, opt for rainfed cultivation of olive trees. As observed, farmers in Elles are under the irrigated system.

These outcomes are confirmed by study which indicates that this is attributed to the low rainfall in the region, leading farmers to frequently rely on renting water cisterns from private entities to meet their water requirements (Dhehibi *et al.*, 2022a).
According to our outcomes, the highest production comes from olive trees, producing about 234.5 tonnes, followed by forage crops and cereals with 121.4 tonnes, then vegetables with 72.5 tonnes, and finally fruit trees with 3 tonnes. This context aligns with findings indicating that In Siliana, there are 8 million olive trees spread across 88,000 hectares, with an estimated production of 28,000 tonnes in 2022 (ODNO, 2022) . In Kef, large olive plantations characterize the landscape and olive tree cultivation covers an area of 50,810 hectares, with an estimated production of 18,699 tonnes in 2022 (ODNO, 2022). Moreover, olive cultivation extends across vast expanses in both Siliana and El Kef, showing a continual expansion trend when compared to cereal cultivation. Additionally, both regions boast farmers with high technical expertise in the cultivation of olive trees coupled with low production costs compared to other crops (Dhehibi *et al.*, 2022b).

3.1.4.2. Sales and own-consumption

Only 7 farmers engage in vegetable production, selling an average of 35.7% of their yield while consuming the remaining 64.28%. Regarding fruit trees, only 2 farmers are selling an average of 85% of their production and consuming the remaining 15%. As for forage crops and cereals, 31 farmers are selling an average of 47.41% and consuming 52.58%. The latter aligns with findings from a survey on farm structures conducted in 2004–2005 (MARH, 2006), indicating that cereal cultivation for personal consumption dominates, which is indeed the case. Finally, olive trees dominate production, with 34 farmers cultivating them. About 60% of the olive yield is sold while 39.41% is consumed domestically. These results are aligned with previous findings (Dhehibi et al., 2007; Chebil and B, 2012; Chebil *et al.*, 2014).

3.1.4.3. Livestock

Farmers predominantly prefer raising sheep as their livestock, with a total of 670, compared to cattle and goats, which have 203 and 93 heads respectively. This production choice can be attributed to several factors, according to findings from the workshop on value chain identification, prioritization and actors mapping took place on December 15th, 2022 in el Kef (North-West Tunisia). Economically, sheep farming provides a consistent source of income annually, with opportunities to capitalize on by-products such as wool and leather, thereby contributing to the revenue of numerous households. The mixed crop-livestock systems reduce animal feed costs, making production financially viable for breeders. Furthermore, wool sales offer women an independent income stream, reducing financial dependence. High consumer demand for sheep products ensures year-round market stability. Socially, sheep farming creates employment opportunities, enhances family well-being, and mitigates rural migration by engaging all family members in the breeding activity. The transect also values specific social aspects of sheep breeding, including the technical expertise of local breeders, intergenerational knowledge transfer, and collaborative knowledge sharing among breeders. Environmentally, sheep farming is well-suited to the local ecosystem, requiring less water and offering composting opportunities.
It promotes soil fertility through legume crop integration and demonstrates adaptability to

climate change (Dhehibi *et al.*, 2022c). Furthermore, there are 22,451 sheep in Elles and 29,500 in Hamam Biadha, indicating a considerable population in both areas (ATLAS, 2013).

3.1.4.4. Variety of olive trees

The most used variety in these areas is Chetoui accounting for 40% of cultivation. In El Kef region, the olive oil value chain's strengths are largely attributed to the prevalent local olive variety, "Chetoui," which constitutes 80% of the total orchards. This olive variety is well-suited to the regional climate and soil conditions, enhancing its adaptability and productivity (Dhehibi *et al.*, 2022a).

3.1.5. Familiarity with AE practices

As evidenced, 47.5% of farmers lack awareness of agroecological practices (Figure 10). This discrepancy underscores the efforts of organizations aiming to promote such practices among farmers, emphasizing the importance of co-designing and implementing agroecological strategies. ICARDA, for instance, has introduced various agroecological practices, including rotation, crop diversification, and forage association etc... into farmers' production systems through research initiatives such as the CLCA project (Alary *et al.*, 2023).

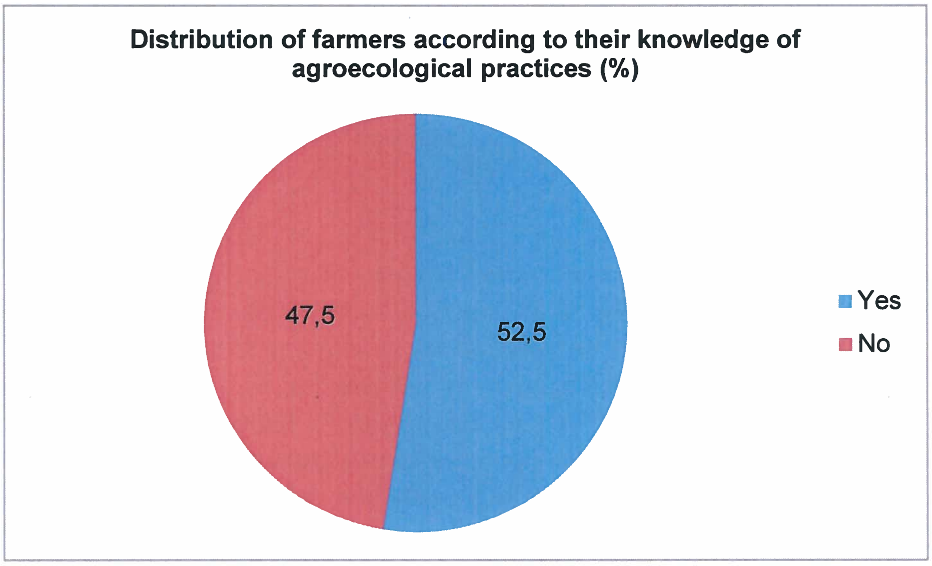


Figure 10. Distribution of farmers according to their knowledge of agroecological practices in percentage (%) (Source: Author's elaboration from analysis of field data, 2024).

3.1.6. Agroecological practices used

Despite the finding that almost half of farmers are unfamiliar with agroecological practices, as indicated by the previous percentages, it is important to note that some of these practices are widely adopted. Crop rotation comes first, with 65%, followed by intercropping, with 60%. Other common practices include composting, forage seed production, and input reduction, with percentage of 50%, 53%, and 40%, respectively.
In contrast, practices such as biofertilization, manure use, zero tillage, recycling and

biodiversity are less common, with respective percentage of 38%, 35%, 30%, 10% and 13%. Finally, biochar, animal health like no antibiotic, local fodder etc... And weed management are among the least used practices (Figure 11). On the other hand, another study shows that the two most common agroecological practices are split fertilisation and the use of plant breeding cultivars.

This appears to be owing to their longer life and the high level of expertise and knowledge that has been accumulated over the last two or three decades, as well as the fact that they do not require a significant amount of system modification (Wezel *et al.*, 2014). Findings were supported by what was reported that farmers employ numerous agroecological practices unknowingly, often as a result of longstanding farming traditions passed down through generations. Empirical findings demonstrate that organic crop fertilisation, crop rotations, and biological pest management are all well-known agricultural techniques that have been in use for many years. However, over the last two decades, they have been increasingly referred to as agroecological practices (Altieri, 1995 and Arrignon, 1987). Additionally, we observe that certain technologies, such as biochar, are scarcely utilized, likely due to their novelty. However, it is worth noting that despite being a well-established technology, biochar production continues to evolve in the Mediterranean Basin Countries like: Tunisia, Spain and Greece (Marks et al., 2020). Regarding animal health, the cost of veterinary services is prohibitively expensive. Studies have shown that the implementation of measures to enhance animal health and welfare is often linked with high costs, resulting in a reduction in overall productivity (Hogeveen *et al.*, 2019).

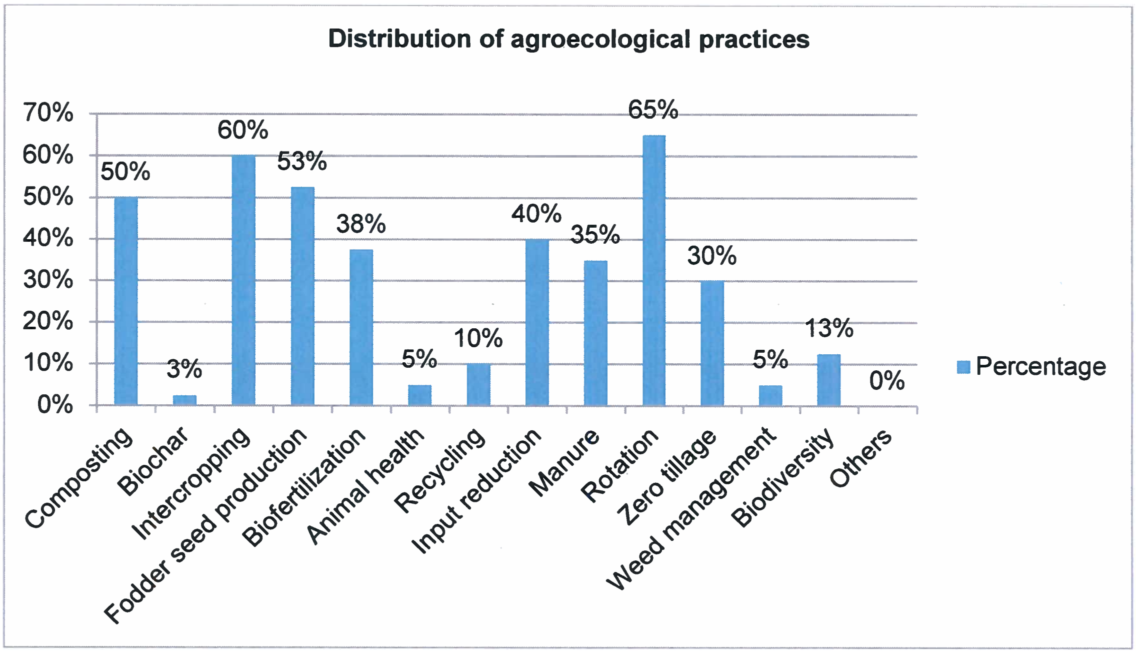


Figure 11. Distribution of Agroecological Practices (%) (Source: Author's elaboration from analysis of field data, 2024).

3.1.7. The barriers that hinder you from using AE practices

Empirical findings revealed an acceptable agreement strength (W) of 0.677, statistically significant at the 1%, leading to the rejection of the null hypothesis (H0) that there was no concordance among farmers regarding their perception of the barriers hindering their adoption of AE practices. Climate change was ranked highest (4.60) as the most perceived barrier by farmers (Table 4), followed by insufficient policy support (4.69), poor infrastructure ranked third, and lack of extension services/technical support came fourth, with lack of knowledge being fifth, with mean ranks of 4.70, 5.05, and 5.55, respectively. On the other hand, farmers perceive the lack of access to resources as the primary low barrier, ranking first with a mean rank of 6.34, followed by limited means of production at 6.80. This is trailed by concerns about large cultivated areas, and access to markets and demand, with mean ranks of 7.95 and 8.33, respectively. In this context, some studies define barriers as "factors that adversely affect the effectiveness of adaptations or transitions, resulting in increased costs for both farmers and society" (Moser and Ekstrom, 2010; Wreford *et al.*, 2017). It's worth noting that the perception of barriers can vary among different actors. What one actor may consider problematic, another might view as beneficial. (Eisenack *et al.*, 2014) argue that the interpretation of barriers is relative to the specific adaptive actions under consideration, the actors involved in those actions, and the context in which they occur. Numerous studies utilize broad definitions for barriers and drivers in Europe, addressing technological, political, and financial factors that could either facilitate or impede an agro-ecological transition. These factors encompass a range of issues, including insufficient knowledge, limited political commitment, and inadequate financial resources to promote agro-ecology (Schiller *et al.*, 2019; Altieri and Nicholls, 2012; Silici, 2014; Wibbelmann *et al.*, 2013) Furthermore, the authors cited the adaptation to climate change as a barrier. In the other hand, in Nicaragua, the lack of timely access to an adequate supply of bio-inputs, including clean native seeds, organic fertilizers, and biological pest- and disease-management products, along with issues like insufficient availability of rural labor, limited access to credit, and infrastructural difficulties in transporting products to markets, are also identified as factors that can impede the adoption of AE practices (Liere *et al.*, 2017; Fiorella *et al.*, 2010).

3.1.8. Technology awareness and its assimilation of the sample studied:

In this section, we selected three agroecological practices: Intercropping, biochar and composting to assess farmers' awareness of them. We aim to determine whether farmers have previously adopted these technologies, are willing to adopt them in the future, and whether they have any prior knowledge or awareness of them.

67.5% affirmed they had heard about composting, while 32.5% responded negatively. Similarly, for intercropping, the distribution was the same. However, for biochar, 75% indicated they had not heard about it, while 25% stated they had.

The majority of farmers, comprising 97.5%, do not utilize Biochar. However, 60% of farmers implement intercropping, and 40% employ composting.

The empirical results indicated a noteworthy agreement strength (W) of 0.302, significant at the 1% level, prompting the rejection of the null hypothesis (H0) suggesting no consensus among farmers concerning the barriers to their adoption of composting.

Limited information was ranked highest (4.34) as the most perceived barrier by farmers (Table 5), followed by limited access to inputs (4.73) then unavailable practice with mean ranks of 4.81. On the other hand, farmers perceive no cash to buy this practice as the primary low barrier, ranking first with a mean rank of 5.09, followed by no credit to make this practice at 5.33. This is trailed by practice's complexity, low yield/not effective and preference for other technologies with mean ranks of 5.36, 6.14 and 6.21, respectively. Findings from the case study conducted in Italy indicate that the implementation of composting practices can be hindered by various barriers. These include a lack of practice-specific knowledge, limited coordination within the Agricultural Knowledge and Innovation System (AKIS), uncertainty regarding the benefits of adopting the practice, low turnover rates in agriculture across generations, inadequate availability of practice-specific machinery, financial constraints for investment among small to medium-sized farms, limited willingness to cooperate, a shortage of rural labor, and insufficient financial resources for investment among small to medium-sized farms (Schwarz *et al.*, 2021).

The results unveiled a satisfactory agreement strength (W) of 0.686, significant at the 1% level, resulting in the rejection of the null hypothesis (H0) indicating no consensus among farmers concerning the obstacles to their adoption of biochar. Limited information was ranked as the highest (3.29) perceived barrier by farmers (Table 6), followed by Unavailable practice (3.68) and limited access to inputs (4,88). On the other hand, farmers perceive the practice's complexity as the primary low barrier, ranking first with a mean rank of 5,41, followed by No cash to buy this Practice at 5.54. This is trailed by concerns about No credit to make this technology, prefer other technologies and Low yield, with mean ranks of 6,01, 7,48 and 7,63 respectively. In the Amphawa district, biochar is seldom utilized in agriculture, despite its efficacity. This can be attributed to farmers' unfamiliarity with biochar manufacturing methods and their limited awareness of the benefits it offers for soil fertilization in agriculture (Niemmanee *et al.*, 2019).

The outcomes revealed a moderate agreement (W) of 0,279, statistically significant at the 1% level, which indicate a concordance among farmers regarding the factors hindering their adoption from using intercropping.

Unavailable practice (4.58) as the most perceived barrier by farmers (Table 7), followed by limited information (4.61) and limited access to inputs ranked third (4,70) and no cash to buy this practice came forth with mean rank of 4.99. On the other hand, farmers perceive the practice's complexity as the primary low barrier, ranking first with a mean rank of 5,31, followed by No credit to make this practice, preference for other technologies and Low yield, with mean ranks of 6,03 and 6,08 respectively. Various studies, highlight the primary barrier to adoption as impediments to mechanization and lack of suitability for market demands (DE PAILHE, 2014). In China, challenges in mechanizing intercropping are attributed to labor shortages due to the labor-intensive nature of the practice (Feike *et al.*, 2010). Similarly, in Southern Africa, mechanization hurdles lead to less frequent utilization of intercropping on large commercial farms (Ogindo and Walker, 2005). In Tuscany, Italy, intercropping requires specialized machinery, which individual farms may find unaffordable to purchase. Thus, it is evident that the common barrier across many countries is the high cost of machinery required for intercropping (Schwarz *et al.*, 2021).

Table 4. Farmers' perception of the barriers that hinder them from using AE practices (Source: Author's elaboration from analysis of field data, 2024)

Items	SD	D	N	A	SA	Mean	Standard deviation	Decision	Mean rank	Rank
Insufficient Policy Support	0	0	0	1 (2.5%)	39 (97.5%)	1.02	0.15	High perception	4,69	2
Lack of extension services/ technical support	0	2 (5%)	0	3 (7.5%)	35 (87.5%)	1.22	0.69	High perception	5,05	4
Lack of knowledge	1 (2.5%)	2 (5%)	1 (2.5%)	5 (12.5%)	31 (77.5%)	1,425	0,9578	High perception	5,55	5
Large cultivated area	4 (10%)	10 (25%)	8 (20%)	6 (15%)	12 (30%)	2.7	1.39	Low perception	7,95	8
Lack of access to resources (Organic inputs, local seeds...)	1 (2.5%)	2 (5%)	10 (25%)	3 (7.5%)	24 (60%)	1.82	1.12	Low perception	6,34	6
Limited means of production (Machines, labor...)	1 (2.5%)	5 (12.5%)	3 (7.5%)	13 (32.5%)	18 (45%)	1.95	1.13	Low perception	6,80	7
Market access and demand (Trails...)	2 (5%)	13 (32.5%)	12 (30%)	3 (7.5%)	10 (25%)	2.85	1.27	Low perception	8,33	9
Poor infrastructure	0	0	1 (2.5%)	0	39 (97.5%)	1.05	0.31	High perception	4,70	3
Climate change (drought)	0	0	0	0	40 (100%)	1	0	High perception	4,60	1
Other...	0	0	0	0	0	0	0	-	1,00	-
N : 40 / Kendall's W [a] 0,677*** / Chi-square 243,690/ df : 9										

Weighted average mean : 1.505 / The mean was measured on a five-point Likert scale. Rank 5 was "strongly disagree" and rank 1 was "strongly agree". [a] Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

Table 5. Factors that can hinder farmer from using composting (Source: Author's elaboration from analysis of field data, 2024).

Items cp	SD	D	N	A	SA	Mean	Standard deviation	Decision	Mean Rank	Rank
Unavailable practice	1 (2.5%)	2 (5%)	0	1 (2.5%)	16 (40%)	0,775	1,1655	High perception	4,81	3
No cash to buy this technology/ Practice	0	4 (10%)	1 (2.5%)	3 (7.5%)	12 (30%)	0,925	1,2687	Low perception	5,09	4
No credit to make this technology	0	4 (10%)	3 (7.5%)	4 (10%)	9 (22.5%)	1,050	1,3578	Low perception	5,33	5
I prefer other technologies	1 (2.5%)	9 (22.5%)	4 (10%)	5 (12.5%)	1 (2.5%)	1,600	1,7802	Low perception	6,21	8
Practice's complexity	0	1 (2.5%)	8 (20%)	3 (7.5%)	8 (20%)	1,050	1,2800	Low perception	5,36	6
Limited access to inputs	0	0	1 (2.5%)	7 (17.5%)	12 (30%)	0,725	0,8469	High perception	4,73	2
Low yield/ Not effective	0	6 (15%)	11 (27.5%)	2 (5%)	1 (2.5%)	1,550	1,6633	Low perception	6,14	7
Limited information (Knowledge, information asymmetry…)	0	0	1 (2.5%)	1 (2.5%)	18 (45%)	0,575	0,6751	High perception	4,34	1
Other……………………..	0	0	0	0	0	0	0	-	3,00	-
N : 40 / Kendall's W [a] 0,302*** / Chi-square 96,651/ df : 8										

Weighted average mean : 0.917 / The mean was measured on a five-point Likert scale. Rank 5 was "strongly disagree" and rank 1 was "strongly agree". [a] Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

Table 6. Factors that can hinder farmer from using biochar (Source: Author's elaboration from analysis of field data, 2024).

Items bioch	SD	D	N	A	SA	Mean	Standard deviation	Decision	Mean rank	Rank
Unavailable practice	0	1 (2.5%)	1 (2.5%)	3 (7.5%)	34 (85%)	1.175	0.6360	High perception	3,68	2
No cash to buy this technology/ Practice	0	6 (15%)	8 (20%)	9 (22.5%)	16 (40%)	2.050	1.1536	Low perception	5,54	5
No credit to make this technology	0	8 (20%)	8 (20%)	11 (27.5%)	12 (30%)	2.250	1.1712	Low perception	6,01	6
I prefer other technologies	2 (5%)	16 (40%)	13 (32.5%)	6 (15%)	2 (5%)	3.175	1.0834	Low perception	7,48	7
Practice's complexity	1 (2.5%)	1 (2.5%)	10 (25%)	12 (30%)	15 (37.5%)	1.950	1.0365	Low perception	5,41	4
Limited access to inputs	1 (2.5%)	2 (5%)	2 (5%)	16 (40%)	18 (45%)	1.725	0.9868	High perception	4,88	3
Low yield/ Not effective	1 (2.5%)	9 (22.5%)	29 (72.5%)	0	0	3.200	0.7232	Low perception	7,63	8
Limited information (Knowledge, information asymmetry…)	0	0	0	0	39 (97.5%)	0.975	0.1581	High perception	3,29	1
Other……………………..	0	0	0	0	0	0	0	-	1,10	-
N : 40 / Kendall's W [a] 0,686*** / Chi-square 219,648/ df : 8										

Weighted average mean : 1.833 / The mean was measured on a five-point Likert scale. Rank 5 was "strongly disagree" and rank 1 was "strongly agree". a Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

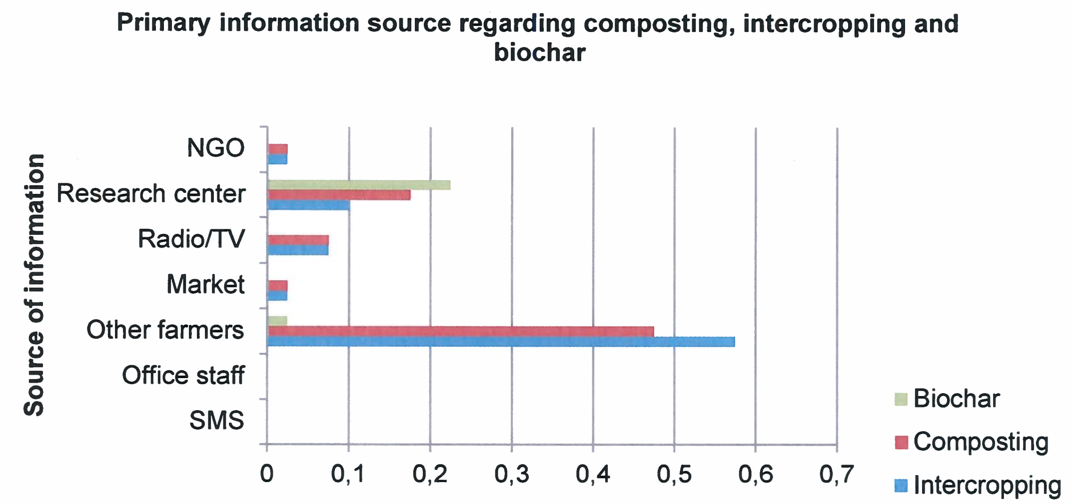
Table 7. Factors that can hinder farmer from using intercropping (Source: Author's elaboration from analysis of field data, 2024).

Items inter	SD	D	N	A	SA	Mean	Standard deviation	Decision	Mean rank	Rank
Unavailable practice	0	0	1 (2.5%)	1 (2.5%)	14 (35%)	0.475	0.6789	High perception	4,58	1
No cash to buy this technology/ Practice	0	2 (5%)	2 (5%)	1 (2.5%)	11 (27.5%)	0.675	1.0952	High perception	4,99	4
No credit to make this technology	0	3 (7.5%)	3 (7.5%)	2 (5%)	8 (20%)	0.825	1.2788	Low perception	5,31	6
I prefer other technologies	1 (2.5%)	6 (15%)	5 (12.5%)	3 (7.5%)	1 (2.5%)	1.275	1.7095	Low perception	6,03	7
Practice's complexity	0	1 (2.5%)	6 (15%)	2 (5%)	7 (17.5%)	0.825	1.2171	Low perception	5,31	5
Limited access to inputs	0	0	1 (2.5%)	3 (7.5%)	12 (30%)	0.525	0.7506	High perception	4,70	3
Low yield/ Not effective	0	3 (7.5%)	13 (32.5%)	0	0	1.275	1.6011	Low perception	6,08	8
Limited information (Knowledge, information asymmetry…)	0	1 (2.5%)	0	1 (2.5%)	14 (35%)	0.500	0.7845	High perception	4,61	2
Other…………………….	0	0	0	0	0	0	0	-	3,40	-
N : 40 / Kendall's W [a] 0,279***/ Chi-square 89,301/ df : 8										

Weighted average mean: 0.708 / The mean was measured on a five-point Likert scale. Rank 5 was "strongly disagree" and rank 1 was "strongly agree". W[a] Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

Main source of information for technologies:

As observed, the primary source of information on composting for the majority of farmers is their neighbors and other farmers, with 47.5%. This is followed by the research center, which accounts for 17.50%. Additionally, a smaller proportion of farmers acquire information from TV or radio (7.50%), as well as from NGOs and markets, each with an average of 2.5% (Figure 12).



	SMS	Office staff	Other farmers	Market	Radio/TV	Research center	NGO
Biochar	0	0	2,50%	0	0	22,50%	0
Composting	0	0	47,50%	2,50%	7,50%	17,50%	2,50%
Intercropping	0	0	57,50%	2,50%	7,50%	10,00%	2,50%

Percentage

Figure 12. Primary information source regarding composting, intercropping and biochar (Source: Author's elaboration from analysis of field data, 2024).

The main source of information for implementing these three agroecological (AE) practices is various organizations. For example, ICARDA has introduced a range of AE practices, such as rotation, crop diversification, and forage association etc... into farmers' production systems through research initiatives like the CLCA project (Alary *et al.*, 2023). Additionally, initiatives from other international NGOs like GIZ, including the IAAA and Prosol initiatives, as well as the PROFITS and PACTE projects (Lestrelin and Jaouadi, 2023). Furthermore, knowledge exchange occurs among other farmers through farming exchanges among association members or at the community level, involving the co-creation of knowledge by applying agroecological principles at living labs, as evidenced by the findings of the workshop conducted at the living lab level and at the value chain level with all the relevant stakeholders through the organization of two workshops were conducted in the governorates of Kef and Siliana.

The first focus group occurred on October 5th, 2022, in El Kef (GDA Sers Rural Women), followed by three additional focus groups in Siliana, where the living lab is represented by SMSA 'Ankoud El Khir', SMSA 'ETTAWEN', and SMSA 'Kouzira'. These focus groups were organized on November 1st, 2nd, and 3rd, 2022. In the second phase of the participatory approach, two workshops focusing on the identification, prioritization, and mapping of key value chains were held on December 8th and 15th, 2022, in Siliana and El Kef (North-West Tunisia). The number of participants was 33 and 30, respectively, in Kef and Siliana. Other studies shows that farmers in developed countries have the opportunity to gain new insights and knowledge through the adoption process itself, as well as through interactions with fellow farmers, researchers, and extension agents (Chatzimichael *et al.*, 2014). According to Pannell *et al.*, (2006), during the initial stages of adoption, uncertainty about new technologies tends to be significant, prompting farmers to rely on their communication networks for information and guidance.

Number of years (total) for the use of the 3 technologies:

A study outcomes in Burkina faso indicates that adopters typically possess more experience, averaging 7.75 years in the practice of these techniques, compared to non-adopters, who have an average experience of just 0.68 years (Tankoano and Sawadogo, 2022). This trend is reflected in our study, with an average of 7.05 years for composting, 8.25 years for intercropping, and 0.25 years for biochar adoption. Regarding agricultural practices, the adoption of composting spans among five farmers for a duration of five years, representing 12.5% of the total. Additionally, intercropping has been embraced by four farmers for one year, another four for two years, and yet another four for 30 years, each accounting for 10% of the total. Moreover, only one farmer has adopted Biochar for duration of 10 years, constituting 2.5% of the total.

Upon analyzing the decision-makers regarding the adoption of the three (AE) practices (Composting, intercropping and biochar), it becomes evident that the majority are heads of households. Wezel *et al.*, (2020) show that the (AE) practices adopted by farmers exhibit diverse origins and histories. While some practices are recent innovations supported by NGOs and research organizations, others have deep roots within the local context. Certain practices are indigenous, having been developed by farmers without external assistance, while others have been introduced from outside sources or co-developed through collaborative efforts.

Co-development of practices is a fundamental aspect of agroecology. When a practice becomes well-established in a particular area, minimal further development is required for additional farmers to adopt it, or it can be modified and adapted over time, eventually evolving into a recognized new practice. Although not explicitly mentioned by respondents, the co-creation of practices has been documented in some studies. For instance, in Ethiopia, the establishment of exclosures involves a collaborative process between communities, NGOs, and government agencies (Nicolétis *et al.*, 2019). On the other hand evidence from findings obtained during the workshop that took place in kef and siliana indicates that knowledge exchange occurs among farmers through farming cooperatives or at the community level, involving the co-creation of knowledge by applying agroecological principles at living labs.

Looking ahead, the majority of farmers express an intention to adopt these practices in the future, indicating a willingness to embrace agroecological methods if provided with necessary facilities. As we can see, the percentage indicating their decision to use agroecological practices in the future is high for each practice: 92.5% for biochar, and 95% for both intercropping and composting (Figure 13).

However, it's crucial to know that two farmers expressed opposition to these practices, underscoring the need for further exploration of potential concerns or barriers. In this context, a study shows by Schoonhoven and Runhaar (2018) that several variables can influence farmers' willingness to adopt innovative practices, including age, gender, social and educational background, farmer knowledge and experience, and farm size. Furthermore, it has been emphasized that various factors play a significant role in the decision-making process of farmers regarding the adoption of sustainable alternatives. These factors include motivations, access to information, social dynamics, government agreements, market demand, specific skills and implementation abilities, legitimization of practices, and the overarching holistic framework that combines personal and contextual elements. Additionally, the multidisciplinary framework integrating aspects of nature conservation and strategies for behavior change further influences farmers' decisions in this regard.

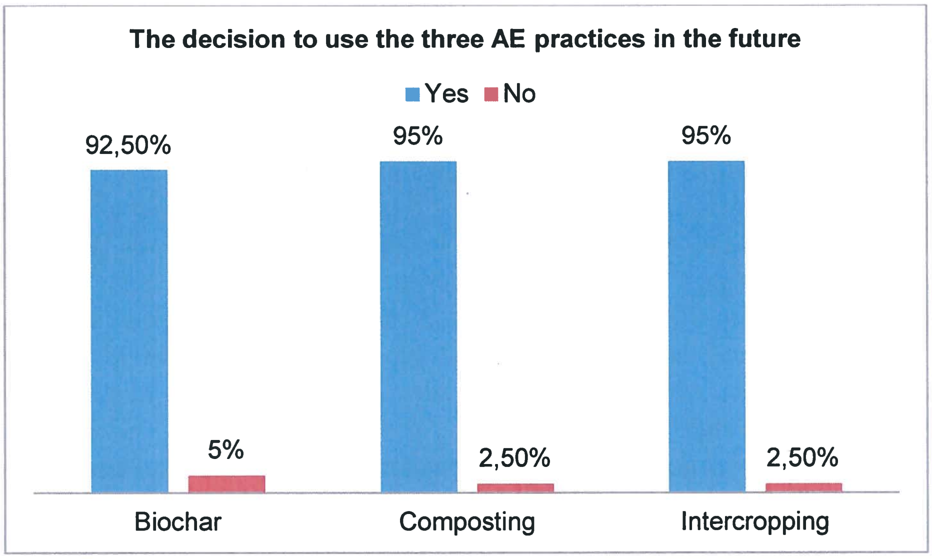


Figure 13. The decision to use the three AE practices in the future (Source: Author's elaboration from analysis of field data, 2024).

3.1.9. Motivations and limitations of adopting AE practices:

3.1.9.1. The perception of the performance of the technology:

The outcomes revealed a moderate agreement (Kendall's W) of 0,347, statistically significant at the 1% level. Knowledge needed is considered as the most perceived factor by farmers, followed by cost of adoption (Table 8). On the other hand, farmers do not highly perceive the access and the intensity of work as limiting factors if they adopt the compost. Consequently, farmers in this transect are unaware of the process of composting, and they perceive it as requiring a financial investment. This aligns with a study conducted in the northwestern of Europe, which indicates that a lack of experience and knowledge may hinder farmers from composting farmyard leftovers. Furthermore, respondents express a lack of information regarding the legislation governing on-farm composting. Notably, almost all non-composting farmers (96%) and one-third of composting farmers were unfamiliar with composting laws adding to that the requisite shredding machines are expensive and need a lot of fuel, hence they are rarely available on farms. Furthermore, the majority of the feedstock has a high volume-to-weight ratio, resulting in significant transport costs, as mentioned by the respondents in the interviews of this study (Viaene *et al.*, 2016).

The empirical results showed a satisfactory agreement level (Kendall's W) of 0.420, statistically significant at the 1% level. Knowledge is considered the most perceived limiting factor by farmers (3.14), followed by the cost of adoption (2.68), and finally, access (2.56), as shown in Table 9. Conversely, farmers perceive the intensity of work as a low factor, with a mean rank of 1.63. This indicates that the intensity of work is not a concern for farmers; however, the financial investment, particularly for machinery, is not feasible due to a lack of knowledge and limited access. A study in Poland identified several possible challenges to farmer adoption, including cost, lack of interest, and belief that the benefits will be worth the effort. Furthermore, the reluctance to the use of biochar was fueled by a lack of access, a belief that the farm was too small, a lack of opportunity, a preference for other ways, and biotechnology (Latawiec *et al.*, 2017).

The findings unveiled a limited agreement (Kendall's W) of 0.188, which achieved statistical significance at the 1% level. Knowledge needed is considered (2.98) as the most perceived factor by farmers (Table 10), followed by cost of adoption (2.79). On the other hand, farmers perceive the access as the primary low factor, ranking first with a mean rank of 2.15, followed by intensity of work if they adopt it, with mean ranks of 2.09. This suggests that farmers find access and the intensity of work manageable for adopting this practice. However, the primary barriers lie in its affordability, particularly the financial aspect, and crucially, the requisite knowledge needed for implementation. Some findings in South Africa demonstrates that fostering the adoption of intercropping for Maize-lablab relies on the sharing of both local and novel knowledge among farmers, as well as with the local community, neighboring communities, and researchers. This process involves social learning and skill acquisition by farmers and other community members. Farmers receive comprehensive training covering all aspects and activities of the field trial, thereby contributing valuable insights into local farming systems, which are crucial for the sustainability of agroecological farming practices in the area. Furthermore, facilitating knowledge exchange to surrounding communities underscores the significance of local cross-visits in establishing informal learning platforms for these communities (Mthembu *et al.*, 2018).

(Griliches, 1957) illustrated the pivotal role of economic factors in shaping the adoption of new practices through a study on the spread of hybrid maize in Iowa, USA. This notion was further corroborated by Mariano *et al.*, (2012) regarding access to credit, while Cavanagh *et al.*, (2017) indicated that economic aspects like total income may influence the adoption of agroecological practices positively or negatively. In our study, the cost of adoption ranked second in terms of high-perceived factors potentially impacting the adoption of these technologies negatively. Some researchers argue that labor availability can affect adoption, with studies using family size as a proxy for labor supply showing varied results (Abadi Ghadim and Pannell, 1999). However, in our study, farmers perceive that these AE practices do not require intensive labor to adopt. For instance, in Malawi, Ward *et al.*, (2017) found that farmers with larger land holdings were more inclined to adopt intercropping, likely due to their access to greater labor resources. Additionally, larger land holdings enable them to tolerate potential yield losses from resource competition between the main crop and intercropping. Kuhfuss and Subervie, (2018) emphasized the importance of collective organizations, such as winery cooperatives in Trento, Italy, in disseminating essential information for winegrowers to target specific practices. Sharing knowledge and experiences within these organizations serve as crucial mechanism for adopting AE practices, facilitating access to equipment, accelerating learning, and promoting information exchange among peers. Membership in cooperatives typically entails adherence to specific standards. In this context, the lack of knowledge can influence farmers' decisions regarding the adoption of AE practices, as evidenced by a study conducted in the Amphawa area, where biochar application in agriculture is less common.

This is primarily attributed to farmers' lack of awareness of the production process and its potential benefits for soil improvement in agriculture (Niemmanee *et al.*, 2019). Moreover another study indicates that the inherent traits of agroecological practices can shape farmers' decision-making processes. For instance, Kuhfuss and Subervie, (2018) elucidated that farmers often decline numerous agroecological innovations due to their specific intrinsic attributes, with winegrowers opting for less demanding agroecological practices over more challenging ones.

3.1.9.2. Ability to adapt the technology/practice in the future

The results show a weak agreement (W) of 0,068, statistically significant at the 5% level. Personal skills and knowledge is considered (2.19) as the most perceived factor by farmers (Table 11). On the other hand, farmers perceive their capacity to pay for inputs as the primary low factor, ranking first with a mean rank of 1.98, followed by availability of inputs or some resources required, with mean ranks of 1.84. To embrace composting, farmers express confidence in their existing skills but acknowledge the need for further enhancement through training to deepen their understanding. As demonstrated in the previous section, they recognize the necessity for additional knowledge to effectively engage in this practice. However, they encounter financial constraints hindering their ability to acquire necessary inputs, alongside challenges related to input availability. Whereas, some study outcomes in Italy, indicate that farmers lack knowledge and financial resources, particularly for investments in machinery, by small to medium farms (Schwarz *et al.*, 2021).

The empirical results demonstrated a low level of agreement (W) of 0.112, which was statistically significant at the 1% level. This led to rejecting the null hypothesis (H0) suggesting no consensus among farmers concerning their motivations to adopt biochar. capacity to pay for inputs or required resources is considered (2.14) as the most perceived factor by farmers (Table 12), followed by the availability of inputs or some resources required (2.09). On the other hand, Farmers perceive their personal skills and knowledge as low, with a mean rank of 1.78. Farmers rate themselves as capable of affording inputs and having the necessary resources, but they lack the knowledge to utilize them effectively. Similar findings were revealed by a study in the Amphawa area, where farmers exhibited a lack of awareness regarding the production process of biochar and its potential benefits for soil improvement in agriculture (Niemmanee *et al.*, 2019).

The data unveiled a limited agreement (W) of 0.118, significant at the 1% level, resulting in the rejection of the null hypothesis (H0) indicating no consensus among farmers concerning their incentives to adopt intercropping. Personal skills and knowledge is considered (2.29) as the most perceived factor by farmers (Table 13). On the other hand, farmers perceive their capacity to pay for inputs or required resources as primary low with a mean rank of 1.94, followed by availability of inputs or some resources required (1.78). Farmers claim that they lack the financial means to implement intercropping, and essential inputs are not readily accessible, although they possess the necessary knowledge. This resonates with findings from studies conducted in China, Europe, and Africa, which reveal constraints in mechanizing intercropping (Mazibuko *et al.*, 2023). Moreover, intercropping demands specific machinery, which individual farms often cannot afford, highlighting financial limitations (Schwarz *et al.*, 2021). Additionally, according to Mouratiadou *et al.* (2024) it can have higher labor requirements compared to conventional monocropping systems, which can be a constraint for farmers, also the economic viability of it may vary depending on the specific context and location. For example, the profitability of intercropping maize with watermelon was higher compared to sole maize but lower compared to sole watermelon in Mozambique.

Table 8. Factors affecting the farmers' perception of the performance of composting (Source: Author's elaboration from analysis of field data, 2024).

Items cp	1=VB	2=B	3=R	4=G	5=VG	Mean	Standard deviation	Decision	Mean Rank	Rank
Access	0	4 (10%)	8 (20%)	19 (47.5%)	9 (22.5%)	3,825	0,9026	Low perception	2.48	3
Knowledge needed	0	0	2 (5%)	19 (47.5%)	19 (47.5%)	4,425	0,5943	High perception	3.16	1
Cost of adoption	0	1 (2.5%)	11 (27.5%)	12 (30%)	16 (40%)	4,075	0,8883	High perception	2.69	2
Intensity of work if adoption	2 (5%)	17 (42.5%)	7 (17.5%)	7 (17.5%)	7 (17.5%)	3,000	1,2403	Low perception	1.68	4
N : 40 / Kendall's W [a] 0,347***/ Chi-square 41,695/ df : 3										

Weighted average Mean : 3.831 / The mean was measured on a five-point Likert scale. Rank 5 was very good and rank 1 was very bad. W[a] Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

Table 9. Factors affecting the farmers' perception of the performance of biochar (Source: Author's elaboration from analysis of field data, 2024).

Items bioch	1=VB	2=B	3=R	4=G	5=VG	Mean	Standard deviation	Decision	Mean rank	Rank
Access	0	1 (2.5%)	7 (17.5%)	13 (32.5%)	19 (47.5%)	4,250	0,8397	High perception	2.56	3
Knowledge needed	0	0	1 (2.5%)	8 (20%)	31 (77.5%)	4,750	0,4935	High perception	3.14	1
Cost of adoption	1 (2.5%)	2 (5%)	5 (12.5%)	6 (15%)	26 (65%)	4,350	1,0513	High perception	2.68	2
Intensity of work if adoption	3 (7.5%)	8 (20%)	15 (37.5%)	5 (12.5%)	9 (22.5%)	3,225	1,2297	Low perception	1.63	4
N : 40 / Kendall's W [a] 0.420***/ Chi-square 50,361/ df : 3										

Weighted average mean : 4.144 / The mean was measured on a five-point Likert scale. Rank 5 was very good and rank 1 was very bad. W[a] Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

Table 10. Factors affecting the farmers' perception of the performance of intercropping (Source: Author's elaboration from analysis of field data, 2024).

Items inter	1=VB	2=B	3=R	4=G	5=VG	Mean	Standard deviation	Decision	Rank mean	Rank
Access	0	4 (10%)	17 (42.5%)	9 (22.5%)	10 (25%)	3,625	0,9789	Low perception	2.15	3
Knowledge needed	0	1 (2.5%)	6 (15%)	14 (35%)	19 (47.5%)	4,275	0,8161	High perception	2.98	1
Cost of adoption	0	1 (2.5%)	8 (20%)	13 (32.5%)	18 (45%)	4,200	0,8533	High perception	2.79	2
Intensity of work if adoption	1 (2.5%)	8 (20%)	9 (22.5%)	13 (32.5%)	9 (22.5%)	3,525	1,1320	Low perception	2.09	4
N : 40 / Kendall's W[a] 0.188***/ Chi-square 22,535/ df : 3;										

Weighted average Mean : 3.906 / The mean was measured on a five-point Likert scale. Rank 5 was very good and rank 1 was very bad. W[a] Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

Table 11. Factors affecting farmers' motivations to adopt composting in the future (Source: Author's elaboration from analysis of field data, 2024).

Items cp	1=VB	2=B	3=R	4=G	5=VG	Mean	Standard deviation	Decision	Mean rank	Rank
Your personal skills and knowledge	9 (22.5%)	8 (20%)	5 (12.5%)	15 (37.5%)	3 (7.5%)	2.875	1.3433	High perception	2.19	1
Your capacity to pay for inputs or required resources	7 (17.5%)	14 (35%)	6 (15%)	12 (30%)	1 (2.5%)	2.650	1.1668	Low perception	1.98	2
Availability of inputs or some resources required	6 (15%)	17 (42.5%)	8 (20%)	9 (22.5%)	0	2.500	1.0127	Low perception	1.84	3
N : 40 / Kendall's W^a 0.068**/ Chi-Square 5,452/ df: 2										

Weighted average mean: 2.675 / The mean was measured on a five-point Likert scale. Rank 5 was very good and rank 1 was very bad. W^a Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

Table 12. Factors affecting farmers' motivations to adopt biochar in the future (Source: Author's elaboration from analysis of field data, 2024).

Items bioch	1=VB	2=B	3=R	4=G	5=VG	Mean	Standard deviation	Decision	Mean rank	Rank
Your personal skills and knowledge	30 (75%)	5 (12.5%)	3 (7.5%)	2 (5%)	0	1.425	0.8439	Low perception	1.78	3
Your capacity to pay for inputs or required resources	20 (50%)	14 (35%)	3 (7.5%)	3 (7.5%)	0	1.725	0.9055	High perception	2.14	1
Availability of inputs or some resources required	19 (47.5%)	16 (40%)	3 (7.5%)	2 (5%)	0	1.700	0.8228	High perception	2.09	2
N : 40 / Kendall's W a 0.112***/ Chi-Square : 8,982 / df : 2										

Weighted average mean: 1.617 / The mean was measured on a five-point Likert scale. Rank 5 was very good and rank 1 was very bad. a Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

Table 13. Factors affecting farmers' motivations to adopt intercropping in the future (Source: Author's elaboration from analysis of field data, 2024).

Items inter	1=VB	2=B	3=R	4=G	5=VG	Mean	Standard deviation	Decision	Mean rank	Rank
Your personal skills and knowledge	8 (20%)	7 (17.5%)	6 (15%)	13 (32.5%)	6 (15%)	3.050	1.3950	High perception	2.29	1
Your capacity to pay for inputs or required resources	8 (20%)	11 (27.5%)	10 (25%)	10 (25%)	1 (2.5%)	2.625	1.1477	Low perception	1.94	2
Availability of inputs or some resources required	6 (15%)	16 (40%)	11 (27.5%)	7 (17.5%)	0	2.475	0.9604	Low perception	1.78	3
N : 40 / Kendall's W a 0.118***/Chi-Square: 9,441 / df : 2										

Weighted average mean: 2.717

The mean was measured on a five-point Likert scale. Rank 5 was very good and rank 1 was very bad. a Kendall's coefficient of concordance. Asterisks indicate significance at: *** 1%; ** 5%; and * 10%;

3.2. Results of the KII

The key informant interviews predominantly featured responses from researchers, consistent with the majority indicated in the accompanying figure.

Figure 14. Stakeholders (Source: Author's elaboration).

1/ What are the key agro-ecological practices that farmers in the Transect are aware of?

From the responses provided by different scientists, there are several key agroecological practices that farmers in the Transect are aware of. While there are common ideas shared among the scientists, there are also some variations in emphasis and specific practices.

Common Ideas

In the Transect region, a variety of agro-ecological practices are observed, each contributing to sustainable farming and environmental stewardship. Intercropping stands out as a prevalent technique, where farmers cultivate different crops together, such as olive trees alongside forage, cereals, or leguminous crops. This approach optimizes land use and promotes biodiversity, reflecting a keen awareness of ecological balance. Additionally, farmers prioritize the utilization of farm manure and crushed pruned wood to enhance soil composition and fertility. Conservation agriculture practices, including reduced tillage and crop rotation, align with national agricultural guidelines and further bolster sustainability efforts. Another noteworthy practice is the utilization of biochar, recognized for its ability to improve soil water retention and economize water usage. Rejuvenation pruning techniques for olive trees contribute to orchard health and productivity, underscoring a commitment to long-term viability. Furthermore, farmers demonstrate a keen understanding of diverse cropping systems, such as intercropping olive and almond trees and planting wheat between olive trees, showcasing adaptability and resourcefulness. Lastly, social and policy considerations are paramount, with scientists emphasizing the importance of cultural attitudes, social norms, and community dynamics in shaping adoption behaviors.

The availability of resources, including finance, technology, and inputs, is also recognized as influential factors in the successful implementation of agro-ecological practices, highlighting the interconnectedness of socio-economic and environmental dimensions in sustainable agriculture.

Different Ideas

Agroecology emerges as a multifaceted approach, integrating diverse practices and principles to foster sustainable agricultural systems, as noted by some scientists. This holistic perspective encompasses rotational schemes involving legumes, the cultivation of specific fodder crops, and the application of semi-direct approaches to enhance tree cultivation. Furthermore, institutional support plays a pivotal role, with organizations like ODESYPANO and Regional CRDA spearheading integrated projects across various domains. These initiatives encompass water and soil conservation, pasture enhancement, tree planting, forest development, and erosion control, reflecting a concerted effort towards holistic land management. Additionally, there are region-specific endeavors highlighted by scientists, such as Tunisia's focus on genetic resource conservation and the establishment of collective carob nurseries. These local initiatives not only foster environmental stewardship but also promote community engagement and collaboration in forest management practices, underscoring the importance of grassroots efforts in advancing agroecological principles.

The reported results were consistent with my findings that several agroecological practices were identified from a workshop involving farmers in the transect for various value chains. For cereal production, farmers implement rotation, conservation agriculture, crop diversification, maintain permanent crops, and utilize fallow land. In olive tree cultivation, practices include input reduction, manure application, recycling by-products, and using benches. Sheep farming involves forage association (Triticale + barley + oats), water conservation methods, manure management, and utilizing fallow land. Fig tree cultivation includes the production of the traditional product "Chriha," while honey production involves making traditional beehives known as "Jebih" and enhancing biodiversity by planting sulla and acacia (Dhehibi *et al.*, 2022b).

2/ How do farmers perceive the benefits and advantages of agro-ecological practices compared to conventional farming methods?

Common Ideas

Farmers in the Transect region perceive several shared benefits and advantages of agro-ecological practices compared to conventional farming methods. The widespread recognition of intercropping stands out as a practice that not only augments income but also provides an opportunity for diversification, potentially attracting tourists and fostering a connection between agriculture and tourism. Key common themes include the promotion of soil health, conservation of water, reduction of pollution, economic profitability, coping with drought, and stabilization of crop yields. The acknowledgment that agroecology influences climate change, environment, and sustainability highlight the importance of prioritizing long-term soil health over immediate production gains associated with conventional farming. Minimum tillage is emphasized as advantageous for avoiding soil disturbance, promoting soil fertility, and positively impacting climate change.

Different Ideas

While the common benefits are acknowledged, there are variations in farmers' perceptions of agro-ecological practices. Some emphasize the economic viability of agroecology in the mid-and-long terms, pointing to reduced input costs due to less reliance on expensive agrochemicals, leading to increased profitability over time.

Others highlight the adaptability and resilience associated with agroecology, strengthening the farm's ability to cope with environmental hazards and contributing to increased productivity and resilience.

However, for some farmers with large farms focused on productivism, agroecology is viewed as less profitable, necessitating the creation and adoption of an inclusive business model based on agroecological principles. Additionally, farmers, especially women and young people, see agroecological practices as improving the quality and nutritional value of their produce, aligning with consumer preferences for healthier, more natural food alternatives.

Similar findings have been reported in various countries. For instance, Majbar *et al.*, (2021) conducted a study in Morocco, exploring farmers' attitudes and willingness to contribute to environmental sustainability through compost production and utilization. In Brazil, Souza *et al.*, (2018) observed that farmers perceive agroecological practices, such as green manure, as beneficial for soil and crop health, facilitating a shift away from reliance on industrial fertilizers and agrochemicals. Likewise, Mamo and Bayih, (2019) found in Ethiopia that farmers regard manure utilization as labor-intensive yet valuable for enhancing soil health and increasing yields. Similar perceptions were reported in studies conducted in India, Brazil, and Senegal, where crop diversification, including crop rotation, intercropping, and integrating crops with livestock, was found by Chappell *et al.*, (2018) to improve crop yields. Additionally, Hayran *et al.*, (2018) noted in Turkey that farmers perceive practices like crop rotation and intercropping to contribute to soil quality enhancement by reducing pest and disease pressure and mitigating soil erosion, ultimately leading to increased crop productivity.

3/ what are the primary barriers that hinder farmers from adopting agro-ecological practices in the Transect el Kef-Siliana? And what factors influence farmers' decision-making processes when considering the adoption of agro-ecological practices?

Common Ideas:

Economic factors consistently emerge as significant barriers to the widespread adoption of agro-ecological practices. Farmers express concerns about the high initial investment costs associated with transitioning, including the purchase of machinery, availability of seeds, and financial constraints, particularly for small-scale farmers. Moreover, the absence of economic incentives, subsidies, and clear financial support from the government exacerbates these challenges. Alongside economic barriers, knowledge and awareness gaps pose significant obstacles. Many farmers lack understanding and awareness about agroecology, compounded by the absence of training programs and difficulty in accessing relevant information. Policy and institutional challenges further hinder progress in agroecology adoption. Agricultural policies often favor conventional practices, such as motorization and large-scale farming, while neglecting to support agroecological approaches. Additionally, the lack of specific labeling or certification for agroecological practices creates confusion and undermines their recognition. Farmers also face obstacles related to land tenure, agricultural policies, and a lack of support from agricultural technicians. Finally, social and cultural factors play a pivotal role in impeding the adoption of agroecological practices. Social aspects like distrust among farmers, resistance to change, and low participation in cooperatives are significant barriers. Cultural norms and unclear distinctions between organic farming and agroecology further contribute to the challenges faced by farmers in embracing these sustainable practices.

Different Ideas:

Farmers' decisions to adopt agro-ecological practices are influenced by various factors that extend beyond mere economic considerations. While economic barriers are prominent, there is growing recognition of the positive environmental impact of such practices.

Concerns about soil degradation, climate change, and the need to enhance resilience to environmental challenges shape farmers' choices. Moreover, market dynamics and consumer demand play a pivotal role, with opportunities for sustainable and organic products driving motivation. The influence of government support and policies cannot be overlooked, as supportive measures like subsidies and incentive programs can significantly sway farmers' decisions. Additionally, the perceived long-term sustainability and resilience associated with agroecological practices weigh heavily on farmers' minds. Factors such as soil fertility enhancement, cost reduction, and adherence to traditional agricultural methods contribute to the overall consideration of adopting these practices. Many studies in Europe indicate that various factors contribute to the challenges faced in promoting agro-ecology. These encompass a range of issues, including insufficient knowledge, limited political commitment, and inadequate financial resources (Schiller *et al.*, 2019; Altieri and Nicholls, 2012; Silici, 2014; Wibbelmann *et al.*, 2013). Furthermore, the authors cited the adaptation to climate change as a barrier. In the other hand, in Nicaragua, the lack of timely access to an adequate supply of bio-inputs, including clean native seeds, organic fertilizers, and biological pest- and disease-management products, along with issues like insufficient availability of rural labor, limited access to credit, and infrastructural difficulties in transporting products to markets, are also identified as factors that can impede the adoption of AE practices (Liere *et al.*, 2017; Fiorella *et al.*, 2010).

4/ Are there any governmental or non-governmental initiatives that have been successful in promoting the adoption of agro-ecological practices among farmers?

Common Ideas

Limited governmental initiatives in promoting agroecological practices are a common concern among respondents, who often perceive the state as minimally involved or absent in this area, highlighting the need for increased governmental engagement. Non-governmental institutions, on the other hand, play a pivotal role in advancing agroecology, with organizations like ICARDA, FAO, GIZ, ATE, and LACT actively leading research, development projects, and awareness-building efforts. These NGOs are acknowledged for their contributions through organizing training sessions, workshops, and projects aimed at promoting agroecology. Moreover, collaborative initiatives between governments and international organizations, such as CGIAR projects, GIZ initiatives like ProSol and IAAA, and various research and development projects such as CLCA, Profits, and PACTE, and PROFITS (diffusion of innovative technologies to Kesra beekeepers) are frequently cited (Lestrelin and Jaouadi, 2023). These partnerships facilitate the dissemination of agroecological practices and knowledge exchange on a global scale. Additionally, training and capacity-building initiatives are integral components of these efforts, focusing on raising awareness among farmers, providing guidance on adopting sustainable practices like minimum tillage, and ensuring effective management of resources and equipment to support the transition to agroecological farming methods.

Different Ideas

Several specific initiatives stand out for their success in promoting agroecological practices, such as the Olive Institute, CRDA (Farmer Field School: Sharing knowledge with development agents (CRDA), development institution (ICARDA) and ODESYPANO, among others. These initiatives have been recognized for their positive impact on sustainable agriculture. Additionally, there is a focus on integrated development projects that extend beyond technical aspects to emphasize the long-term viability of the development model.

These projects advocate for a holistic and sustainable approach to agricultural development. Governmental strategies and policies, such as the National Strategy for Sustainable Development in Tunisia, play a crucial role in mainstreaming agroecology into national development objectives, reflecting a broader commitment to sustainable agriculture. At the grassroots level, community and association involvement are essential drivers of agroecological practices. Local associations, farmer groups, and development associations, like the Sidi Hmada Farmers Associations in Siliana, actively promote sustainable agriculture through community-based initiatives. For instance, the involvement of Farmer Organizations (FOs) like SMSA Chouarnia and GDA Sers in prior initiatives, such as the CLCA-2 project coordinated by ICARDA and funded by IFAD from 2018 to 2021, exemplifies this collaborative approach between local associations and international organizations to advance sustainable agriculture (Alary *et al.*, 2023).

5/ What impact do agro-ecological practices have on the environment, farmers' livelihoods, and overall agricultural productivity in Tunisia?

Common Ideas

Agro-ecological practices offer multifaceted benefits across various dimensions of agricultural sustainability. Firstly, they consistently improve soil health and fertility through techniques like composting, manure incorporation, and increasing organic matter, thereby enhancing overall agricultural productivity. Moreover, these practices contribute significantly to water conservation, particularly crucial in water-scarce regions, thereby supporting sustainable agriculture and mitigating environmental challenges. Additionally, agro-ecological approaches promote crop and income diversification through strategies such as intercropping and livestock integration, reducing risks associated with mono-cropping and providing multiple income sources for farmers. Furthermore, they foster economic resilience by reducing dependency on external inputs like chemical fertilizers and pesticides, leading to lower production costs and increased economic stability, especially beneficial for smallholders. Moreover, agro-ecological practices play a vital role in biodiversity conservation by breaking disease cycles and enhancing functional biodiversity through methods like crop rotation and organic farming. They are also recognized for their contribution to climate change adaptation, offering resilience against climate-related challenges such as water scarcity and changes in weather patterns. Furthermore, these practices have significant community and cultural impacts, fostering a sense of community, preventing rural migration, and alleviating social tensions while enhancing the region's cultural and economic vitality through local product promotion, territorial labeling, and agrotourism. Finally, although there may be an initial adjustment period, agro-ecological practices are deemed essential for the long-term sustainability of agriculture by stabilizing yields, reducing costs, and decreasing reliance on external resources.

Different Ideas

A holistic approach to agro-ecology is emphasized, linking it to the creation of employment opportunities, the generation of added value, and the potential for attracting investment, thus inducing a reverse immigration movement and contributing to local wealth. Collaboration among farmers, scientists, and researchers is highlighted as instrumental, fostering increased yields, economic viability, and overall agricultural sustainability. These initiatives also spark collective debates, enhancing social interactions and community cohesion, with social impacts intertwined with environmental and economic considerations.

Furthermore, agro-ecological practices are recognized for improving product quality, enhancing the market's perception of local produce, and accessing niche markets, supported by direct marketing strategies. Additionally, they enhance self-consumption, increase income, and improve knowledge among farmers, bolstering the overall sustainability and success of farming systems. Specific practices within agro-ecology, such as pruning for circular economy benefits, not only improve soil fertility but also contribute to a circular economy by utilizing waste materials effectively. Finally, agro-ecology is seen as promoting agricultural sovereignty by reducing dependence on imported products and is expected to enhance product quality. Milheiras *et al.* (2022) indicate that higher agroecological intensification has been found to increase the yield of staple crops. Additionally, the implementation of agroecological practices has shown to enhance farmer well-being across multiple dimensions, particularly in material and security aspects, signifying significant improvements. In Cuba, by Parachini *et al.* (2020) a study shows that Agroecological practices offer evident environmental benefits, including the promotion of organic matter, improvement of soil conditions and recovery, mitigation of soil erosion, and enhanced resilience against pests and climatic events. Moreover, the social advantages, spanning from the household to national levels, are substantial and diverse, fostering social cohesion within communities and beyond. These practices also contribute to specific improvements such as increased employment opportunities, leading to a higher number of jobs. Also the National Strategy for the Development of Organic and Agroecological Production of the Republic of Guatemala 2013-2023" asserts that organic and agroecological agricultural production systems represent alternative and distinct approaches, capable of generating diverse income streams within family and subsistence farming contexts. These systems ensure food security and contribute to enhancing the quality of life for individuals involved in this crucial productive sector.

3.3. Results of the focus group discussion

Through two workshops in Kef and Siliana, a participatory approach engaged relevant stakeholders at the value chain level in focus group discussions. The primary aim was to analyze current business models within the olive oil value chain, understanding their functionality, inclusion indicators, and value propositions using a business model canvas. This process aimed to gather input and refine proposed business models, particularly for the olive oil value chain, which emerged as promising for integrating agroecological principles. Notably, a proposed business model focused on olive oil labeling, encouraging growers to produce labeled olive oil to boost incomes, livelihoods, and incorporate the land's value (terroir). These discussions centered on agroecological practices, aiming to integrate them into selected value chains' business models. By engaging stakeholders, the workshops sought to identify opportunities for co-development and enhancement of business models, integrating High-Level Panel of Experts (HLPE) agroecological principles. The participatory approach facilitated exploration into incorporating agroecological practices, such as advocating for organic certification, adopting agroecological practices, and enhancing product value for export. Ultimately, these focus group discussions were instrumental in aligning business models with agroecological principles and practices.

3.4. The SWOT analysis

Strengths:

Presence of Agro-ecological Practices:

Farmers employ numerous agroecological practices unknowingly, often as a result of longstanding farming traditions passed down through generations, as affirmed by Altieri, (1995) and Arrignon, (1987) that organic crop fertilisation, crop rotations, and biological pest management are all well-known agricultural techniques that have been in use for many years. However, over the last two decades, they have been increasingly referred to as agroecological practices.

Scientific and Institutional Support: There is significant support from scientific institutions and non-governmental organizations promoting agroecology. Initiatives such as those by ICARDA, FAO, GIZ, and local associations contribute to research, training, and capacity-building efforts (Lestrelin and Jaouadi, 2023).

Environmental and Economic Benefits: Agro-ecological practices offer numerous benefits, including soil health improvement, water conservation, economic profitability, diversification of income streams, and biodiversity conservation (Médiène *et al.*, 2011). These practices also enhance resilience to environmental challenges (Malézieux *et al.*, 2009; Jackson *et al.*, 2007; Tilman *et al.*, 2006; Loreau, 2000; Vandermeer *et al.*, 1998 , 2002) and contribute to climate change adaptation (Dittmer *et al.*, 2023).

Weaknesses:

Economic Barriers: Economic factors pose a significant barrier to the adoption of agro-ecological practices, including initial investment costs, lack of economic incentives, and financial constraints for small-scale farmers (Gava *et al.*, 2022; Rodriguez *et al.*, 2009).

Knowledge and Awareness Gap: Insufficient understanding and awareness about agroecology among farmers, coupled with limited access to training programs and information, hinder adoption efforts (Schwarz *et al.*, (2021); Kernecker *et al.*, (2021)).

Policy and Institutional Challenges: Existing agricultural policies favoring conventional practices, coupled with the absence of clear labeling or certification for agroecological products, create confusion and hinder adoption (Migliorini and Wezel, 2017). Additionally, the limited involvement of the government in promoting agroecology presents a challenge while some countries have started implementing policies specifically designed to support agroecology. Examples include Argentina, Brazil, France, India, Nicaragua, and Senegal, where policies have been enacted to facilitate transitions aligned with agroecological principles. These policies aim to diversify fields and diets, draft sectoral and cross-sectoral strategies, enhance agricultural research on agroecology, and promote exposure to agroecology in educational curricula (Le Coq *et al.*, 2020 ; Place *et al.*, 2022).

Opportunities:

Market Demand and Consumer Preferences: Increasing market demand for sustainable and organic products presents an opportunity for farmers practicing agro-ecological methods to access niche markets and command premium prices (Migliorini and Wezel, 2017).

Government Support and Policy Reform: Reforming agricultural policies to favor sustainable practices could facilitate widespread adoption. For exemple governments need to provide the necessary policy framework and funds to support sustainable farming systems, attract younger farmers, and adopt appropriate technologies for sustainability (Organisation for Economic Co-operation and Development, 2001).

Community Engagement and Collaboration:
Strengthening community-based initiatives and partnerships between farmers (cooperatives, associations...) for example local interfarm cooperation can serve as a foundation for implicit and informal sharing and management of immaterial resources (knowledge, social values and identity, collective responses and strategies to resist external pressures and regulations, etc.) (Emery, 2015; Lucas, 2018; Nicourt and Girault, 2006; Wynne-Jones, 2017). Scientists, and local associations can enhance knowledge-sharing, capacity-building, and adoption efforts at the grassroots level (FAO).

Threats:

Resistance to Change: Resistance to change among farmers, influenced by social norms, cultural attitudes, and perceptions of profitability, poses a threat to the widespread adoption of agro-ecological practices (Rodriguez *et al.*, 2009).

Lack of Government Support: Limited governmental involvement and absence of clear policies supporting agroecology present a significant threat to adoption efforts. Without adequate support, initiatives may struggle to gain momentum and achieve widespread impact (Parachini *et al.*, 2020).

Competing Agricultural Practices: Conventional farming methods, supported by existing agricultural policies and economic incentives, continue to compete with agro-ecological practices for exemple there's some policies tend to subsidize synthetic fertilizers and prioritize cash crops, rather than supporting agroecology initiatives (Parachini *et al.*, 2020). Farmers may opt for conventional methods due to perceived short-term gains or lack of alternatives. For exemple in USA a study shows that the transition towards agroecology can be perceived as risky by farmers due to an economic environment that generally favors conventional agriculture (Reed, 2004).

Table 14. Summary of the SWOT analysis (Source: Author's elaboration from analysis of field data, 2024).

Strengths	**Weaknesses**
- Presence of various agro-ecological practices - Scientific and institutional support - Environmental and economic benefits	- Economic barriers such as initial investment costs - Knowledge and awareness gap among farmers - Policy and institutional challenges
Opportunities	**Threats**
- Market demand for sustainable products - Government support and policy reform - Community engagement and collaboration	- Resistance to change among farmers - Lack of government support for agroecology - Competing conventional farming methods

Conclusion and Recommendations

This exploratory study provided a contextualization of agriculture in Hamam Biadha and Elles, focusing on landscape features, stakeholders, and characterizing farms within the scope of agroecology. It identified challenges and barriers that farmers are facing, evaluated their motivations and awareness regarding this transition, as well as the factors driving adoption. The study also defined current agroecological practices that could support an agroecological transition in the Tunisian transect. Agriculture in this area commonly relies on systems combining cereal-tree-small ruminant farming. Although farms demonstrated a relatively low integration of agroecology on average, there is room for improvement. However, it is important to consider the limitations of the framework; further adjustments could be made to include a broader range of variables and provide more accurate insights into farms' agroecological performances.
According to our results the analysis of agroecological drivers showed that the most commonly performed practices are traditional and inherent to the farm systems where they occur, such as rotation (65%), intercropping (60%) and composting (50%), the most common combinations of agroecological practices were inherent to the mixed farm systems. Most of the agroecological practices found were traditional: Rotation accounted for the highest percentage (65%), followed by manure (35%), and lastly, biochar (3%). Results reveal that farmers are facing several barriers. Drought emerged as the primary impediment to adoption of agroecological practices (100%), followed by resources access constraints (eg. organic inputs and local seeds) (60%) and market-related factors, such as trails and roads (25%). Future initiatives should prioritize cooperative support to facilitate the transition toward agroecological practices, and bolstering food system resilience. The study concludes that the adoption of agroecological practices has economic, political, social, and institutional components. Generally, most farmers (94%) are willing to adopt the majority of agroecological (AE) practices in the future. However, the constraints mentioned earlier make the path to adoption difficult for them.
The establishment of a supportive stakeholder in the form of a farmers' organization faces challenges due to a lack of trust among farmers. Therefore, the organization's goals must be clearly defined: whether to disseminate knowledge through training sessions, improve access to means of production like mechanization, provide inputs, or initially support agroecological value chains using farms already implementing agroecological practices. Additionally, creating a specific label or certification (Example DOP, Slow food etc....), especially for the olive oil value chain, could add significant value to the local product given its high production levels. Regardless of the chosen approach, establishing such a collaborative organization requires careful consideration of social dynamics among participants to ensure collective benefits and sustainable cooperation.
When it comes to making changes, to policies it's important to think about the impact. For example when implementing measures in agriculture it's essential to empower farmers so they feel a sense of ownership and continue using them. Using AE methods has shown promise in increasing household incomes reducing poverty and improving productivity (Manyanga *et al.*, 2023; Mouratiadou *et al.*, 2024). This presents opportunities for enhancing livelihoods. It's crucial to customize policies based on the needs of the target population, social connections, available technologies and the limitations are facing the farmers by prioritizing practices that are proven to be effective in the local context and

promote their adoption across the transect using well-performing farms as examples. In addition, offering subsidies for inputs could affect how widely AE practices are adopted and have implications for government support, in agricultural development.
As well, political support and investment in agroecological training, provision of resources, and access to agricultural equipment can facilitate the adoption of these practices among small-scale farmers (Coulibaly *et al.*, 2019). Moreover, further continuity of this research and additional investigation might be recommended to extend the number of stakeholders to be interviewed in order to consolidate the findings out of this research.

References

Abadi Ghadim A. and Pannell D. (1999). A conceptual framework of adoption of an agricultural innovation. *Agricultural Economics*, 21: 145–154. doi: 10.1016/S0169-5150(99)00023-7.

Adedibu P.A. (2023). Ecological problems of agriculture: impacts and sustainable solutions. *ScienceOpen Preprints*. doi: 10.14293/PR2199.000145.v1

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

Alary V., Frija A., Ouerghemmi H., Idoudi Z., Rudiger U., Rekik M., Souissi A., Dhehibi B., Bahri H. and Mekki I. (2023). Context document Tunisia. *Context Assessment for Transformation in the Tunisian Agroecological Living Landscape*. CGIAR.

ALiSEA. (2018). ALiSEA SGF Identifying Barriers in the Adoption of Agroecological Practices in Rural Laos. ALiSEA. *Agro-ecology Learning alliance in South East Asia*. Retrieved from https://ali-sea.org/item/alisea-sgf-identifying-barriers-in-the-adoption-of-agroecological-practices-in-rural-laos/.

Altieri M. and Nicholls C. (2012). Agroecology Scaling Up for Food Sovereignty and Resiliency. *Sustainable Agriculture Review*, Vol. 11, pp. 1–29. doi: 10.1007/978-94-007-5449-2_1.

Altieri M.A. (1995). *Agroecology: the science of sustainable agricultura*. Estados Unidos de América: WESTVIEW PRESS.

Amoak D., Luginaah I. and McBean G. (2022). Climate change, food security, and health: Harnessing agroecology to build climate-resilient communities. *Sustainability*, 14(21): 13954.

Arfa C. and Elgazzar H. (2013). *Consolidation and transparency*: Transforming Tunisia's health care for the Poor. World Bank, Washington DC.

ATLAS. (2013). *Ministère de l'équipement, de l'habitat : Atlas numériques des gouvernorats*. Retrieved March 31, 2024, from http://www.mehat.gov.tn/fr/principaux-secteurs/amenagement-du-territoire/schemas-directeurs-damenagement-des-territoires-et-atlas-cartographiques/atlas-numeriques-des-gouvernorats/.

Bezner Kerr R., Liebert J., Kansanga M. and Kpienbaareh D. (2022). Human and social values in agroecology: A review. *Elementa: Science of the Anthropocene*, 10(1): 90. University of California Press.

Cavanagh C.J., Chemarum A.K., Vedeld P.O. and Petursson J.G. (2017). Old wine, new bottles? Investigating the differential adoption of 'climate-smart' agricultural practices in western Kenya. *Journal of Rural Studies*, 56: 114–123. doi: 10.1016/j.jrurstud.2017.09.010.

CGIAR. (2023). *Co-creating a Timeline for Agroecological Transition in Tunisia*. Retrieved March 31, 2024, from https://www.cgiar.org/news-events/news/co-creating-a-timeline-for-agroecological-transition-in-tunisia/.

Chappell M.J., Bernhart A., Bachmann L., Gonçalves A.L., Seck S., Nandul P. and dos Santos A.C. (2018). *Agroecology as a pathway towards sustainable food systems*. MISEREOR IHR Hilfswerk.

Chatzimichael K., Genius M. and Tzouvelekas V. (2014). Informational cascades and technology adoption: Evidence from Greek and German organic growers. *Food Policy*, 49: 186–195. doi: 10.1016/j.foodpol.2014.08.001.

Chebbi H.E., Pellissier J.-P., Rolland J.-P. and Khechimi W. (2019). *Rapport de synthèse sur l'agriculture en Tunisie*.

Chebil A., Abbas K. and Frija A. (2014). Water Use Efficiency in Irrigated Wheat Production Systems in Central Tunisia: A Stochastic Data Envelopment Approach. *Journal of Agricultural Science*, 6:. doi: 10.5539/jas.v6n2p63.

Chebil A. and B A. (2012). Irrigation water use efficiency in collective irrigated schemes of Tunisia: determinants and potential irrigation cost reduction. *Agricultural Economics Review*, 13: 39–48.

CIDSE. (2018). *The Principles of Agroecology – CIDSE*. Retrieved March 31, 2024, from https://www.cidse.org/2018/04/03/the-principles-of-agroecology/.

Coulibaly A., Motelica-Heino M. and Hien E. (2019). Determinants of Agroecological Practices Adoption in the Sudano-Sahelian Zone. *Journal of Environmental Protection*, 10: 900–918. doi: 10.4236/jep.2019.107053.

Dhehibi B., Dhraief M.Z., Oueslati-Zlaoui M., Souissi A., Majri R., Frija A., Ouerghemmi H., Alary V., Ouji M. and Idoudi Z. (2022a). *Scoping study report on potential existing value chains in the North-West region of Tunisia*. International Center for Agricultural Research in the Dry Areas.

Dhehibi B., Dhraief M.Z., Oueslati-Zlaoui M., Souissi A., Majri R., Frija A., Ouerghemmi H., Alary V., Ouji M. and Idoudi Z. (2022b). *Value chain analysis and actors mapping: Case of Tunisia*. International Center for Agricultural Research in the Dry Areas.

Dhehibi B., Dhraief M.Z., Oueslati-Zlaoui M., Souissi A., Majri R., Frija A., Ouerghemmi H., Alary V., Ouji M. and Idoudi Z. (2022c). V*alue chain identification, prioritization and actors mapping in Kef ALL*. International Center for Agricultural Research in the Dry Areas.

Dhehibi B., Lachaal L., Elloumi M. and Messoud E. (2007). Measuring irrigation water use efficiency using stochastic production frontier: An application on citrus producing farms in Tunisia. *The African Journal of Agricultural and Resource Economics*, 1: 1–15.

Dhifallah S. (1970). Agroecological-economic system of Tunisia: an emergy analysis approach. WIT Transactions on Ecology and the Environment, 22:16.

Eisenack K., Moser S., Hoffmann E., Klein R., Oberlack C., Pechan A., Rotter M. and Termeer C.J.A.M. (2014). Explaining and overcoming barriers to climate change adaptation. *Nature Climate Change*, 4: 867–872. doi: 10.1038/NCLIMATE2350.

Emery S. (2015). Independence and individualism: conflated values in farmer cooperation? *Agriculture and Human Values*, 32. doi: 10.1007/s10460-014-9520-8.

FAO (2018a). *The 10 elements of agroecology*.

FAO (2018b). *FAO's work on agroecology: A pathway to achieving the SDGs*. Rome: FAO.

Feike T., Chen Q., Graeff S., Pfenning J. and Claupein W. (2010). Farmer-developed vegetable intercropping systems in southern Hebei, China. *Renewable Agriculture and Food Systems*, 25: 272–280. doi: 10.1017/S1742170510000293.

Ghali M., Ben Jaballah M., Ben Arfa N. and Sigwalt A. (2022). Analysis of factors that influence adoption of agroecological practices in viticulture. *Review of Agricultural, Food and Environmental Studies*, 103(3): 179–209. doi: 10.1007/s41130-022-00171-5.

Gliessman S.R. (2004). Agroecology and agroecosystems. *Agroecosystems analysis*, 43: 19–29.

Google Maps. (n.d.). Aerial view of Hammam biadha and Elles. *Google Maps*. Retrieved March 20, 2024, from https://www.google.it/maps/dir/Elles,+Tunisie/Hammam+Biadha+Nord,+Tunisie/@36.3432938,8.8925093,32084m/data=!3m1!1e3!4m14!4m13!1m5!1m1!1s0x12fb8c9ca53aac75:0x5e1a52848a570d20!2m2!1d9.0972012!2d35.9489092!1m5!1m1!1s0x12fb7010fb184cf9:0xe38c0d1fb71dd530!2m2!1d8.9797467!2d36.4329608!3e3?entry=ttu.

Griliches Z. (1957). Hybrid Corn: An Exploration in the Economics of Technological Change. *Econometrica*. 25(4): 501–522. doi: 10.2307/1905380.

Hayran S., Gul A., Saridas, M. A., and Donwload P. (2018). Farmers' sustainable agriculture perception in Turkey: The case of Mersin province. *New Medit*, 3: 69-78. DOI: 10.30682/nm1803f

Hogeveen H., Steeneveld W. and Wolf C. (2019). Production Diseases Reduce the Efficiency of Dairy Production: A Review of the Results, Methods, and Approaches Regarding the Economics of Mastitis. *Annual Review of Resource Economics*, 11: doi: 10.1146/annurev-resource-100518-093954.

Kernecker, M., Seufert, V., & Chapman, M. (2021). Farmer-centered ecological intensification: Using innovation characteristics to identify barriers and opportunities for a transition of agroecosystems towards sustainability. Agricultural Systems, 191: 103142. doi: 10.1016/j.agsy.2021.103142.

Kuhfuss L. and Subervie J. (2018). Do European agri-environment measures help reduce herbicide use? Evidence from viticulture in france. *Ecological economics*, 149: 202–211. doi: 10.1016/j.ecolecon.2018.03.015.

Latawiec A.E., Królczyk J.B., Kuboń M., Szwedziak K., Drosik A., Polańczyk E., Grotkiewicz K. and Strassburg B.B. (2017). Willingness to adopt biochar in agriculture: the producer's perspective. *Sustainability*, 9(4): 655. doi.org/10.3390/su9040655

de Lattre-Gasquet M., Moreau C., Elloumi M. and Ben Becher L. (2017). Vers un scénario « Des usages agro-écologiques des terres pour une alimentation diversifiée et de qualité et un système alimentaire territorialisé » en Tunisie en 2050. *OCL*, 24(3): 1-20. doi: 10.1051/ocl/2017025.

Lestrelin G. and Jaouadi R. (2023). *Inventory of agroecology related initiatives in Tunisia (1999–2023)*. International Center for Agricultural Research in the Dry Areas.

Lucas, V. (2018). *L'agriculture en commun: Gagner en autonomie grâce à la coopération de proximité: Expériences d'agriculteurs français en CUMA à l'ère de l'agroécologie* (Doctoral dissertation, Université d'Angers).

Majbar Z., El Madani F.-Z., Khalis M., Lahlou K., Ben Abbou M., Majbar E.B., Bourhia M., AL-Huqail A.A., El Askary A., Khalifa A.S., Ouahmane L., Taleb M., El Haji M. and Rais Z. (2021). Farmers' perceptions and willingness of compost production and use to contribute to environmental sustainability. *Sustainability*, 13(23). doi: 10.3390/su132313335.

Mamo T. and Bayih T. (2019). Perceptions of farmers on compost and chemical fertilizers in soil fertility improvement in Hawela Tula in Southern Ethiopia. *Archives of applied science research*, 11: 1–18.

Manyanga, M., Pedzisa, T., & Hanyani-Mlambo, B. (2023). Adoption of agroecological intensification practices in Southern Africa: A scientific review. Cogent Food & Agriculture, 9(1), 2261838. doi: 10.1080/23311932.2023.2261838

Mariano M.J., Villano R. and Fleming E. (2012). Factors influencing farmers' adoption of modern rice technologies and good management practices in the Philippines. *Agricultural Systems*, 110: doi: 10.1016/j.agsy.2012.03.010.

Marzin, J., Bonnet, P., Bessaoud, O., & Nu, C. T. (2016). Study on small-scale agriculture in the Near East and North Africa region (NENA): overview, CIHEAM-IAMM; FAO.

Mazibuko D.M., Gono H., Maskey S., Okazawa H., Fiwa L., Kikuno H. and Sato T. (2023). The sustainable niche for vegetable production within the contentious sustainable agriculture discourse: Barriers, opportunities and future approaches. *Sustainability*, 15(6): doi: 10.3390/su15064747.

Médiène S., Valantin-Morison M., Sarthou J.-P., de Tourdonnet S., Gosme M., Bertrand M., Roger-Estrade J., Aubertot J.-N., Rusch A., Motisi N., Pelosi C. and Doré T. (2011). Agroecosystem management and biotic interactions: A review. *Agronomy for Sustainable Development*, 31: 491–514. doi: 10.1007/s13593-011-0009-1.

Mekuria, W., Dessalegn, M., Amare, D., Belay, B., Getnet, B., Girma, G., & Tegegne, D. (2022). Factors influencing the implementation of agroecological practices: Lessons drawn from the Aba-Garima watershed, Ethiopia. *Frontiers in Environmental Science,* 10: 965408. doi.org/10.3389/fenvs.2022.965408

Migliorini P. and Wezel A. (2017). Converging and diverging principles and practices of organic agriculture regulations and agroecology. A review. *Agronomy for Sustainable Development*, 37: doi: 10.1007/s13593-017-0472-4.

Milheiras S. G., Sallu S. M., Loveridge R., Nnyiti P., Mwanga L., Baraka E., and Pfeifer M. (2022). Agroecological practices increase farmers' well-being in an agricultural growth corridor in Tanzania. Agronomy for Sustainable Development, 42(4): *Political Agroecology: Advancing the Transition to Sustainable Food Systems* doi: 10.1201/9780429428821.

Moser S. and Ekstrom J. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the national academy of sciences of the United States of America* 107: 22026–31. doi: 10.1073/pnas.1007887107.

Mouratiadou I., Wezel A., Kamilia K., Marchetti A., Paracchini M.L. and Bàrberi P. (2024). The socio-economic performance of agroecology. A review. *Agronomy for Sustainable Development*, 44(2): 1–21. Springer. doi: 10.1007/s13593-024-00945-9.

Mthembu B.E., Everson T.M. and Everson C.S. (2018). Intercropping maize (Zea mays L.) with lablab (Lablab purpureus L.) for sustainable fodder production and quality in smallholder rural farming systems in South Africa. *Agroecology and sustainable food systems*, 42(4): 362–382. doi: 10.1080/21683565.2017.1393649

ben nasr J., Chaar H., Bouchiba F. and Zaibet L. (2021). Assessing and building climate change resilience of farming systems in Tunisian semi-arid areas. *Environmental Science and Pollution Research*, 28: 1–12. doi: 10.1007/s11356-021-13089-0.

Nicolétis É., Caron P., El Solh M., Cole M., Fresco L.O., Godoy-Faúndez A., Kadleciková M., Kennedy E., Khan M. and Li X. (2019). *Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition.* A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. FAO.

Nicourt C. and Girault J.-M. (2006). Une co-construction territoriale des règles du travail d'éleveur? Économie rurale. *Agricultures, alimentations, territoires*, (291): Société Française d'Économie rurale. doi :10.4000/economierurale.598

Niemmanee T., Kunya B. and Nindam T. (2019). Farmer's perception, knowledge and attitude toward the use of biochar for agricultural soil improvement in Amphawa district, Samut Songkhram province. IEEA (19): *Proceedings of the 8th International Conference on Informatics, Environment, Energy and Applications*, p. 43. doi: 10.1145/3323716.3323758.

OCDE. (2013). *Global Food Security*. doi: 10.1787/9789264195363-en.

ODNO. (2022). *Office de Développement du Nord-Ouest*. Retrieved March 10, 2024, from https://odno.nat.tn/.

Ogindo H. and Walker S. (2005). Comparison of measured changes in seasonal soil water content by rainfed maize-bean intercrop and component cropping systems in a semi-arid region of southern Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, 30: 799–808. doi: 10.1016/j.pce.2005.08.023.

Organisation for Economic Co-operation and Development. (2001). *Adoption of Technologies for Sustainable Farming Systems: Wageningen Workshop Proceedings : Agriculture and Food.* Organisation for Economic Co-operation and Development. Retrieved from https://books.google.it/books?id=PoptMgAACAAJ.

Pannell D., Marshall G., Barr N., Curtis A., Vanclay F. and Wilkinson R. (2006). Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture - AUST J EXP AGR*, 46: doi: 10.1071/EA05037.

Parachini M., Justes E., Wezel A., Zingari P.C., Kahane R., Madsen S., Scopel E., Héraut A., Bhérer-Breton P. and Buckley R. (2020). *Agroecological practices supporting food production and reducing food insecurity in developing countries.* Joint research Center, Commission Européenne.

Place F., Niederle P., Sinclair F., Estrada-Carmona N., Gueneau S.G.E., Gitz V., Alpha A., Sabourin E. and Hainzelin E. (2022). *Agroecologically-conducive policies: A review of recent advances and remaining challenges*, 1: doi: 10.17528/cifor-icraf/008593.

Ploeg J.D. van der, Barjolle D., Bruil J., and Wezel A. (2019). The economic potential of agroecology: Empirical evidence from Europe. *Journal of Rural Studies*, 71: 46–61. doi: 10.1016/j.jrurstud.2019.09.003.

Polonio A. and Rahmani D. (2021). Adoption and diffusion of agroecological practices in the horticulture of Catalonia. *Agronomy*, 11: 1959. doi: 10.3390/agronomy11101959.

Raney T., Anríquez G., Croppenstedt A., Gerosa S., Lowder S.K., Matuschke I. and Skoet J. (2011). The role of women in agriculture. *ESA Working Papers*. Food and Agriculture Organization of the United Nations, Agricultural Development Economics Division (ESA). Retrieved from https://ideas.repec.org//p/ags/faoaes/289018.html.

Reed M. (2004). *More than just fashionable foods-the importance of the social sciences in organic research*.

Rodriguez J., Molnar J., Fazio R., Sydnor E. and Lowe M. (2009). Barriers to adoption of sustainable agriculture practices: Change agent perspectives. *Renewable Agriculture and Food Systems*, 24: 60–71. doi: 10.1017/S1742170508002421.

Schoonhoven Y. and Runhaar H. (2018). Conditions for the adoption of agro-ecological farming practices: a holistic framework illustrated with the case of almond farming in Andalusia. *International Journal of Agricultural Sustainability*, 16: 1–13. doi: 10.1080/14735903.2018.1537664.

Schwarz G., Prazan J., Landert J., and Smith P. (2021). *Report on key barriers of agro-ecological farming systems in Europe and co-constructed Strategies*. doi: 10.5281/zenodo.5549542.

Shimi A. (2014). *Enjeux sociaux, économiques et politiques d'utilisation des ressources en eau dans le Nord-Ouest tunisien*. (Doctoral dissertation, Paris 1).

Silici L. (2014). Agroecology what it is and what it has to offer. *International Institute for Environment and Development issue paper.*

Sinaga R., Lubis M., Nasution F. and Sembiring E. (2022). The challenges of implementing agroecology as a social movement by members of The Serikat Petani Indonesia. Presented at the IOP Conference Series: Earth and Environmental Science, *IOP Publishing*, 1115: p. 012101. doi: 10.1088/1755-1315/1115/1/012101

Sinyangwe S., Mwamakamba S., Mkandawire R. and Madzivhandila T. (2023). *Opportunities and challenges for the promotion of transitions to agroecological practices for sustainable food production in Sub-Sahara Africa*. Preprints. doi: 10.20944/preprints202305.0009.v1.

Souza, B. D. J., Lopes do Carmo, D., Silva Santos, R. H., & Alves Fernandes, R. B. (2018). Perceptions of agroecological farmers on green manure use in Southeast Minas Gerais, Brazil. Idesia (Arica), 36(3), 15-25. doi.org/10.4067/S0718-34292018005000902

Tankoano M.E. and Sawadogo M. (2022). *Farmers' perceptions and adoption of agroecological practices in the Central-North region of Burkina Faso*. 3: 2658-931.

Vandermeer J., Lawrence D., Symstad A. and Hobbie S. (2002). Effect of biodiversity on ecosystem functioning in managed ecosystems. *Biodiversity and ecosystem functioning: synthesis and perspectives. Oxford University Press, Oxford*, 221–233.

Vandermeer J., van Noordwijk M., Anderson J., Ong C. and Perfecto I. (1998). Global change and multi-species agroecosystems: Concepts and issues. *Agriculture, Ecosystems & Environment*, 67(1): 1–22. doi: 10.1016/S0167-8809(97)00150-3.

Viaene J., Van Lancker J., Vandecasteele B., Willekens K., Bijttebier J., Ruysschaert G., De Neve S. and Reubens B. (2016). Opportunities and barriers to on-farm composting and compost application: A case study from northwestern Europe. *Waste Management*, 48: 181–192.

Wezel A., Casagrande M., Celette F., Vian J.-F., Ferrer A. and Peigné J. (2014). Agroecological practices for sustainable agriculture. A review. *Agronomy for sustainable development*, 34(1): 1–20. doi: 10.1007/s13593-013-0180-7

Wezel A., Gemmill-Herren B., Kerr R., Barrios E., Luiz A., Gonçalves R. and Sinclair F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development*, 40: 1–13. doi: 10.1007/s13593-020-00646-z.

Wibbelmann M., Schmutz U., Wright J., Udall D., Rayns F., Kneafsey M., Trenchard L., Bennett J. and Lennartsson M. (2013). *Mainstreaming Agroecology: Implications for Global Food and Farming Systems*. Coventry University. doi: 10.13140/RG.2.1.1047.5929.

Wynne-Jones S. (2017). Understanding farmer co-operation: Exploring practices of social relatedness and emergent affects. *Journal of Rural Studies*, 53: doi: 10.1016/j.jrurstud.2017.02.012.

Yadav S.K., Banerjee A., Jhariya M.K., Raj A., Khan N., Meena R.S. and Kumar S. (2021). Agroecology towards environmental sustainability. *Sustainable intensification for agroecosystem services and management*, 323–352.

Annexes

Annex 1 Farmer survey

Survey questionnaire

Investigator	
Governorate	
Region	

1. Farmer Identification

1= Name and surname	
2= Phone number	
3= Age	
4= Gender	*1= Man, 2= Woman*
5= Education level	*1= Illiterate ;* *2= Primary ;* *3= Secondary ;* *4= Professional training;* *5= University*
6= Household size	
7= Household location	*1= In the farm; 2= far about ....Km*
8= Farming activity	*1=Primary source, 2=Secondary source*
9= Land ownership	*.........Ha*
10= Monthly income	*1= >600DNT ; 2= 601-1200 ; 3= 1201-2000 ;* *4= 2000-3000 ;5= >3000*

2. Operating characteristics

Occupation		*14= Olive trees*	*13= Forage crop/Cereals*	*12= Fruit trees*	*11= Vegetables*
Area in Ha	*Irrigated*				
	Rainfed				
Yield / Ha (of the last year)					
Sale (%)					
Own-consumption (%)					

Livestock (head)	*17= Goat :*	*16= Sheep :*	*15= Cattle :*

33= Variety of olive trees:...

18= a/ Are you familiar with AE practices?	*1= Yes; 2=No*

19= b/ What kind of AE practices are used?	*1= Composting* *2= Biochar* *3= Intercropping (legume/ cereals/ sulla ...)* *4= Fodder seed production* *5= Biofertilization (Rhizobium)* *6= Animal health (no antibiotic/ local fodder...)* *7= Recycling (Exple: Use of olive trees by-products...)* *8= Inputs reduction (Minimizing the usage of chemicals inputs)* *9= Manure* *10= Rotation* *11= Zero (semi direct) or minimum tillage* *12= Weed management under conservation agriculture* *13= Biodiversity (Caroube/Meliferous Crops for Beekeeping...)* *14= Others...*

20= c/ If no, what are the barriers that hinder you from using AE practices?	*Acceptance level (1: Strongly agree....5: Strongly disagree)*				
Factors affecting acceptance	*1*	*2*	*3*	*4*	*5*
1= Insufficient Policy Support					
2= Lack of extension services/ technical support					
3= Lack of knowledge					
4= Large cultivated area					
5= Lack of access to resources (Organic inputs, local seeds...)					
6= Limited means of production (Machines, labor...)					
7= Market access and demand (Trails...)					
8= Poor infrastructure					
9= Climate change (drought)					
10= Other...					

3. Technology awareness and it's assimilation (Acceptance and adoption):

AE practices	*21= Have you heard talk about this technology?*	*22= Have you ever used this technology?*	*23= If not at the qst 2, what is the main reason?*	*24= Main source of information on this technology?*	*25= Number years (total) for the use of this technology?*	*26= Who makes the decision of adoption?*	*27= What is the main source of technology used this year? (if not the last time it was used)*	*28= Is that you plan to use the technology in the future?*	*29= If not, what is the main reason?*
Compost	*1= Yes; 2=No;*	*1= Yes; 2=No;*	*A Code*	*B Code*	………..	*C Code*	*D Code*	*1= Yes;* *2= No;*	*A Code*
Biochar					…………				
Intercropping					………….				

A code	*AE Practices*														
	Compost					*Biochar*					*Intercropping*				
Technical barriers	*Level of acceptance (1: Strongly agree…..5: Strongly disagree)*														
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
1= Unavailable practice															
2= No cash to buy this technology/ Practice															
3= No credit to make this technology															
4= I prefer other technologies															
5= Practice's complexity															
6= Limited access to inputs															
7= Low yield/ Not effective															
8= Limited information (Knowledge, information asymmetry…)															
9= Other……………………..															

B code	*AE Practices*		
	Compost	*Biochar*	*Intercropping*
Information sources			
1= Extension SMS			
2= Extension/ office staff			
3= Other farmers (neighbors/ relative)			
4= Market			
5= Radio/ TV programs			
6= Research center (trials/demos)			
7= NGO or government. Develop. Assistance			

C code	*AE Practices*		
	Compost	*Biochar*	*Intercropping*
Decision maker			
1= Head of household			
2= Spouse			
3= Head of household and spouse jointly			
4= Others............................			

D code	*AE Practices*		
	Compost	*Biochar*	*Intercropping*
Source of the practices			
1= Own production/ Ownership			
2= Other farmers in the village			
3= Cooperatives			
4= Extension staff demonstration			
5= Other.............................			

A code	*AE Practices*														
	Compost					*Biochar*					*Intercropping*				
Technical barriers	*Level of acceptance (1: Strongly agree.....5: Strongly disagree)*														
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
1= Unavailable practice															
2= No cash to buy this technology/ Practice															
3= No credit to make this technology															
4= I prefer other technologies															
5= Practice's complexity															
6= Limited access to inputs															
7= Low yield/ Not effective															
8= Limited information (Knowledge, information asymmetry...)															
9= Other.........................															

4. ***Motivations and limitations of adopting AE practices:***

AE practices	*30= Ask for their perception of the performance of the technology(ies)*				*31= How would you rate your own ability to adapt (technology/ practice) to the next season in terms of*			*32= How dependent are you on your environment/ others to be able to adopt this technology?*
	1= Access	*2= Knowledge needed*	*3= Cost of adoption*	*4= Intensity of work if adoption*	*1= Your personal skills and knowledge*	*2= Your capacity to pay for inputs or required resources*	*3= Availability of inputs or some resources required*	
Compost								*F code*
Biochar								
Intercropping								

E code
1= Very bad
2= Bad
3= Regular
4= Good
5= Very good

F code	*AE Practices*		
	Compost	*Biochar*	*Intercropping*
1= I only depend on me			
2= Depends to a small extent			
3= Depends to a large extent			

Annex 2 Key informant interview

Unveiling Agro-Ecological Frontiers: Understanding Challenges, Barriers, and Determinants in the Tunisian Transect "Siliana el Kef"

The objective of my research is to explore the challenges, barriers, and determinants influencing farmers' adoption of agro-ecological practices in the Tunisian transect "Siliana el Kef." It also seeks to measure farmers' perceptions and examine the factors that shape their decisions regarding the adoption or dis-adoption of agro-ecological practices.

Adresse e-mail

....
....

Name, Surname

....
....

Position

....
....

Affiliation / Organization / Institution

....
....

1/ What are the key agro-ecological practices that farmers in the Transect are aware of?

....
....

2/ How do farmers perceive the benefits and advantages of agro-ecological practices compared to conventional farming methods?

....
....

3/ What are the primary barriers that hinder farmers from adopting agro-ecological practices in the Transect el Kef-Siliana? (Economic, social, cultural, etc...)

……

……

4/ What factors influence farmers' decision-making processes when considering the adoption of agro-ecological practices? (Economic incentives, environmental concerns, policy support, etc…)

……

……

5/ Are there any governmental or non-governmental initiatives that have been successful in promoting the adoption of agro-ecological practices among farmers?

……

……

6/ What impact do agro-ecological practices have on the environment, farmers' livelihoods, and overall agricultural productivity in Tunisia?

……

……

Annex 3 Analysis of data in SPSS

Gender

		Fréquence	Pourcentage	Pourcentage valide	Pourcentage cumulé
Valide	Man	34	85,0	85,0	85,0
	Woman	6	15,0	15,0	100,0
	Total	40	100,0	100,0	

Education level

		Fréquence	Pourcentage	Pourcentage valide	Pourcentage cumulé
Valide	Illiterate	5	12,5	12,5	12,5
	Primary	19	47,5	47,5	60,0
	Secondary	10	25,0	25,0	85,0
	Professional training	1	2,5	2,5	87,5
	University	5	12,5	12,5	100,0
	Total	40	100,0	100,0	

Household size

		Fréquence	Pourcentage	Pourcentage valide	Pourcentage cumulé
Valide	1,0	1	2,5	2,5	2,5
	2,0	1	2,5	2,5	5,0
	3,0	5	12,5	12,5	17,5
	4,0	9	22,5	22,5	40,0
	5,0	12	30,0	30,0	70,0
	6,0	8	20,0	20,0	90,0
	7,0	3	7,5	7,5	97,5
	8,0	1	2,5	2,5	100,0
	Total	40	100,0	100,0	

Monthly income

		Frequency	Percentage	Valid percentage	Cumulative percentage
Valid	600<	22	55,0	55,0	55,0
	601-1200	13	32,5	32,5	87,5
	1201-2000	4	10,0	10,0	97,5
	2000-3000	1	2,5	2,5	100,0
	Total	40	100,0	100,0	

Tableau croisé Age * Gender

		Gender		Total
		Man	Woman	
<29	Effectif	2	1	3
	% dans Age	66,7%	33,3%	100,0%
	% du total	5,0%	2,5%	7,5%
	Résidus ajustés	-,9	,9	
30-45	Effectif	10	3	13
	% dans Age	76,9%	23,1%	100,0%
	% du total	25,0%	7,5%	32,5%
	Résidus ajustés	-1,0	1,0	
46-60	Effectif	11	2	13
	% dans Age	84,6%	15,4%	100,0%
	% du total	27,5%	5,0%	32,5%
	Résidus ajustés	,0	,0	
61<	Effectif	11	0	11
	% dans Age	100,0%	0,0%	100,0%
	% du total	27,5%	0,0%	27,5%
	Résidus ajustés	1,6	-1,6	

Tableau croisé Area * Ft Area

			Ft Area			Total
			0	Irrigated	Rainfed	
Area	Elles	Effectif	15	1	0	16
		% dans Area	93,8%	6,3%	0,0%	100,0%
		% du total	37,5%	2,5%	0,0%	40,0%
		Résidus ajustés	-,3	1,2	-,8	
	Hamem biadha	Effectif	23	0	1	24
		% dans Area	95,8%	0,0%	4,2%	100,0%
		% du total	57,5%	0,0%	2,5%	60,0%
		Résidus ajustés	,3	-1,2	,8	
Total		Effectif	38	1	1	40
		% dans Area	95,0%	2,5%	2,5%	100,0%
		% du total	95,0%	2,5%	2,5%	100,0%

Tableau croisé Area * Vg Area

			Vg Area			Total
			0	Irrigated	Rainfed	
Area	Elles	Effectif	10	6	0	16
		% dans Area	62,5%	37,5%	0,0%	100,0%
		% du total	25,0%	15,0%	0,0%	40,0%
		Résidus ajustés	-2,7	3,3	-,8	
	Hamem biadha	Effectif	23	0	1	24
		% dans Area	95,8%	0,0%	4,2%	100,0%
		% du total	57,5%	0,0%	2,5%	60,0%
		Résidus ajustés	2,7	-3,3	,8	
Total		Effectif	33	6	1	40
		% dans Area	82,5%	15,0%	2,5%	100,0%
		% du total	82,5%	15,0%	2,5%	100,0%

Tableau croisé Area * Fc Area

			Fc Area			Total
			0	Irrigated	Rainfed	
Area	Elles	Effectif	1	14	1	16
		% dans Area	6,3%	87,5%	6,3%	100,0%
		% du total	2,5%	35,0%	2,5%	40,0%
		Résidus ajustés	-2,0	5,7	-3,8	
	Hamem biadha	Effectif	8	0	16	24
		% dans Area	33,3%	0,0%	66,7%	100,0%
		% du total	20,0%	0,0%	40,0%	60,0%
		Résidus ajustés	2,0	-5,7	3,8	
Total		Effectif	9	14	17	40
		% dans Area	22,5%	35,0%	42,5%	100,0%
		% du total	22,5%	35,0%	42,5%	100,0%

Tableau croisé Area * O Area (HA)

			O Area (HA)			Total
			0	Irrigated	Rainfed	
Area	Elles	Effectif	6	10	0	16
		% dans Area	37,5%	62,5%	0,0%	100,0%
		% du total	15,0%	25,0%	0,0%	40,0%
		Résidus ajustés	3,3	4,5	-6,3	
	Hamem biadha	Effectif	0	0	24	24
		% dans Area	0,0%	0,0%	100,0%	100,0%
		% du total	0,0%	0,0%	60,0%	60,0%
		Résidus ajustés	-3,3	-4,5	6,3	
Total		Effectif	6	10	24	40
		% dans Area	15,0%	25,0%	60,0%	100,0%
		% du total	15,0%	25,0%	60,0%	100,0%

Heard-Compost

		Fréquence	Pourcentage	Pourcentage valide	Pourcentage cumulé
Valide	yes	27	67,5	67,5	67,5
	no	13	32,5	32,5	100,0
	Total	40	100,0	100,0	

Heard-Biochar

		Fréquence	Pourcentage	Pourcentage valide	Pourcentage cumulé
Valide	yes	10	25,0	25,0	25,0
	no	30	75,0	75,0	100,0
	Total	40	100,0	100,0	

Heard-Intercrop

		Fréquence	Pourcentage	Pourcentage valide	Pourcentage cumulé
Valide	yes	27	67,5	67,5	67,5
	no	13	32,5	32,5	100,0
	Total	40	100,0	100,0	

Production	Olive trees	Forage crops and cereals	Fruit trees	Vegetables
Yield (T/Ha)	234,5	121,4	3	72,5

Statistiques

		Composting	Biochar	Intercropping	Fodder seed production	Biofertilization	Animal health	Recycling	Input reduction	Manure	Rotation	Zero tillage	Weed management	Biodiversity	Others
N	Valide	40	40	40	40	40	40	40	40	40	40	40	40	40	40
	Manquant	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moyenne		50%	3%	60%	53%	38%	5%	10%	40%	35%	65%	30%	5%	13%	0%
Ecart type		,5064	,1581	,4961	,5057	,4903	,2207	,3038	,4961	,4830	,4830	,4641	,2207	,3349	0,000
Minimum		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Maximum		1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,0

Are you familiar with AE practices?

		Fréquence	Pourcentage	Pourcentage valide	Pourcentage cumulé
Valide	Yes	21	52,5	52,5	52,5
	No	19	47,5	47,5	100,0
	Total	40	100,0	100,0	

Annex 4 Photos from the fieldtrips and workshops

Workshop in Kef about the business model of olive oil value chain 10/10/2023

Workshop in Siliana about the business model of olive oil value chain 11/09/2023

Design a business model in Siliana during the workshop

Field visit in "El Krib" 06/12/2023