The evolution of western Mediterranean agricultural landscapes to better adapt farming to the climate crisis: a diachronic approach

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Agricultural landscapes are a consequence of climatic, environmental, and management factors. Throughout the evolution of agriculture, agricultural landscapes have been shaped by people in dialogue with these local and regional factors, together with the socioeconomic, technological, and even political context. The agricultural practice is expressed within the space in a constantly evolving modification of the geographic milieu (Santos, 2000). In that regard, understanding how agricultural landscapes change is central to attain the current challenges that agricultural production faces, especially its sustainability and the adaptation to and mitigation of climate change. The understanding of agricultural landscape change, production capacities, and environmental, as well as climatic conditions constitutes a body of actionable knowledge in contemporaneous agricultural planning (Pswarayi et al. 2008).

The reconstruction of agricultural conditions throughout significant long periods (thousands of years) combines a wide range of climatic, environmental, and agronomic variability within a specific region. Modeling, for instance, climatic variations and their effects on crops can be approached through empirical archeological evidence, historical archives, and for the last hundred years to present-time through aerial and satellite images. The spatial understanding of agricultural landscapes by interpolating historical agricultural data from multiple data sources makes a significant contribution in the spatial understanding of agricultural characteristics of a certain region. This approach goes beyond the record of concrete local evidence or computer-based modelling approaches without empirical data. Such understanding allows defining what an agricultural landscape can sustain and to better define adequate management approaches, crops features, and farmland suitability. Therefore, this spatial understanding contributes to plan advanced and well-tailored agricultural landscape.

The Mediterranean region is an area with a long-time agricultural activity. The region is characterized by a high environmental and climatic variability (i.e. water, temperature, soil fertility) that has shaped Mediterranean agricultural landscapes. Moreover, the Mediterranean region is one of the most affected by global change and population pressure for resources is high. In this regard, the northeast of the Iberian Peninsula (in the western Mediterranean Basin) is a region highly impacted by climatic change and human activities, and therefore with a significant need to address improved planning and understanding of the regional agricultural landscapes. Thus, Catalonia and its surrounding areas constitute an ideal region for this study. The number of early agricultural sites (i.e. older than ca. 4000 y BP) excavated or under excavation (and with published reports) is relevant and distributed quite evenly across the territory, and the already available archaeobotanical material (grains, charcoal) to reconstruct agricultural conditions is abundant. Additionally, the region is characterized by a huge variability in present-time environmental conditions, with different agroclimatic zones in Catalonia that vary in temperature and water status. These environmental differences translate into highly variable yields depending on year, location and variety, with productive ranges that can be as variable as from 1 to 9 Mg ha^{-1}. Understanding how agriculture has adapted from its adoption to the present through such wide range of environmental scenarios may give evidence to better design future agricultural landscapes. The regional features evidence an historical impoverishment of climate conditions (Ferrio et al. 2006) with agriculture being progressively practised under drier conditions (Araus and Buxó, 1993).

Catalonia constitutes an area with important agricultural records and a well-connected scientific network that can contribute to forming a highly detailed agricultural landscape evolution understanding, that has not yet been studied in detail. The novel spatial interpolation of archeological grains and charcoal records, as well as archaeological literature from these sites, together with historical archives and, since the 1940s to the 2020s highly detailed aerial images and, relatively well-defined production and crop type statistics, will contribute to the objective of **building a cross-disciplinary and robust database of agricultural landscapes evolution in the NE Iberian Peninsula**. **The project will address the evolution of agricultural landscape and associated agricultural conditions through a diachronic approach embracing three key moments.**

1) **Appearance of agriculture in the region.**
2) **Agriculture between the twenties and sixties of the last century.**
3) **Present-time scenario and modelling future sustainable agricultural landscapes.**

We will run this diachronic approach on the specific locations where archaeobotanical material allows to reconstruct landscape, environmental conditions, and agronomical practices at the onset of agriculture to this date and interpolate spatially the data. The limitations of historical data of our approach, such as for example the long chronological period elapsing between the onset of agriculture and the beginning of the 20th century, including technological innovations (e.g. metal moldboard plow) or large-scale changes in crops (e.g. vineyards, olive groves), will be overcome by using the most of historical agrarian archives and geographic data. Moreover, we will focus on cereal and legumes as the main herbaceous crops

historically cultivated in the region. The datasets will be organized to match data into a geographic information system database in which historical agricultural landscape changes can be linked within a region and overlap with future climatic scenarios.

1.- Agricultural establishment. Agricultural landscapes were first stablished with the appearance of agriculture, which in the case of the Western Mediterranean dates back from ca. 7500 y BP and extends to 3600 y BP. This rather wide chronological range, embracing the "first agricultural occupations", is justified based in a relatively low populations and agricultural pressure at a regional scale, and the evident similarities in the type of settlements and crops. We will explore published data from archaeology, paleoclimatology, and paleo-ecology of the chosen sites and conduct analyses on stable carbon of charcoal and stable carbon and nitrogen isotopes, total nitrogen content and the size of caryopsides of cereals and grain legumes, using methods developed by our team (Aguilera et al. 2012; Araus et al. 2014). Using habitat- and agent-based models, the team intends to explore the relationships between the environment, agricultural practices, and society aiming to get insights on the long-term agricultural sustainability. Members of two Agrotecnio teams participating in this proposal have already reported on the lack of sustainability of early agricultural sites in Andalusia (Aguilera et al. 2008). Several members of the proposal have also experience on diachronic reconstructions, in this case comparing a preceramic Neolithic site (10.000 BP) from the Middle Euphrates with its present conditions (Ferrio et al. 2012).
All the sites included in the proposal are Neolithic and cover Catalonia and surrounding areas. Some of them are still under excavation, while the others, already excavated, have produced rather abundant literature on the archeological context, and collected samples and even, for some of them, analyzed data from caryopsides and charcoal is available. These sites cover a wide range of present-time climatic conditions, particularly in terms of precipitation and evapotranspiration, which represents an added value, in terms of comparing patterns of adaptations. The main Neolithic sites under excavation include two directed by the UAB: La Draga (Banyoles, Girona), Chronology 5290-4800 cal BC) and Coves del Fem, (Ulldemolins, Tarragona). Chronology 6065-5988 cal BC to 4699-4545 cal BC; plus another two directed by the UdL: Cantorella (Maldà, l'Urgell, Lleida): Final Neolithic: 3500-2100 cal. BC and Minferri (Juneda, les Garrigues, Lleida), Final Neolithic: 3500-2100 cal. BC. Another Neolithic sites (ranging 5000-4000 BC) from where isotopic data from caryopsides has been published and/or it is available for the project include: Auvelles, Cova de l'Or, Montou, Plansallosa, Pou Nou and Camp del Colomer.
2.- Agriculture between the twenties and sixties of the last century. This historical period represents a key moment (turning point) of the agriculture landscape, when technological transformations (widening the use of fertilizers, beginning commercial varieties, spreading the irrigation areas), together with social changes (migration to cities, depopulation of the countryside) and related consequences in terms of "industrial" agriculture (larger exploitations, introduction of machinery, abandonment of the less productive lands) took place. Regarding the characterization of the last 80 years, aerial photogrammetry has been useful to characterize agricultural landscapes in contemporaneous times (Segarra et al., 2023a). The Spanish online platform from the Spanish National Geographic Institute (https://fototeca.cnig.es/fototeca/) allows open access to a large dataset of aerial orthophotos. Moreover, the national institute of statistics (INE) allows an open access to agricultural production records for several crops, with especial interests in cereals and leguminous as the basis of the Mediterranean agricultural landscape. Wheat grain yield data at the Spanish provincial level, starting on the beginning of 20th Century, will be obtained from INE. Furthermore, grain yield at specific sites may be estimated from current yield data through the extrapolation of neighboring local differences. Moreover, actual grain-yield local data may be available for mid-20th Century, prior to the modernization of cereal production in Spain, from the former *Instituto Nacional para la Producción de Semillas Selectas* (National Spanish Seed Institute) created in 1947 and responsible for an extensive network of testing sites across all Spanish production areas. As for the climate data, the Meteorological Service of Catalonia has accessible continuous climate records from 1950.
3.- Present-time scenario. Present-time agricultural landscape is the consequence of strong changes encountered during the last 60 years[7] (Segarra et al. 2023a). Moreover, agricultural landscape in the western Mediterranean is increasingly being affected by the vagaries of the climate change and other factors such as the increase in the occurrence and violence of fires due to the changes in vegetation (e.g. increase in forested areas). Present-time data on grain yield, grain weight and protein content from wheat and barley cultivated will be obtained from the annual reports (https://genvce.org/productos-genvce/informes/) published by GENVCE (Grupo para la Evaluación de Nuevas Variedades de Cultivos en España). Environmental variables will be derived from the Catalonian Institute for Statistics (https://www.idescat.cat/indicadors/?id=aec&n=15192&lang=es) and the Meteorological Service of Catalonia as stated above. The data will be matched to build suitability maps and plan agricultural landscapes (Segarra et al 2023b)

Proposal alignment. The proposal aligns well with the operational objectives of the Agrotecnio strategic plan:

- *Operational objective 1.2.- Provide incentives for transdisciplinary cooperation across the Agrotecnio research lines to explore and leverage synergies.* Members of three different Agrotecnio groups are participating, with expertise in (i) paleorecontraduction of agricultural and environmental conditions and landscape; (ii) changes in cereal productivity and breeding/agronomical conditions during the last century; (iii) changes in agricultural landscape during the last century, through the use of different remote sensing approaches; (iv) crop and forest ecophysiology
- *Operational objective 1.3.- Gain added value by promoting external collaborations with the aim of reinforcing the Agrotecnio's Research Lines.* Collaborations with four different institutions: two from Catalonia (Universitat Autònoma de Barcelona I Universitat de Lleida), together with another from the State (Aula Dei, CSIC) and a credited foreign institution.
Operational objective 1.4 – Develop a policy of collaborations and alliances to fill gaps in competence (such as expertise in agricultural economics or sociology related agriculture). The proposal aims to investigate agricultural-driven changes in the landscape and by extension in the organization of the territory.

Our proposal aligns with three of the four different types of activities prioritized in the call: it aims to pave the way for subsequent submissions to a competitive call, while to support with complementary funding recently funded actions, which will allow to extend the actions envisaged while exploring synergies. The proposal satisfies the following criteria:
- *Multidisciplinarity and/or cooperation*. Three different AT groups are involved and the approaches presented are multidisciplinary in nature (crop ecophysiology, forest ecophysiology, remote sensing, GIS, crop management, breeding). The collaborative nature of the project with four teams will complement AT's expertise within social sciences in relation to agriculture (archeology, history).
- *Translational Research paving the way to transfer fundamental science discoveries to applications.* The combined expertise will produce a comprehensive view of agroenvironmental conditions across Catalonia. This can be translated to practical knowhow through, for example, consulting actions to the public and private sectors.
- *Demonstrable Impact Activities will be a key component of future CERCA center evaluations.* The nature of this research (combining past and present and exploring the interactions between environment, society and land use) secures a societal impact. The topic is amenable for different sectors of the society. The project will contribute to valuing the agricultural landscape, both at a heritage level and at a sustainable adaptation to the environment, with its potential economic implications in sectors such as tourism or land management.
- *Potential for future submission to a competitive proposal.* List of potential calls where to submit competitive applications is included in the proposal summary. Besides, we already have funded collaborations covering the onset of agriculture as well as the evaluation of present time agriculture at the local/regional scales. In one hand members of two AT teams are involved in providing training in stable isotope analysis of archaeobotanical remains, including sample preparation, data analysis and interpretation for the following ongoing ERC Grants (we have an EU-contract for the first one):
ERC Starting Grant, Amaia Arranz Otaegui. Palaeorigins: Tracing The Epipalaeolithic Origins of Plant Management in Southwest Asia. Euskal Herriko Unibertsitatea.
ERC Consolidator Grant, Maria Ivanova-Bieg, Sustainability of Agriculture in Neolithic Europe (SUSTAIN), Vor-und Frühgeschichtliche Archäologie
On the other hand: The remote sensing (aerial / satellite) local / regional component is secured through the project:
Holistic wheat phenotyping: ideotype identification and technological integration across multiple scales (HolisticWheat). PID2022-138307OB-C21. Ministerio de Ciencia e Innovación, Spain.

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