Land use in medieval Iberian frontier societies

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Rowena Banerjea, Luca Mattei, Alex Brown, Lionello Morandi and Phillip Toms

Introduction

This chapter provides a comparative study of historical territories within the modern Spanish provinces of Guadalajara, Granada and Málaga, to evaluate diachronic land use with a particular focus on cultivation, pasture, forestry and quarrying. It examines the changing landscape through the adoption, extension or abandonment of Andalusi terraces and irrigation channels following the Christian conquests in the case study regions, integrating geoarchaeological and digital geoarchaeological approaches, such as GIS mapping. It draws on palynological studies, landscape archaeology, written and cartographic sources to investigate the impact of regime change on the organisation of economically productive land around the following case study sites (as detailed in Chapter 3) Atienza and Molina de Aragón (both Guadalajara), Cartuja, Agicampe (both Granada), and Cártama and Teba (both Málaga). Soil and sediment micromorphology has considerable potential to investigate agricultural soils to provide not only pedological but geomorphological information on the addition of soil to a terrace, its transformation, including amelioration and irrigation, weathering through bioturbation and tillage as well as soil erosion (Adderley *et al.* 2018; Brown *et al.* 2021).

It is well understood that human activity has played a central role in shaping the environment, particularly the modification of flora and physical landscapes due to past land management practices; modulated by varied, often interconnected, natural and anthropogenic factors including climate, topography, hydrology, soils and social, economic and political influences. Agriculture, together with industrial activities (e.g. mining) and the requirements for timber as a vital commodity in medieval society were important drivers of landscape evolution. The palaeoenvironmental record is evaluated and synthesised for central Spain and Andalusia. It is not the intention here to provide a detailed overview of the vegetation history of these regions, but rather to highlight selected key studies and patterns of environmental change as evidence for broad patterns of medieval land use in conjunction with spatial analysis of settlement patterns for our case study areas and their geology maps, soil maps, current and documented historical land use.

To obtain the data from the land-use capacity maps, in the cases of Andalusia (Cartuja, Agicampe, Teba and Cártama), information available on the web and provided by the Andalusian Environmental Information Network (REDIAM) has been used. Based on the characteristics and analysis of the soils, four main groups have been classified: lands with excellent use capacity, lands with good or moderate use capacity, lands with moderate to marginal use capacity and marginal or unproductive lands. In case studies within the territory of Guadalajara, the Autonomous Community of Castilla La Mancha does not have this type of open data. To obtain this information, other types of land-use references have been reclassified, such as CORINE Land Cover (CLC), a project of the European Environment Agency that was born with the objective of obtaining a European occupation database of the soil updated to several reference years. From this information we have been able to reclassify through an equivalence table that represents the same four groups of distinction of capacity of use, as in the case of Andalusia. To obtain the data from the geological maps (Plates 5.1–6), we have relied on the National Geological Cartography, more specifically on the visualisation service (WMS) of the geological map which represents the result of the cartographic homogenisation of the MAGNA geological map series. These data are presented in order to examine land use of the case study areas in their geological context which influences factors such as soil capacity and the selection of locations for settlement, agriculture and defence.

In the case studies of Agicampe and Cartuja (Plates 5.7, 5.8) we can see how the plains of the Granada basin provide large portions of excellent and fertile lands adapted to intensive irrigated cultivation, territory known respectively as the Vega of Granada and the Vega of Loja, both articulated on the fluvial axis of the Genil river. In the case studies of Cártama and Teba (Plates 5.9, 5.10) it is striking how, despite having two river courses such as the Guadalteba and the Guadalhorce, these do not generate lands of excellent capacity along their route. The opposite is the case, as the large amount of forest land generates extensive portions of marginal or unproductive land. Drawing on multiple sources of evidence enables the adoption of a multi-scalar approach to understanding historic land use.

As discussed by Banerjea *et al.* (2019), whilst there have been geoarchaeological investigations into the evolution of arid and semi-arid agriculture associated with medieval rural settlements in several areas in Spain, including Murcia (Puy and Balbo 2013; Puy 2014), Galicia (Ferro-Vázquez *et al.* 2014) and the Basque country (Quirós Castillo *et al.* 2014; Quirós Castillo and Nicosia 2019), castles are rarely included within studies of the different agrarian landscapes in Iberia, despite being central points in the distribution of settlements. Our understanding of the patterns, timing and scale of landscape change in medieval Iberia are best informed using scientific data, which includes palaeoenvironmental analyses of microfossils (e.g. pollen) contained in lake sediments, peat bogs and archaeological features. Numerous such studies are available across Spain, most recently synthesised in the *Paleoflora y Paleovegetación Ibérica: Holoceno* (Carrión 2022), with relevant studies distributed across all landscape zones from mountain to fertile lowlands and coasts. The strengths and limitations of the use of these palynology studies in understanding landscape change and land use in medieval Iberia is assessed in this chapter, as well as how they are supported and strengthened by geoarchaeological analyses.

Guadalajara

Upland land use

Within central Spain, while numerous pollen sequences are available, these are largely located to the west and south-west of Atienza and Molina de Aragón within the Guadarramá mountain range of the Central System, and further to the south-west within the Montes de Toledo. Blanco-González *et al.* (2014) have undertaken an important synthesis of the pollen data from the Central System. The authors highlight the paucity of high-resolution palynological studies from this area, which vary in their temporal resolution, and in common with palynological studies across the Iberian Peninsula tend to concentrate within later prehistoric rather than historic periods. Blanco-González *et al.* (2014) recognise two broad phases of land use during the medieval period, first involving localised land-use impacts to the north of the Central System from the 5th to 12th centuries, followed from the 12th century by colonisation of upland areas. The region saw impacts during the preceding Visigothic period (5th to early 8th century), with a reduction in oak woodlands in lowland settings and pine in upland environments, together with an expansion of cereals and evidence for pastoral activity. This pattern is visible in pollen sequences from Peña Negra mire (Abel-Schaad and López-Sáez 2013), Lanzahíta (López-Sáez *et al.* 2010) and Pelagallinas (Franco-Múgica *et al.* 2001).

The Islamic conquest and fall of the Visigothic Kingdom are marked by both evidence for continued anthropogenic activity in lowlands along with evidence for some forest recovery in high-altitude settings. Within upland frontier landscapes, settlement is likely to have been patchy and impacted by sporadic conflict between Christian and Islamic states. To the south with the Toledo Mountains, pollen from Bermu and other sequences indicate that the landscape was predominantly open in the Islamic period, with upland areas utilised for grazing pasture lands and lowlands for cereal cultivation (Luelmo-Lautenschlaeger *et al.* 2018).

There is an increase in evidence for land use from the 11th century, reflecting the southwards movement of the frontier following the conquest of Toledo in 1085, together with milder climatic conditions associated with the Late Medieval Warm Period; indicators of cereal cultivation along with the cultivation and management of olive and sweet chestnut.

Settlement intensification during the late medieval period (12th–13th centuries) is apparent in both upland and lowland landscapes, with increasing land use evidence in palynological sequences. Woodland clearance increases in mountainous areas used for seasonal pastoralism with cultivation of rye, olive and sweet chestnut apparent from lowland environments. Evidence for an increase in olive is apparent in the pollen sequence from Pelagallinas, c. 17km west of Atienza (Franco-Múgica *et al.* 2001). Pollen data from the region provide a longer-term perspective on land-use change. A pollen core from Somolinos – very near Atienza – indicates that the first very strong vegetation change occurred as early as the 2nd century BC. At that time, arboreal taxa (notably *Pinus*) dropped significantly, while herbaceous plants increased (Currás *et al.* 2012). This shift is accompanied by clear signs of grazing pressure in the area, evidenced by the presence of coprophilous fungal spores. Further vegetation changes, including a continued rise in herbaceous plants and an increase in *Quercus* (oak) pollen, occurred before Late Antiquity, during the Classical period. These findings suggest that human-induced landscape transformation, including deforestation and pastoral activity, began centuries before the medieval period. Desiccation of the lake begins from the 4th century onwards and chronological resolution for the period between 8th–13th centuries AD is very low.

The Cañamares area (Currás Domíngez 2012) was characterised by a deforested landscape around the 5th century AD. The pollen record reflects the landscape transformation that occurred between the late Middle Ages and the early modern period. The development of livestock farming documented since the late 13th century AD had favoured a partially forested landscape in which some type of agroforestry system could be implemented. The low values of tree taxa indicate that this vegetation cover configuration remained stable and the tree layer did not undergo any regeneration process until the 12th century AD. From the 9th and 10th centuries AD, a greater influence of human activities has been detected, the effects of which are evident in the recovery of cultivated taxa and the development of ruderal taxa such as *Rumex acetosa*-t or open-environ taxa such as Asterioideae. An increase in *Olea* is also recorded, which could demonstrate the spread of olive groves at a regional level. The sequence reveals the presence of other indicators, sometimes linked to pasture areas in Mediterranean ecosystems. Crop indicators reveal stable land use during the 10th and 11th centuries AD.

Prospection in the territory of the castle of Molina de Aragón, as part of the Landscapes of (Re)Conquest project, did not identify any usable lacustrine sequences for palaeoenvironmental reconstruction of the castle's hinterland (Plate 5.11). The sequences that were recovered were all shallow (< 1m in depth), minerogenic, and had been subjected to frequent wetting and drying cycles evidenced by oxidised iron laminations throughout. While low counts of pollen were observed from a core at La Yunta, no plant macroremains were recovered for radiometric dating, and so pollen grains were extracted producing the following dates from the following depths, indicating some mixing of the peaty deposits within the sequence between the depths of 42–47cm: 8940 ± 30 BP at 42–43cm; 3320 ± 30 BP at 43–44cm; 5540 ± 30 BP at 45–46cm; 3480 ± 30 BP at 46–47cm. Given the shallow depth of the sediment in the lake and the prehistoric dates, it is hypothesised that these shallow lakes have a very slow sediment accumulation rate and experience regular wetting and drying cycles; consequently, they are unsuitable for palaeoenvironmental reconstruction.

Cultivation

In the case studies of the province of Guadalajara we find a territory that presents more heterogeneous lands where there are some plots of land with excellent soil capacity. In the case of Molina de Aragón they are structured around the Gallo river (Plate 5.12), in the case of Atienza they are generated near streams in the open land around the village (Plate 5.13). The data for the maps of irrigated terraces and dryland terraced plots have been obtained in a different way depending on each of the case studies. In the case of Molina de Aragón (Plate 5.14), we can see how there are irrigated terraces along the Gallo river, described and regulated from the Communal Charter of the town of Molina dating in 1152–1154, which have been analysed and interpreted in a recent work as Andalusí. It would be previously irrigated spaces that the new rulers inherited and regulated their operation, based on the needs and demands of the new society that was being formed (García-Contreras Ruiz *et al.* 2023). At the same time, another investigation was carried out to detect the crop terraces that were still exploited and visible in the photograph of the 1956–1957 American flight, and were immediately abandoned after (Flores Navarlaz 2021). In 2015, excavation of the terrace system adjacent to the fortification revealed the following profile, base to surface (Garcia-Contreras Ruiz *et al.* 2016): C horizon; buried soil; colluvium; and modern topsoil. A single fragment of medieval pottery was recovered in the make-up of the terrace wall, and an OSL sample produced an age estimate of AD 930–AD 1160 (Toms 2025) for the sediment at the base of the buried soil. The terrace soil may have received manuring up to the 20th century as attested by a fragment of ceramic produced between the 19th and 20th centuries. The colluvial sediment above did not contain any material culture.

In the case of Atienza (Plate 5.15), we can see how the irrigated areas associated with Andalusí pottery are small, and are found both along water courses and in some plots on terraces irrigated by springs. Some dry land terraces abandoned at the beginning of the second half of the last century are also documented.

In 2016, coring prospection and subsequent test trench excavation located an irrigated field system in Molina de Aragón and geoarchaeological samples were collected. A 1m × 1.5m trench was dug in an irrigated allotment area of the town, which was in use in 2016 by inhabitants of the town for growing vegetables. The ceramic chronology identified the earliest deposits as the establishment of a medieval field system beginning in the feudal period. The allotment area (coords) is near the river Gallo and visible from the castle (Plate 5.16). The trench was excavated to a depth of 1.5–2.0m below the surface, reaching alluvial sediment relating to over-bank flood deposits from the River Gallo. The calcareous natural riverbed alluvial sediment (SU 6007) is at the base of the profile, over which an additional alluvial deposit (SU 6006), containing 12th–13th century AD ceramics, was recorded at the current water table. The ceramics are abraded and rounded and considered to be a secondary deposit that has resulted from river action and sediment transport from a nearby location upstream. Stratigraphically above SU 6006 is SU 6004, which was another heavily compacted and waterlogged stratum, and lies below the modern agricultural soils that contain plastic and modern glass fragments (SU 6001 and SU 6002). SU 6004 was considered to be an older agricultural soil containing 15th-century ceramics, and is cut by an old irrigation ditch (*acequia*), which was filled with a silty sediment (SU 6003).

Four micromorphology samples, from which a total of six thin sections were prepared, were analysed to aid the identification of an earlier phase of the irrigated area (see Banerjea 2025 for the dataset). The analysis confirmed the presence of buried soils and the location of a historic irrigation ditch (*acequia*), which was distinguished through a minor but important difference in particle size (sandy silt loam particle size in channel, SU 6003; sandy clay loam/loamy sand in other buried soil horizons). The buried soil horizons comprise a series of A (surface) and B (sub-soil) horizons, the earliest of which formed at the base on the alluvium and the A horizon was identified in SU 6006, at the base of slide 4b. SU 6004 was identified in the field and overlaid SU 6006. Micromorphological analysis shows that SU 6004 actually consists of a B horizon at its base in slides 4a and 4b and an A horizon further to the top in slides 6a and 6b. There is substantial evidence for bioturbation in these slides in the microstructure, as well as infillings, and earthworm biospheroids occur throughout units in samples 4 and 6, suggesting that there could be several phases of bioturbation (Canti 2017; Kooistra and Pulleman 2018). The A horizon in SU 6004 was also identified in the base of the sample. The irrigation channel appears to have been cut into SU 6004 and the fill of the channel represents it 'silting up', i.e. infilling with sediment forming SU 6003. The top of the sediment that infills the channel is the basal unit of sample 7. The channel was probably recut (as channels are still present today), but this is not represented in the excavation trench. The A horizon continued to form over the infilled channel and is represented in SU 6002, the modern agricultural soil.

In comparison to B horizons, the units which are classified as A horizons have a greater abundance of burnt residues and dung, which have been added to the soil as fertilisers (Plate 5.16). The B horizon (SU 6004, slides 4a and 4b) contains greater abundances of fragments of building materials. These coarser, less organic components may have not been worked into the A horizon in the same way as the organic burnt materials and dung. The fertiliser materials represent waste from a range of household, industrial and husbandry activities, possibly taking place in the nearby fortification, and comprise domestic refuse (bone, including burnt, calcined, non-burnt and fish, eggshell, ceramic fragments from tableware), slag, charred wood, omnivore coprolite and herbivore dung fragments. Omnivore coprolite and herbivore dung may have been deposited by animals being grazed in this field system to increase soil fertility (García-García and Moreno 2018). Livestock were also grazed within the walled area of the citadel at Molina, but this was only evident in the post-medieval strata (Banerjea *et al.* 2019).

Aggregates of water-laid sediment crust (Zhuang *et al.* 2025) occur mainly in sample 3, from the base of the historic irrigation channel, base of SU 6004 (B horizon) and lowest A horizon, SU 6006. These fragments of crust indicate the aggregation of fine (clay) material that has accumulated through slow water inundation (from irrigation), which has subsequently been reworked by several phases of bioturbation and soil forming processes. Aggregates or nodules of calcareous sediment occur in SU 6002, 6003 and 6004 (slides 6a, 6b and 7), which have been reported to occur in soils with long-term historic irrigation derived from calcareous alluvium (Adderley 2018), as is the case with this irrigated field system in Molina. Fragmented rhizolith features, whereby the organic component of root fragments has been replaced by calcite mineral, occur toward the base of the profile in SU 6006, slide 4b; these features have also been observed in Peruvian terraces where there has been deep root bioturbation (Goodman-Elgar 2008). Wetting and drying processes are evident in the soils forming various calcitic pedofeatures developed through dissolution and reprecipitation in calcareous soils under wet or irrigated cultivation (Lang and Stump 2017; Adderley 2018). Few, 2–5%, redoximorphic pedofeatures also occur.

Andalusia (present day)

Upland land use

The physical geography and climate of Andalusia is varied, characterised by two mountain ranges, the comparatively low-lying Sierra Morena to the north and the Betica Ranges to the south, including the peaks of the Sierra Nevada. Between lies the fertile lowlands of the Andalusian Plains focused on the valley of the Rio Guadalquivir, and fertile coasts to the south of the Sierra Nevada. Present-day land-use maps (Plate 5.17) show that the area of the Sierra Nevada to the east of Granada is characterised by pasture and patches of woodland, which may represent a continuation of historic arboriculture and pasture identified in the pollen record, and irrigated cultivation between Granada and Loja along the Rio Genil (Plate 5.18) with also pasture to the south of Loja and Agicampe (Plate 5.17).

The majority of available data on the environmental history of Andalusia derives from pollen sequences located in upland, high altitude settings, most notably from the Sierra Nevada. There are comparatively few studies from the more intensively settled lowlands. Moreover, most studies cover several thousand years, and specific periods such as the medieval often lack the associated sample and chronological resolution to distinguish beyond broad trends in vegetation.

The environmental history of this region, as much as Iberia itself, is characterised by millennial scale variability defined by phases of increased aridity (e.g. Bellin *et al.* 2013) and consequent variability in regional climate and vegetation. From Padul located in the Sierra Nevada, there are environmental indicators of arid conditions between AD 400 to 1400, with colder conditions during the post-Roman period and warmer conditions during the Medieval Climatic Optimum.

Multi-proxy analysis of lake sediments at Laguna de la Mosca demonstrated that there was a reduction in tree cover within the Sierra Nevada, associated with peaks in microscopic charcoal brought on by increased aridity from 4000 years ago. The vegetation history of the Sierra Nevada is heavily influenced by climate variability, though in the last 1000 years the pollen sequence from Laguna de la Mosca shows an increase in olive and chestnut reflecting human activity (arboriculture) in high altitude settings. A similar picture is evident from other lakes in the Sierra Nevada, including Laguna de la Mula, showing a period of aridity from AD 100 to 1300, with a decrease in oak and increased fire incidence. A component of the charcoal is likely linked to human activity, but the most marked evidence is considered to relate to mining activity documented during the Roman period (Jiménez-Moreno *et al.* 2013).

Evidence for arboriculture and pastoral activity is also apparent from the pollen sequence from Laguna de Río Seco (Anderson *et al.* 2011), including an increase in chestnut and olive apparent from pre-Roman times.

Cultivation

The Land of Aynadamar, within the 'castlescape' of the Alhambra, is located on high ground on a geological formation comprising conglomerates, sandstones, red clay, marl, limestone and carbonates (Plate 5.2). Again, the present-day excellent soil capacity (Plate 5.8) is in irrigated areas at the valley bottom (Plate 5.19), which, in the medieval period, was supplied by the Channel of Aynadamar. The case study of the Cartuja of Granada (Plate 5.19) has also shown an irrigated space with several terraces in Nasrid time (García-Contreras Ruiz *et al.* 2017), but the most relevant thing that is evident are the large irrigated spaces close to the city such as its Vega (Jiménez Puertas 2012), thus like Vega of Huétor and the Cenes terraces. Also in this case, there are salt mines in the wide Granada basin, more specifically in the territory of Quempe and in the Malahá *alquería*.

The soil micromorphological study of the Land of Aynadamar allows us to delve into both the Nasrid productive strategies and, above all, the transformations, including periods of disuse and reuse, which took place after the Castilian conquest when the landscape of orchards and vineyards, pools and ditches, was replaced by a centralised model of agriculture of dry land destined to satisfy the demands and commercial needs of the new Christian elite which include the Carthusian monks. The soil micromorphological analysis revealed that the changes arising from the Castilian conquest, which are articulated in documentary sources, took a few decades and were not immediate (Banerjea *et al.* 2024). It shows the processes of change in four areas of Aynadamar covering the 13th to 16th centuries, which encompassed agricultural terraces, an external space in an area occupied by a community of Moriscos (García-García *et al.* 2021), the remains of a *cármenes* (a peri-urban farm) and an *almunia* (small palace) from the Nasrid period.

The soil micromorphological analysis (Banerjea *et al.* 2023, 2024) identified the construction process of agricultural terraces dating to the 15th–16th centuries (from the Castilian conquest) and man-made garden soils adjacent to a structure of Nasrid date. Soil micromorphological analysis indicates that there were two phases of use, and that soil may have been deliberately repurposed from the local surrounding area and deposited onto the terrace 'cut and fill' construction (Brown *et al.* 2021, fig. 1). In the first phase, soil from the local surrounding area was repurposed and brought to the terrace as topsoil. The second phase is characterised by a further deposition of soil creating a profile with an A and B horizon. The soils contained fragments of herbivore dung and domestic refuse which may originate from material used as fertiliser. The terrace soils showed indications of chemical alteration and ongoing bioturbation. The occurrence of iron nodules, impregnative redox pedofeatures (Vepraskas *et al.* 2018), probably arose from cycles of wetting and drying (Lang and Stump 2017; Adderley *et al.* 2018). Rhizoliths occur in the soils lower half of the profile (22007a and 22007b), which could indicate deep root bioturbation (Goodman-Elgar 2008). Carbonates are not present in the groundmass of the A-horizon (22007a). Unlike the other units in this profile, it does not have a crystallitic b-fabric and is different in colour, which may be due to an increased humic content and carbonate leaching from weathering. Of note, albeit in soils from the Netherlands, decalcification of topsoils in orchards can occur where there is no earthworm activity (Jongmans *et al.* 2003; Adderley *et al.* 2018), which is absent from A-horizon (22007a).

The 14th-century 'garden soils' adjacent to a Nasrid wall (Trench 24.000) share similarities in formation and composition with *terra preta*, which is an anthrosol for cultivation in the Amazon, formed because of enrichment due to the decomposition of habitation refuse (Arroyo-Kalin 2010), European Dark Earths (Devos *et al.* 2022) or garden soils found in urban areas (Davidson *et al.* 2006). The garden soil in Trench 24.000 contains sediment from the local area, anthropogenic inputs comprising charred wood, bone fragments and building materials, and shows the potential recycling of soil and ongoing pedogenesis. Phytoliths, which could indicate cultivated crops, were not observed in either the terrace or the garden soil, which could be due to poor preservation in alkaline sediments. The ‘garden soils’ do not show the same effects of irrigation as the terrace soils. They have few redoximorphic pedofeatures, but no calcite features. This may suggest that water was used on these soils from the nearby well, rather than from an irrigation system. The garden soil in Trench 24.000 was covered with a further, more sterile soil, which could relate to the disuse of the area during the late 15th to mid-16th centuries. Other abandonment/end-of-life deposits from this period at the end of Nasrid rule were identified elsewhere in Aynadamar, including Nasrid buildings in Trench 29.000 and in proximity to the *almunia* at the top of the hill. The *almunia* was deliberately remodelled and pool infilled in stages. There was a short period of disuse where sediment accumulated, then soils formed *in situ* inside of it on substrate comprising sediment deposited during deliberate infilling which took place before 1640. Further infilling took place after this and included modern material culture. These periods of disuse and deliberate infilling are considered to be contemporary with some of the periods of disuse associated with the pathway to the entrance of the *almunia* (Banerjea *et al.* 2024), which was still thought to be in existence after the Christian conquest of 1492, c. 1520, when a new house was built to the north of the pool.

Further west of Cartuja along the Rio Genil, Torre de Agicampe, an *alqueria* (Plate 5.20), in addition to having demonstrated a Nasrid irrigated space associated with the same settlement (García Porras *et al.* 2020), reveals a proximity to an abundant area of extensive irrigated systems. Some of them such as Frontil or Tajará have been dated early (8th century), while others have developed from the growth of the city of Loja (10th–11th centuries) (Jiménez Puertas 2007). These are linked both to the terraces of the Genil river in the area between Loja and Huétor Tájar, and to the terminations of its tributaries Salar creek and Cacín river. Other important natural resources in its surroundings are the Fuente Camacho salt flats that were exploited in the medieval period. Torre de Agicampe is located in an area which today has unproductive to moderate soil capacity (Plate 5.7), and lies on the same geological formation as Cartuja. In its surrounding area, today, the excellent soil capacity locations (Plate 5.7) are around the river systems, particularly the irrigation systems to the south by the Genil (Plate 5. 20). The moderate to good soils (Plate 5.7) are used for woodland (or arboriculture) and pasture (Plate 5.17). The unproductive soil by Agicampe may have been a contributory factor in the medieval period leading to the construction of irrigated terraces around the tower as a strategy for soil retention and amelioration. Two seasons of geoarchaeological fieldwork were conducted in the fields adjacent to Torre de Agicampe: the first in spring 2018, and the second in October 2018 (García Porras *et al.* 2020). The lower levels of the upslope sondages nearest to the farmhouse produced Nazari pottery, 13th–15th century; whereas the sondage further downslope produced post-15th-century pottery. The spring and October 2018 upslope sondages found the remains of terraces and buried soils at the base of the profile from which geoarchaeological samples were collected.

Soil micromorphological and phytolith analyses were conducted on samples collected in spring 2018 from an upslope sondage; phytoliths are plant microfossils made from silica and are found in some plant tissues and persist after the decay of the plant. The soil micromorphology samples (Plate 5.21) were collected from an upper and lower soil on the terrace, and the phytolith samples were collected from the upper and lower soils and from two 0.5cm columns above the upper and lower terrace soils. OSL samples (Plate 5.21) were collected from the upper and lower soils at the base of the profile on the terrace and returned age estimates of AD 870–AD 1000 for the lower soil (OSL 1) and AD 1120–AD 1250 for the upper soil (OSL 2). The date for OSL 1 should be accepted tentatively owing to significant Uranium disequilibrium; whereas the age estimate for OSL 2 had no analytical issues (Toms 2025). The soil micromorphological and phytolith analyses have characterised and identified terrace soils from the Nasrid period at the base of the profile from the sondage that was sampled in spring 2018. The soils were fertilised using domestic midden material, and there is a strong possibility that they were managed by irrigation and ‘stubble-burning’ to remove old vegetation. Soil micromorphological analysis identified two B-horizons (or sub-soils): one for the upper soil and one for the lower soil. The upper soil also has an A-horizon (top soil); the A-horizon of the lower soil may have been removed by soil erosion, and the profile from the sondage recorded in October 2018 shows that the terrace platform and wall were rebuilt (Plate 5.21). Both soils contain inclusions relating to domestic refuse, which could indicate that midden material was used to improve the soils, as also observed on the irrigated field at Molina de Aragón and the terraces from Aynadamar (Granada). The upper and lower soils both contain fragments of bone and charred wood. The upper soil also contains fragments of coprolites and a fish tooth, and the lower soil contains fragments of eggshell. The reported effects of manuring and liming on soil microstructure are largely explained by increased bioturbation. This can result in the development of crumb microstructure, increased soil porosity, particularly microporosity, and the development of the channel (Adderley *et al.* 2018). The practice of clearing vegetation by managed fire regimes is adopted for many different purposes worldwide. Micromorphological features can include charcoal, burned soil fragments and exotic components such as phytoliths (Adderley *et al.* 2018), all of which are present in these samples, which lends support to the idea that the terrace system was managed by burning the stubble. Aggregates of burnt soil were only observed in the upper soil and many of the grass-type (that could include cereals) phytoliths that were recovered through extraction are burnt. The direct effects of fire on soil are dependent on the texture and mineralogical composition of the soil and on the intensity, oxygen regime and temperature of the fire (Adderley *et al.* 2018). The soils in this profile have been subjected to ongoing biological reworking and possibly irrigated, which makes temperature determination and estimation of duration of any fire difficult to determine from the observed features in the soil microstructure.

The most commonly reported effects of irrigation on soil microstructure are disaggregation of aggregates and a decrease in porosity. This structural degradation was most pronounced in clay-rich soils. Infilling of pores by disaggregated materials also led to a decrease in porosity (Adderley *et al.* 2018). Microstratigraphic Unit (henceforth MU)1 and MU3 in both the upper and lower soils have compound packing voids and an intergrain aggregate related distribution, which forms where the finer sediment infills the void spaces between coarser components. As this is an upland cultivation system, comparing this decrease in porosity with those features recorded in wet cultivation of rice (in Adderley *et al.* 2018) to determine irrigation is approached with caution here. There are also pedofeatures that could also indicate irrigation. The upper and lower soils at Agicampe show reprecipitated gypsum. In irrigated calcareous or saline soils, various pedofeatures may develop through dissolution and reprecipitation, such as impregnative calcitic features (Adderley *et al.* 2018). In soils under wet rice cultivation, impregnation and depletion of pedofeatures of iron and manganese oxides are common features (Adderley *et al.* 2018). The formation of amorphous iron nodules and neformed manganese nodules is observed in the upper and lower soils, which can indicate alternating wetting and drying of the soils (Adderley *et al.* 2018; Vepraskas *et al.* 2018).

Further to the south-west, less evidence is available to spatially assess cultivation around Tebá and Cártama. Teba does not have an irrigation system nearby; while in Cártama there are two irrigation ditches, but it is uncertain whether they date from the Andalusian period.

At Cártama, the identification of a broad range of plant remains in the deposits (Banerjea *et al.* submitted) dating to the 13th century (from a *fumier* sequence discussed below) demonstrate the integral relationship between plants and animals (García-García and Moreno-García 2018). In the plant macrobotanical record, the presence of pearl millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) is particularly noteworthy, as these are medieval Muslim introductions that remain rare in the Iberian Peninsula (Pérez-Jordà *et al.* 2024). The integrated phytolith and soil micromorphological analyses also provided an insight into agrarian technology where one of the samples produced an articulated silica skeleton of millet (Banerjea *et al.* submitted, fig. 10h) that had been cut by a threshing sledge (Anderson 2003). Although the pollen in these deposits mostly reflects the fodder composition and the animal diet (herbs), it also captures the existence of mixed oak forests characterised by cork oak in association with lime trees around the site. Sporadic pollen of pine was probably transported over larger distances (a few tens of km) and higher elevations. Arecaceae phytoliths were prevalent in the assemblage from the *fumier* sequence and the dwarf palm, *Chamaerops humilis,* occurs in the macrobotanical assemblage (charred seed and stipe) and, it is thought that palms were the main fuel used as tinder to start the fire to burn the dung (Banerjea *et al.* submitted).

Pastoral activity

Pastoralism is an exceptionally opaque reality in written documentation and rarely appears in these sources (García-García and Moreno-García 2018). The livestock of the former kingdom of Granada is the best known in al-Andalus due to the relative abundance of written documentation generated during the Nasrid period and the period immediately following the Castilian conquest, expanded by a growing *corpus* of recent zooarchaeological research (eg. García-García 2017, 2023; Grau-Sologestoa 2017) and isotopic studies (e.g. Alexander *et al.* 2019; Inskip *et al.* 2019).

In addition to pastoral activity in the uplands evidenced through palynology, the application of soil micromorphology is a well-established research technique for identifying and interpreting *in situ* stabling deposits on archaeological settlements (e.g. Polo-Díaz and Fernández Eraso 2010; García-Suárez *et al.* 2018; Banerjea *et al.* 2020; Banerjea *et al.* 2021; Polisca *et al.* 2025) and is applied to a series of deposits in this study from a profile at Cártama, in conjunction with the analysis of plant macroremains, phytoliths, pollen, non-pollen palynomorphs (NPPs) and faecal lipid markers (Banerjea *et al.* submitted). The multidisciplinary micro- and bioarchaeological analyses of 13th-century Almohad deposits from suburban Cártama, Málaga, Spain, have, for the first time, confidently identified open-air *fumier* deposits. *Fumier* (French) translates to 'dung' or 'manure' and it refers to animal waste, such as excrement from stables and barnyards. In archaeology, *fumier* sequences (overlapping of burnt and unburnt sedimentary layers) play a primary role in the study of livestock management and the use of space in prehistoric pastoralist societies in sheepfold caves and rock shelters (Brochier *et al.* 1992; Macphail *et al*. 1997; Angelucci *et al*. 2009; Alonso-Eguiluz *et al.* 2017, 2024; Morandi 2020). The integrated analyses identified the presence of dung, livestock alimentation, *in situ* depositional and burning processes, and indications of trampling, which make the case for this feature (UE 354) being a small corral, where livestock sheltered taking advantage of the hollowness of a 'robber trench', occupying an area of approximately 4.00m × 3.40m. This demonstrates that Andalusi livestock husbandry practices included periodically burning animal dung within corrals and pens, which is a long-standing practice in the Mediterranean region also observed in prehistoric transhumance. The site itself is situated in an area of pastoral land use (Plate 5.22).

Summary of multi-scalar approaches

Despite the variability in coverage of the sources of data that are available across al-Andalus for this period, it has been possible to successfully glean multi-scalar information about cultivation, pastoralism and the use of pasture and forestry in both Islamic and Christian contexts.

At the microscale, it has been possible to identify micromorphological features of agricultural practice, which come with the caveat that experimental research is required to examine these processes in soils across the Iberian Peninsula. Irrigation practices from both the Nasrid and Christian periods have been identified. Upland terrace irrigation, without water saturation, is evident at Agicampe, with an OSL age estimate of AD 1120–AD 1250 for the second phase of soil directly on the terrace, placing it in the late Almohad–early Nasrid dynasty, with material culture deriving from soil amelioration spanning the 13th–15th centuries. The unproductive soil by Agicampe may have been a contributory factor in the medieval period leading to the construction of irrigated terraces around the tower as a strategy for soil retention and amelioration, as observed across the Mediterranean (Brown *et al.* 2025). Soil micromorphology revealed terrace erosion and recording of the terrace profile in spring 2018 showed that it had been rebuilt. GIS and cartographic analysis showed that Torre de Agicampe is located in proximity to an irrigated area linked both to the terraces of the Genil river in the area between Loja and Huétor Tájar, and to the terminations of its tributaries Salar creek and Cacín river, some of them as Frontil or Tajará have been dated early (8th century), while others have developed from the growth of the city of Loja (10th–11th centuries).

Another panorama offers the area of Granada during the Andalusian Nasrid era (Plate 5.18), whose settlement has an important connection with the areas of irrigated crops, both linked to the Vega of Granada and the valleys that flow into it, all areas of excellent soils. The soil micromorphological study of the 'Land of Aynadamar' (Banerjea *et al.* 2024), showed that the 14th-century 'garden soils' (in an area later occupied by a community of Moriscos) do not show the same effects of irrigation as the later, 15th–16th century, Christian terrace soils, as a nearby well may have been used. This is an interesting observation as the written sources after the Castilian conquest refer to the landscape of orchards and vineyards, pools and ditches being replaced by a centralised model of agriculture of dry land destined to satisfy the demands and commercial needs of the new Christian elite which include the Carthusian monks (Torres Martín 2007). The soil micromorphological study of the terrace soils indicates that substantial upland irrigation took place with some evidence in the earliest soils that is comparable with orchard soils and deep root bioturbation. This could indicate that dryland agriculture was not yet established when the terrace was constructed and may have been established post-16th century when the second phase of the terrace was constructed (Banerjea *et al.* 2024). In the first phase, soil from the local surrounding area was repurposed and brought to the terrace as topsoil. The second phase is characterised by a further deposition of soil creating a profile with an A and B horizon. This mode of construction has also been observed from an early Islamic terrace at Ricote, Murcia (Puy and Balbo 2013), which shows that there is some continuity in using established construction techniques. The soil micromorphological evidence for soil amelioration in Molina de Aragón (irrigated field), Aynadamar ('garden soils' and agricultural terrace) and Agicampe (agricultural terrace) is very similar with domestic refuse, ceramics and building materials used. Dung was observed in the irrigated field soils at Molina de Aragón, which could indicate field grazing by livestock (García-García and Moreno García 2015). There is some evidence that the terrace system was managed by burning the stubble at Agicampe.

Evidence of irrigated agriculture from the Christian conquest was recovered at Molina de Aragón in an extension of the agricultural land use around the castle. The terrace system adjacent to the castle was established AD 930–AD 1160, indicated by OSL dating. The ceramic chronology shows that the material from the earliest soils in the irrigated field system by the river Gallo dates to the feudal period between 12th–15th centuries AD. The historic irrigation channel and earliest soils were identified, and the soil micromorphological evidence shows long-term historic irrigation derived from calcareous alluvium has deep root bioturbation (Goodman-Elgar 2008), and the aggregation of fine (clay) material that has accumulated through slow water inundation (from irrigation). There are various calcitic pedofeatures developed through dissolution and reprecipitation in calcareous soils under wet or irrigated cultivation (Lang and Stump 2017; Adderley 2018). Where at Cartuja we see a gradual transition to dry agriculture with a gradual reconfiguration of Aynadamar,at Molina de Aragón, the irrigated field system is still in use today, and although the Islamic terrace has been abandoned, terracing still continues in the local area. GIS mapping shows that in the province of Guadalajara there are heterogeneous lands where there are some plots of land with excellent soil capacity. In the case of Molina de Aragón they are structured around the Gallo river and in the case of Atienza they are generated near streams in the open land around the village.

The latest maps attempt to interpolate the settlement with the different resources in addition to associating at the same time the capacity for use of the land in the territory. In the case studies of Guadalajara (Plate 5.23), it is observed how during the Islamic era the settlement of Atienza was close and connected to the salt mines (García-Contreras Ruiz 2021), which raises the suspicion of inland salt mine exploitation by the Andalusian communities that lived in these lands. Regarding the feudal era in Guadalajara (Plate 5.24) we can see how the Atienza salt flats will continue to be used (García-Contreras Ruiz 2021), and how in the territory of Molina, one of the most used resources is metallurgical (Hernández-Casas 2022), although in both cases there is more diversification with the cultivation of some irrigated cultivation spaces associated with good lands, especially along river courses. The wider synthesis of pollen data from Guadalajara shows land use and clearance intensifying into the medieval period. Settlement intensification during the 12th–13th centuries is apparent in both upland and lowland landscapes, with increasing land-use evidence in palynological sequences. Woodland clearance increases in mountainous areas used for seasonal pastoralism with cultivation of rye, olive and sweet chestnut apparent from lowland environments and evidence for an increase in olive is apparent around Atienza, which is characterised by a deforested landscape around the 5th century AD. The pollen record reflects the landscape transformation that occurred between the late Middle Ages and the early modern period. The development of livestock farming documented since the late 13th century AD had favoured a partially forested landscape in which some type of agroforestry system could be implemented.

Diversely to the area of Granada, for the Nasrid period around Cártama and Teba (Plate 5.25), there is a connection of settlement with exploitation of the lesser productive lands, which may indicate more livestock strategies and fruit orchard and dryland areas. It is noteworthy that the soil micromorphological and micro botanical evidence for livestock management and alimentation from Cártama is unlike any of the other case studies in this project, adding support for this hypothesis and inferring Andalusi livestock husbandry practices included periodically burning animal dung within corrals and pens, which is a long-standing practice in the Mediterranean region also observed in prehistoric transhumance. In Granada (Plate 5.26), some changes can be seen in lowland areas (Martínez Vázquez 2016), although the big change that we can see is in the mountain areas that previously occupied the border area. It is in this territory that we can observe how a high number of farmhouses (*cortijo*) arise (Luna Díaz 1989), that are installed on marginal lands or with little productivity, land that has been obtained by obtaining new cultivation spaces for the dry land by clearing certain areas next to the farmhouses. In the territory of Málaga (Plate 5.27), changes similar to Granada are perceived, with the constitution of Villas where there were fortifications and other villages in areas with more livestock and dryland resources.

As discussed, the majority of available data on the environmental history of Andalusia derives from pollen sequences located in upland, high-altitude settings, most notably from the Sierra Nevada, and there are comparatively few studies from the more intensively settled lowlands and with low chronological resolution. The vegetation history of the Sierra Nevada is heavily influenced by climate variability, though in the last 1000 years the pollen sequence from Laguna de la Mosca, like Pelagallinas and Cañamares (Atienza) shows that there is an increase in human activity and evidence for land use. A similar picture is evident from other lakes in the Sierra Nevada, including Laguna de la Mula, showing a period of aridity from AD 100 to 1300, with a decrease in oak and increased fire incidence. Evidence for arboriculture and pastoral activity is also apparent from the pollen sequence from Laguna de Río Seco (Anderson *et al.* 2011). More widely, in Murcia, environmental data from a lowland coastal setting (Azuara *et al.* 2020), shows that the 11th and 12th centuries are characterised by deforestation and evidence for pastoralism, associated with the growth of Murcia and a period of economic growth. There is no evidence for reforestation in the late medieval and post-medieval periods, despite Christian control of Murcia, as with Andalusia, seeing the repression and reduction of Muslim populations in the region. This is argued to have led to a more specialised land use strategy involving extensive livestock farming, maintaining open habitats in the region.

Concluding remarks

This review of land use in Iberia during the Islamic and Christian states provides a foundation for future research applying multi-scalar techniques to understand nuances in land-use change and continuity. Variability in open-source data for land use, the suitability of coring locations for palaeoenvironmental reconstruction and the number of current geoarchaeological studies in the Iberian Peninsula for this period are all factors that need to be addressed as this area of research starts to gain momentum.

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