EasyChair Preprint

№ 15880

Data on Land Cover Transitions and Threats to Almond Tree Diversity in the Central-East of Tunisia

Waddah Ghenimi, Hassouna Gouta, Emmanuel Geoffriau, Nathalie Carcaud, Faiza Allouche Khebour and Hichem Rejeb

March 3, 2025

Data on land cover transitions and threats to almond tree diversity in the Central-East of Tunisia

Waddah Ghenimi[1*]
Higher Institute of Agronomy of Chott-Mériem (ISA-CM), Horticulture, Paysage, Environnement, University of Sousse, B.P47, 4042 Chott Meriem Sousse, Tunisia.
waddah.ghenimi@agrocampus ouest.fr

Hassouna Gouta[2]
Olive Tree Institute, Sustainability of Olive Growing and Arboriculture in Semi-Arid and Arid Regions (DOLARIDE), B.P. 40, 4061, Sousse, Tunisia.
zallaouz@yahoo.fr

Emmanuel Geoffriau[3]
Univ Angers, Institut Agro, INRAE, IRHS, SFR 4207 QUASAV, F-49000 Angers, France.
emmanuel.geoffriau@institut-agro.fr

Nathalie Carcaud[4]
Univ Angers, Institut Agro, Agrocampus Ouest, ESO CNRS-UMR 6590, Angers, France.
nathalie.carcaud@agrocampus-ouest.fr

Faiza Allouche khebour[5]
High Institute of Agronomic Science of Chott Mariem, Department of Engineering and Landscape Planning, Sousse University, B.P 47, 4042 Chott Meriem Sousse, Tunisia.
allouchekhebour@yahoo.fr

Hichem Rejeb[1]
Higher Institute of Agronomy of Chott-Mériem (ISA-CM), Horticulture, Paysage, Environnement, University of Sousse, B.P47, 4042 Chott Meriem Sousse, Tunisia.
hrejeb0962@gmail.com

Abstract— Over the past decade, rapid urbanization and climate change have impacted urban and peri-urban agriculture, as well as the diversity of indigenous fruit tree ecotypes, particularly in Kalâa Kebira, in the Sousse governorate. This study, based on satellite imagery (Landsat 5, 7, and 8) analyzed using QGIS, mapped the evolution of urbanization and the degradation of almond orchards between 1980 and 2023. In 1980, tree crops covered 3,234.2 hectares, while urban areas spanned 145 hectares. By 2012, urbanization reached 890 hectares, with a slight increase in tree crops (3,266.9 hectares). However, in 2023, a loss of 621 hectares of tree crops was recorded, while urbanization progressed by 46.83%, reaching 1,307.2 hectares.
Survey data analysis highlights an urgent threat to almond cultivation, specific to this region where agriculture, particularly almond farming, holds significant socio-economic importance. Three types of agriculture are identified: entrepreneurial, focused on commercial and professional practices; family-based, centered on food self-sufficiency; and mixed, combining commercial and subsistence aspects while maintaining a strong interaction with the urban environment. Furthermore, the results emphasize the richness and preservation of indigenous almond tree ecotypes in Kalâa Kebira, preserved through seed exchanges and farmers' preference for local cultivars, well adapted to environmental conditions and offering high nutritional value. However, these farmers express concerns about the future of this biodiversity, threatened by urbanization, land sales, and the lack of knowledge transfer to future generations.
The results highlight the urgency of adopting sustainable management of indigenous fruit trees, particularly almonds, by implementing an in-situ conservation strategy. Without these measures, this diversity could be replaced by foreign cultivars and disappear due to drought, leading to a significant loss of biodiversity.

Keywords—c Remote Sensing, Anthropogenic Pressure, Urban Dynamics, Urban and Peri-Urban Agriculture (UPA), Indigenous Almonds.

I. Introduction

Global population growth is expected to reach 9.7 billion by 2050, with 1.2 million square kilometers of land urbanized by 2030 (UNFPA, 2023). In Tunisia, the population is currently 11.8 million, and the urbanization rate exceeds 70% in 2023, projected to rise to 80.2% by 2050 (INS, 2023). Since the 1980s, major Tunisian cities, including Sousse, have undergone significant transformation, becoming hubs of economic development, which has driven massive rural migration. Sousse, with a population of 674,818 in 2020 and a growth rate of 2.17%, had an urbanization rate of 80% (DGAT, 2021).

Agriculture in the region remains vital, with 205,371 hectares of arable land, 77.55% of which is exploitable. Plant production, including fruit trees, represents 41% of total agricultural output, while animal production makes up 38%. Urban and peri-urban

agriculture (UPA) contributes 60% to this production (DGAT, 2021). Local cultivars, such as the almond tree, which has been passed down since the Carthaginian era, are central to this agricultural heritage. In 2021, Sousse had 1,595 hectares dedicated to rain-fed almond cultivation, yielding 1,455 tons, while 66 hectares were irrigated, producing 480 tons (DGAT, 2021). Almonds account for 7% of the total agricultural production value and employ 3.06% of the local workforce.

These agricultural systems face challenges from rapid urbanization, climate change, and the fragmentation of natural habitats. This threatens the local biodiversity, particularly almond tree ecotypes, which are crucial to food security in urban and peri-urban areas (Serra-Garcia et al., 2018). The study, focused on Kalâa Kebira, aims to map spatial expansion between 1980, 2012, and 2023, assessing the impacts of urban growth on agriculture and almond tree diversity. The research has three main objectives: (1) analyzing agricultural land degradation and the threats to almond tree diversity, (2) exploring the role of UPA in biodiversity conservation, and (3) identifying policies to mitigate the challenges posed by urbanization and conserve agricultural biodiversity.

II. STUDY AREA AND DATA SETS

A. *Study area*

The study was primarily conducted in the Sousse Governorate, located in the central-eastern part of Tunisia, between coordinates 35° 49′ North latitude and 10° 38′ to 3° 12′ East longitude (Fig. 1). This governorate spans an area of 4,500 km², representing 1.7% of the national territory. Established in 1956, it consists of 16 delegations and had a population of 674,818 inhabitants in 2014. Sousse is characterized by a high urbanization rate, reaching 80%, making it a particularly dynamic region. Precipitation in the governorate ranges from 200 mm in the south to 400 mm in the north, with an average annual precipitation of 325 mm over a fifty-year period. Rainfall is primarily concentrated in the fall and winter, accounting for 72.8% of the total annual precipitation. December and January average twelve days of rain, with extremes of 830 mm and 139 mm observed. The average annual temperature is 18.6°C, with a summer maximum not exceeding 40°C due to the coastal influence. Temperatures range from 11.5°C in January to 26.6°C in summer, with a thermal amplitude of 13°C. Humidity is higher in winter and lower in summer, influencing the comfort level.

The study specifically focused on the Kalâa Kebira delegation, chosen for its significance in agricultural production and its substantial contribution to agricultural employment. This delegation plays a key role in the local and regional economy, making it an important site for understanding the agricultural and urban dynamics of the region.

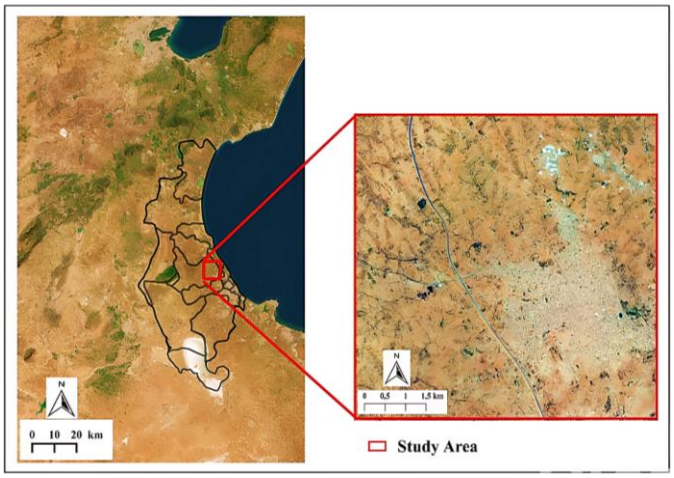

Figure 1: Location of the Sousse Governorate within the study area of the Kalâa Kebira delegation, Tunisia (Maps created by the authors using Google Satellite imagery and QGIS software, 2024).

Location of t the study (Maps created by the authors using Google Satellite imagery and QGIS software, 2024).

B. *Models and Tools*

This study thoroughly investigates the process of spatial expansion of the urban metropolis in the Kalâa Kebira delegation during the 1980s, as well as in 2012 and 2023, highlighting the urban dynamics and transformations that negatively impact urban agriculture in general, and the indigenous almond tree ecotypes cultivated both in the city center and on its outskirts. These land-use changes are supported by field surveys conducted with local farmers to assess the importance of these almond tree ecotypes in the urban and peri-urban agriculture (UPA) of the region, emphasizing their crucial role in maintaining community resilience in the face of urban pressures. Special attention is given to these ecotypes, including an analysis of their distribution, socio-economic value, adaptation to local conditions, and, most importantly, the type and extent of the degradation of this local diversity in the studied delegation. This integrated approach aims to provide an in-depth understanding of the interactions between urban development and agriculture, within the context of environmental and socio-economic changes.

C. *Data collection and software used*

Satellite imagery, survey data, and field observations formed the foundation of this study. The selected images for this work are Landsat 1 for the year 1980, Landsat 7 for the year 2012, and Landsat 8 for the year 2023, which appear to be the most suitable for our needs. Their extended acquisition period, combined with adequate spatial and spectral resolution, makes them effective tools for analyzing urbanization and spatial consumption. The Earth Explorer site of the USGS is a valuable resource for downloading these images, providing easy access and a wide range of available data for our study. This approach is described by Toko et al. (2010)

All images were analyzed using QGIS software (version 3.34.3 - Prizren).

To assess the significance of urban and peri-urban agriculture, as well as diversification strategies in local almond orchards, a series of surveys was conducted with 30 farmers from the delegation of Kalâa Kebira. Out of a total of 355 farmers in Kalâa Kebira, 250 are in urban and peri-urban areas and own almond plots. The 30 farmers selected for the survey were chosen randomly, without distinction of gender or cultivated area. This survey was conducted in collaboration with various public agricultural organizations, including the Territorial Extension Cells (CTV) and the Regional Commission for Agricultural Development (CRDA). The profile and socio-economic characteristics of the producers were analyzed using Microsoft Excel and R software.

II. Results

A. Spatio-temporal study of urbanization dynamics and constraints faced by urban and peri-urban agriculture and landscape anthropization

a) Validation of image classification

The Landsat image classification enabled the production of three land-use maps for the years 1980, 2012, and 2023, with specific categories for each delegation. For the delegation of Kalâa Kebira, the maps include four classes: Urban Area and Street, Arboriculture (primarily based on almond and olive trees in intercropping), Diverse Cultivation (including vegetable and cereal crops), and Pasture. To evaluate the accuracy of this image classification, confusion matrices are utilized (Table.1). This analysis reveals that the images studied exhibit high overall accuracy for both study areas, varying from 94.16% to 99% across the three years, with a Kappa index ranging from 0.89 to 0.99.

Table 1: Accuracy of the classification for the images of 1980, 2012, and 2023 for the delegation of Kalâa Kebira

Type of Evaluation	1980	2012	2023
Overall Accuracy (%)	99	94,16	94,85
Class Accuracy « Urban Area and Street »	0,98	0,96	0,94
Class Accuracy « Arboriculture (Almond + Olive) »	0,99	0,89	0,86
Class Accuracy « Mixed Crops »	0,97	0,99	0,99
Class Accuracy « Pasture »	0,99	0,99	0,99
Kappa Index (Khat)	0,99	0,89	0,91

b) Landscape dynamics along the urban-periurban gradient: Composition and structure from 1980 to 2023 of the Kalâa Kebira delegation

Quantitatively, Table 2 highlights the spatial evolution of the study area, which spans 5,271 hectares and has undergone significant land-use transformations over time. In 1980, the land-use map revealed a landscape dominated by tree crops, primarily almond and olive trees, occupying 3,234.2 hectares, or 61% of the total area (Fig.2A). Vegetable, cereal, and forage crops accounted for 1,521.4 hectares (29%), reflecting a traditional agriculture reliant on sufficient rainfall for profitable production. Uncultivated land (Pasture) represented 7% (370.4 hectares), while the urban area occupied only 145 hectares (3%).

By 2012, urban expansion reached 890 hectares, reflecting an 83.72% increase since 1980 (Fig.2B). This growth came at the expense of agricultural land, with vegetables and cereal crops shrinking by 75.4 hectares to 374.6 hectares. Meanwhile, pasture areas expanded by 50.87%, reaching 739.5 hectares, indicating a shift in land use. Tree crops, particularly almonds, showed a marginal 1% increase, totaling 3,266.9 hectares, highlighting farmers' growing interest in arboriculture.

By 2023, agricultural land further declined, with tree crops, including almonds, losing 621 hectares (18.99% compared to 2012), and vegetable and cereal crops decreasing by 111.1 hectares (29.58%) (Fig.2C). These losses were concentrated on the city's outskirts, where farmland was increasingly replaced by urban expansion, which surged from 890 hectares in 2012 to 1,307.2 hectares in 2014 (+ 46.83%). Orchard plots, especially those with almonds and intercropped olive trees, are being converted into residential and industrial zones. Additionally, persistent drought has exacerbated agricultural degradation in the region.

Table 2: Evolution of land use and land cover Areas for 1980, 2012, and 2023 in the Kalâa Kebira Region.

Land Use Unit	**1980**		**2012**		**1980-2012**		**2023**		**2012-2023**	
	Area		**Area**		**TCA**		**Area**		**TCA**	
	In ha	%	In ha	%	+/- ha	%	In ha	%	+/- ha	%
Urban Area and Street	145	2,74	890	16,89	+745	83,72	1307,2	24,8	+417,2	46,83
Tree Crops (Almond and Olive)	3234,2	61,4	3267	61,97	+32,7	1	2645,9	50,2	-621	-18,99
Mixed Crops	1521,4	28,8	374,6	7,11	-1147	-75,4	263,5	5	-111,1	-29,58
Pasture	370,4	7,08	739,5	14,03	+369	50,87	1054,4	20	+314,7	42,55
Total	5271	100	5271	100			5271	100		

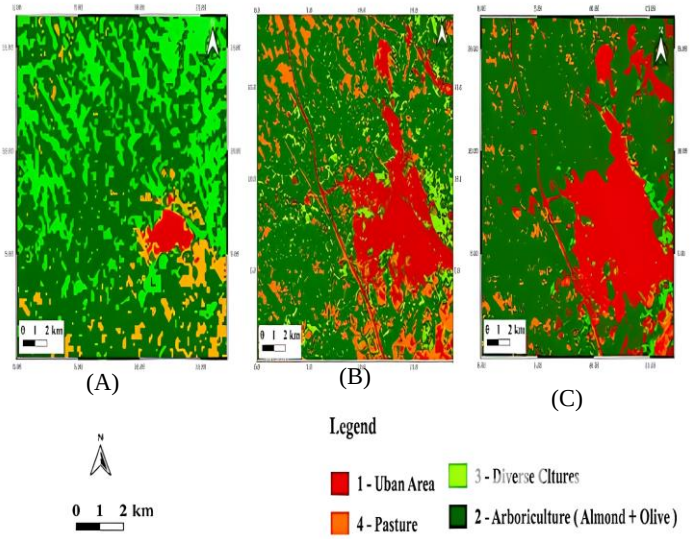

Figure 2: Land use map of the Kalâa Kebira Region: Evolution between 1980 (A), 2012 (C) and 2023 (B).

B. Agro-biodiversity of urban and peri-urban agriculture: A study of the almond tree, heritage, and environment in the context of urban sprawl and climate change in the case studies of Kalâa Kebira

a) Socio-demographic profile of farmers

The survey analysis of 30 farmers, particularly in Kalâa Kebira, reveals key agricultural dynamics *(*Fig.3). Male farmers dominate the sector, representing 86.67% of participants, while women account for only 13.33%. The majority (83%) are aged between 40 and 80 years, indicating an aging workforce that may challenge the long-term sustainability of agricultural practices.

Education levels show that 47% of farmers have secondary education, which can foster better farm management and innovation. Additionally, 63% of farmers are migrants from other regions, reflecting both a lower local retention rate and the role of urban and peri-urban agriculture in providing employment.

Regarding experience, 76% of respondents have been farming for over 20 years, highlighting strong agricultural expertise and the importance of intergenerational knowledge transfer in the local economy.

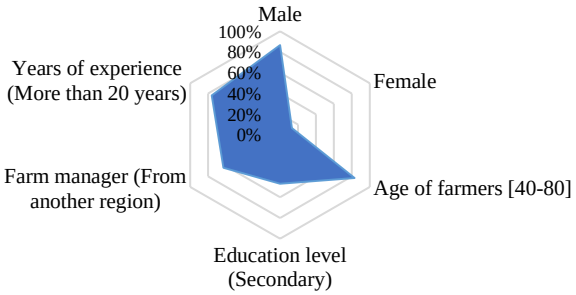

Figure 3: Analysis of the socio-demographic profile of farmers in urban and peri-urban areas in the Kalâa Kebira Region.

b) The Importance of the coexistence of almonds in proximity to urban areas

The proximity of agricultural areas to urban centers has significantly improved the living conditions of farmers in the Kalâa Kebira region, facilitating access to essential daily services and needs. According to surveys conducted in this region (Fig. 4), 17% of farmers highlighted that urban proximity enhances their security and access to consumer goods. This proximity also improves access to education, with 17% of farmers indicating that their children can benefit from easier access to schooling. The issue of mobility was also addressed, with 30% of farmers stating that access to public transport is facilitated, contributing to improved connectivity. Furthermore, 23% of farmers noted that access to education and public transport is crucial for their daily lives. Another significant advantage of urban proximity lies in access to water, as 100% of farmers are connected to the urban water network. This connection not only ensures adequate water supply for agricultural needs but is also vital for the sustainable management of water resources in the region.

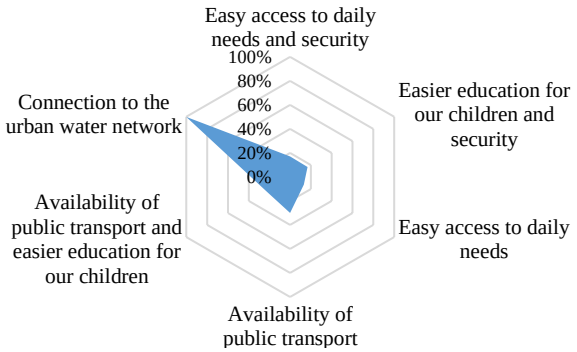

Figure 4: Proximity to urban centers and their benefits for farmers in the Kalâa Kebira Region.

C) Perspectives of urban and peri-urban agriculture for the preservation of almond tree diversity

Understanding urban and peri-urban agriculture among local residents is a crucial issue, directly influencing urban quality of life, environmental sustainability, and the promotion of local agricultural practices (Fig.5). In Kalâa Kebira, a significant majority of 90% of respondents report being well-informed on the subject, reflecting a high level of awareness in the region. However, despite the importance of this form of agriculture,

subsidies to encourage its practice remain insufficient, and the situation is particularly concerning as 100% of respondents report an imminent threat to agricultural land due to urban expansion. This urban evolution significantly affects agricultural lands by 2030 and 2050, with 47% of farmers estimating that urbanization will impact 90% of their land. Current threats include the construction of new residential neighborhoods, road infrastructure, and industrial zones, with projects such as the main road connecting the governorates of Sousse, which promote the expansion of industrial areas, thus reducing agricultural space. The most fertile plots, especially those cultivated with indigenous almond trees, are particularly vulnerable, risking their disappearance. In the absence of adequate legislation to protect these lands, farmers are often compelled to sell their plots, lured by the high land value and higher returns from non-agricultural activities, leading to growing disillusionment. In Kalâa Kebira, 67% of farmers do not wish for their children to continue this activity.

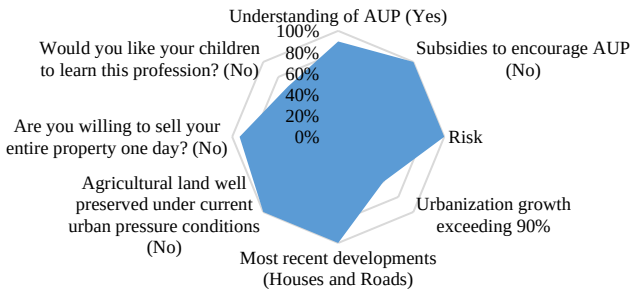

Figure 5: Future of urban and peri-urban agriculture

III. Discussion

A. *Typology and contribution of urban and peri-urban almond cultivation to socio-economic development*

The study of the socio-economic impacts of urban and peri-urban agriculture in Kalâa Kebira, particularly almond cultivation, highlights the transformations driven by urbanization and increasing drought. The reduction of agricultural land affects production systems, although this sector retains significant socio-economic value.

Agriculture in this region remains predominantly male-dominated, despite initiatives such as Agricultural Development Groups (GDAs) aimed at enhancing women's participation (Bacha, 2018). Additionally, the arrival of migrants seeking economic opportunities illustrates a migratory flow towards these areas (Rejeb, 2011). Furthermore, the proximity of urban farms improves access to infrastructure and facilitates direct sales of agricultural products, meeting the growing demand for local food while reducing transport-related pollution (Helman, 2014). Urban agriculture in this region is divided into two main categories: patrimonial agriculture, rooted in local traditions, and commercial agriculture, oriented toward the local market.

B. *Spatio-temporal dynamics of almond tree areas*

The spatial analysis of Kalâa Kebira over three reference years (1980, 2012, and 2023) confirms a classification accuracy of 92% to 99%, aligning with the acceptability thresholds defined by Congalton (1991). This high accuracy validates the reliability of image interpretation over the studied periods.

Urban expansion in the region followed two distinct phases. Between 1980 and 2012, dense and continuous growth led to the emergence of new peripheral neighborhoods, while agricultural land particularly almond orchards expanded by 32.7 hectares as farmers adapted to land scarcity. The intensification of arboriculture reflected a strategic response to urban pressure, with previously uncultivated areas converted into tree crops.

However, the 2012–2023 period marked a sharp decline in agricultural land, with a total loss of 621 hectares, an 18.99% reduction compared to 2012. This decline, driven by urban sprawl and land conversion, threatens both food production and biodiversity, intensifying land-use conflicts and posing long-term sustainability challenges for local farmers.

B) *The local almond tree: Balancing biodiversity conservation and genetic erosion in urban and peri-urban agricultural systems*

The survey analysis conducted in Kalâa Kebira highlights the critical role of urban and peri-urban agriculture, particularly the cultivation of almond ecotypes. Most of the land allocated to this crop consists of small plots, averaging approximately one hectare, due to urban expansion limiting available space. This constraint favors the selection of crops suited to small-scale farming.

A significant proportion of the almond trees in the region exceed 50 years of age, underscoring their historical and environmental value. These trees originate from direct seeding, reflecting a strong preference for indigenous varieties well-adapted to local climatic conditions (Gouta et al., 2010). Furthermore, the exchange of these seeds among families enhances biodiversity, preserves local traditions, and supports agricultural sustainability (Helman, 2014). Farmers maintain these ecotypes through traditional knowledge networks and agricultural practices, ensuring the intergenerational transmission of expertise.

However, the introduction of foreign cultivars, despite their potential for higher yields, presents long-term risks due to lower resilience. Bellon et al. (2009) emphasize that genetic erosion threatens income stability and weakens the adaptive capacity of agricultural systems in response to climate change and emerging threats.

C) Impacts of urban sprawl on the future of almond trees and urban and peri-urban agriculture: A forward-looking perspective

The growing urbanization significantly impacts agriculture, particularly almond cultivation, as seen in the Kalâa Kebira region. With rapid urbanization reaching a 100% rate in recent years, agricultural land has been drastically reduced. The conversion of agricultural spaces into residential and industrial

areas has driven up land prices, which have increased by 49% from 1990 to 2023. Factors such as population growth, land pressure, and urbanization policies contribute to this rise in land prices.

The scarcity of agricultural land due to urbanization has a dual effect: it limits fertile areas for food production and disrupts traditional farming lifestyles, often pushing farmers to migrate towards non-agricultural sectors. This trend is reflected in the fact that 7% of farmers are considering selling their properties, citing the challenges of seasonality, climate dependency, and unpredictable production costs as key factors in their hesitation.

Despite these challenges, most farmers remain committed to their agricultural activities due to their strong attachment to their land and way of life. However, seasonal, climatic, and economic difficulties continue to test their determination.

To ensure the sustainability of urban and peri-urban agriculture, solid management plans must be developed. Protecting agricultural spaces is vital for biodiversity conservation, natural risk reduction, and supporting local food markets. An integrated agricultural policy is needed to protect farmland while promoting sustainable urban development. Additionally, effective enforcement of existing laws is essential to safeguard crucial crops like almonds, ensuring the continuity of agriculture amid urban pressures. This balanced approach will strengthen the resilience of local communities in the face of future challenges.

ACKNOWLEDGMENT

The diversity of the almond tree in the urban and peri-urban areas of the coastal part of Tunisia is under threat due to a rapid urban growing that occurs from 2012 to 2023, exacerbated by climate change-induced drought and genetic erosion that are compromising its sustainability. This species plays a fundamental role in the local socio-economic landscape by providing fresh food products, supporting various agricultural activities, and contributing to the education and food security of children. Three agricultural typologies were identified in the studied areas: entrepreneurial, mixed, and family-oriented farming. Although farmers demonstrate resilience for facing urbanization challenges, some contemplated selling their lands to relocate to less urbanized areas. To preserve this achievement, it is crucial to integrate the impacts of urbanization and drought into urban planning. Thoughtful management of population growth and land use is necessary to support urban and peri-urban agriculture and maintain ecotypes diversity, whether by on farm, in situ or ex situ conservation. Additionally, policy makers must propose assistance to farmers and promote effective resource management. Collaboration among local authorities, community organizations, and agricultural stakeholders is essential for developing policies that protect this diversity, support urban and peri-urban agriculture, preserve the region's farming and cultural heritage, and enhance its sustainability and resilience against future challenges.

REFERENCES

[1] United Nations Population Fund UNFPA. 2023. https://www.unfpa.org/fr/ news/demystifier-8-idees-recues-sur-les-8-milliards-dindividus-qui-peuplent-la-planete.

[2] Institut National de la Statistique (INS). 2023. Population estimates as of January 1. Available at: https://www.ins.tn/sites/default/filesftp/files/publication/pdf/Estimation%20de%20%20la%20population%201er%20Janvier%202023.pdf.

[3] Direction Générale de l'Aménagement du Territoire (DGAT). 2021. Digital Atlas of the Sousse Governorate. Available at: http://www.mehat.gov.tn/fileadmin/userupload/Amenagement_Territoire/AtlasSousseDec2020Fr.pdf.

[4] Serra-Garcia, M., Peri, V., Süsstrunk, R., Bilal, O. R., Larsen, T., Villanueva, L. G., & Huber, S. D. 2018. "Observation of a phononic quadrupole topological insulator." Nature, 1, 342–345. https://doi.org/10.1038/s41567-018-0221-6.

[5] Bacha, A. 2018. "Operational and organizational issues of Women's Agricultural Development Groups and their impact on the profitability of farms in the irrigated areas of Nadhour." Final Project, Applied License in Agricultural Business Management, Higher School of Agriculture of Mograne, University of Carthage, Tunisia.

[6] Rejeb, H. 2011. "The challenges of urban and peri-urban agriculture in Tunisia." CIHEAM Watch Letters, 18, 4.

[7] Helman, V. 2014. "Urban fringes: towards new city-field interfaces to sustainably fix the urban boundary and preserve peri-urban agriculture." Le Philotope, 13, 71

[8] Congalton, R. G. 1991. "A review of assessing the accuracy of classifications of remotely sensed data." Remote Sensing of Environment, 37(1), 35-46. https://doi.org/10.1016/0034-4257(91)90048-B.

[9] Gouta, H., Guenichi, H., Rezgui, R., Mars, M., Zarrouk, M., & Mliki, A. 2010. "Production systems and genetic resources of almond (Prunus dulcis L.) in the West Central Tunisia." Revue des Régions Arides, 24, 106–111. https://doi.org/10.1111/j.1601-5223.2010.02125.x

[10] Bellon, M. R., & Janick, J. 2009. "Diversity of cultivated crops and its implications for sustainable agriculture." Crop Science, 49(4), 1152-1162. https://doi.org/10.2135/cropsci2008.07.0465.