

Agroecological Transition in the Kébili Oasis: Insights from the NATAE Field School

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ABSTRACT

Context, Research Problem, Practical and Theoretical Background

Traditional agroecological systems form critical infrastructure for ecological resilience and rural livelihood sustainability in arid environments amid accelerating climate change and variability, embedding generations of knowledge on resource management, biodiversity conservation, and adaptive strategies honed through interaction with complex arid ecosystems [1,2]. Yet, these systems face mounting threats from agricultural intensification, groundwater overexploitation, soil degradation, demographic shifts, and climate-driven water scarcity [3,4]. The Kebili Oasis in southwestern Tunisia (33°42'N, 6°38'E), spanning 22,450 km² with 170,402 inhabitants, exemplifies this dynamic as a pastoral-oasis system sustained by the Terminal Complex (CT) and Continental Intercalary (CI) aquifers, vital yet finite resources vulnerable to intensified extraction [5,6]. Its traditional three-strata polyculture date palms (*Phoenix dactylifera* L.) in the upper layer, fruit trees and vegetation in the middle, and market gardens with herbs below optimizes scarce water through complementary root zones and transpiration, while preserving soil organic matter via continuous cover and upholding agrobiodiversity for household food security and income [1,2]. This equilibrium now frays under interacting stressors: monoculture-driven intensification with heavy inputs, salinization and organic matter loss, hydrological imbalances from overexploitation, urban land conversion, and climate-exacerbated aridity via higher temperatures, erratic rains, and elevated evaporation. This study bridges a key knowledge-action gap: despite broad recognition of traditional agroecology's value, pathways to bolster it against change lack practical support from policy and institutions. The research frames three linked challenges ecological sustainability, knowledge integration prioritizing inclusion of youth, women, and cooperatives often sidelined in decisions and governance reform. The Kebili Replication Lab (RL) tackles these through participatory action research: field diagnosis of practices and knowledge, capacity-building workshops, co-design for water management, crop diversification, and product valorization, iterative field-tested feedback, and governance experiments aligning farmers, cooperatives, water associations, government, markets, and civil society.

Keywords: Agroecology, Oasis, Water Management, Participatory Approach, Tunisia

Purposes and Questions

This participatory diagnostic aimed to analyze agroecological practices within the Kébili oasis system, to identify challenges

and opportunities for sustainable agricultural transformation, to assess stakeholder roles in agroecological transition processes and to generate context-specific recommendations for scaling strategies. Key research questions addressed: How can ecological sustainability be ensured when natural resources are severely limited by overexploitation and climate stress? What roles can

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traditional knowledge, youth, women, and farmer cooperatives play in agroecological transition? How can public policies and development projects support resilient and equitable resource management in oasis territories?

Design, Methodology, Approach

The study employed participatory diagnosis during the NATAE Field School (12th to 19th April, 2025), combining qualitative and systems-thinking approaches suited to understanding complex social-ecological dynamics. Data collection comprised first 25 semi-structured interviews with farmers, Agricultural Development Groups “Groupement de Développement Agricole” (GDA), technical center staff, and local authorities, conducted across three thematic areas, biodiversity conservation, water management practices, and agricultural value chains. Second, direct field observations documenting farming practices, soil conditions, water infrastructure, and land-use patterns and finally, participatory visits to diverse oasis typologies including traditional oases, modern extensions, women’s GDAs, and the “Centre Technique des Dattes” (CTD).

Analytical methods included: SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis to assess internal and external factors influencing agroecological transition, problem tree analysis to identify causal chains and dynamic territorial modelling to visualize interactions between system components.

Findings

The participatory field diagnostic identified a diverse portfolio of agroecological practices employed by oasis farmers. These include agroforestry systems integrating date palms (*Phoenix dactylifera* L.) with fruit trees and complementary vegetation, intercropping of cereals on farm compounds in combination with livestock and utilisation of palm waste and animal manure for soil amendment, alongside value-added use of date by-products for livestock feeding. These practices represent generations of accumulated agroecological knowledge, continuously adapted to local arid and semi-arid conditions [1,2].

The SWOT analysis (Figure 1) revealed a complex agroecological system characterised by significant strengths alongside critical vulnerabilities.

- **Strengths:** The system demonstrates remarkable resilience grounded in deep traditional knowledge specifically adapted to arid conditions. Notable strengths include the unique multi-functional integration of light, water, and soil utilisation across agro-artisanal production units, exceptional agro-biodiversity, and demonstrated capacity to withstand extreme climatic variability and water stress.
- **Weaknesses:** The system faces structural constraints including: limited access to appropriate innovation and agricultural financing; progressive erosion of ancestral agroecological practices among younger generations; low economic valorisation of traditional oasis products in regional and international markets; and increasing dependency on external inputs incompatible with agroecological principles.
- **Opportunities:** Emerging policy support for agroecology at national and regional levels creates new opportunities for oasis system development [3,5]. Additional opportunities include: development of organic and fair-trade market

channels; potential for collaborative participatory research and learning networks; and international engagement through platforms including NATAE, RFIMA, and RADA0 [7].

- **Threats:** The oasis agroecological system faces severe and escalating threats. These include accelerated resource degradation affecting water availability, soil functionality, and agrobiodiversity; intensifying competition from standardised industrial agriculture systems; climate change-induced water scarcity affecting irrigation feasibility; and physical encroachment by urban expansion and land use conversion [3,4]. These threats collectively undermine the sustainability of traditional oasis farming systems.

The field diagnostic findings reveal oasis agroecological systems that represent sophisticated, context-specific adaptations to arid environments, incorporating multiple knowledge systems and demonstrating long-term resilience. The identified practices align with agroecological principles emphasizing ecosystem services, biodiversity, and resource cycling [2]. However, the SWOT analysis indicates that despite significant agroecological strengths, oasis systems face an asymmetrical vulnerability profile characterised by systemic threats outweighing emerging opportunities. This suggests that without policy intervention and targeted support, traditional knowledge-based systems may continue to erode. The sustainability assessment framework indicates that comprehensive evaluation using tools such as SAFA (Sustainability Assessment of Food and Agriculture Systems) would provide quantitative evidence of system performance across ecological, economic, and social dimensions [6]. The identification of policy opportunities, particularly through national strategy frameworks and international collaborative platforms suggests viable pathways for strengthening oasis agroecological systems. Participatory research approaches combined with strategic policy support could transform current vulnerabilities into adaptive capacity and enhance system resilience under climate change scenarios [8,4].

Figure 2 showed water scarcity and system fragility. The problem tree analysis identified water scarcity as the central constraint with multiple interconnected root causes. Primary causes include: uncontrolled proliferation of illegal boreholes, intensified by solar-powered pumping since 2019, causing aquifer drawdown; poor irrigation management with 30-40% water losses in traditional flood irrigation; inadequate institutional coordination preventing integrated planning; increasing water salinity; and climate change reducing precipitation whilst prolonging droughts. These pressures generate a cascade of negative consequences. Facing declining water availability and rising extraction costs, farmers increasingly abandon traditional three-strata polyculture in favor of mono-varietal Deglet Nour cultivation, abandoning indigenous cultivars. This compromises biodiversity, reduces resilience to pests and diseases, and triggers greater reliance on phytosanitary treatments—escalating costs, polluting soil and water, and threatening health. Economically, the system faces declining yields, reduced quality, and insufficient incomes, driving rural exodus. Youth out-migration is particularly pronounced.



Figure 1: SWOT Analysis of Agroecological Transition in Kébili Oasis

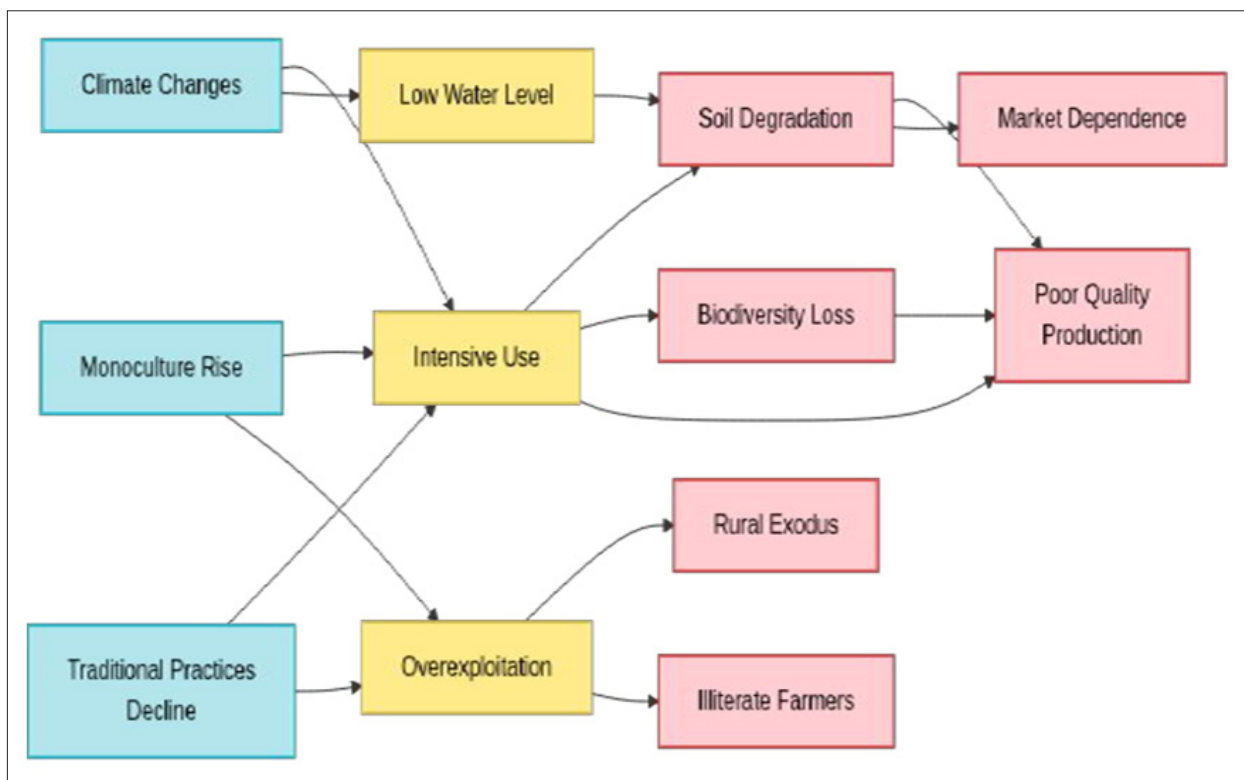


Figure 2: Problem Tree - Root Causes of Agricultural System Degradation in Kébili Oasis

Dynamic territorial model analysis revealed critical interactions across five dimensions: water resource availability shaped by aquifer depletion, salinity, and climate; energy transition enabling solar-powered extraction but amplifying overexploitation; land-use change from polyculture to monoculture, driving fragmentation; socio-economic pressures from market volatility, inadequate post-harvest infrastructure, and poor price coordination; and social dynamics including gender roles, knowledge transmission failures, and limited collective action.

The analysis revealed divergence between traditional and modern oases. In established oases, water stress drives system simplification and abandonment. In modern extensions with better water access, some farmers experimentally restore three-strata systems whilst concentrating in high-value Deglet Nour monoculture, creating tension between resilience and profitability. Moreover, merging local

initiatives demonstrate women's GDAs valorizing palm products; youth experimenting with agroecological methods and farmer associations implementing water-efficient irrigation. However, these remain dispersed without structural support and market linkages. The findings underscore the importance of recognising oasis agroecological systems as legitimate, knowledge-intensive production systems deserving of targeted policy and financial support to ensure their continued viability for food security, rural livelihoods, and environmental conservation in North African arid regions.

Practical Implications

Agroecological transition in oasis systems demands integrated approaches bridging farm-level implementation, policy reform, and development practice. The documented three-strata agroforestry systems constitute validated, climate-adaptive models for ecological restoration, operationalized through first, the adoption of water-efficient micro-irrigation technologies reducing consumptive use by 40 to 60% whilst maintaining crop yields. Second, the systematic polyculture restoration through intercropping climate-resilient varieties, third the integrated soil conservation combining organic matter amendment with controlled mulching to reduce synthetic chemical dependency; and finally, the institutional strengthening of farmers' cooperatives (GDAs) for equipment-sharing, coordinated marketing, and knowledge exchange. Concurrently, policymakers must implement urgent water governance reforms through strict regulatory enforcement against unauthorized extraction and evidence-based allocation quotas reflecting aquifer recharge rates; strategic investment in post-harvest infrastructure enabling value addition and income stabilization; legislative reform addressing land fragmentation through protective frameworks securing oasis integrity; and targeted youth engagement plans combining agroecological training with innovation subsidies and entrepreneurship support.

Development practitioners must operationalize these transitions through participatory methodologies validating farmers' traditional ecological knowledge alongside scientific innovation, dedicated programming for women's economic empowerment within cooperative structures and value chains, establishment of formal intergenerational knowledge transmission mechanisms

linking elder farmers with youth through apprenticeships and farmer field schools and also creation of multi-stakeholder engagement platforms institutionalizing coordination among farmers, local authorities, extension services, and market actors for adaptive governance of shared resources. This integrated three-tier approach, connecting farm-level innovation, policy enabling conditions, and practitioner-led implementation, anchors agroecological transition in oasis contexts within coherent frameworks of social-ecological resilience, inclusive governance, and sustainable livelihood security.

Theoretical Implications

This research adds theoretical insights to agroecology. It shows that, in resource-poor areas, sustainable change needs a deliberate mix of traditional ecological knowledge and modern science and technology. It also suggests that local farming systems, although adapted to their environments, still need outside support in terms of innovation, funding, market access, and public policies to face industrial agriculture and cope with new climate conditions. Second, social-ecological resilience, the dynamic territorial model illustrates frameworks conceptualizing agricultural systems as coupled social-ecological arrangements where biophysical factors interact with social structures (institutions, ancestral knowledge, markets, governance).

Analysis validates resilience theory propositions that diversity (crop variety, livelihood diversification, stakeholder heterogeneity) and adaptive capacity (innovation, learning, flexibility) are fundamental for sustainability. Biodiversity decline and the expansion of monocultures indicate a reduction in the system's adaptive capacity. Commons governance, illustrated by documented water governance failures and overuse despite shared institutions, highlights the difficulties of collective resource management under weak institutions, unequal access to information, and strong external pressures. These findings reinforce work on sustainable commons, which stresses the need to align institutions, resource characteristics, diverse user groups, and broader governance settings. Finally, the participatory field school confirms that action research is effective for producing locally grounded knowledge while strengthening stakeholder capacities. Participatory diagnosis help raise awareness of agroecological transitions and consolidate local coalitions, in line with transformative learning theory.

Conclusion

The NATAE Field School documented agroecological systems of considerable complexity and adaptability, shaped by generations of ancestral knowledge, yet increasingly vulnerable to convergent pressures of resource degradation, climate change, and market competition. The tension between traditional practices based on collective resource management and three strata polyculture versus intensifying monoculture and individualized extraction strategies represents a critical juncture for oasis futures. However, research revealed encouraging evidence of local agency and emerging initiatives women's value-addition groups, youth experimenting with agroecological methods, farmer networks implementing water-efficient technologies, demonstrating that agroecological transition is an ongoing process already underway in practice. Critically, agroecological transition is inseparable from institutional reform, water governance, market structure,

land rights security, and climate adaptation, it is fundamentally a territorial sustainability and social equity question.

Success requires articulating local knowledge and innovation, strengthening governance capacity, and constructing collective visions of sustainable oasis futures integrating ecological integrity, economic viability, and social inclusion. The urgency is apparent in aquifer statistics, climate projections, and demographic data revealing outmigration. Yet potential is equally evident in demonstrated resilience, diversified practices, and stakeholder commitment.

Agroecological transition in Kébili is not only possible, it is already underway. The critical task is scaling initiatives through enhanced institutional support, coherent policy frameworks, and sustained stakeholder engagement.

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