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Land selection for irrigation in Al-Andalus, Spain (8th century A.D.)

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The Andalusi hydraulic systems of the Iberian Peninsula, constructed by Arabs and Berbers between A.D. 711 and the feudal conquest of Al-Andalus (11–15th centuries A.D.), are today among the most productive agricultural areas in Europe. Their current extension is the result of several enlargements made to the original Andalusi design, irrigating lands initially rejected by the first builders. Understanding the reasons that led Arabs and Berbers to select or reject lands for irrigation is essential for documenting the formation processes of these agricultural areas. Here the topic is approached using the hydraulic system of Ricote (Murcia, Spain) as a case study. Through hydraulic archaeology, excavations, and GIS, it is shown that deep, flat, well-insolated (i.e., exposed to sunlight), slightly saline, colluvial soils were preferred for irrigation while slopes, shady areas, floodplains, and highly saline soils were rejected. Optimizing the water supply for irrigation was not a top priority. The results highlight the need to consider topographical features when studying how past agrarian societies introduced irrigated agriculture to new environments.

Keywords: Al-Andalus, irrigation, Mediterranean, hydraulic archaeology, GIS, terraces, intensive agriculture

Introduction

Around A.D. 711 a large number of Arabs and Berbers crossed the Strait of Gibraltar and entered the Iberian Peninsula (Al-Andalus) (Lévi-Provençal 1950; Guichard 1976; Barceló 2004). This migration was related to the diffusion of Islam after A.D. 632, which contributed to the spread of knowledge accumulated by *filāḥa hindiyya* (Indian agriculture). This knowledge included techniques for the catchment, channeling, and distribution of water, the construction of terraces and hydraulic systems, and the management and maintenance of a wide range of Asian crops, such as orange and lemon trees, artichoke, spinach, cucumber, eggplant, and sugar cane, among others (Glick 1991, 1992, 2009; Watson 1974, 1983; Barceló 1995, 2004). After A.D. 711 these crops and techniques were introduced to the western Mediterranean and extended to a range of new environments, such as the alluvial plains in València, Catalonia (Guinot 2005, 2008), hillsides in Casarabonela, Málaga, Andalucía (Retamero 2011), and gullies and riversides in the Balearic Islands of Mallorca, Menorca, and Ibiza (Kirchner 1997, 1998; Barceló and Retamero 2005). The colonization of such heterogeneous terrains implies that the Arab and Berber groups arriving in the Iberian Peninsula were already adapted to the topographical diversity of the Mediterranean and its microregions (Horden and Purcell 2000: 53–88). Today the majority of these irrigated areas, known in Spain as *huertas*, are still operative, and are considered to be among the most productive agricultural lands in Europe (Acosta *et al.* 2011: 1056).

The successful introduction of an agrarian system to a new environment relies on the ability of the newcomers to assess the topographical, climatic, edaphic, vegetational, and hydrological features of the landscape (Rockman 2003). This process can take time, but it is essential before the construction of the fields. Some of the factors taken into account by farmers selecting lands for cultivation are the soils, their degree of exposure to sunlight, the degree of slope, susceptibility to flooding, and the volume of water available for irrigation (Brookfield 2001: 80, 157–173). Once these factors are assessed, lands are selected in relation to the productive needs and agrarian strategies of the group. Since topography plays a central role in the process, a detailed knowledge of the local environment is necessary to understand the logic behind farmers' choices and preferences (Netting 1974: 24). In the study of Andalusi hydraulic systems, that means knowing the criteria prioritized by Arab and Berber groups when deciding where to establish the first Asian crops in the western Mediterranean.

Research on Andalusi hydraulics started with Glick's (1970) pioneer study of the Medieval huerta

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of València and Bazzana and Guichard's (1981) work on the Júcar channel in Castellón. Barceló and his team from the Universitat Autònoma de Barcelona adopted a more systematic approach in the early 1980s, conducting several studies, mainly in the Balearic Islands and Andalucía (Barceló *et al.* 1986, 1989, 1990, 1998). The analysis of these data allowed Barceló (1989, 1995) to identify the basic principles involved in traditional hydraulic systems. First, they depend on gravity for water flow. A design prior to construction is mandatory to ensure proper articulation between water catchment, channels, and irrigated fields. Builders must study slopes in detail to avoid the water stagnating or arriving in the fields too fast, causing erosion. Second, as a consequence of this physical constraint, hydraulic systems tend to have rigid and recognizable limits. In order to maintain an effective system, later transformations and additions must remain faithful to the original design. Unless the original system has been obliterated, the original layout and later additions or modifications should be discernible. These principles form the basis of hydraulic archaeology (Kirchner and Navarro 1993; Glick and Kirchner 2000), which uses survey and written records to identify the original design of Andalusi hydraulic systems from later additions, mostly made after the feudal conquest of Al-Andalus (11–15th centuries A.D.). To date, more than 200 case studies have identified original Andalusi irrigated fields within hydraulic systems systematically enlarged over the last 800 years (Sitjes 2006). However, despite the influence of topography on farmer decision making, no systematic attention has been paid to the environments selected for irrigation agriculture.

The potential of integrating hydraulic archaeology and GIS to study the formation processes of Andalusi hydraulic systems is explored here. The combination of such techniques provides new information concerning Arab and Berber preferences for the location of these sustainable, resilient, and intensive installations; the selective mechanisms involved in the earliest adaptation of Asian plants to western Mediterranean environments; and the evolution of these agricultural landscapes over time. The hydraulic system of Ricote village (Murcia, Spain)—one of the first irrigated areas in the Iberian Peninsula, built shortly after A.D. 711 (Puy and Balbo 2013)—is used to identify the choices made by Arabs and Berbers during the selection of lands for irrigation.

The Ricote Valley

The hydraulic system of Ricote village is located in the Ricote Valley, an area situated within the region of Murcia, in the southeastern Iberian Peninsula (FIG. 1A). The mountains around the valley consist of

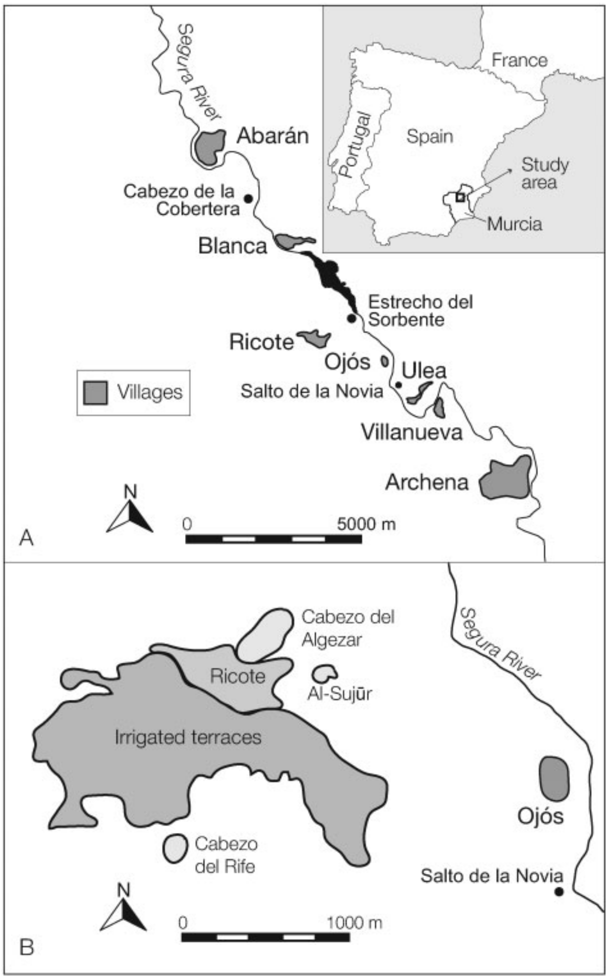

Figure 1 A) Map of the Ricote Valley with villages and the most significant archaeological sites; B) Map of the hoya of Ricote, showing the location of Ricote village, the irrigated terraces, and the three identified Andalusi settlements: the Al-Sujūr fortress (9th–13th centuries), the Cabezo del Algezar (11th–13th centuries), and the Cabezo del Rife (9th–13th centuries).

calcareous rock, polygenic conglomerates, and dolostone (Ortiz Silla 1983: 201–202). The slopes are populated by *Pinus halepensis*, *Quercus coccifera*, and *Pistacia lentiscus*, although xerophytic vegetation—e.g., *Cistus ciprus*, *Retama sphaerocarpa*, and *Rosmarinus officinalis*—dominates. The average summer temperature is 31–34°C and in winter it ranges from 1–5°C. Annual rainfall oscillates between 200 and 350 mm and evapotranspiration is between 750 and 900 mm (López Bermúdez 1973: 80–81). Sporadic torrential rains are common, especially in October (Hérin 1980: 32). The numerous seasonal streams of the valley channel the water runoff, which can be destructive in the event of flooding (Avellaneda Martín and García Martínez 1993). The soils are predominantly calcareous fluvisols, leptosols, regosols, and calcisols (FAO 2006), which are generally poorly developed. According to the climatic classification by Huddart and Stott (2010), these features allow the characterization of the Ricote Valley as a

A

B

Figure 2 Photographs of the hydraulic systems of the Ricote Valley. A) The Estrecho del Sorbente stretch. Note the contrast between the green vegetation of the valley floor (caused by irrigation) and the aridity of the surrounding slopes; B) An irrigation channel of the Ricote huerta excavated directly into the soil. This is one of the few channels in the huerta that maintains the original features and has not been covered with concrete to minimize evapotranspiration.

semiarid environment. Despite this designation, the valley floor is lush and green (FIG. 2) as a result of numerous dams, channels, and waterwheels built beside the Segura River. These devices ensure the irrigation of the alluvial plain and lower slopes.

The hydraulic system of Ricote village is situated in an *hoya*—a flat basin surrounded by mountains, crossed by three independent seasonal streams—above the main valley floor. This is the largest hydraulic system in the Ricote Valley and it draws water from a spring located southwest of the hoya. The original channels supplying the huerta are still visible and operative and most are covered with concrete to minimize evapotranspiration. Overall, the irrigated terraces cover 120 ha, encompassing the lowest lands at the bottom of the hoya and the slopes of the surrounding mountains. All terraces within the hydraulic system receive water from the aforementioned spring. As is often the case with large hydraulic systems, the huerta of Ricote is divided into *pagos,* or historical parcels of land (with associated toponyms), frequently used in Mediterranean Spain to locate specific plots within these vast agricultural areas.

Historical and archaeological context

Historical evidence for human occupation in the valley prior to the arrival of the earliest Arab and Berber groups is scarce. There seems to have been a settlement dating to the 4th–5th century in Salto de la Novia, between Ojós and Ulea (Ramallo Asensio 1987) (FIG. 1A). After A.D. 711, however, the region became densely populated. Several fortifications were built in the valley during the Andalusi period, such as the fort of Blanca (De Meulemeester and Eiroa Rodríguez 2005, 2006) and the Berber fortified granary in Cabezo de la Cobertera, between Abarán and Blanca, the first of its kind to be identified in the Iberian Peninsula (Amigues *et al.* 1999; De Meulemeester 2005). The earliest reference to Andalusi hydraulic systems is from the 11th century, when the geographer and historian Al-Bakrī observed that men "sucked off" the Segura River in a place known as Estrecho del Sorbente, located between Blanca and Ojós (Carmona 2005: 130) (FIG. 1A).

Three different Andalusi settlements have been identified in the hoya of Ricote. The first is the fortification of *Al-Sujūr* ("Rocky Outcrop"), currently Ricote's castle northeast of the village. According to the 11th-century historian Ibn Hayyān, the fortification was already established by A.D. 896 (Carmona 2005: 134–135). The Andalusi occupation lasted until the 13th century, as suggested by pottery sherds recovered during the survey of the fortification (Puy 2012a: 91–96). The second settlement was located in Cabezo del Algezar, where surface pottery dating to the 11th–13th centuries has been recorded (FIG. 1B) (Manzano Martínez 2002: 680; Puy 2012a: 86–87). The third settlement was located in Cabezo del Rife, in front of the modern village of Ricote. Several surface fragments of 9th–13th-century Andalusi pottery and the remains of stone walls built with lime and mortar, both on top and on the slopes of the hill, have been identified (Puy 2012a: 96–103). All three of these settlements were situated around the original Andalusi hydraulic system, which may have been built as early as the 8th century A.D. (Puy and Balbo 2013). Therefore, until the 13th century, the hydraulic system of Ricote was managed and shared by at least three different Andalusi groups who collaborated to ensure proper management of the irrigated fields (FIG. 1B).

Starting in the 11th century, with an expanding feudal system and a rising crusader spirit against Muslim and pagan societies (Bartlett 1993), the Christian kingdoms to the north of the Iberian Peninsula set out to conquer Al-Andalus. Murcia was taken in A.D. 1243 and in 1285 the Castilian king Sancho IV awarded Ricote Valley to the Order of Santiago, the most powerful military order in the region (del Pilar Gil García 1986: 208). The members of the order administered the region from their headquarters in Ricote village. It is likely that the feudal conquest of Murcia caused the three Andalusi settlements identified in the hoya to be abandoned. The Arab and Berber groups of Cabezo del Algezar, Cabezo del Rife, and the al-Sujūr fortress may have been forced to gather in a newly built settlement, the origin of the current Ricote village (Puy 2012a: 257–259). From the 13th century onwards, the hydraulic system (FIG. 1) was managed by the Order of Santiago and the Ricote *Mudéjares*, a term used to refer to Muslims living under Christian rule. The *Morisco* population (Christians of Muslim origin, baptized in A.D. 1502) remained in the Ricote Valley until 1613, when Felipe III expelled them from Spain (García Avilés 2007).

Methods

The location of the original Andalusi irrigated terraces within the current 120 ha of the hydraulic system of Ricote was determined based on the principles of hydraulic archaeology (Kirchner and Navarro 1993; Glick and Kirchner 2000). The entire system was systematically surveyed following the direction the water flows and drew its constituent elements onto a plan, and by using 1:5000 high definition ecw (Enhanced Compression Wavelet) raster maps as well as higher resolution maps where necessary. Recording involved the determination of the route followed by each channel, the morphology of each irrigated terrace, and the location of the pagos and hydraulic devices (e.g., watermills or pools). Topographical features, such as seasonal streams and hills, were only recorded if situated inside the hydraulic system. The aim was to produce a plan reflecting the current state of the irrigated area (FIG. 3A).

The resulting plan was analyzed and irrigation blocks were identified—i.e., groups of terraces supplied by branches from the same main channel. The relationship between channels and terraces and the distribution of water throughout the system was examined. The delimitation of irrigated blocks allowed for a simplified analysis of the plan through the reduction of the hydraulic system to its key lines. The irrigation blocks were numbered along with their main channels (FIG. 3B)—i.e., all of the terraces in Block 9 receive water from branches of Channel 9a. The assumption behind the morphological analysis was that every irrigation block could represent a specific construction stage of the hydraulic system (Puy 2012a: 137–139, 2012b).

Next the layout alongside historical records was examined including integrating all references to additions to the plan, and these historical references were used to establish a relative chronology for the irrigation blocks. The documents include those written by the Order of Santiago between A.D. 1495 and 1505 (Eiroa Rodríguez 2006, Archivo Histórico Nacional, sección Órdenes Militares-AHN, OOMM); by the Moriscos immediately prior to their expulsion in A.D. 1613 (García Díaz and Otero Mondéjar 2010); and the land related transactions executed in Ricote between the 16th and 19th centuries A.D. (Archivo Histórico Provincial de Murcia, sección Protocolos-AHN, Protocolos) (FIGS. 4, 5). There is no written evidence for the hydraulic system of Ricote before the 15th century.

I used a GIS approach to identify topographical features associated with the hydraulic system. José Gabriel Gómez Carrasco (Aerograph Studio) and I produced the GIS using Miramón GIS and Autocad software packages. The spatial analysis included calculations of slope and elevation, orientation of the fields, distance between each irrigation block and the water source, and identification of areas prone to flooding from the three seasonal streams that traverse the hoya.

The plans resulting from fieldwork were incorporated into the GIS and georeferenced. The GIS also incorporated four UTM ED50 georeferenced sheets of the regional topographical map of the Ricote hoya (1:5000, 912-4-1, 912-4-2, 912-5-1, and 912-5-2) produced by the region of Murcia (covering 3.378 ha, with 5 m contour intervals). A three-dimensional grid was created using DTM software. The grid, formed by 10 m quadrangular cells, represented a mathematical model of the terrain surface. Plans from fieldwork were combined with the grid and several digital transects were drawn in order to determine slope, elevation, and distance between each irrigation block and the water source (FIGS. 6, 7). Mean values of the distance between the water source and the closest and farthest fields within each irrigation block were also calculated. Field orientation was identified using DTM software on the polyhedric grid (FIG. 8). The flood risk areas were defined in the GIS as those lands without any degree of slope against the stream banks (FIG. 3B).

Finally, two trenches were excavated, each in a single terrace of two different irrigation blocks. The

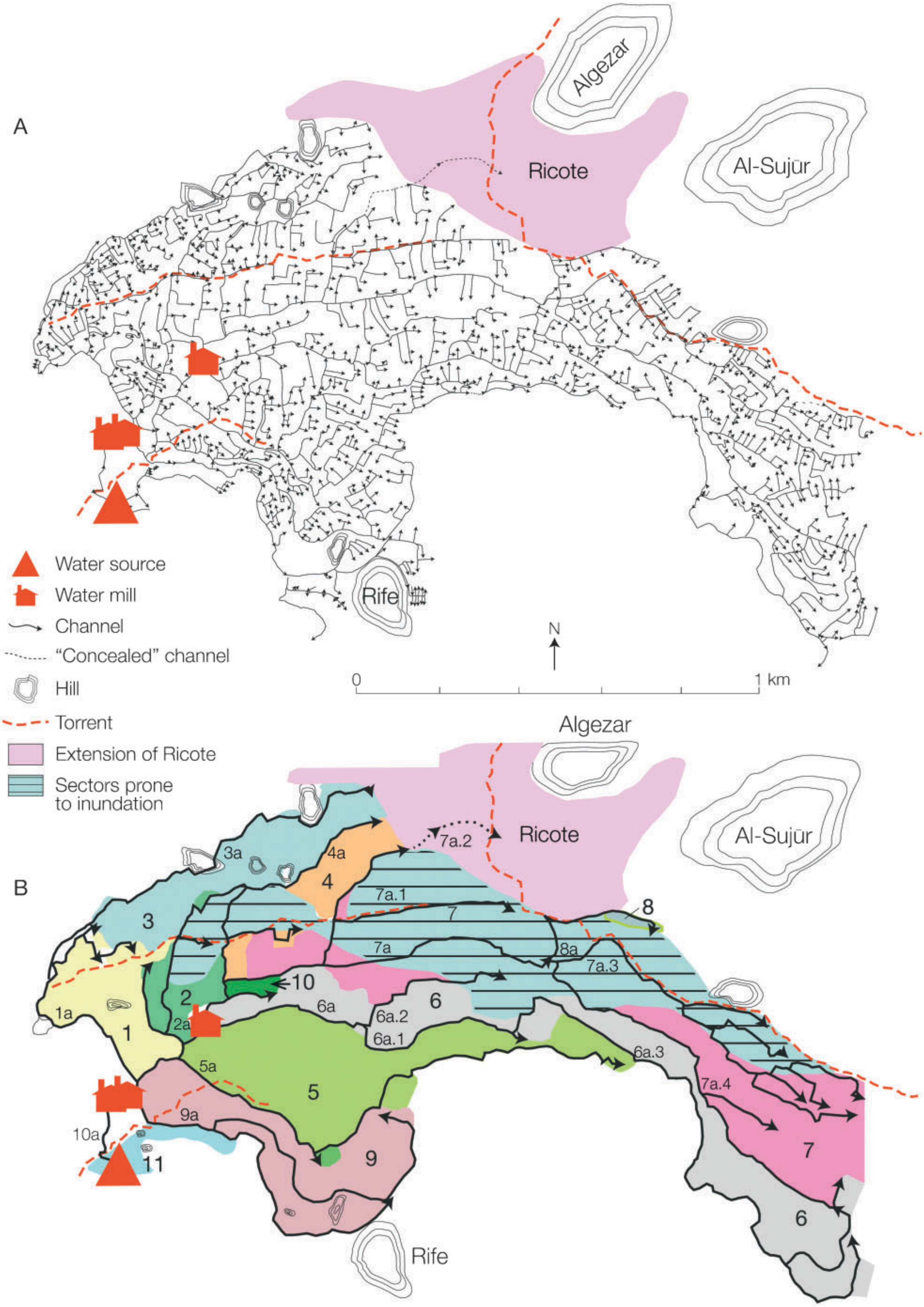

Figure 3 Plans of Ricote's hydraulic system. A) Reconstruction based on field survey. The arrows indicate the direction of water flow; B) Irrigation blocks. Numbers 1–11 designate individual irrigation blocks identified by morphological analysis and ground-truthing during survey. For the main channels of each irrigation block the number of the block is followed by a letter. The scratched blue buffer shows inundation areas according to slope calculation in GIS.

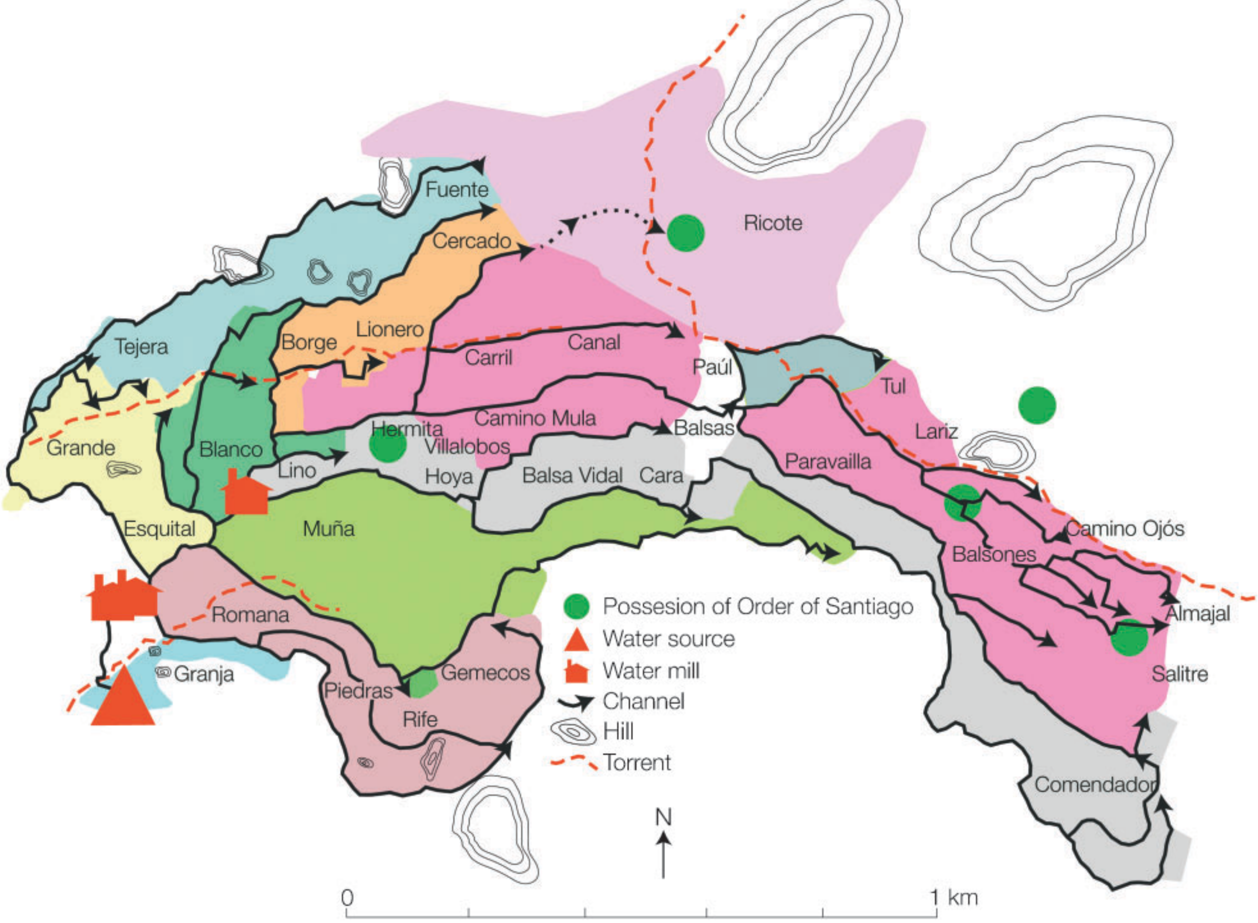

Figure 4 Plan of Ricote's hydraulic system showing the location of the irrigated properties owned by the Order of Santiago in the late 15th century and the different pagos into which the huerta is divided.

aim of the trenching was to obtain data regarding the history and techniques of terrace construction, as well as to assess the condition of the terrain prior to terrace construction. Bare, uncultivated areas were selected and oriented the trenches perpendicular to the inner face of the retaining walls. The first terrace was excavated with a mechanical digger and the second was excavated manually, since lemon trees prevented use of the digger. The trenches were ca. 6 sq m in area and 2.8 and 2.06 m deep respectively, and they were described and photographed.

Results

Figure 3 contains the results of the systematic survey and morphological analysis. The main axis of the hydraulic system is Channel 10a, which irrigates Block 10 and supplies the remaining channels except Channel 3a, which is supplied by Channel 1a (FIG. 3B).

Figures 4 and 5 summarize information collected from written records, including previous work on the the identification of irrigated lands owned by the Order of Santiago between A.D. 1495 and 1505 (Puy 2012b). Three of these properties were located in areas irrigated by channels of Block 7, and another, in the Hermita pago, is supplied by channels located between Blocks 6 and 7. This suggests that at least Block 7 and Channel 6a—including 6a.1 and 6a.2—were already established by the late 15th century. By A.D. 1613 written records of pagos located in all irrigation blocks, except Blocks 1, 10, and 11, can be found (FIG. 5). However, morphological analysis suggests that Blocks 1 and 10 were already in place by A.D. 1613, since Channel 10a plays a central role in the overall system and Channel 1a is necessary for the irrigation of Block 3.

Table 1 shows the result of the topographic analyses. Based on the GIS data, the lowest and flattest terrains in the hoya (234–314 masl) were plowed for the construction of Blocks 4, 7, 8, and 10 and the northern part of Block 2 (FIGS. 6, 7). All of these except for Block 10 are exposed to flooding during torrential rains. Block 6 was built on higher ground (318 masl) and the slopes of the hoya were plowed for the construction of Blocks 1, 3, 5, 9, and 11 and the terraces irrigated by Channel 6a.3. The steeper slopes—with an inclination between 12.16% and 29.54%—contain Blocks 3, 5, and 9 and the terraces irrigated by Channel 6a.3. Regarding orientation,

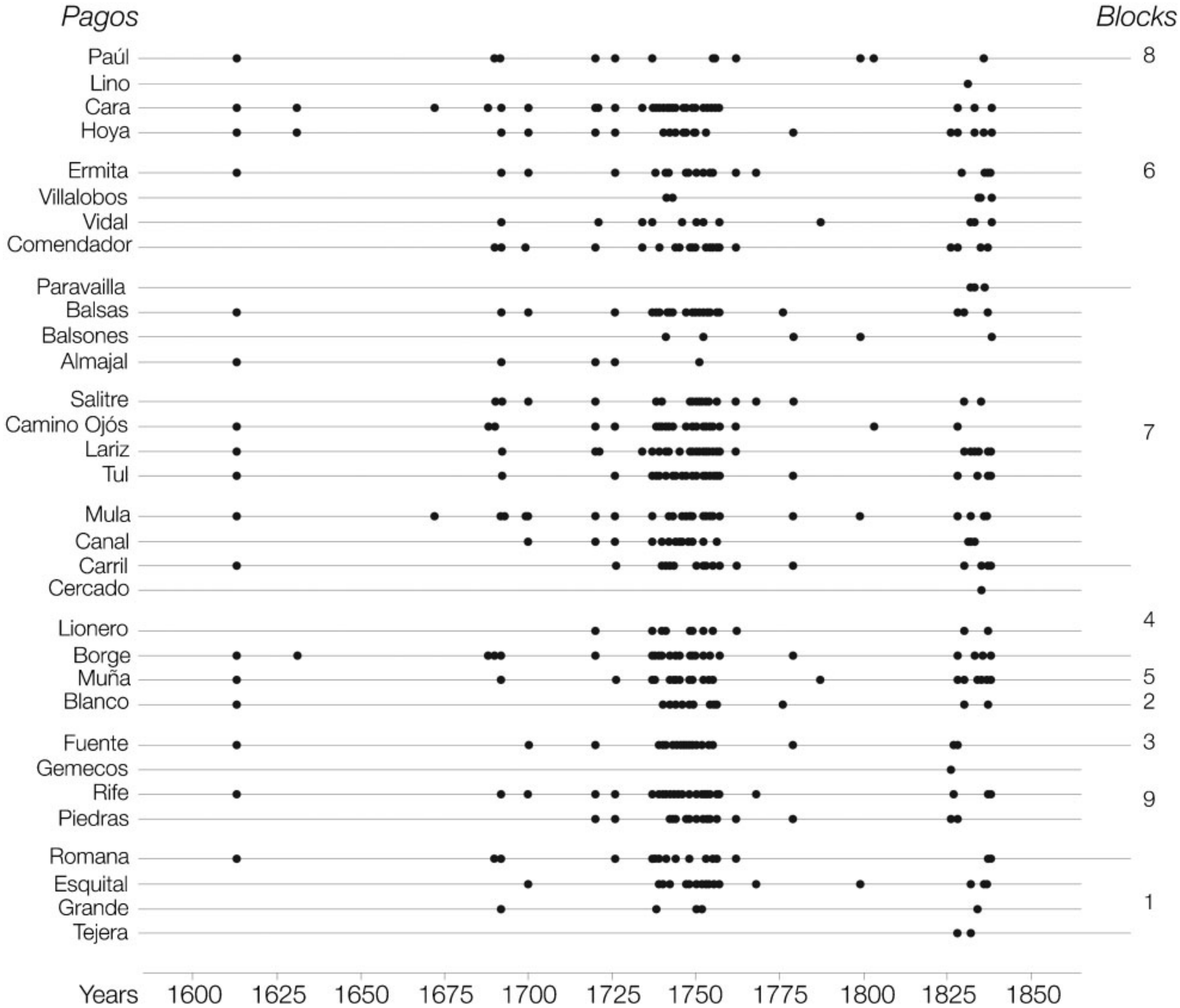

Figure 5 Graph showing the chronological sequence (16th–19th centuries) of written references to irrigated terraces within pagos and identified irrigation blocks.

Blocks 3, 4, 7, and 8 are oriented south-southeast; Blocks 5, 6, and 10 are east-southeast; Blocks 1, 2, and 9 are east-northeast; and Block 11 is north-northeast. As for the mean distance to the water source, fields within irrigation Blocks 1, 9, and 11 are located less than 500 m away; fields within Blocks 2–5 and 10 are situated between 500 and 1000 m away; and fields within Blocks 6–8 are located more than 1000 m away from the spring.

Slope management

Slope is a key aspect in the construction of irrigated terraces as it determines the size and shape of retaining walls and the amount of sediment to be shifted along the slope. In general, retaining walls for terraces are technically more challenging on steep slopes, while the construction of the fill is more laborious in flatter soils (Treacy and Denevan 1994: 96). Terraces in Blocks 1, 3, 9, and 11 are narrow (3–20 m wide), whereas those in Blocks 7 and 10, and the terraces irrigated by Channels 6a.1, and 6a.2 are much wider (40–60 m wide). Hudson (1995: 241) notes that narrow terraces on steep slopes can be as effective as wider ones if they are planted with trees or sown with crops that can be harvested in a staggered manner. In Al-Andalus irrigation terraces were built in both types of terrains: steep slopes of Casarabonela, Málaga (Retamero 2011) and flat valley floors of the Balearic Islands (Sitjes 2006).

Historical texts attest to Andalusi expertise regarding the management of slopes for water flow, but also in terms of erosion and sedimentation processes. The *kutūb al-filāḥa* ("Books of Husbandry," agricultural knowledge compiled between the 11th and 13th centuries by agronomists linked to the Andalusi state; see Retamero 1998: 80–81) make frequent references to the erosion of sediments downslope. The 12th–13th-century agronomist Al-Awwām (1988: 45–47), for example, stated that he preferred lowlands over highlands because the former were softer due to the accumulation of water and soil eroded from the mountains. Al-Awwām's statement is a subjective

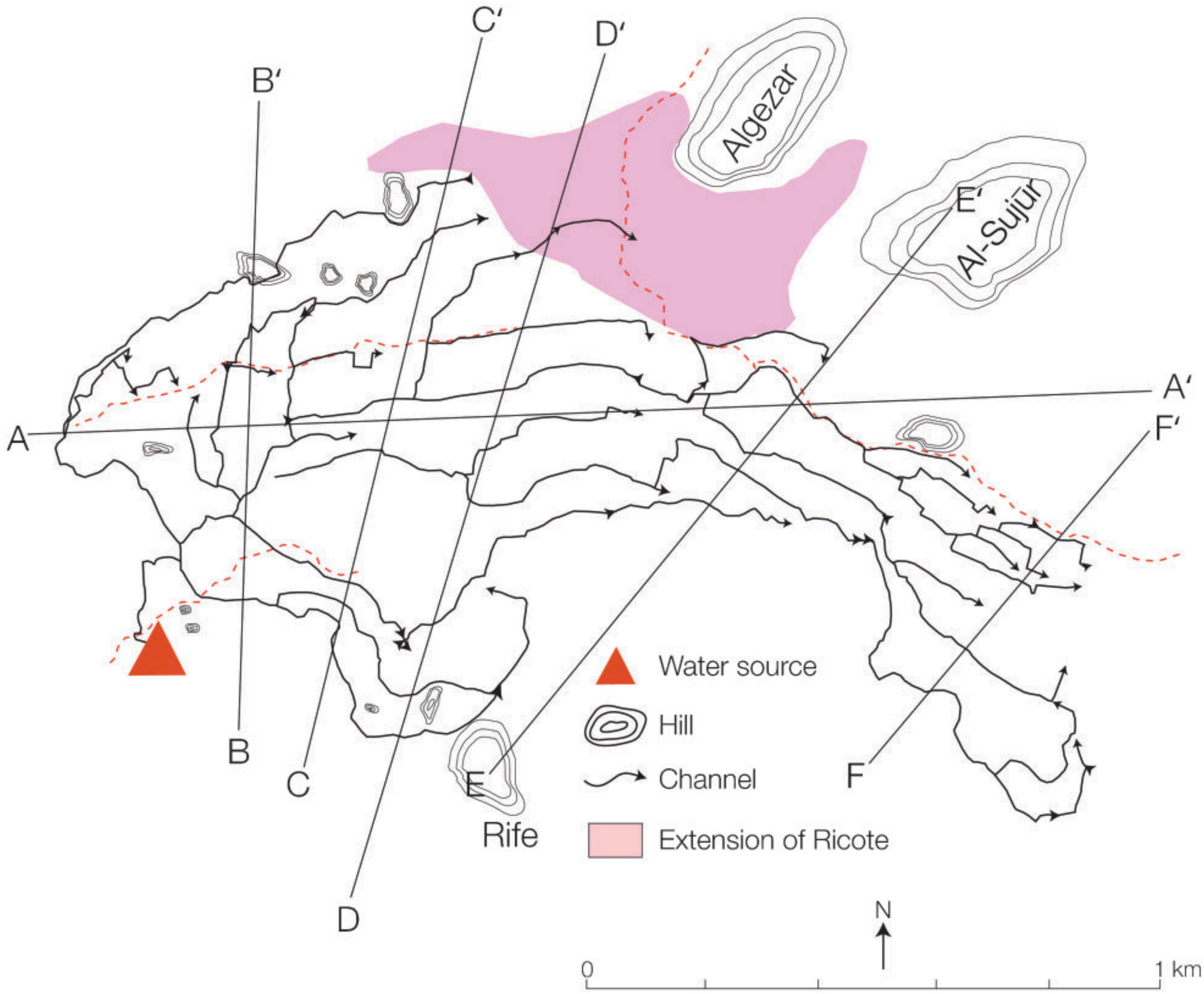

Figure 6 **Main transects drawn onto the plan for the calculation of slope, elevation, and distance from the water source for each irrigation block.**

opinion based on an observable reality: in dry and mountainous areas erosion is capable of significantly modifying soil depth. In general, erosion is mainly effected by the prevailing vegetation and the way the soil is being managed. Other contributing factors include the gradient of the slope and the intensity of the rain (García-Ruiz 2010: 1). In arid environments with poorly developed soils and frequent torrential rains, the steepness of the slope has a significant effect on the intensity of erosion (Hudson 1992: 145–146, 1995: 56–65). Eroded sediments tend to accumulate in the flatlands below, forming deep soils of colluvial origin. The natural aridity of the southeastern Iberian Peninsula, attested from the beginning of the Holocene (ca. 11,170 B.P.), became more pronounced after the Roman period (3rd century B.C.–5th century A.D.) (Garcia Latorre *et al.* 2001: 77–78; Pantaléon-Cano *et al.* 2003), and episodic torrential rains are noted in Murcian records since the 13th century (Hérin 1980: 32). The recent study of a paleosol in Ricote suggests that semiarid environmental conditions dominated when Arab and Berber groups arrived (Puy and Balbo 2013). The portions of the hoya where soils and sediments from the surrounding slopes accumulated were used for the construction of irrigation Blocks 4, 7, 8, and 10 and the terraces irrigated by Channels 6a.1 and 6a.2. Initially, these areas probably contained flatter, deeper soils, although their low elevation made them more vulnerable to frost than the slopes (García Avilés, personal communication 2012).

Orientation

Orientation is another important factor when building irrigated terraces, as the successful cultivation of crops and trees partially depends on the amount of solar radiation that they receive. In the northern hemisphere, slopes oriented to the south may get up to six times as much solar radiation as those oriented towards the north (Nevo 1997; Auslander *et al.* 2003: 405–406), and there exists a strong correlation between standing biomass and the accumulation of intercepted radiant energy (Monteith 1994: 213). This does not mean that the most insolated (i.e., most exposed to sunlight) areas are necessarily the most

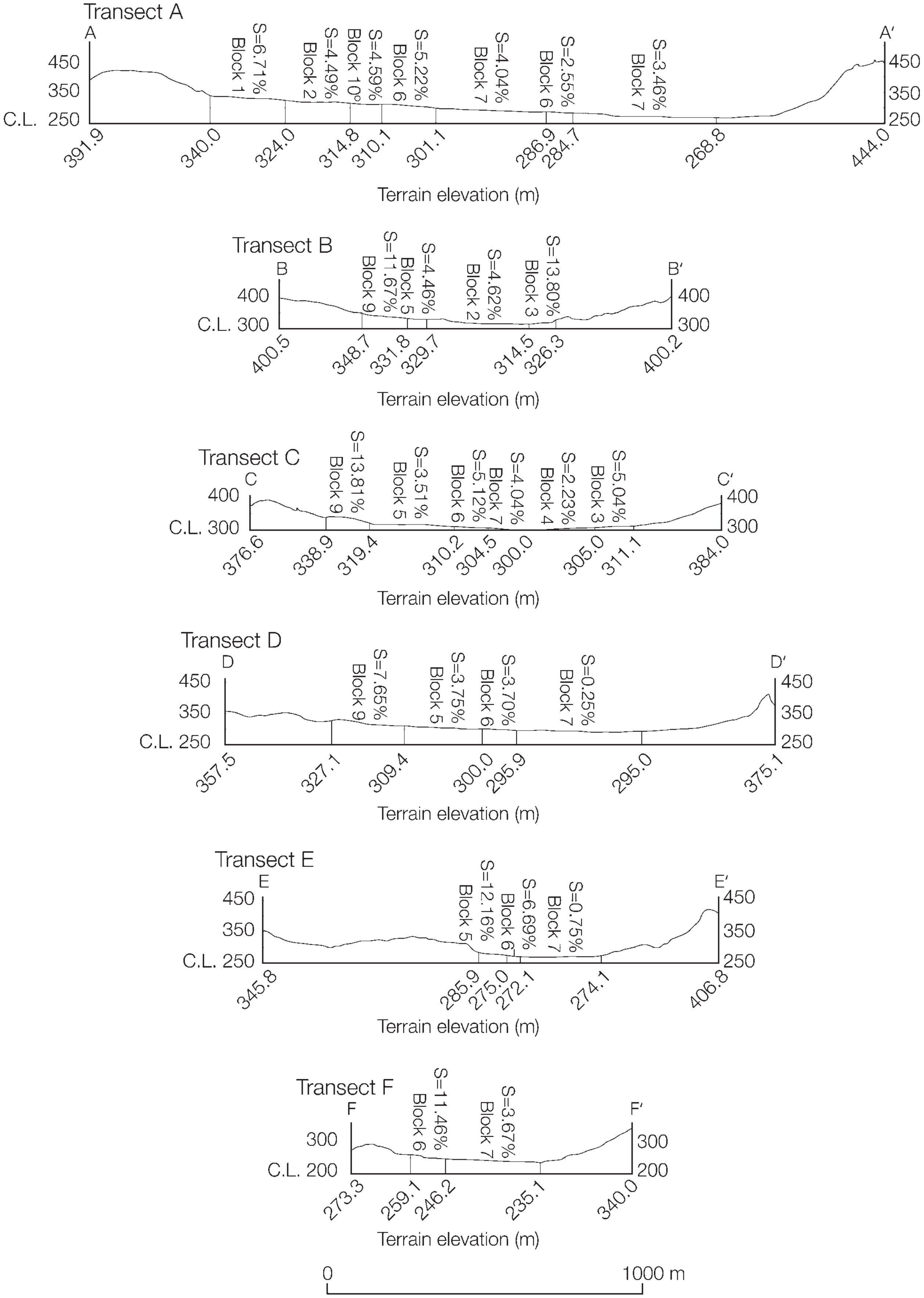

Figure 7 Digitally generated transects A–F.

desirable for cultivation. Plant growth is also affected by edaphic characteristics such as moisture retention, organic matter, and soil pH. The kutūb al-filāḥa frequently mention the ideal soil temperature (dependent on solar radiation) for successful cultivation. For example, Al-Awwām (1988: 39–42) described

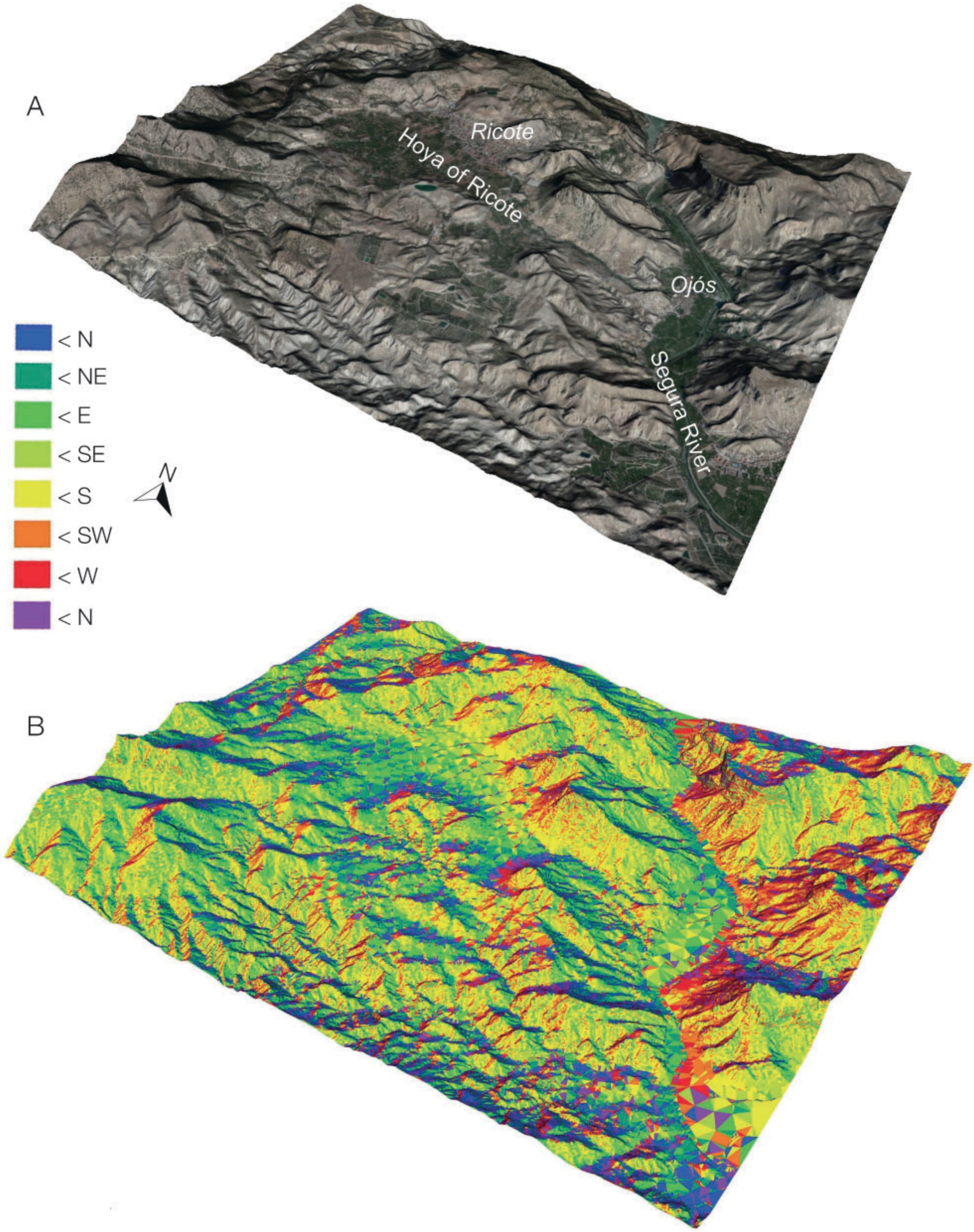

Figure 8 Topographical interpretation modules. A) Three-dimensional view of the hoya of Ricote and the valley; B) Orientation of slopes within the hoya of Ricote and the valley.

shady soils as undesirable, and ranked them last in terms of agricultural potential. In general, there seems to have been a preference for well insolated soils with the ability to retain humidity (Bolens 1974: 61–62). In Ricote, the most insolated soils are found in irrigation Blocks 3, 4, 7, and 8. Blocks 6 and 10 are also in well insolated areas, whereas Blocks 1, 2, 5, 9, and 11 have less sun exposure. According to Torró (2007: 94–95), Andalusi farmers tended to avoid overly exposed areas; i.e., those oriented towards the south. This practice is also documented in Israel, although it does not involve irrigation (Ron 1966: 38). Despite these accounts, there are Andalusi examples where the areas with maximum sun exposure were indeed selected for irrigation; e.g., in Casarabonela (Málaga), where irrigated fields covered a slope oriented towards the south (Retamero, personal communication 2012).

Distance between irrigation blocks and the water source

In arid and semiarid environments the distance between the water source and the irrigated area influences the amount of water reaching the fields. Water loss through leakage and evaporation is proportional to the length of the channel (Mateu 1989: 168), and it may be as high as 40 % for earthen channels (Farrington 1980: 287). In that sense, constructing the fields near the water source optimizes the amount of water available for irrigation, an important variable for the cultivation of Asian crops (e.g., lemon and orange trees, artichoke, cucumber) that require moist conditions. This practice has been documented in the Balearic Islands, where Andalusi irrigated fields were established less than 465 m away from the water source (Sitjes 2006). This layout is well suited to the hydrological regime of the Balearic Islands, which is characterized by small, irregular waterways and modest natural springs.

In other places, different priorities prevailed and irrigated fields were prepared at a considerable distance from the water source, despite the arid conditions. In Yemen, for example, the Sedd Al-Ajmār dam diverted water collected from two different *wadis* (intermittent streams) into two agricultural areas, one of which was located over 2 km away from the dam (T. J. Wilkinson 2006: 58). In Oman, the hydraulic systems captured water from semipermanent springs in mountain wadis and, through gravity, channeled it towards the agricultural fields, which could be as far as 35 km away (T. J. Wilkinson 1976: 75–76, 1980: 127; J. C. Wilkinson 1977: 74, 106; Costa 1983: 274). The traditional farmers of Oman were not focused on maximizing the available water for irrigation, but instead they wanted to cultivate the land they deemed to be the best regardless of the distance from the water source (Costa 1983: 274). In Ricote the lands closer to the water source were terraced with irrigation Blocks 1, 9, and 11. The lands farther from the spring were those at the bottom of the hoya, where Blocks 6–8 were constructed. The smallest volume of water reaches the terraces irrigated by Channels 6a.3, 7a.3, and 7a.4 owing to the distance from the spring (up to 1.8 km for terraces in the Almajal and Salitre pagos). Today farmers with plots in this area are forced to plant drought resistant crops, mostly olive trees, because of the scarcity of water.

The flood zones

There are many examples of ancient societies selecting flood zones for agriculture. In ancient Egypt, for example, the planting season coincided with the last stage of the Nilotic flood. The agricultural calendar was thus adapted to the fluctuations of the river to take advantage of the silts and clays deposited on its shores (Brown 1997: 1–13). The sporadic use of flood waters to irrigate crops has been documented in Mesoamerica, South America, the Near East, and North Africa as far back as 2000 years ago (Gilbertson 1986: 8; Prinz and Malik 2002; T. J. Wilkinson 2006: 46). This strategy is also documented historically in Al-Andalus. Geographers and historians such as Al-Rāzī, Al-Magribī, and Al-Maqqarī describe how the farmers living along the Segura River rushed to plant their crops the moment the silts and clays deposited by the river became stable (Catalán and de Andrés 1975: 34, footnote 4; Al-Magribī 1997: 244–245; Al-Maqqarī 1967: 68). The use of floodplains forces farmers to adapt the agricultural calendar, the total surface under cultivation, and the type of crops sown to seasonal fluctuations (Denevan 2001: 61).

In contrast, hydraulic systems are devised so that the adaptation of agrarian strategies to seasonal variations can be reduced to a minimum. Because of the regular supply of water, plant maturation is accelerated reducing dependence on precipitation and allowing simultaneous cultivation of multiple crops with different growth rates. Agricultural tasks can be distributed throughout the year, turning summer into a growing season. For these reasons, Andalusi farmers tended to avoid the construction of hydraulic systems in flood zones, which could potentially jeopardize their structured growing strategy. The practice of avoiding flood zones has been documented in Ibiza (Kirchner 2007: 27), Menorca (Barceló and Retamero 2005), and Mallorca (Sitjes 2008: 215–222) and seems to have been a standard practice.

In Ricote, the topographical analysis suggests that the floor of the hoya, which contains Blocks 4, 7, and 8 and the northern portion of Block 2, is susceptible to flooding in the event of torrential rains. Avellaneda Martín and García Martínez (1993) use an historical perspective to reveal the damage caused by brief, high energy flood events in the irrigated fields of Ricote. Following a flood event, farmers had to invest large amounts of labor to remove sand and gravel deposited in the fields. In addition, the runoff flushed the topsoil, modified its texture, and reduced its capacity to retain moisture. To minimize the risk of terrace destruction and soil erosion after flood events, farmers constructed the irrigated fields at right angles to the streams, thereby exposing less surface of the terrace stonewall to the flood. This practice has been documented during fieldwork in terraces of Blocks 4, 7, and 8.

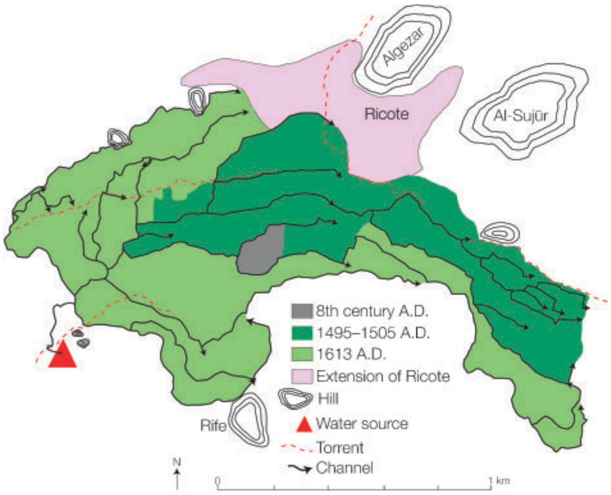

Figure 9 Evolution of the hydraulic system of Ricote.

Evolution of the Ricote Hydraulic System

The 15th-century irrigated area

The combination of archaeological survey and historical texts suggests that irrigation Blocks 7 and 10 and Channels 6a, 6a.1, and 6a.2 were already in place by the late 15th century, when the total irrigated area was around 50 ha. Written records indicate that the irrigated fields owned by the Order of Santiago between A.D. 1495 and 1505 covered over 3 ha (Puy 2012a: 192), thus comprising only 5–6% of the total irrigated area at that time (FIG. 4). The crops grown in the fields of the Order included plum, olive, apricot, orange, lemon, lime, fig, and cherry trees, myrtle, grapevines, pomegranates, cedar, and alfalfa (Puy 2012b: 205–206). This diversified planting strategy was adapted to the topography of the hoya: crops requiring better edaphic conditions (e.g., low salinity, well drained and humid soils) and more water, such as orange, lemon, and cherry trees, and myrtle, were planted in the fields irrigated by Channel 7a.2 and between Channels 6a.2 and 7a. Those that were better adapted to dry, well insolated, saline soils, such as olive, apricot and fig trees, and alfalfa, were planted in the field irrigated by Channel 7a.3 (Puy 2012b: 205–207) (FIG. 4). Although there is no information available on the specific crops grown in the rest of the hydraulic system, it seems unlikely that the huerta of Ricote was fully dedicated to cash crop production at the end of the 15th century. The crops listed above were probably not cash crops, since the diversity of produce points to a non-market based production strategy.

Block 7 is susceptible to flooding, which suggests that it was not built by the first Andalusi farmers. At this stage of the analysis, the terrains most likely to contain the original irrigated fields were located in Block 10 and those irrigated by Channels 6a, 6a.1, and 6a.2. One trench was excavated in each of these areas to test this hypothesis and pinpoint the location of the original Andalusi irrigated fields. Eighty fragments of Andalusi pottery from the 11th–13th centuries, a 50 cm thick stone wall, and a secondary human burial dated by AMS between 1020 ± 30 B.P. (969–1120 CAL A.D., Beta-315214) were found in a single layer beneath a terrace and overlying a buried soil in Block 10 (Puy 2012a: 212–222). Since terraces are never built in isolation (Barceló *et al.* 1998; Torró 2007), these materials indicate that neither the terrace nor Block 10 could have been built before the 13th century. Therefore, they were not part of the original design of the hydraulic system.

A second trench was excavated in a terrace between Channels 6a.1 and 6a.2. The organic matter embedded on the topmost horizon of a buried soil underneath the terrace fill provided an AMS date of 1310 ± 40 B.P. (647–778 CAL A.D.; Beta-292733). This suggests that the area between Channels 6a.1 and 6a.2 (1.9 ha) was terraced in the late 8th century A.D. and was the preferred area for the construction of the first Andalusi irrigated fields (Puy and Balbo 2013) (FIG. 9).

The irrigated area prior to the expulsion of the Moriscos (A.D. 1613)

By A.D. 1613 all irrigation blocks observable today (120 ha in total) had been documented historically, with the exception of Block 11 (2 ha) (FIG. 5). This suggests that the hydraulic system was expanded significantly between 1505 and 1613, extending irrigation from the lowest parts of the hoya up the hillsides. Overall, the hydraulic system more than doubled in area over a single century. The expansion of irrigation agriculture coincides with a 155% demographic increase attested for the Ricote village between A.D. 1507 and 1549 (Puy 2012a: 197–198), and with the documented expansion of several Murcian hydraulic systems, both in the capital and in the surrounding regions, during the 16th century (Pérez Picazo *et al.* 1979: 92; Pérez Picazo and Lemeunier 1984: 62–84, 1985: 27–32). After Genovese merchants introduced sericulture (silk farming) to Murcia and Valencia, landlords in these regions promoted the enlargement of hydraulic systems to increase the production of silk for export (Pérez Picazo and Lemeunier 1987). As a result, the mulberry tree was the principal crop in the huerta of Ricote in A.D. 1533 (Chacón Jiménez 2000: 12–13). By 1613, olives had become the primary crop (García Díaz and Otero Mondéjar 2010). Therefore, in the first decades of the 16th century the hydraulic system of Ricote was specialized for cash crop production. Even though there are no specific data regarding the individuals responsible for the enlargement of the system and its economic reorientation, it seems reasonable to assume that the landlords and the Order of Santiago were behind the initiative with the objective of increasing revenues.

Discussion

The combination of hydraulic archaeology, excavation, and a GIS based spatial analysis allowed the identification of the land selection process followed by Arab and Berber groups in Ricote. The original irrigated fields (located between Channels 6a.1 and 6a.2) were constructed on gentle slopes with deep colluvial soils. Such lands are located in the lower elevations of the hoya, although not the lowest because these were vulnerable to flooding. They also preferred lands that were exposed to sunlight, although not the most exposed area of the hoya, and located 1.2 km away from the water source.

Gentle slopes with deep colluvial soils allow the construction of broad terraces and provide abundant material for terrace fill. Broad terraces require a greater investment of labor to build up and level the planting surfaces, but less effort to construct the terrace walls since shallower slopes require lower retaining walls (Treacy and Denevan 1994). The deep colluvial soils were a good source of terrace fill in contrast to soils from the hillsides, which tend to be shallow and unstable in arid and semiarid environments. Selecting these deep soils saved the farmers from having to invest additional labor to import fill material for terraces. The construction of terraces using imported soils and sediments has been documented in Yemen (T. J. Wilkinson 2006: 43), Peru (Keeley 1985), and Israel (Ackermann *et al.* 2005); however, in Ricote the evidence suggests that terrace fill was sourced in situ (Puy and Balbo 2013). Ibn Baṣṣāl (1995: 61–65), an 11th-century agronomist, mentioned the use of draft animals in Al-Andalus to move local sediments during terrace construction. Farmers equipped oxen with *alcharof*, a type of shovel, to drag sediment from upslope and move it downslope to the terrace wall. Owing to the shallowness and instability of sediments on steep slopes, this labor-saving strategy may have been employed only on gentle slopes with colluvial soils.

Broad terraces also support the cultivation of a wider selection of plant species, which accords with the variety of crops used in the Muslim tradition. Hudson (1995: 241) notes that smaller terraces that require less fill are equally effective when regular cultivation is not required, such as for tree crops. More intensive forms of agriculture, especially irrigation agriculture, require more investment of time and labor in the field, but have greater productive and diversification potential (Retamero 2008). Intercropping, or the cultivation of several plant taxa with different growth rates in the same field (Gallant 1991: 38–39), is documented in the kutūb al-filāḥa (Al-Awwām 1988; Ibn Baṣṣāl 1995). Wide planting surfaces are better for intercropping because they do not limit the types nor the spacing of the crops grown. This is consistent with observations made by Barceló and colleagues (1998: 43) and Torró (2007: 102), who point out that Andalusi farmers constructed wide terraces in order to maximize the cultivable area with the smallest possible retaining walls.

Regarding the elevation and orientation of the selected terrain, it was neither the deepest nor the most insolated in the Ricote hoya. Blocks 4, 7, and 10, for example, which seem to have been constructed after the feudal conquest of the 13th century, are at low elevations and are more exposed to sunlight. In semiarid environments like Murcia, high temperatures can contribute to salinization of the soil, as salts from the geological substratum rise to the surface during evapotranspiration. Sun exposure plays a critical role in this process because it affects the temperature of the soil. On the other hand, the lower the terrain within a landscape, the more likely it is to suffer salinization (Jordán *et al.* 2004: 449). Saline soils limit plant growth due to an increase in the osmotic potential of the soil solution (Hillel 2004: 178–180). Andalusi farmers were aware of the unsuitability of saline soils as well as the techniques used to identify them (e.g., observation of the vegetation, tasting the soil) (Al-Awwām 1988: 56–72). The selected terrain between Channels 6a.1 and 6a.2 was indeed saline, as a recent study has shown (Puy and Balbo 2013). The aridity of the region before A.D. 711 suggests that every soil in the Ricote hoya may have had a certain level of salt content due to the imbalance between evaporation and water inputs. However, the salt content of the area where the original irrigated terraces were located was half that of the land where Blocks 7 and 10 were constructed (Puy 2012a: 164–165, 242–243).

Optimizing the water available for irrigation was not a top priority for the first Arab and Berber groups as the selected terrains were located 1.2 km away from the water source. Today the amount of water that reaches the terraces between Channels 6a.1 and 6a.2 is sufficient for the cultivation of lemon and orange trees, which require a significant amount of water. The spring at Ricote provides 12–13 L of water per second (García Avilés 2000: 163) and supplies those terraces without significant losses. Unlike farmers with fields in the Salitre and Almajal pagos (FIG. 4: Block 7), those with fields located between Channels 6a.1 and 6a.2 are not limited in their selection of crops by hydrological considerations.

These environmental conditions—including access to water, the presence of deep, flat, colluvial soils with moderate salinity, good sun exposure, and protection against flooding—seem to have been critical for the introduction of Asian crops and irrigated agriculture in Ricote. It is likely that Arab and Berber farmers

Table 1 GIS data.

	Terrain elevation (masl)				Slope (%)			Distance from water source (m)		
	Max	Min	Difference in height	Orientation	Max	Min	Inundability	Max	Min	Mean
Block 11	390.00	345.83	44.17	N-NE	–	–	No	296.00	0	148.00
Block 1	340.20	324.06	16.14	E-NE	–	6.71	No	558.50	233.70	396.10
Block 9	350.45	309.00	41.45	E-NE	19.32	7.65	No	714.00	183.50	448.75
Block 3	335.82	305.00	30.82	S-SE	13.80	4.86	No	1113.30	468.10	790.70
Block 2	329.76	309.87	19.89	E-NE	5.58	4.62	Yes	727.40	350.60	539.00
Block 5	331.82	292.49	39.33	E-SE	12.16	3.36	No	1270.00	320.90	795.45
Block 4	309.00	299.00	10.00	S-SE	7.00	1.34	Yes	1067.90	535.50	801.70
Block 10	314.86	310.00	4.86	E-SE	12.38	4.59	No	590.90	505.50	548.20
Block 7	304.59	234.24	70.35	S-SE	5.49	0.75	Yes	1816.00	609.90	1212.95
Block 6	318.24	246.71	71.53	E-SE	*29.54	1.71	Yes†	1813.00	439.90	1126.45
Block 8	282.28	274.12	8.16	S-SE	–	5.18	Yes	1434.00	1237.70	1335.85

* Area irrigated by Channel 6a.3
† Easternmost area irrigated by Channels 6a.1 and 6a.2

implemented this agricultural regime following their own initiative without any external political influence. The area they selected was probably terraced and irrigated shortly after A.D. 711, when the Andalusi state was far from being consolidated (Retamero 2000: 141–165, 213, 2006: 306–310). In fact, in A.D. 896 Ibn Hayyān named Ricote as one of the places that rejected the authority of the Emir of Al-Andalus, the Ummayad Abd ‘Allah (Carmona 2005: 134–135). It is also significant that the size of the original irrigated area (1.9 ha) is consistent with small scale subsistence agriculture rather than cash crop production (Netting 1993: 2–4; Puy 2012a: 21–22). Therefore, the most likely scenario is that the foundation of the hydraulic system in Ricote was established by autonomous Arab and Berber groups. Using their knowledge of Mediterranean environments, they were able to quickly assess the landscape and establish fields in the most appropriate places for their agricultural needs.

Conclusions

The addition of a GIS analysis can provide valuable data regarding the environments selected for agriculture. In the case of Ricote, the GIS data revealed a complex topography. The current hydraulic system, which covers 120 ha, encompasses flat terrains and steep slopes, deep soils and bare hillsides, well-insolated and shady sectors, as well as potential flood zones. This system is the result of numerous additions incorporating new lands with varying characteristics. This stands as an example of a Mediterranean microregion with diverse conditions in what appears to be a uniform landscape. Horden and Purcell (2000: 53) use the term “subdivision” to describe the topographical diversity of the Mediterranean. The different groups responsible for the construction of Ricote’s hydraulic system were well aware of these subdivisions, and they chose the areas to be irrigated following their own preferences and selection criteria. Naturally, each phase of construction reduced the amount of land available for later growth.

Arab and Berber groups in Ricote constructed the first irrigated terraces in an area with deep, colluvial, well-insolated, slightly saline soils, a gentle slope, and protection from flooding. Steep slopes and shady areas were incorporated into the hydraulic system between A.D. 1495 and 1613. The initially selected terrain was not necessarily the best or the most fertile, since the concept of fertility is not absolute and has been criticized by several authors (Fitzpatrick 1974: 130–131; Horden and Purcell 2000: 56). Some crops and agricultural strategies require slopes, shade, and humidity, while others require flat, deep, and dry soils. The land selection process is the result of a complex set of priorities related to the productive logic of the farmers themselves. Human modification of the landscape produces fertility via terracing, irrigation, cultivation, weeding, or manuring. As Reboul (1989: 31) points out, “*le sol cultivé est en même temps le produit*” (“The soil cultivated is also the soil produced.”)

The combination of hydraulic archaeology and GIS provides high resolution data to trace the evolution of Andalusi hydraulic systems, defining a relative chronology for major construction phases and inferring selection criteria. Owing to the diversity of terrains colonized by Andalusi groups, similar studies in different environments are necessary to identify patterns in the selection of terrains for irrigation, and also to what extent the criteria defined for Ricote relate to different topographical contexts. This will promote a better understanding of the construction process of the first agrarian areas dedicated to the acclimation of Asian crops in the medieval west, nowadays one of the most distinctive features of the western Mediterranean.

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