

# Mapping agricultural land use dynamics through integrated biophysical analysis for Mediterranean farming systems

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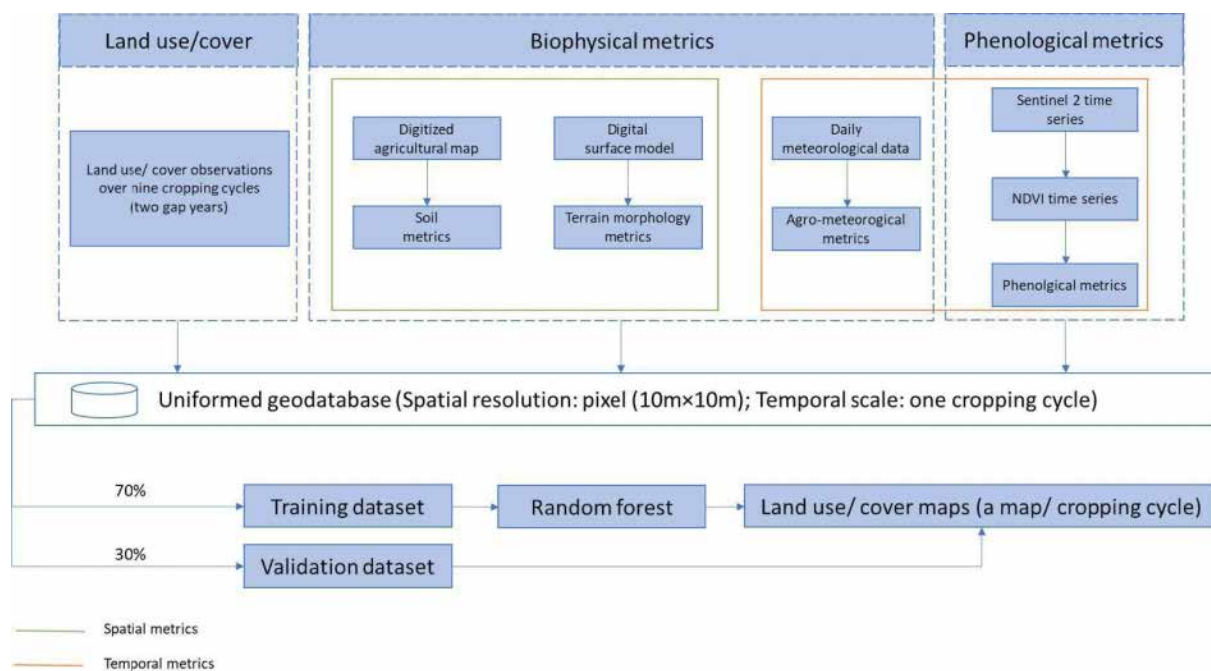
## Introduction

Mediterranean agriculture has evolved over millennia under distinctive climate and terrain constraints (Zeder, 2008). The region's fragmented systems—marked by diverse management intensities, cultivation strategies, and socio-environmental disparities (Scorsino and Debolini, 2020)—exhibit notable spatial heterogeneity (Biarnès et al., 2021). This heterogeneity is expected to increase as Mediterranean systems face accelerated vulnerability to global changes (Malek and Verburg, 2017). Matching this increasing heterogeneity with the management of resources like soil and water is a wicked problem of increasing complexity (Esgalhado et al. 2021). Addressing such complexity requires analytical approaches calibrated to the spatial level at which environmental processes occur to better inform the decision-making of the concerned socio-technical systems (Rizzo et al., 2013). However, current regional mapping and modelling approaches inadequately integrate biophysical and socio-technical drivers of farmers' decision-making in a spatially explicit way, limiting the reliability of land use trajectory analyses for informing farming system design. This is partly due to the lack of land use mapping series consistent with the high fragmentation, particularly outside Europe (Biarnès et al. 2021). This study presents a multi-annual mapping method for Mediterranean rainfed agricultural systems contributing to broader research on farmer decision-making and the co-design of farming scenarios with local stakeholders, based on land use spatial-temporal dynamics.

## Methods

The method uses multi-annual biophysical data to generate annual, detailed land use maps. Due to the absence of plot boundary datasets and the fragmented nature of Mediterranean agriculture, a pixel-based approach was adopted to capture land use dynamics from 2015 to 2024. While each pixel reflects local cropping decisions, the resulting maps will enable subsequent analysis of land use spatial configuration and connectivity. Moreover, the result helps to analyze farming system and landscape dynamics, linking biophysical drivers to spatial configurations and climate adaptation trends.

The study focuses on a typical fragmented rainfed agricultural area located in the Lebna watershed (210 km<sup>2</sup>, northeastern Tunisia) with approximately 80% of agricultural plots <1 ha. The framework (Figure 1) integrates spatial metrics (terrain morphology and soil characteristics) and temporal metrics (meteorological conditions and phenological responses of the cultivated crops). We used five datasets: (1) land use field observations as described in (Biarnès et al., 2021); (2) a 1-meter digital surface model (Durand, 2019) to compute terrain metrics; (3) precipitation and temperature daily records collected by the OMERE observatory; (4) a digitized agricultural map of Nabeul Governorate to derive soil characteristics; (5) Sentinel-2 imagery (2015-2024) to calculate phenological metrics based on NDVI time series.



**Figure 1.** General workflow

## Results

Preliminary results are a series of nine historical land use maps, one per cropping season. The multi-annual, context-sensitive method mitigates training data availability limitations, enabling robust class differentiation even for cropping cycles with sparse ground-truth information. Such detailed mapping facilitates the detection of recurrent patterns in agricultural land uses, thereby revealing land management strategies and providing insights into the complex interplay between environmental constraints and farmers' crop choice.

## Discussion and Perspectives

This framework bridges a key methodological gap by integrating spatial configuration and temporal dynamics---often treated separately in spatial models and time-series analyses. While multi-temporal phenological analysis (Liu et al., 2018) and biophysical drivers' integration (Pacheco de Castro Flores Ribeiro et al., 2021; Zabel et al., 2025) have been applied in agricultural studies, their combined application for mapping land uses from field observations to watershed extent in fragmented Mediterranean systems remains, to our knowledge, unexplored. The framework's contribution lies in systematically merging spatial and temporal metrics to tackle the challenges of mapping fragmented Mediterranean farming systems under high climatic variability.

Future work could consolidate this framework by integrating socio-technical variables to capture farmer decision-making and coupling it with watershed agro-hydrological models to assess climate-driven impacts on productivity and resource availability.

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