Articles

Irrigation Agrosystems in Eastern Spain: Roman or Islamic Origins?

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Abstract. The long-standing controversy concerning Islamic diffusion of cultivars and irrigation technology to Spain is approached by comparing Roman and Islamic agrosystems at the general, regional, and local levels. We describe the Roman intensification of the older Mediterranean agrosystem and then examine the subsequent agricultural and demographic decline between A.D. 250 and 800. The operation, organization, and evolution of large, intermediate, and small-scale irrigation are analyzed in seven case studies from the Valencia region of eastern Spain. The largest systems were refurbished in Islamic times, but during a period when Berber and Arab settlement was thin and acculturation of the indigenous population incomplete. As a result the Roman agrosystem and irrigation networks remained largely unchanged, despite the presence of new technologic features and cultivars. Later transfer of irrigation agriculture to the adjacent mountain valleys followed the Roman model, but with more Islamic elements apparent. Muslim agriculture in the area remained characteristically Mediterranean after the Christian Reconquest (A.D. 1238), and it survived largely intact into the present century, even after the Muslim expulsion in 1609. By focusing on the cultivars and the technology, as well as on the agrosystems as a whole, we are able to compare Roman and Islamic intensification objectively. They differed in degree rather than kind, with far more continuity than change. Finally, we examine the processes of Islamic diffusion and indigenous adaptation.

Key Words: Mediterranean agrosystems, adaptation, diffusion, Islam, intensification, irrigation, Spain.

MEDITERRANEAN agriculture has a long tradition. After four millennia of proto-agricultural experimentation, manipulation, and consolidation, a standardized complex of cereals, legumes, and herd animals—in association with village settlement—emerged in the Eastern Mediterranean Basin 7,500 years ago (Butzer 1982, 306–8). By 3200 B.C., olive and grapevine, the key orchard components, were in place (Stager 1985). Supplementary irrigation was certainly applied to gardens by Homeric times (*Iliad:* 21.257–59), and both manuring and tree grafting were understood by Theophrastus (died c. 285 B.C.) and later by Roman authors (White 1970). The roots of this agricultural system are to be found in the native biota of the eastern Mediterranean and western Asia and in the ecology to which they were so well adapted—mild, rainy winters and warm, dry summers. The dispersal and establishment of this tradition of agriculture, cuisine, and the ritual use of food must be attributed to a long and complex prehistoric trajectory, subsequently reinforced and expanded by Phoenician, Greek, and Roman demographic growth, economic expansion, and colonization.

This is our long-term view of the development of Mediterranean agriculture. Such a perspective focuses on agrosystems, here defined as successfully "tested" packages of technology, domesticates, and organizational strategies. In dealing with the crystallization and change of

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cultures, we are concerned with ecology, adaptation, and response to stress or to new information. Stimuli may be external—namely diffusion or migration. Yet culture change may also involve interacting social, demographic, economic, and ideological shifts that are unrelated to external influences but represent the outcome of adaptive choices between alternative strategies in a pre-existing repertoire of information (Butzer 1982, 290–94; Denevan 1983).

To test the relative importance of these two, alternative processes of change—external diffusion or internal adaptation—we have focused our attention on what is widely perceived as *the* great break in the Mediterranean world: the incursion of Islam (see Hodges and Whitehouse 1983). Arabists and other students of Islam are duly impressed by the material imprint of that culture and by the erudition of Arabic scholarship that played a catalytic role in the cultural heritage of Western Europe (Watt 1972). But in the case of Spain, there also is a tendency to overemphasize Arabic toponyms, Arabic-derived names for plants, and the glowing descriptions of Arabic authors of Medieval horticulture—to the point where modern Spain is assumed to be deeply rooted in its Islamic past. In this perspective, the older traditions of Iberia are deemphasized in favor of views ranging from significant migration and diffusion to wholesale cultural replacement. The implications are that the Islamic agrosystem differed significantly in crops and techniques from that of the preceding Roman Mediterranean world and that this difference is explained by diffusion, a view expressed most recently in a well-documented economic study by Watson (1983).

An alternative perspective can also be proposed, namely that the Islamic conquest of Spain affected demography, market demand, and other selective pressures on adaptation but did not fundamentally alter the available range of cultivars and technology. An evaluation of these two, alternative interpretations requires comparison of the Roman and Islamic agrosystems, both in the broader historical context and in a specific, regional setting.

Roman Intensification of the Mediterranean Agrosystem

The basic food complex of emmer and einkorn wheat, barley, sheep, goat, cattle, and pig that developed in the eastern Mediterranean world was firmly established in the coastlands of the western Mediterranean during the fifth millennium B.C. (Martí 1983; Lewthwaite 1981; Guilaine 1976). Intensification (see Boserup 1965) of this rudimentary, dry-farming agrosystem was, however, long delayed in the west, pending domestication and adaptation of olives, grapes, and figs in the increasingly commercialized wheat, oil, and wine economy of the Levant and Lower Egypt during the later fourth millennium (Stager 1985). In Greece and on the Ionian coast of Turkey, evidence for the cultivated olive (but without the grape) appears unambiguously in five pollen records, varying proportionally with increases of weedy plants and inversely with the ratio of key forest trees. Calibrated radiocarbon ages here date the first appearance of the olive in cultivated landscapes between 2000 and 1575 B.C. (Middle Bronze Age) though in one instance even as early as 4000 B.C. (Late Neolithic); in each profile the olive almost disappeared during the ensuing Iron Age (Wright 1972; Greig and Turner 1974; Zeist, Woldring, and Stapert 1975).

The first report of olives and grapes in eastern Spain is given by a Greek navigation guide of 530 B.C. (Schulten 1957, 549, 553). Olive oil had been exported from Sagunto to Rome since the third century B.C., wine since the first century A.D. (Pla 1980). The figs of Sagunto were noted during the early second century B.C. (Cato: 8). Carbonized olive wood in abundance has been found in a site near Alicante and dated 2330 B.C. (calibrated radiocarbon); although identified as *Olea europaea* (Hopf 1981), it is in fact too difficult to distinguish wild from cultivated olive wood to be conclusive, and its absence from countless later Bronze Age sites must be considered significant negative evidence. In the absence of archaeological materials to support an earlier date, it appears that the Phoenician and Greek commercial and colonial enterprises in the region since c. 650 B.C. introduced the olive-grape-orchard complex and subsequently maintained demand for these crops. Archaeological evidence in eastern Spain for irrigation prior to the first century A.D. is limited to a single Late Bronze Age site with small canals apparently designed to conduct rainwater into a storage cistern (Pla 1980).[1] Nonetheless, the great coastal irrigation networks between Valencia and Burriana, discussed below, may have been developed during the last millennium B.C. Intensification of agriculture in eastern Spain should consequently be seen as an incremental process after 650 B.C., in response to Phoenician, Greek, and later, Roman market demand.

A characterization of this intensified agrosystem can be drawn from the Roman agronomic authors (second century B.C.–first century A.D.), of whom Columella (mid-first century A.D.) was a native of Hispania. Although it is essential to consult their original writings, specific documentation for most of our synopsis is available in White (1970) (see also Bolens 1981 on the heritage of classical agronomy). Supplementary archaeological evidence from the area north of Rome is presented by Bradford (1957) and Potter (1979).

In regard to cultivars and cropping practices, the key elements are: (1) selection of plant species or varieties best suited to the season, region, soil type, or edaphic situation; (2) intercropping of cereals among vines or olive groves, with house gardens and fruit orchards complementing field agriculture; (3) elaborate seedbed preparation, rules for spacing plants, and complex furrow arrangements on terraced hillsides (on terracing see Homer's *Odyssey:* 24.223–25); and (4) a detailed agricultural calendar for soil preparation, planting, watering, and harvesting.

Soil types and fertility matters were equally well understood, including: (1) criteria for a complex classification of soils; (2) specification of mineral fertilizers, animal manures, compost, "green" manure, as well as wood ash (from stubble) and seaweed; and (3) interjection of fallow years on all but the best alluvial soils, in either a two- or three-year sequence (Pliny: 18.91).

Irrigation was used to water pastures, house gardens, orchards, vineyards, alfalfa fields, and occasionally cereals (Cato: 1.7; Columella: 1.5, 2.3 and 17, 10.33–38, 47–51; Pliny: 17.40, 18.47; Virgil: 1.106–110). In some cases, irrigation was small scale (Vitruvius: 11.3; Columella: 9.3); in others it involved large-scale canalization, aqueducts, or underground conduits (*Digesta of the Codex Justinianus,* see Ware 1905: sects. 185–249, 310) as well as drainage reclamation, flood control, and navigation (White 1970, 157–72). The following technology was available for water lifting or collecting, although not necessarily applied on a large scale:

(1) The Archimedean screw or "water-snail" (because of its internal, helicoidal structure). Turned by hand, this cylinder was used in Egypt (where Archimedes saw and adapted it c. 250 B.C.) to draw water out of irrigation ditches. The Romans appear to have been interested mainly in nonagricultural applications of this manual pump (Vitruvius: 5.12, 10.6; Drachmann 1963, 153–55), and Strabo (3.2.9) mentions its use to remove water from mine shafts in Andalusia.

(2) The *shaduf,* a lever device which uses a mounted, flexible pole that is weighted on the short arm and has an attached bucket on the long. The bucket is dipped into the irrigation ditch, then swung around and emptied into a higher ditch or canal. Like the Archimedean screw, the shaduf is operated by one person to raise water as much as 1.5 m to irrigate gardens. Known in Egypt since at least 1500 B.C. (Butzer 1976, 44–46) and derived from Mesopotamia, the shaduf principle is ignored by the Classical authors. It was sufficiently common in late Roman Hispania, however, that Isidore of Sevilla (c. 630 A.D.) (20.15.3) noted "this instrument is called a *ciconia* by the Spaniards." That term is the root of the modern Castilian designation *cigueña,* or *cigonyal* in Catalan. The device has traditionally been used through much of Europe, even in Scandinavia (Caro 1955a).

(3) The animal-drawn, "Persian" waterwheel or *cenia.*[2] This well-lift operated on the principle of toothed gear wheels mounted at right angles to each other (Caro 1955b). Donkeys, cattle, or water buffalo turn the horizontal wheel while the vertical wheel lowers and raises a series of pots through the water below, emptying them into a small canal above. Non-stop irrigation of several hectares of cropland can be achieved in this way, and water can be raised as much as 5 m, e.g., from a river channel onto the floodplain during low water stage or from the aquifers underlying piedmont alluvial plains. *Cenia* use in Egypt since the fifth century B.C. has been verified (Schnebel 1977, 73–84). Vitruvius (10.4) in c. 25 B.C. described a device (*tympanum*) that raised water vertically from great depths by a double iron chain with a set of buckets; the mechanics were different because men had to tread on the wheel to rotate it. The *tympanum* was basically modeled on the *cenia,* but it is unknown whether it was ever applied in practice, let alone widely used. That the Romans did indeed understand the principle of geared wheels is unquestionable since their "undershot" water mill is a reversed *cenia,* with power delivered by the current below to turn the mill-stone above (Vitruvius: 10.5.2). *Cenias* are unknown archaeologically or

ethnohistorically from Italy, and the device does not appear to have found acceptance in classical Rome.

(4) The simpler but more impressive "undershot" current-wheel, mounted in a perennial river, lacked gears but also raised water in troughs or buckets to be then piped to the bank (Caro 1954). Such paddle-wheel lifts appear to have been quite familiar (Vitruvius: 10.5.1; Pliny: 19.4), and Isidore (17.15.1) identifies them under the term *rota* in a late context. They do not appear to have been significantly different from those admired by Medieval Arabic authors at Cordoba and Toledo.

(5) The most elaborate irrigation method involves mining of aquifers by subhorizontal tunnels or *qanats* that were cut and maintained by vertical shafts at regular intervals; the water so collected was delivered to distant canal systems. Originally of Persian origin, *qanats* were built in Roman Tunisia (Solignac 1953, 60) and in modified form applied to provide municipal water supplies or to implement drainage in both Italy and Gaul (English 1968; White 1970, 147; Glick 1970, 182), including the *cuniculi* of Veii and Velletri as well as tunnel systems dug to inject water in siege operations (Vitruvius: 10.16.11).

Livestock raising was also integral to intensified agriculture. The Romans viewed pastoralism as characteristic of backward hill peoples. Instead they themselves focused their attention on more ecnonomical raising of improved breeds of cattle and sheep (for milk, meat, and wool) or of oxen (for plowing, threshing or transport) and horses (for riding). Manure was an important by-product, and animals were pastured on stubble to maintain soil fertility. Veterinary concerns were important to keep animals healthy and productive. The intensive character of livestock-raising is indicated by the surprising range of and emphasis on fodder crops (White 1970, 207–23), and nothing comparable is known from Pharaonic Egypt.

The commercial nature of agriculture on the best lands of central Italy and the key food-exporting areas of other provinces is amply documented. An almost insatiable demand for grain and vegetables by the population of Rome stimulated commercialization, and the large-scale and systematic importation of wheat, olive oil, and wine from the Mediterranean provinces is well known. In addition to the small traditional holdings of tenant farmers and free proprietors, there was a rapid increase of larger estates (20–125 ha) and latifundia (over 125 ha) during the first century A.D. (Smith 1979, 98–102), even in distant areas such as the interior of Spain (Martial: 12.31). Roman absentee landlords invested heavily in such estates, and the agronomic authors provided shrewd economic advice for their efficient management in terms of cropping systems, organization, labor supplies, market access, and slaveholding. The archaeological evidence indicates mass production of commercial crops by such large, rural villas.

In effect, the Roman agrosystem was sophisticated and highly effective at the peak of its elaboration, tightly integrating Spain, modern Tunisia, Egypt, and Gaul into a functional market economy of an unprecedented scale. Only during the later second century A.D. is there increasing evidence of labor shortages, servilization of small landholders, and a lagging application of the available technology that impaired ability to meet demand (Heitland 1921, ch. 50; Boak 1955; White 1970, ch. 14). This decline extended over several centuries. It was accelerated by population loss resulting from pandemics, farm abandonment because of insecurity, and rural depopulation resulting from more attractive opportunities in the cities; the decline was also fueled by increasingly rapacious taxation that saddled shrinking farming communities with collective responsibility for constant or rising revenue demands. The Islamic cycle of renewed intensification and improved productivity gains undue prominence because of this ultimately catastrophic decline.

The Late Roman to Islamic Historical Framework for Spain

In A.D. 711, a force of Near Eastern Arabs and North African Berbers crossed the Straits of Gibraltar, and during the subsequent decade Visigothic Spain was incorporated into the expanding world of Islam. Although waves of Berber colonization, in conjunction with a small but steady influx of Arabs, continued through the end of the twelfth century (Gayangos 1964; Dubler 1943), there is reason to believe that North African and Near Eastern settlers remained a small minority in comparison with the indigenous Hispano-Roman population. But the prestige of Islamic civilization, coupled with political and economic pressures, led to the essentially complete assimilation and eventual conversion of the Hispano-Roman Christians within Islamic Spain. This process of arabization and islamization may have been largely completed by the early twelfth century (Bulliet 1979, 114–27), at a time when the Christian *Reconquista* was already well under way in the center of the peninsula.

Roman Iberia had been characterized by dual lifeways. The south and east were intensively romanized, heavily agricultural, and partially urbanized; the center, west, and north were at best superficially romanized and overwhelmingly pastoral, a frontier zone precariously maintained by military outposts (Strabo: 3.2–3; Pliny: 3.1 and 3 and 4.20–22; Barbero and Vigíl 1974, 67–103; Bishko 1963; Guichard 1977; Glick 1979, 51–53). Intensive Islamic irrigation agriculture was also effectively limited to the floodplain *huertas* of southern and eastern Iberia, as described by the late twelfth-century Spanish geographer Idrisi (Dozy and De Goeje 1968, 206–66) (Fig. 1.) The vast, remote and water-poor interior remained a thinly settled world of dry-farming, pastoralism, and widely spaced, smaller cities. Irrigation agriculture had been and remains anchored in the river plains and coastal regions of subhumid and semiarid Spain and Portugal.

The Arabs conquered a depopulated land that preserved but a shadow of the Roman prosperity it had enjoyed during the first century A.D. The third-century economic, demographic, and political crisis of the empire had drastically curtailed urban life and resulted in a decline of rural productivity. About the year A.D. 260, a group of Franks rampaged through northeastern Spain (Blázquez 1964, 80–81, 164–70; Tarradell and Sanchís 1965, 169–73; Llobregat 1980), apparently setting off peasant or slave revolts that lasted until 296. Cities were sacked and latifundia destroyed, many of them permanently abandoned. After the Barbarian breakthrough of 409, the Roman authorities accelerated rural depopulation by relentless and counterproductive tax-farming, while providing little or no security (Grosse 1947, 42–43; Thompson 1982, 181)—processes to which the small farmers were more susceptible than the large estate owners. A pan-Mediterranean epidemic of bubonic plague swept through Spain in 542–43, with major recurrences in 580–82 and 588 (Grosse 1947,136,

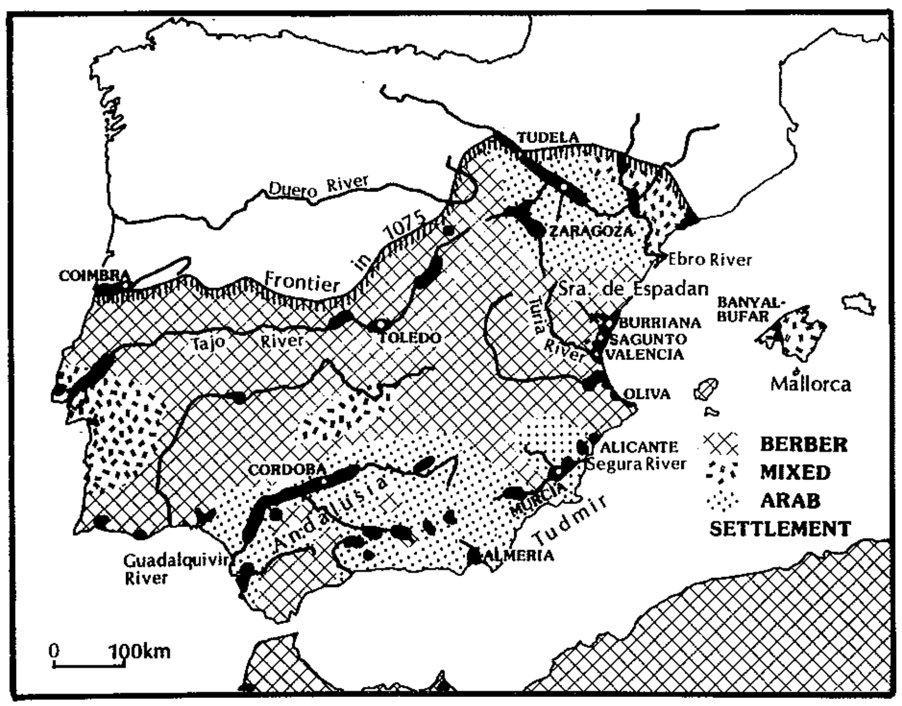

Figure 1. Irrigated areas of the Iberian Peninsula (shown in black) as inferred from the Medieval Islamic authors, with the Islamic-Christian frontier of about A.D. 1075 and areas of Arab and Berber settlement.

184, 208; Biraben and Le Goff 1969). In Valencia the city had shrunk so much that outlying cemeteries were abandoned and new ones opened in what had once been the heart of the city (Ribera 1983, 112). Catastrophic locust or drought-related famines are indicated c. 636–40, during the late 640s, and c. 680–81 (Grosse 1947, 295, 309, 343), with further national calamities and drought c. 700–702 and 707–709, and again in 738 and 748–753 (Olagüe 1974, 25ff.; Guichard 1977, 191–92).

The progressive depopulation of Spain is verified archaeologically by the extreme paucity of late Roman, Visigothic, and early Islamic sites and materials (Palol 1966), a national pattern confirmed to an even greater degree in eastern Spain between the Segura and Ebro rivers (Fig. 1) (Bazzana and Guichard 1976). Most latifundia around Valencia appear to have been abandoned during the fifth century, and little Islamic settlement is archaeologically verified prior to the tenth century. About A.D. 930, Al-Razi (Levi-Provençal 1953) noted the ruins of Sagunto, using a new name, Murbaytir (later Morvedre, from *Muro veteri*, "Old Wall," (Barceló 1982, 28)), for the city had lost its name; there was a castle but no contemporary town on the site. Only in the twelfth century did Sagunto revive, regaining some reputation as the birthplace of several illustrious people (al-Yaqut, see Abd-al-Karim 1974, 4.486). Valencia itself had shrunk from a surface area of 50 ha during the second century to only 13.5 ha during the fourth, as indicated by the walls of c. 300 A.D. (see Ribera 1983, map 3); the eleventh-century walls enclosed an area of 45.5 ha (Rosselló 1980), and at the time of the Reconquest in 1238 the area, including suburbs, was about 53 ha.[3]

Visigothic Iberia of the sixth and seventh centuries was characterized not only by a rural society rife with paganism and ineffectually penetrated by urban Christian institutions (Hillgarth 1980; Epalza and Llobregat 1982), but also by an extreme dearth of population and a poorly integrated and rudimentary market economy (King 1972, 190–200). The year 711 did not, therefore, represent a socioeconomic rubicon, but the midway point of a long period of agricultural and urban decline, during which Hispano-Roman institutions atrophied (Sánchez-Albornoz 1943; Lacarra 1959).

It would, however, be erroneous to conclude that the Roman agrosystem had lost its commercial components. The comprehensive Visigothic legal code of 654, augmented in 681 (Zeumer 1902; King 1972, 208–15), for example, indicates that vineyards were important, were protected by law, had an official vintage season, and were regularly renewed (Zeumer 1902: 2.1.12, 8.13.15, 10.1.6, 10.3.2). Olive trees were the most expensive of all; new groves were planted, and oil was occasionally distributed to the poor (Zeumer 1902: 8.3.1, 10.1.6; King 1972, 213). There were fruit orchards (*pomiferae*), including fig trees, as well as house gardens (*horti*) (Zeumer 1902: 8.2.2–3, 8.3.1 and 7, 10.1.6, 10.3.2). Isidore (17.10), in fact, devotes a chapter to *horti* that has no organizational precedent in the earlier Roman authors. There are references to irrigation in dry regions, and "stolen" water had to be financially reimbursed at an hourly rate that depended on the strength of flow (Zeumer 1902: 8.4.31, 12.2.D; Zeumer 1886: 8.18). Isidore's list (20.15) of water-lifting devices, again a novel theme for a Latin encyclopedist, is relevant here. Finally, there are abundant indications that agriculture was expanding during the more prosperous century of Visigothic rule (c. 580–680), with clearing of forests and reclamation of wasteland for cultivation, pasture, and vineyards (Zeumer 1902: 8.4.23, 28, 10.1.3, 6–7, 9, 13). In this connection, Isidore (17.2) provides a succinct statement that good plowing, fertilization, and fallow were essential to achieving the productivity of former times. In conjunction with references to exports from Spain (King 1972, 195, 215) that included wheat, olive oil, and possibly horses, these data argue that a degree of intensification persisted in some regions, despite the generally dismal state of Spanish agriculture.

The Arabs initially appropriated two-thirds of Spanish landholdings, leaving the remaining third to the traditional landlords, exactly as the Visigoths had done when they moved into Spain in larger numbers after 494 (Vallvé 1978, 1982). The ninth- and tenth-century economic and demographic revival of Spain coincided with the early stages of assimilation and conversion (Bulliet 1979, 124–25), and the Christian majority in what is now Andalusia revolted repeatedly during the ninth century and subsequently provided the major support for a sustained revolutionary war A.D. 890–928 (Simonet 1967). In the region of Valencia, Islamic biographies cite only nine notable personages for the eighth to tenth centuries, out of a total of over 500 for all Spain and Portugal (Guichard 1969). The first Arab family was established in the Valencia area during the early tenth century; the settling in of an Arab elite only began after A.D. 1010, but even then Berber colonists of agricultural or pastoral backgrounds remained preeminent among the immigrants (Guichard 1969; Guichard 1977, 267–75; Chalmeta 1975), as noted by the geographer Yaqubi (Wiet 1937, 220) (Fig. 1). With exception of discontinuous areas of rural Berber settlement (Dubler 1943; Guichard 1977, ch. 6; Barceló 1984, 133–36; see also the reservations of Epalza 1984), it appears that the new social order was not effectively imposed outside of Andalusia until the tenth century.

There was, then, more cultural continuity than has generally been allowed, particularly in the irrigated lands of eastern Spain. In fact, the ninth- and tenth-century revival of population and agriculture appears to have been carried out primarily by the indigenous Hispano-Roman majority. The point is illustrated by the Arabic farmer's almanac known as the Calendar of Cordoba (Pellat 1961) and dated shortly after A.D. 961. This comprehensive work represents three major traditions—Christian ecclesiastical, Arab astronomical, and Andalusian agronomic; it is the product of Arab science in a Christian Andalusian, agricultural context.

The question now arises whether agricultural intensification during the ninth- and tenth-century economic revival involved new crops and techniques, or simply a shift of choice among the alternatives already available in the traditional Mediterranean agrosystem. The evidence to resolve this problem can best be generated through a number of case studies.

A Methodology to Study Irrigation Agriculture in Eastern Spain

In dealing with the thorny question of economic, social, and cultural change in Medieval Spain, historians, arabists, and geographers have generally attempted to deal with the issues on a general rather than a regional level. The result has been a century of poorly focused and inconclusive arguments, with each supportive example followed by a counter-example.

Notable exceptions have been the thoughtful studies of Glick (1970), López (1974a, 1975), and Bazzana and Guichard (1981). The last authors delineated the settlement history of eastern Spain and examined a set of examples of Medieval irrigation in terms of their landscape ecology and historical framework. López synthesized the archaeological evidence for the major irrigation networks and critically examined the diverse water regulations of each. Finally, Glick has evaluated, primarily on the basis of the Valencian archives, the processes of Medieval irrigation administration in eastern Spain. The case studies presented here complement the contributions of these authors by dealing with the agrosystems directly and at different scales. Such a study is facilitated by the classic works on irrigation in eastern Spain by Aymard (1864), Markham (1867), and Brunhes (1902).

Our data and perspectives are based on an interdisciplinary study of the historical archaeology and geography of the Sierra de Espadán, a low mountain massif north of Valencia, a long-term project including excavation, archival research, cultural anthropology, and land use mapping. The present study is focused on a larger region, however, between Valencia and the Mijares River, an area conquered by the Arabs in 714 and reconquered by the Christians 1233–38. A large part of the Muslim population was allowed to continue in residence here until the Expulsion of 1609. Effective islamization of the economically rebounding, regional agricultural system was limited to about 300 years. After the Reconquista of the 1230s, the prevailing rules were institutionalized by the king of Aragón, with only limited changes over the centuries (Glick 1970; López 1975). Consequently there is unusual access to the Medieval past, not only in archaeological and archival terms, but also by way of the strong continuity between Medieval and traditional "landscapes," made tangible in terms of irrigation features, land use, and organization.

Our research strategy reflects the fact that irrigation in eastern Spain was and is practiced at three different scales. At the *macro* scale, several corporate communities, either villages or towns, jointly manage water distribution. This generally involves several thousand cultivators and a complex canal system, requiring construction of diversion dams (*assut*, in Valencian) and considerable, long-term maintenance. Such irrigation networks typically cover some 50 to 100 km^2. At the *meso* scale, a single corporate community, consisting of one or more villages and hamlets, regulates water allocation from one or more major springs. This involves up to several hundred cultivators and a network of small distribution canals that carry water mainly intermittently for fixed times during the key summer growing season. Little maintenance is required and the irrigated land rarely exceeds 100 hectares or so. At the *micro* scale one or several cultivators, often from an extended family, operate a small number of irrigation ditches fed by a cistern or small spring. Irrigation covers substantially less than a hectare.

These three systems relate to different environmental mosaics and opportunities and entail substantially different levels of technology and cooperation. They require separate analysis from the perspectives of physical operation, community organization, and historical evolution. Our focus will be on "traditional" water use and, in general, we shall examine systems that were already established during Islamic times.

Macro-Scale Irrigation

Physical Arrangements. The large-scale irrigation networks are found on large floodplains, such as those of the Ebro and Segura rivers, or along suitable parts of the coastal plain where rivers emerge from the higher country. Three such systems are considered here: (1) the south bank of the Mijares River, centered around the cities of Vilareal and Burriana; (2) the area around Sagunto, fed by the Palancia River; and (3) the Valencia region, linked to the waters of the Turia River.

The South Mijares irrigation covered some 67 km^2 during the nineteenth century and comprises two sets of major transverse canals that run perpendicular from the river; their waters then spread coastward through a complex of smaller canals that follow the general slope. Water is removed from the river by proximal diversion dams.

The Sagunto system is fed by elaborate feeder canals, taking in water from as far upstream as Sot de Ferrer, 22 km away. Downstream there are arterial canals on both sides of the river, supplying a network of diverging lines that traditionally watered an area of 58 km^2.

The Valencia irrigation system, prior to extensive drainage of the coastal marshlands during the nineteenth century, covered 105 km^2, with water supplied by three arterial canals on each side of the river. In 1820 the related diversion dams were located within 8 km of Valencia (Jaubert de Passa 1844), whereas today waters are tapped 4–10 km further upstream. The key canals radiate out onto the coastal plain like deltaic distributaries, but the northernmost, Moncada Canal, follows the base of an irregular line of hills to link up with the Sagunto system 17 km north of Valencia.

Historical Development. The evolution of the three irrigation networks is shown on Figs. 2 to 4. In the case of the South Mijares region, three morphological units can be identified (Fig. 2). (1) To the west is a section traditionally watered by *cenias*. However, several Roman canals cross the area, identified via aqueducts, rock-cut and masonry-sealed canals, tunnels, and diversionary dams with characteristic construction features (Doñate 1966, 1969). They imply that this section, now dry-farmed or limited to well-irrigation, was once supplied by a canal network serving a number of abandoned village sites. (2) The intermediate sector is interlinked with another generation of canals, still functional today and oriented with respect to the city of Vilareal, founded in 1274. Intensive development of this sector, with very few Arabic toponyms (Domingo, Vicent, and Barceló 1977, 171), came with the influx of Christian settlers during the first century or so after the Reconquista; the opening of the new main canal from the Mijares, past Burriana to Nules, is documented in 1273 (Domingo, Vicent, and Barceló 1977, 177–78, 219–20). (3) The eastern third of the South Mijares irrigation area is rich in Arabic toponyms and related canals, centered on the former Islamic city of Burriana (Domingo, Vicent, and Barceló 1977, 167, 171). This is part of the area by the sea, between Burriana and Sagunto, described by Idrisi during the mid-twelfth century as dotted with populous hamlets among orchards and vineyards and profusely irrigated land (Dozy and De Goeje 1968, 232). This third sector appears to have been the focus of pre-Reconquista settlement (Bazzana and Guichard 1981). It presumably was continuous with—but superimposed upon—an older, pre-Islamic agricultural landscape.

Although many of the Muslims vacated the South Mijares after the capitulation of Burriana in 1233 (Burns 1973, 142), some of the villages and towns retained a Muslim population until 1609. A series of documents of 1309, 1343, 1599, and 1607 (Domingo, Vicent, and Barceló

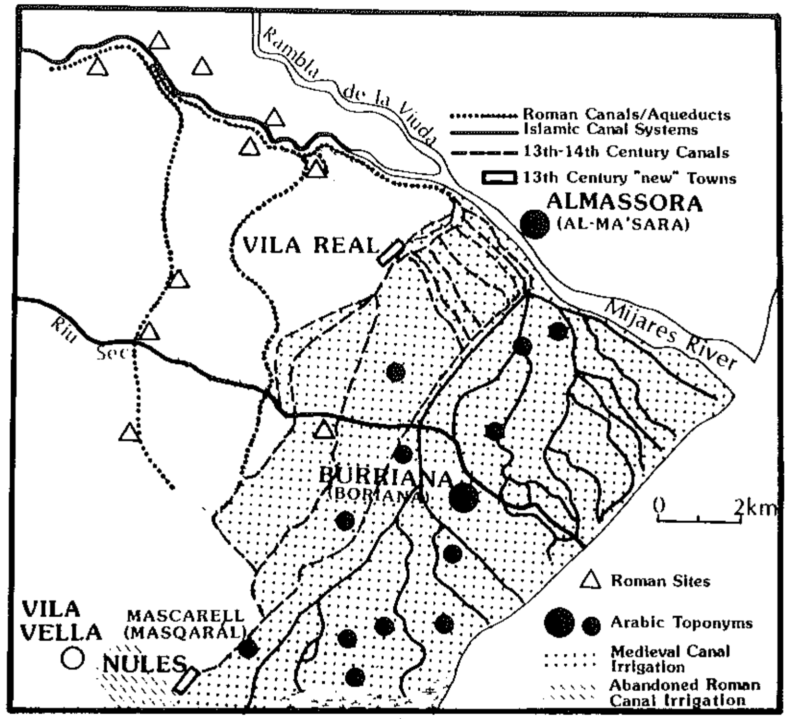

Figure 2. Roman to late Medieval irrigation networks south of the Mijares River, near Burriana. Arabic names are given in parentheses; Hispanic names are given in their Valencian form except for Burriana. For sources see text.

1977, 186–87; Domingo 1983, 186–87) shows that these native cultivators focused their efforts on wheat, barley, linseed, figs, almonds, and vineyards (for raisins). They also produced small quantities of pomegranates, peaches, apricots, pears, cherries, plums, carobs, various citrus trees, apples, and mulberry trees (for silkworms). In other words, the agricultural staples were typically "Mediterranean," but there was an additional but minor element of the partly exotic, "eastern" tree crops that unduly fascinated Spanish Arabic authors such as Ibn Bassal (Millás and Aziman 1955) and Ibn al-Awwam (Clément-Mullet 1977). A generally ignored fact is that of these tree crops all but the apricot, citrus, and silkworms (as opposed to mulberry trees per se) are part of the late Roman inventory compiled c. 630 A.D. in Sevilla by Isidore (17.9).

The *Palancia-Sagunto* irrigation network retains ample evidence of aqueducts, masonry-walled canals, underground siphons, and diversion dams of Roman or even earlier date that were extensively rebuilt during later periods, as indicated by Islamic brick and concrete structures (Pla 1963; López 1974a). These extend some 10 km from Algar to Sagunto, eventually on both sides of the river. The two distributary canals on the coastal plain north of the Palancia carry pre-Islamic names, as do several of the adjacent villages (Fig. 3, after Barceló 1982). The two main canals to the south retain Arabic names. The system evidently predates A.D. 714, and segments may even pertain to the third century B.C. But it was rebuilt or reconstituted and probably extended south of Sagunto during the Islamic period.

Sagunto surrendered on favorable terms in 1234 and the Muslim population remained largely intact. The city itself was overwhelmingly Muslim well into the fourteenth century (Pavón 1978), and most of the villages of the lower Palancia and the interlinked Vall de Sego (Fig. 3) remained Muslim to the eve of the Expulsion in 1609. The historical documentation shows that during the thirteenth century agriculture was focused on the typical Mediterranean staples. Eastern exotics such as rice, sugar cane, mulberry trees, and citrus fruits were also cultivated, however (Pérez 1968, 77ff.), and this region is described by Idrisi as one of teeming hamlets and irrigated orchards.

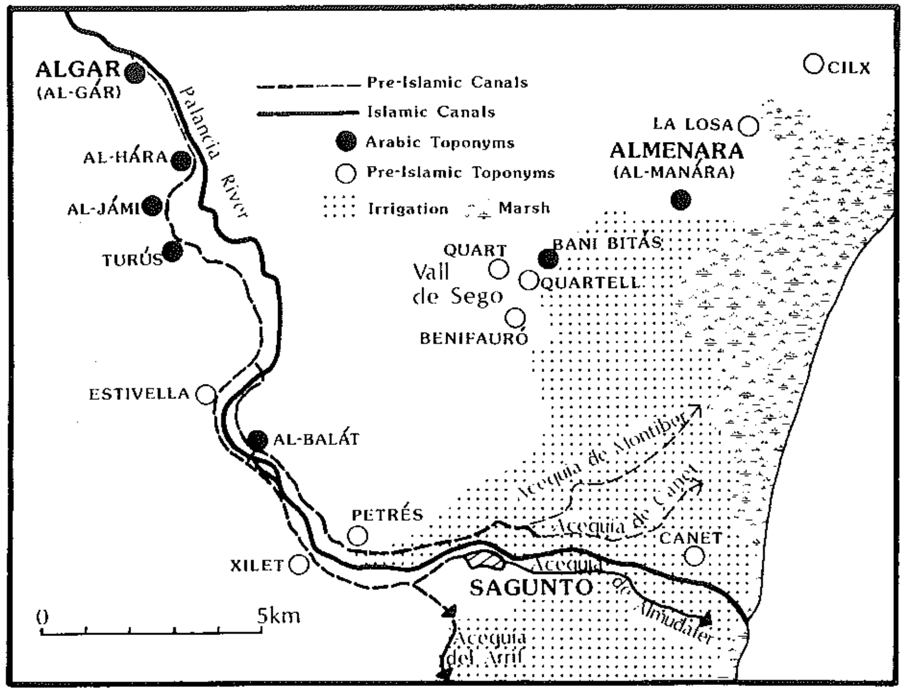

Figure 3. Roman and Medieval irrigation network along the lower Palancia River, near Sagunto. Except for Sagunto, toponyms are given in their thirteenth-century, archaic Hispanic or Arabic forms, or both, after Barceló (1982). For sources see text. The Arríf and Almudáfer canals have Arabic names.

The *Valencia* canal system is the most elaborate (Fig. 4) and it, too, has pre-Islamic origins. On the south bank of the Turia there are abundant vestiges of two parallel canals, diversion dams, tunnels, *qanat*-type access wells, and aqueducts running from Maria de la Pea to Manises and on to Valencia; these include Roman pottery, confirming the evidence of the masonry and brickwork (Valls 1902; Pla 1958; Fletcher 1964; Llorca 1964; Tarradell and Sanchís 1965, 147–51; Ventura 1972, 136–39). On the north bank there are less complete traces of up to three such ancient canals running from the Barranco Fondo to the late Roman site of Vélez and on past Paterna, with hints of older construction downstream to beyond Puig (Fletcher 1964; López 1974a). The antiquity of the irrigation network is further corroborated by a string of pre-Arabic toponyms along the Valencian *huerta* as well as within it (see Barceló 1982), and by Roman marker tiles found near ancient canal bifurcations (Llorca 1964). Particularly impressive, too, is the record of Roman rectangular subdivisions (centuriations), now reflected by canal, road, and field patterns from Meliana northward beyond Puig (Cano 1974) and again south of the Faitanar Canal (Pingarrón 1981).

That the canal networks in the southern *huerta* were rebuilt or expanded is suggested by the Arabic names of the key canals here (Glick 1970, 24) (Fig. 4). During the mid-twelfth century, Idrisi (Dozy and De Goeje 1968, 233) noted that waters from the river were carefully utilized to irrigate the fields, gardens, orchards, and country estates around Valencia. Other Islamic impressions of the Valencian garden landscape during the twelfth and thirteenth centuries were assembled by al-Himyari during the 1450s (Maestro 1963, 101–5). Saffron was important by the tenth century (Al-Razi, in Levi-Provençal 1953), although it had been known in seventh century Iberia (Isidore: 17.9.5).

The lists of Christian parishes and the taxes on Muslim communities recorded for the 1260s to 1280s indicate that most of the Muslim settlers of the *huerta* villages and Valencia proper had been expelled or otherwise dispossessed after the capitulation of the city in 1238 (Burns 1967, 311–17; Burns 1981, 122–29). Yet fifteenth century-cultivation focused on much the same crops

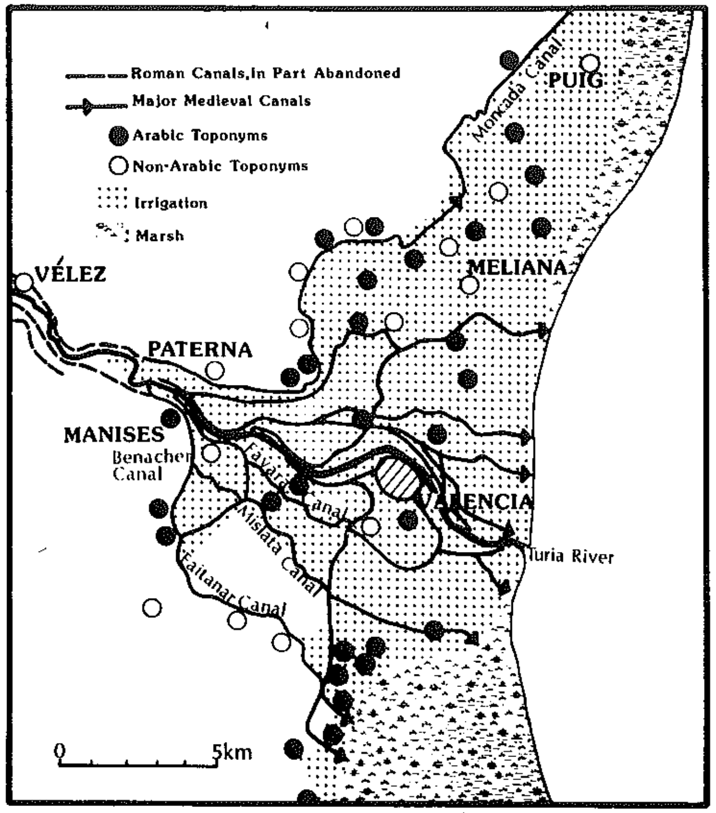

Figure 4. Roman and Medieval irrigation network along the lower Turia River, around Valencia. For sources see text. The Favara, Mislata, Faitanar, and Benacher canals carry Arabic names; only those non-Arabic toponyms verified at the time of the Reconquista are shown in open circles.

as along the Mijares and Palancia: spring and winter wheats, barley, beans, vineyards, carobs, figs, and oranges (Glick 1970, 28–30); only carobs and oranges qualify as exotic to the Roman base datum.

These three case studies show that the large irrigation networks of the study area predate the Islamic invasion, while not precluding refurbishment, reconstruction, or local expansion during the Islamic Middle Ages. A problem is that regional population density was very low c. 450–900 A.D. (Palol 1966; Bazzana and Guichard 1976). Valencia itself was destroyed by the caliph after an insurrection in 778 and lay waste for 20 years (Ubieto 1975, 118–19); Sagunto suffered a similar fate and, in general, expansion of the urban centers was delayed until c. 1000 A.D. (Butzer, Miralles, and Mateu 1983). The pollen record of Torreblanca, on the coastal plain north of Burriana, indeed shows a decline of disturbed vegetation, coupled with expansion of woodland, from the fourth to the tenth centuries (data extracted from Menéndez and Florschütz 1961). It is therefore probable that the Roman network had atrophied and partially fallen to disuse. The Arabs evidently revived the system, but at least around Sagunto and Valencia they closely followed the existing features, and in the Burriana sector they operated only a part of a once substantially larger network.

It is also noteworthy that the Arabs did not significantly modify the subsistence patterns, which continued to depend overwhelmingly on those staples characteristic of the Roman Mediterranean world. The key additions were rice, sugar cane, citrus fruits, silkworms, as well as sorghum—an important crop recorded in fifteenth- to sixteenth-century archaeological and archival documentation for the region (see Janer 1857, 320–21; Butzer et al. 1985).

Irrigation Organization. The regulations governing access to water in Valencia are described by Glick (1970, ch. 2–3, 11), Burriel (1971, ch. 2), López (1975), and Maass and

Anderson (1978, ch. 2). Water comes with the land and allocation is guaranteed, proportional to the size of the property. This is the so-called Syrian system, in contrast to the Yemenite, whereby water rights can be bought and sold independent of the land. There is, however, no implicit case for diffusion of these land-water relationships from the Near East because the underlying criteria represent an either/or proposition and the two types have essentially worldwide distribution (Hunt and Hunt 1976); the Syrian water-land linkage is typical of macro-scale irrigation networks, where water is relatively abundant and the sale of water is difficult to implement.

In Valencia, water was distributed proportionally among the eight key canals, in relation to the size of their service areas. Gates between the major bifurcation points took a proportional share of the water passing at that point. Each major canal section received a given volume of water, in a system of rotation that satisfied the needs of communities down the line. The unit of volume was the *fila*, an abstract measure determined by the size of the gate opening and the number of hours of flow; its purpose was to set a specific quota of water for each canal of a particular system and for its downstream components, over the stated number of days that it took to complete one "turn" (Glick 1970, 209–13). Fluctuation in water flow related to droughts or rainy periods were compensated by varying the length of the permissable irrigation periods and, in times of extraordinary shortage, water amounts were allocated according to the requirements of the specific crops planted by individual cultivators.

The irrigation communities represented along each of the main canals had a spokesman (*síndic*), who argued their case in disputes concerning intraregional distribution. The preeminent position of the city of Valencia, however, with its need for irrigation and drinking water, shifted the balance of forces to the disadvantage of the outlying villages. Conflicts between individual cultivators were adjudicated at the water tribunal in Valencia. Although all landowners had an equal voice in determining the *modus operandi* of the system, the fact that water was allocated proportional to the size of holdings implies that the system was not entirely egalitarian. Because outsiders could not acquire water rights without land, however, they could not achieve control over the local farmers.

The Valencian arrangement also applies to the South Mijares and Palancia systems, although intercommunity competition between the principal towns and villages in each took on different aspects (Traver 1909, 472–77; Pérez 1968, 77–84; Glick 1970, 126–31; López 1975; Domingo, Vicent, and Barceló 1977, 177–78). In 1346 each key town received specific quantities of water—or in times of drought, hours— in a fixed sequence. This is then a mixed time and volume arrangement. The community of Nules was joined to the new canal from Vilareal in 1273 but, because it did not traditionally belong to the Mijares network, had to pay for water in proportion to the land irrigated. In the Palancia system water was also allocated on a mixed time and volume basis in 1527 (Iborra 1981, 109): the upstream communities received water for one day, after which the coastal plain network divided the water of the next seven days on a proportional, *fila* basis.

The basic social organization of these three macro-irrigation networks has changed little since the Reconquista, when existing Islamic conventions were confirmed by the king of Aragón (Glick 1970, 232–40; López 1975). The question is whether this scheme of water laws was introduced by the Arabs or whether it was already in place prior to 714. The public character of water, the allocation of water in proportion to landholdings, the rotational system based on fixed time units, the priority according to use type for times of shortage, and the responsibility of the individual in local canal maintenance are all basic to Mediterranean irrigation practices as embodied in Roman law (Ware 1905: sects. 250–86, 294–96, 301–4, 308–11; Glick 1970, 193; Glick 1979, 73). What can be specifically attributed to the Arabs is the solution to proportionality provided by the *fila*, which is more sophisticated than the Roman system of hours or days and which is similar to the arbitrary units of volume used in Syria since 742 A.D. (compare Glick 1970, 213–16, 264–65 with López 1975 on this issue). Equally relevant is the extensive Arabic terminology for irrigation items and procedures that has persisted in use in eastern Spain (Glick 1970, 217ff.); its importance transcends the linguistic sphere, as indirect evidence of a fundamental imprint of Islam on the organizational structures of irrigation.

These characteristics can be most economically explained by a significant degree of Islamic elaboration of earlier Hispano-Roman organization, that continued to function even as Berber and Arab settlers began to trickle into the region. As in the case of the physical irrigation network and the subsistence system, the applications and the externalities were changed, but not the range of available options. Adaptation within a traditional context was more significant than diffusion in terms of the bigger picture, although the new Islamic components permitted or stimulated greater efficiency.

Meso-Scale Irrigation

We studied and mapped seven villages and hamlets in the Sierra de Espadán, west of Burriana (Fig. 5). Irrigation waters in these local networks are derived from springs or productive wells, which traditionally appear to have been exploited by *cenias*. Water is temporarily stored in large tanks (Valencian: *bassa,* singular) and then dispersed via canals that also provided power to operate grist mills. The percentage of cultivated land for these communities ranges from 26 to 67 percent, but only 2.2–5.8 percent of that cultivated is also irrigated. Nonetheless the productivity and value of the *huerta* tracts is disproportionately high. Rainfall is generally sufficient for crop growth except during the summer months, and irrigation is critical between late June and mid-October. During this period, the fixed dates of which vary from one village to the next, allocation of water is entrusted to an elected and paid irrigation officer, the *regador,* according to a traditional system of turns, proportional to the size of individual plots and sectors. In contrast, the *sequier,* who was responsible for assigning maintenance tasks and keeping records of the related costs, was not paid.

All of these villages were exclusively Muslim until the Expulsion of 1609, after which they were resettled by Christian colonists from nearby areas. The physical layout of the irrigation networks in each village thus remained intact, and the basic division of water did not change in a significant way, because thirteenth-century rulings invariably stipulated that Islamic customs for allocations would remain in force (Glick 1970, 240, 374; Burns 1973, 255–57).

Ahín. The community of Ahín (Valencian: Aín, also Arabic, for "Spring") receives its water primarily from a strong, perennial spring, the Font de la Caritat. Waters are temporarily stored in three major cisterns and then distributed on both sides of the stream (Fig. 6). Peripheral sections of the network are watered by minor springs, e.g., the Teuleria area and the distal, right bank sectors. Although supplementary watering is desirable by late April, controlled irrigation traditionally began on June 29, and the left bank (Pla de l'Horta, La Solana) received water on Mondays, Tuesdays, Wednesdays, and Saturdays. The right bank (L'Ombria) received its water on Thursdays, Fridays, and Sundays. Water was abundant, so that each

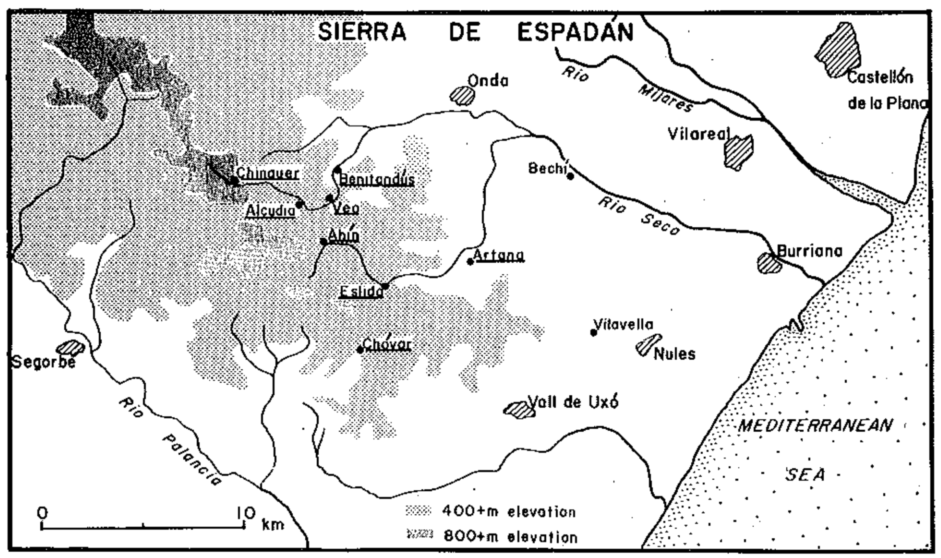

Figure 5. The Sierra de Espadán, north of Valencia. Underlined villages have been studied by the writers.

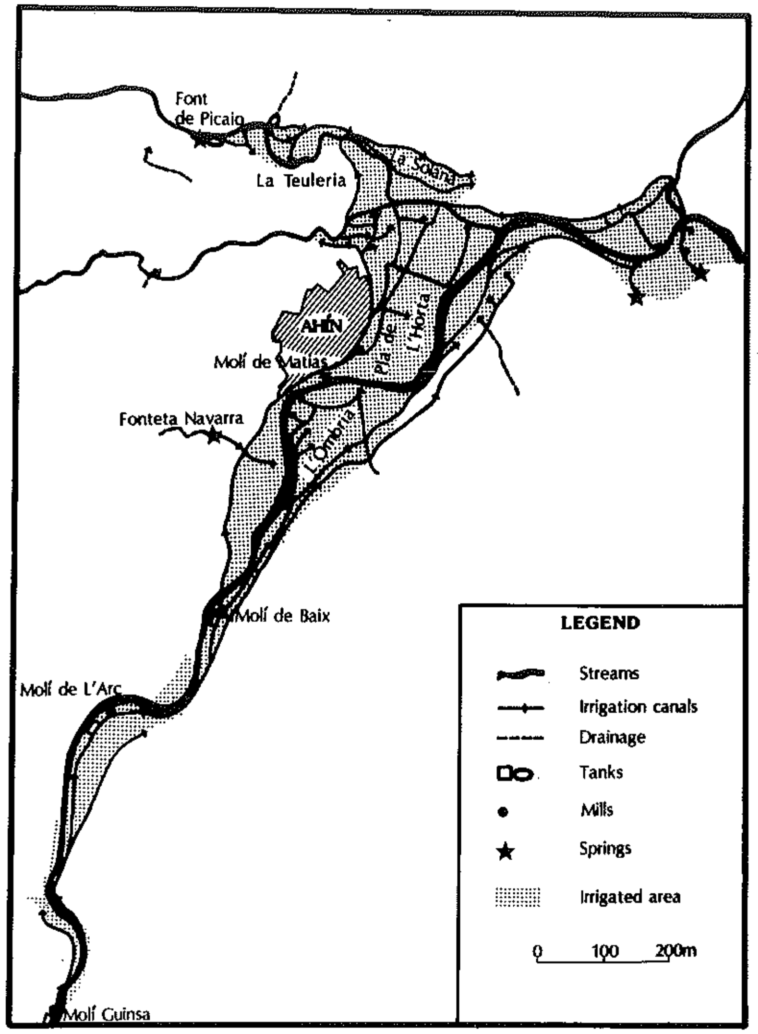

Figure 6. The traditional irrigation network of Ahín, Sierra de Espadán. Mapped by K. W. Butzer.

landholder could take as much as was needed. During one year the sequence of irrigation was from upstream to downstream, and the next from downstream to upstream.

During the nineteenth century the irrigated lands were primarily used to grow wheat, maize, beans, and fruits (Madoz 1846) such as cherries, almonds, and apples. Most of the 128 farmers (see IGE 1876) had some plots among the 14 irrigated hectares (0.11 hectares average), although the 1950 cadastral inventory indicates that the better land was to some degree concentrated in the hands of the wealthier families. Out-migration during the twentieth century reached crisis proportions, and by the 1960s there no longer was a sufficient labor supply to continue the traditional irrigation system. Land was switched from cereals and vegetables to tree crops, and many fields are no longer irrigated. For Ahín the office of *regador* has become meaningless, and no records have been kept for some 15 years.

The present irrigation features, such as mills and tanks, are no older than the 1920s, although some of the masonry is older. An ancient lever-and-bucket device, to feed a cistern from a well, is preserved downstream from Artana (Fig. 7). This shaduf was built on the edge of the former channel at a time when the streambed was 1.8 m higher than today. Subsequently the channel was scoured and lowered during a period of flash floods that stripped away all finer sediment, except for the cobbles and boulders. Twice the shaduf well was deepened and lined with cement

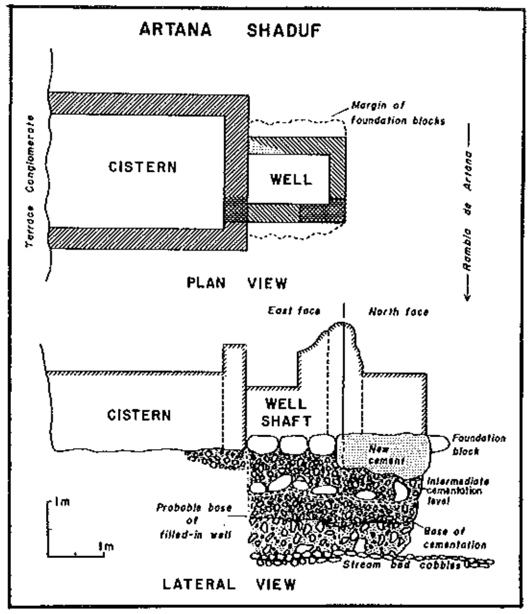

Figure 7. Medieval, shaduf irrigation device near Artana.

to keep apace before it was ultimately abandoned. The superstructure was rebuilt at least twice during the course of time, and pottery fragments were added in the process. The oldest repair (or original structure) incorporates the rim shard of a storage vessel, with a light red paste and sealed on the interior with a light green glaze. The next repair incorporates a fragment of a plate with a homogenous, buff paste and a stannous white glaze decorated with blue, schematic florals; this is a Manises product, no younger than the sixteenth or early seventeenth century (I. Miralles, pers. comm.). The final repairs include pieces of an entire storage vat with a red paste; this *lebrillo* is undecorated and was once repaired with copper wires; it is of "traditional" type, used as recently as the last century. The succession of repairs and the pottery inclusions indicate that this shaduf was built during Medieval times, probably during the fifteenth century.

Alcudia and Veo. The municipality of Alcudia de Veo includes two villages, Alcudia and Veo, as well as two outlying hamlets, Chinquer and Benitandus. The two major communities, with 133 and 43 farmers respectively (IGE 1876), shared water from two springs, both of which originated on the land of Alcudia proper. On the north bank (Fig. 8), the spring of San Pedro feeds a tank directly adjacent to Alcudia, via a canal, after which the waters are carried along the contours of a steep hillside down to the cistern of Veo, from where they are distributed over three field sectors (Solana, Veo, Alfara). On the south bank, the Chelva spring provides water to the contiguous *huerta*, is then led along the valley floor to be collected in a tank above the Tórcas sector, and is finally carried to the fields opposite Veo.

Irrigation is formally organized between June 24 and October 18. During that period, use of the San Pedro waters is rotated between Alcudia (two days) and Veo (four days), with La Solana receiving water for one day, the *huerta* of Veo two days, and Alfara one day. The Chelva waters are used by Alcudia from Sunday noon through Wednesday (La Chelva, Tórcas), and by Veo from Thursday to Sunday noon. During the remainder of the year—if and when Veo requires irrigation or drinking water—a notice must be posted in Alcudia, which allows Veo to use the water of San Pedro for four days at a time. Each village had one, water-powered flour mill, located on the edge of the settlement. The disproportional advantage of Veo in water use, despite its smaller size (530 vs. 867 inhabitants in 1900), reflects the location of the springs, which can only irrigate the small *huertas* downstream of Alcudia and which are inaccessible to Alcudia's large dry-farming sector upstream.

During the nineteenth century, irrigation was primarily devoted to wheat and millet (*paniso*) in Alcudia, with some potatoes, onions, garlic, and alfalfa, and to wheat, maize, beans, fruits, and mulberry trees in Veo (Madoz 1846). Of the 40 ha irrigated, most were on Veo property, overall averaging 0.23 ha per farmer. The areas irrigated from La Chelva are somewhat neglected today, but those watered from San Pedro are still fairly intensively cultivated.

The mills are no longer preserved, and the only pottery found in or around the modern canals pertains to the eighteenth and nineteenth centuries (M.P. Soler, pers. comm.). However, in the *huerta* of Veo there is an 80 m-long irrigation tunnel, with good masonry work. This may originally have been a Medieval construction.

Chóvar. The municipality of Chóvar has two separate irrigation networks. One is fed by a spring in the Barranco del Carbón. Temporary storage is provided by two cisterns, and the canals water about seven ha today and an additional two ha in the recent past (Fig. 9). The

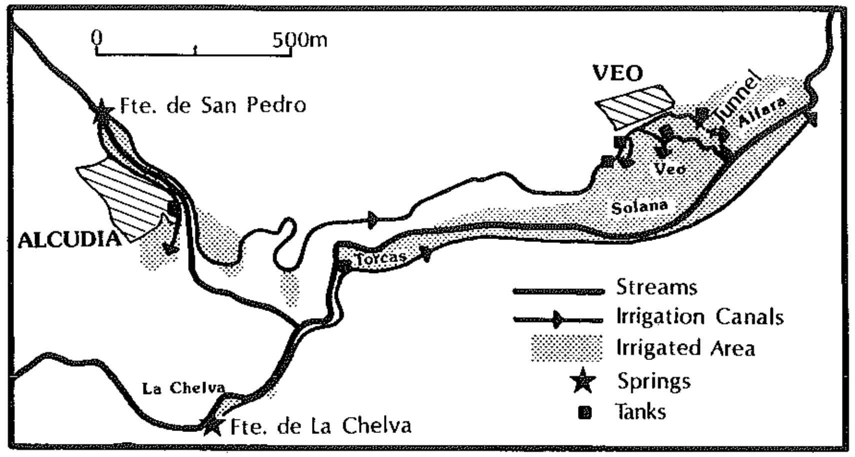

Figure 8. The key irrigation canals of Alcudia and Veo, Sierra de Espandán.

second is much more elaborate and fed primarily by a large storage dam, complemented by former canals tapping spring seeps on either bank of the Barranco de Ajuez (Fig. 9). The reservoir has an upstream check dam to catch the sediment entrained since nineteenth-century mining activities upvalley and has a maximum capacity of 30,000 m^3 of water. Water released from the gate is carried by one canal to a distributor tank from which it feeds canals that radiate through the fields. In recent years water has been so scarce that it is distributed only on Sundays, each average plot receiving 15 minutes of water, still meticulously recorded by a *regador*. A curious water-clock or *clepsydra* (Arabic, *tabbun* (Griffin 1960, 132)) is used to measure this dosage. The device itself is simple but modern; the principle of a set of perforated pots is quite ancient and derived from North Africa (Glick 1969). Some 4.6 ha are irrigated by the reservoir today and, as during the nineteenth century, are sown with vegetables such as onions, garlic, tomatoes, and cabbages (Madoz 1846). At least one additional ha was formerly irrigated, includ-

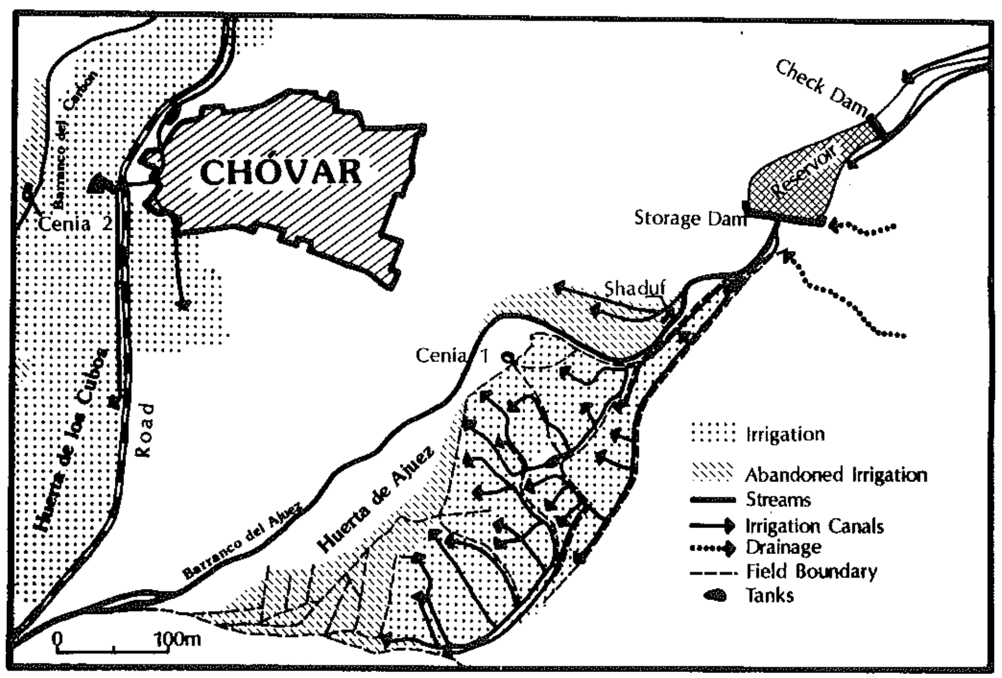

Figure 9. The traditional irrigation networks of Chóvar, Sierra de Espadán. Mapped by K. W. Butzer and J. F. Mateu.

ing a section of the east bank fed by canals leading directly from the streambed. The 209 farmers of Chóvar during the nineteenth century (IGE 1876) cultivated some 15 ha of irrigated land (0.07 ha on the average).

The Chóvar system is particularly interesting because it contains numerous old structures. The Ajuez storage dam, for example, shows three stages of enlargement from an original overflow level of 6.5 m to a final one of 11.5 m (Fig. 10). In its present form the dam dates from the late 1920s, according to local informants. The original, unbuttressed structure had a spillway; the buttresses added with the first enlargement are similar to those supporting an aqueduct built c. 1300 A.D. at Morella (Grewe 1985), so that the original dam may well date back to the Islamic Middle Ages. In the center of the *huerta* de Ajuez there are ruins of a very large storage tank. On the west bank there is an abandoned shaduf, undermined by downcutting on the channel so that it is non-functional (Fig. 11). On the east bank of the Barranco de Ajuez there also is an old, flood-damaged diversion dam that once fed water to an abandoned *cenia* (Fig. 11), the interior of which has late Gothic arches that date no later than the fifteenth or early sixteenth century.[4] This *cenia* has not been used in living memory.

Finally, on the west bank of the Barranco de Carbon is another *cenia* (Cenia 2, Fig. 11), that has unfortunately been cemented shut. It functioned at a time when the channel floor was 1.5 m higher than today. Although an attached tank with a capacity of 3 m³ is preserved, there no longer is any evidence of canals to carry water along the western margin of the stream. Next to it are the ruins of a circular structure, possibly pertaining to an earlier *cenia*. The antiquity of Islamic irrigation in this valley is documented in a murder process of June 1357, when a man was killed "in the Riu del Carvon on the old *assut* of [Chóvar]" (Archivo del Reino de Valencia, Real Justicia, vol 806, 118).

All in all, the Chóvar irrigation systems are decidedly archaic by virtue of preserving an array of structures that predate 1609: a large storage dam, two *cenias*, and a shaduf. We have found long-abandoned *cenias* in two other sierra communities, so that these relicts appear to be representative of the range of architectural features that once graced the irrigation networks of other sierra communities like Ahín and Alcudia de Veo in Medieval times.

Discussion. The three representative meso-scale systems described here are closely modeled on the macro-networks discussed earlier.

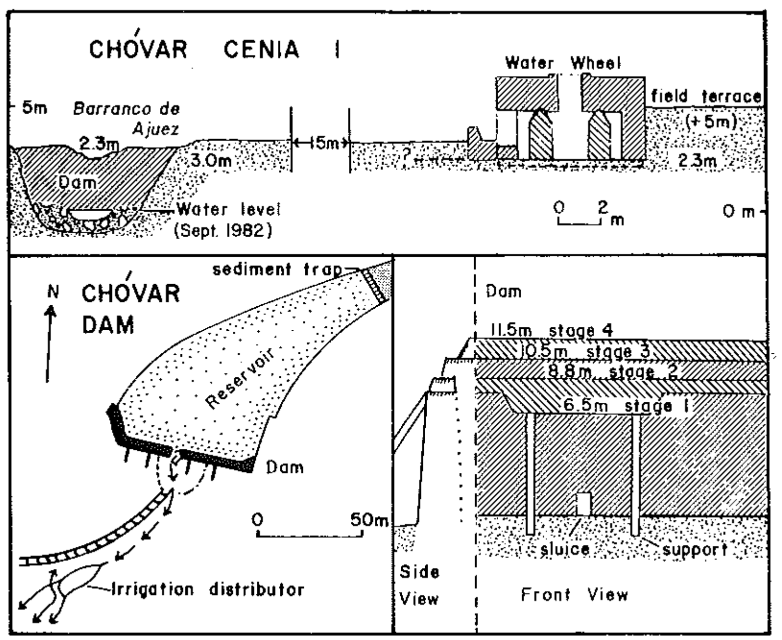

Figure 10. Medieval irrigation devices at Chóvar, including Cenia 1 and the reservoir (*pantano*), front and lateral view of the storage dam. The present form of the dam dates to the 1920s, the original structure is probably Islamic.

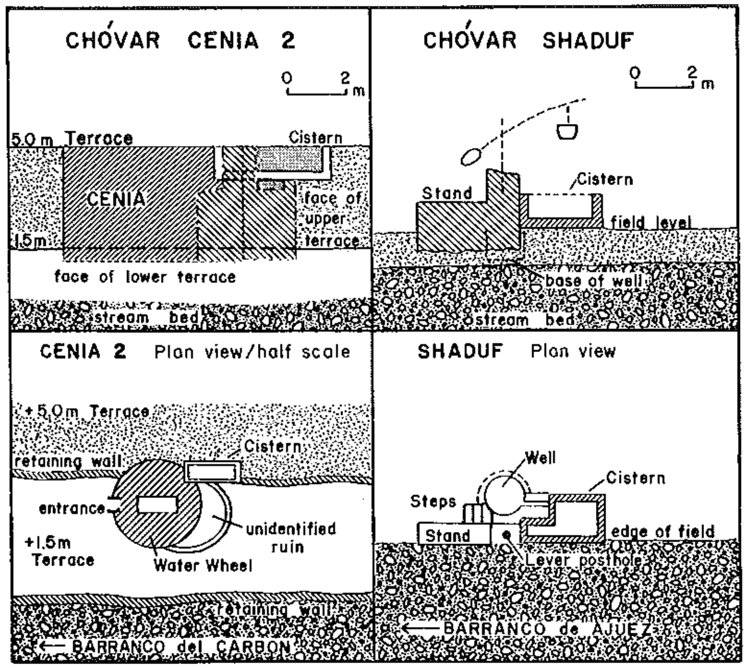

Figure 11. Other irrigation devices at Chóvar, including Cenia 2 and a shaduf.

This applies to the physical arrangements, the Syrian method of linking water with land, and the allocation of water by time units in prescribed rotations—the last based on the more archaic rotation by days still evident in the Mijares and Palancia areas. That these time-unit rotations date to the Middle Ages is confirmed by a set of documents from the adjacent Vall de Uxó, dated 1535 (Peñarroja 1984, 521–26). Although some of the Sierra de Espadán villages in the mid-thirteenth century had non-Arabic toponyms (Barceló 1982; Butzer et al. 1985), there is little tangible evidence of Roman settlement in the area, and the existing communal irrigation networks presumably came into being during the settlement expansion of the eleventh and twelfth centuries. Both the physical and social arrangements were evidently modeled on those of the coastal macro-systems.

The irrigation devices described from Artana and Chóvar, specifically the *cenia* and shaduf, as well as the water-clock or *clepsydra*, remain characteristic of the Near East and North Africa today; since *clepsydras* have not been identified from the coastal macro-systems, they may represent a more direct North African introduction (T. F. Glick, pers. comm.). The storage dam at Chóvar is similar to the South Arabian *kharíf* (see Serjeant 1964), but comparable dams with spillways like those at Chóvar are known from Roman Tripolitania (Vita-Finzi 1969, 17–44), which does not however preclude Islamic diffusion.[5] The *cenia* represents another bonafide Islamic introduction, that made well irrigation more efficient (the "noria revolution" of Glick (1979,74)), especially on the alluvial piedmonts. The shaduf was known, however, in late Roman Hispania (Isidore: 20.15.3). In sum, the lift and storage technology of the sierra in particular and the Valencian irrigation sphere in general indicates a combination of classical and Islamic roots. Introduction of the animal-driven waterwheel implies greater efficiency and will have facilitated Islamic intensification of agriculture in previously unirrigated areas.

Micro-Scale Irrigation

A third set of perspectives on the Islamic impact on regional irrigation can be derived from a small-scale investigation near Ahín that involved both contemporary land use study and archaeological excavation. The field tract in question (*partida*) is known as Benialí, after a now-abandonded fourteenth- to sixteenth-century Muslim hamlet located 1.1 km south of Ahín.

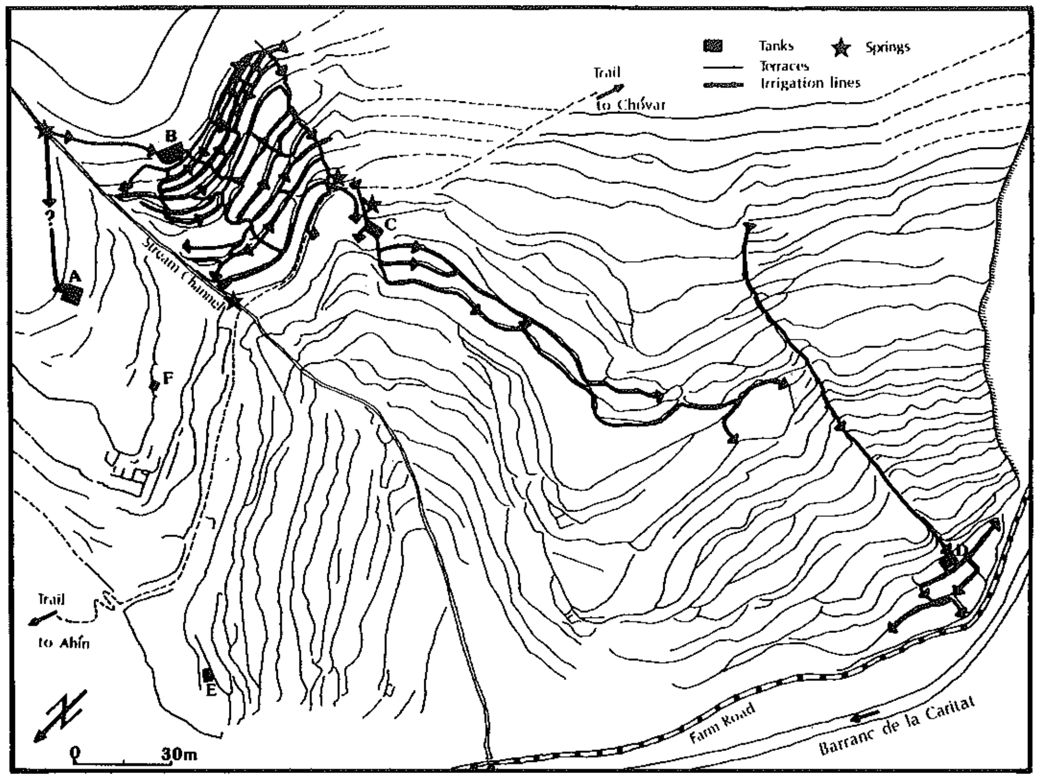

Figure 12. Hillside agricultural terraces at Benialí, municipality of Ahín, showing irrigation (B, C, D, traditional, and A, E, F, Medieval) tanks and water lines. Mapped by Pavel Kraus.

The artificial terrace network and the irrigation features of this area were mapped at a scale of 1:250 and studied by Kraus (1984). They are shown in Fig. 12. The 1950 cadastral plats and taxation inventories (preserved by the municipality of Ahín) indicate an average cultivated parcel size of 768 m^2 (7.7 areas, or 0.077 ha). The entire tract once cultivated measures 4.7 ha, of which 11.9 percent were irrigated.

There are three irrigated units, and in each case the limited waters of a minor spring or seep are collected in temporary storage tanks or cisterns. The smallest area measures 820 m^2 and is fed by a seep below a drainage line that is collected in a tank (D in Fig. 12); water is shared by seven landholders. The second and largest measures 2620 m^2 and is fed by a spring, via a cistern (C) that dispenses water by means of two or three furrows to an elongated area utilized by two landholders. The third measures 2150 m^2 and obtained its water from a tank (B) formerly fed by a pipe linked to a 35 m-distant stream seep; it was cultivated and irrigated by three first cousins. The son of one of them, Pascual Esteve Tomás, identified the features mapped in detail and explained how this micro-system was operated and applied while it was last in effective use during 1945–46.

The tank of the Esteve Tomás property held 33.2 m^3 of water and took four days to fill. This water was then distributed to the fields in 1.5 to 2 hours, which sufficed for only a quarter of the attached fields. Consequently a single irrigation cycle took 16 days, distributing water at a rate of 620 m^3 per ha (Kraus 1984). The water passed through unlined soil furrows along the inside of each terrace, zigzagging back and forth, to cross the terrace faces by means of small sluices or broad ramps (Fig. 12). The furrows were cleaned and recut twice annually. During one year irrigation proceeded from above to below, during the next from below to above. Irrigation was practiced from late April through early October.

The traditional cycle of agriculture spanned eight years, with winter wheat, barley, and potatoes marking the first three, followed by alfalfa for five years to restore soil nitrogen. Summer maize was sown only once, to avoid excessive soil depletion. Irrigation was used during the last month of winter crop growth, for the summer maize crop, and for the alfalfa, which was harvested eight times a year, every three to four weeks in summer, bimonthly in winter. Olive trees were also grown at intervals along these terraces, although they have been partly replaced by almonds in recent years.

This micro-irrigation system is one of interest in its own right, because such units have not been described in detail for Spain (Kraus 1984), although they appear to be relatively common on hillsides above communal *huertas*. It is further important because excavation at Benialí uncovered a Medieval tank (A in Fig. 12), with fifteenth-century pottery, in a mirror image position on the other side of the small valley from the Esteve Tomás tank (Butzer et al. 1985) (Fig. 12). The 52 m water line linking the Medieval cistern to its apparent water source is not preserved, but conspicuous rock cuts are evident along a level grade in the hillslope, and hollowed-out olive logs may have been once used to carry the water—a North African technique, also well known to our informant. The tank itself was cement-floored and built of masonry, with a rectangular, 6.2 by 9.6 m floor; the rock-cut back wall indicates an original depth of about 1.3 m and a capacity of as much as 83 m^3. Its existence suggests that the modern Esteve Tomás tank represents the site of another, Medieval one, also used to supply the abandoned settlement with drinking and irrigation water. The excavations provide no evidence, however, for systematic hillside terracing, other than widely spaced ramparts of rock and soil, similar in type to the French *rideau* (Humbert 1975) or British *lynchet* (Bowen 1961, 14–39).

The paleobotanical record of Medieval Benialí indicates that "hard" winter wheat as well as (summer ?) breadwheat were the staples, together with durra sorghum (a summer crop), flax and false flax (*Camelina sativa*) (winter crops), green beans, almonds, olives, and fruit trees such as plums, peaches, and figs (Butzer et al. 1985). This suggests that hard wheat or flax were planted on dry-farmed slopes in the autumn, with an additonal crop of spring wheat, sorghum, or vegetables on irrigated land. Sorghum is an African domesticate, but the other crops are circum-Mediterranean, and *Camelina* was traditionally grown in the Low Countries and southern Germany to provide a substitute for sesame oil. This again shows how most of the cultivar package was pre-Islamic.

The possible role of storage tanks in the Roman world has yet to receive attention. Such devices are part of the less conspicuous, lower-level technology, despite their critical role in making micro- and meso-scale irrigation possible. Various kinds of pools and tanks are archaeologically verified from ancient Egyptian and Roman estates, and we have seen several at excavated sites south of Valencia. Columella (1.5.1–2, 1.6.21, 11.3.8) notes that if a farm is not located next to a permanent spring or stream, then a well, a large cistern for people, and two ponds (one for cattle and geese, the other for soaking plants) are suggested; irrigation of adjacent fields is recommended from a stream or from well-water. The Roman architect Vitruvius (c. 25 A.D.) (8.6.14) recommends that on hillsides, water should be collected from roofs or runoff in one or more cement cisterns, implicitly of square or rectangular shape; on a larger scale, he also notes (8.6.7) that reservoirs were built at intervals along major aqueducts, whereas reservoirs providing urban water supplies should feed into smaller receptacles at different levels (8.6.1–2), presumably to provide temporary storage and allow sediment to settle (Frontinus: 1.16, 19). These comments basically include the range of tanks or cisterns functioning at a small scale on the hillsides of Ahín and Benialí, and at an intermediate scale, regulating the arterial canal that supplies Ahín or supplementing this central network from smaller, lateral springs.

The spring-fed tank and furrow micro-irrigation of Benialí must also be considered in the Islamic context. Similar rectangular cisterns are found in the central sierra of Spain, where they are called *alberca* (from Arabic, *al-birka*, "pond") (Kress 1970, 129). That area was settled by Berbers during the ninth to eleventh centuries, and provides widespread evidence of abandoned irrigation works among mountainside terraces (Hinderdink 1969, 31–32). In the eastern Rif Mountains of northern Morocco a similar irrigation method, based on spring seepage, serves to complement that from stream-fed canals on terraced hillsides (Coon 1931, 52–54; Despois 1956; Hart 1976, 108; J. F. Troin, pers. comm.), whereas unirrigated slopes are only imperfectly graded by means of *rideaux*. The presence of *alberca* or equivalent placenames in 11 Spanish and Portuguese provinces may indicate that such micro-irrigation has been or remains surprisingly widespread (Kress 1970; Garulo 1980). As far away as Oman the same word is applied to circular, rather than rectangular tanks, similarly used to build up a sufficient head of water and ensure a steady flow (Costa 1982).

This discussion suggests that tank irrigation, at small or intermediate scales, has long been both circum-Mediterranean as well as Near Eastern in its distribution. Consequently no argument can be made for Islamic diffusion, even though the Medieval and traditional tank-and-furrow irrigation of Benialí corresponds to the Islamic *alberca* model. Both the features and the method are too ancient and too commonplace to infer either classical continuity or Islamic reintroduction.

Regional Evaluation

The scale categories employed above to present the regional evidence for eastern Spain have allowed us to clarify the question of Islamic vs. pre-Islamic origins and to interpret the archaeological and documental evidence more consistently than has been possible previously. Beyond the significance of the particular historical problems examined here, the scale analysis contributes effectively to the study of irrigation systems, which are frequently lumped together indiscriminately (T. F. Glick, pers. comm.). The linking of scale to environmental variables further establishes the geographic significance of this method of analysis.

The picture that emerged shows that Hispano-Roman roots survived as a fundamental, even dominant component in the traditional agrosystems of Valencia. Without implying that these findings can be generalized to larger parts of Spain, several interim conclusions may be drawn, prior to re-examining the larger picture.

(1) Traditional or nineteenth-century technology in eastern Spain includes diversion dams, rock-cut and masonry-lined canals, cisterns or tanks, and the shaduf, all of which were widely known in the Roman Mediterranean world. But the *cenia* and *qanat* were important Islamic introductions to Spain. Storage dams may also have been novel, despite their antiquity in Roman Africa.

(2) The archaeological record of canals, as well as related aqueducts, underground siphons, and diversion dams, indicates that the macro-scale irrigation systems of Valencia were in place during Roman times. Furthermore, these systems are linked with villages and canals that carry pre-Arabic placenames, as well as with checkerboard Roman development projects (centuriations). The antiquity of these large networks did not escape the Arabic authors, and al-Himyari remarked that "the ancients" already cut a canal through the mountainside north of the Segura Valley (Maestro 1963, 365).

(3) It is probable that these Roman macro-systems were partially abandoned by the fifth century and that they were rebuilt or locally extended in Islamic times, judging by Arabic canal or placenames. However, the bulk of the population of the region probably continued to speak a Latin tongue during the first half of the ninth-to-twelfth-century demographic and economic revival of eastern Spain; although there were Berber settlers in the area, there were almost no Arab proprietors. It is therefore probable that the initial phases of reconstruction of these macro-systems were the work and responsibility of indigenous Hispano-Romans.

(4) The meso- and micro-scale networks in the adjacent mountains were not superimposed on pre-Islamic irrigation layouts. They represent a significant expansion of irrigation into new eco-habitats, presumably during the second half of the economic revival (eleventh and twelfth centuries) and were probably the work of settlers whose forebears had already been acculturated as Arabic-speaking Muslims.

(5) The communal water laws and allocation system used in the Valencia area for each scale of irrigation was based on a single model (explicated above in the discussion of macro-scale irrigation organization), basically derived from Roman or more general Mediterranean roots. An Islamic imprint can also be specifically identified in the terminology and the measures used, namely the abstract unit of volume (the *fila*) and the water-clock (*clepsydra*). Some North African modes of irrigation organization are similar to those of eastern Spain, presumably reflecting similar Mediterranean (but non-Roman) traditions; the Islamic terminological imprint in Spain may therefore be important as an indicator of more pervasive but intangible influences. Another problem is that the basic historical stability of macro-organization for Burriana, Sagunto, and Valencia since the Reconquista may well be unusual. The thirteenth-century Christian expansion of irrigation at Vilareal with the regular "sale" of water to the new commu-

nity of Nules represents a phenomenon that López (1975) shows was common in several irrigation networks that lie between Valencia and Alicante. In some there has also been substantial loss of community rights to their water. Finally there is the question of the origin of the Yemenite system of water sales (associated with a Yemenite proportionality measure) in the intermediate-scale irrigation systems around Alicante. These several caveats suggest that broad, regional characterizations of water traditions are best avoided, because they may obscure the complex cultural inputs, ecological refinements, and evolutionary changes in response to social pressures.[6] These traditions should not be interpreted as immutable reflections of past Roman or Islamic systems: the Christian Reconquest led to the formalization—not fossilization—of Muslim water practices.

(6) The basic staples of Medieval irrigation farming in the Valencia area, regardless of scale, were part of the pre-Islamic, circum-Mediterranean agrosystem. Of ten field crops verified for the thirteenth to sixteenth centuries from Muslim settlements on the coastal plain and at Benialí, only sorghum, rice, and sugar cane qualify as Islamic introductions. Of 13 specific tree crops, only the carob, apricot, orange and mulberry/silkworm were new. Rice, silkworms, and sugar, in that order, undoubtedly represented important commercial crops in Medieval Valencia. Wheat was not a lowly subsistence staple but, in terms of value, undoubtedly the major export from the Valencia area to Rome in the first century as well as the major import by the rapidly growing city of Valencia in the fifteenth century (Häuptle 1982). The archival records, from the first royal charters after 1238 to the Expulsion in 1609, show that the substantial Muslim residual population of the Valencia area continued to concentrate cultivation on traditional Mediterranean staples.

This invalidates Watson's (1983, 184) generalization that after the Reconquest "the more productive crops of Islamic times" were abandoned in favor of "the production of grains, pulses, and vines, i.e., the traditional crops of feudal Europe." The degree to which Islamic commercial crops continued to flourish after 1238 depended on many factors: market demand (low for oranges, high for silk), the availability of labor (perennially in short supply, e.g., for sugar cane), health considerations (rice cultivation in the coastal marshland was repeatedly interdicted because of the malaria problem). The late Medieval decline of sugar production in the Mediterranean region was not limited to Christian countries, and reflected competition by new suppliers. Some of the new plants such as cotton and bananas had been rare in Islamic times, even in Andalusia (see Watson 1983, 40, 54, 156, 161, 167), and may not have gained wide acceptance. Sorghum, despite its versatility in a summer dry environment, remained a low-prestige crop (Watson 1983, 87, 185) and was displaced by maize after 1600 (López 1974b). The only tangible Christian prejudice against Muslim cultivars was in regard to the cucumber-melon-eggplant category, omitted from the c. 1300 A.D. Castilian translation of Ibn Bassal (Millás and Aziman 1955, 26) and belittled in Christian polemic writings at the time of the Expulsion. Finally, the notion that Christian Valencia, especially after the Expulsion, saw a simplification of the agrosystem from multiple to single cropping (Watson 1983, 212) is simply contrary to the facts.

This detailed, regional study illuminates the complexity of the data base and is indispensible for realistic, synthetic assessment of the larger picture.

An Islamic Agricultural Revolution?

Islamic agricultural change in Spain was an incremental process of intensification, involving traditional crops and methods, not the wholesale importation of a new system. Nonetheless, a number of new elements was introduced. The chroniclers mention that Abd al-Rahman I (756–788) created gardens of exotic plants and ornamental trees in Cordoba, while Abd al-Rahman II (822–852) and III (912–961) laid out irrigation canals (Hoehnerbach 1970, 64, 82; Levi-Provençal 1932, 106). The Calendar of Cordoba (c. 961) gives ample testimony of intensification on the Roman model and provides a first record of silk and many new cultivars (see Table 1): lemon, apricot, rice, cotton, banana, cauliflower, watermelon, eggplant, henna, safflower, and jasmine (Pellat 1961, 36, 62, 72, 76, 88, 90, 132, 172). Sugar and spinach are first enumerated by al-Razi c. 930 (Levi-Provençal 1953), taro by Abu-l-Jayr before 1038 (Millás 1955). The carob tree is mentioned c. 1050 by Ibn Bassal (Millás and Aziman 1955), and sorghum and indigo by an unknown author of c. 1100 (Asin 1943, 355, 65). Finally, the grapefruit is added by Ibn al-Awwam in 1158 (Clément-Mullet 1977). The literary record of irrigation devices, new or traditional, is sparse by comparison. *Qanats* are first referred to near Cordoba in A.D. 754, with other tenth- and eleventh-century records that have been verified in the field (M. Barceló 1983). A *cenia* is archaeologically verified from the tenth century (Bazzana 1983). Al-Razi (Levi-Provençal 1953) mentions current-driven waterwheels at Cordoba and Tudela, and in the early twelfth century Idrisi lists other current wheels at Zaragoza, Toledo, Murcia, Almeria, and Coimbra (Dozy and De Goeje 1968, 222, 228, 236–37, 240). Allowing for the incompleteness of the record, both irrigation development and the effective incorporation of the new cultivars in Spain appears to date from c. 800–1100, essentially simultaneous with economic growth and demographic expansion.

An initial stimulus to diffusion from Mesopotamia or Egypt to Spain, in part via Tunisia, appears to have been a royal whim to display exotic plants in palace gardens (Watson 1983, 89, 100, 117, 119). But the subsequent adoption of new crops and irrigation devices in the agricultural sector was part of a more complex, positive feedback system between population growth, agricultural productivity, capital and labor investment, and economic demand. A lucid model of this process in terms of demand and supply is presented by Watson (1983, 87–122).

To what degree was Islamic intensification c. 800–1100 different from its Roman counterpart, that culminated in the second century A.D.? Watson (1983, 123–38) argues that it was fundamentally different, including the first effective summer crop routine, crop rotation, understanding and applying fertilizers, and developing irrigation to its maximum potential, with a deeper penetration of both agriculture and a monetary economy into the interior of Spain. The evidence presented here suggests that the differences were of degree rather than kind.

Of 134 economic plants and trees listed by the Islamic agronomists of Spain (see Millás 1943; Millás and Aziman 1955; Pellat 1961; Clément-Mullet 1977), 41 have been claimed as probable or certain Islamic introductions (Kress 1970, 92–94; Watson 1983). However, closer examination of the inventory assembled in Table 1 with reference to the classical authors, eliminates all but 19 of these plants. The Islamic introductions were indisputably important as commercial crops: rice, sugar, cotton, citrus fruits, and the silkworm industry, adapted to native mulberry trees. The Spanish evidence, however, shows that these crops no more than supplemented a market economy based on much more common and productive, traditional staples. The Roman (and even the Visigothic) datum demonstrates that spring wheat,[7] two species of millet, a dozen or so orchard trees, and a wide range of fodder crops and vegetables were grown in summer, generally with some level of irrigation. To this broad array the Arabs added sorghum (late and always lowly), four fruit trees, and a number of commercial crops that generally remained outside the means of the bulk of the peasantry.

Our review of the Roman agrosystems shows that crop rotation was as well understood (or practiced) as it was in Islamic times. The Roman farmer planted both winter and summer crops, in part on the same plots, and the agricultural calendar kept farmers fully occupied throughout the year (Columella: 11). It is a misconception to assume that multiple cropping, such as the three successive wheat crops per year noted by Theophrastus (8.7.4) for Babylon, was possible with the cool to cold winter climate of Spain, even on the best alluvial soils with unlimited water.

The Islamic mastery of soil fertilization, despite its importance, differed only slightly from that of the Romans, and it was explicitly based in concept and in almost all of its details on the Roman prototype (Bolens 1972, 1981, esp. Tables I and II). Much the same has been shown for the technology of tree grafting and improved fruit varieties (Bolens 1981, e.g., Table I, Appendix).

Roman irrigation, as we have shown, was sophisticated and well established. The Arabs, however, added to the efficacy of irrigation organization by introducing both the proportional measure of the *fila* to facilitate distribution in complex macro-systems and the water-clock or *clepsydra* to assist in meso-scale irrigation. The Arabs extended irrigation to some new areas; they also added the *qanat*, of which relatively few examples are known and no explicit mention is made by Islamic authors, as well as the simpler *cenia*, which was of greater importance in tapping diffuse piedmont aquifers but which near Burriana substituted for a Roman canal system. The only device marveled at in the Arabic

Table 1. Plants Widely Considered as Arab Introductions to Spain, Compared with Classical Authors. Convincing Introductions Italicized.

Plant	Latin name	Key classical authors citing plant
Fruit trees		
Date palm	Palma	Theophrastus 2.6; Varro 1.47; Columella 9.5.4; Pliny 18.6.26; Isidore 17.7.1
Carob[a]	Ceronia	Theophrastus 4.2.4; Pliny 13.16, 23.79
Pomegranate	Malum granatum	Theophrastus 2.7.3; Cato 51; Varro 1.4.9; Columella 12.46.5; Pliny 15.9; Isidore 17.7.6
Quince	Mala cydonia	Theophrastus 2.2.5; Cato 51; Varro 1.49; Columella 12.47.2; Pliny 15.16; Isidore 17.7.4
Pear	Pirum, Myrapia	Theophrastus 1.14.4; Cato 40; Columella 12.10.4; Pliny 15.16; Isidore 17.7.15
Cherry	Cerasus	Columella 11.2.11; Pliny 15.30; Isidore 17.7.16
Peach (varieties)	Persicum	Columella 11.2.11; Pliny 15.11, 13; Isidore 17.7.7
Apricot	—	
Lemon	—	
Grapefruit	—	
Bitter orange	—	
Banana	—	
Mulberry[b]	Morus	Theophrastus 1.10.10; Columella 10.403; Pliny 15.27; Isidore 17.7.19
Grains		
Hard wheat[c]	Triticum	Cato 35; Columella 11.2.20; Pliny 18.20; Isidore 17.3.4
Common millet[d]	Milio campania	Theophrastus 8.7.3; Cato 6; Columella 11.2.72; Pliny 18.10; Isidore 17.3.12
Italian millet[e]	Panico	Theophrastus 8.7.3; Cato 6; Columella 11.2.72; Pliny 18.10; Isidore 17.3.13
Durra sorghum[f]	—	
Asiatic rice[g]	Oryza	
Vegetables and fodder crops		
Lupine (sainfoin)	Lupinus	Theophrastus 8.7.3; Cato 5; Columella 11.2.75; Pliny 18.36; Isidore 17.4.7
Spinach	—	
Cauliflower	—	
Artichoke[h]	Cinara	Theophrastus 6.4.11; Columella 11.3.28; Pliny 19.43
Taro (Colocasia)	—	
Asparagus	Asparagus	Theophrastus 6.4.2; Cato 141; Columella 11.3.45; Pliny 19.42; Isidore 17.10.19
Safflower[j]	—	Theophrastus 6.4.5
Sugar cane[k]	—	
Alfalfa (lucerne)[m]	Medica	Theophrastus 8.7.7; Varro 3.16; Pliny 18.43; Isidore 17.4.8
Fenugreek	Fenum graecum	Theophrastus 8.8.5; Cato 27; Columella 11.2.71; Pliny 18.39
Gourd plants		
Honey melon	—	
Watermelon	—	
Eggplant (aubergine)	—	
Condiments, dyes, and aromatics		
Capers	Capparis	Columella 11.3.54; Isidore 17.10.20
Saffron	Croceus	Theophrastus 6.6.10; Columella 9.4.4; Pliny 19.31; Isidore 17.9.5

Table 1—*Continued*

Plant	Latin name	Key classical authors citing plant
Indigo[n]	—	
Henna	—	
Madder	Rubia	Theophrastus 9.13.6; Pliny 19.17.47; Isidore 17.9.68
Rose	Rosa	Theophrastus 6.6.6; Varro 3.16; Columella, Arb. 1.2; Isidore 17.9.17
White lilly	Lilium	Theophrastus 6.6.11; Columella 9.4.4; Isidore 17.9.18.
Jasmine	—	
Fiber plants		
Old World cotton	—	
Hemp	Canabis	Varro 1.23; Pliny 19.56

[a] Theophrastus gives an accurate description of the tree, its flowers, and fruit pods under the name *ceronia*, but notes that it was only found in Syria, Anatolia, and the Aegean area. Pliny simply repeats this information. Carob pods have been reported from a Bronze Age site of the Valencia area, dated (calibrated radiocarbon) c. 2025 B.C. (Arnal, Prades, and Fletcher 1968), but require confirmation. Since there also was a sweet variety (*Siliqua praedulce*, Pliny 15.26) there is some confusion in the classical terminology. Cassianus (c. 650 A.D.) (10.72) discusses *siliqua* among tree crops and notes it was planted much like olives, in moist places. Isidore equates *siliqua* with the Greek *xyliglycon* ("sweet pod"), noting that its (characteristic) gum extract is called (incorrectly) *acacia* (which does produce gum arabic). Columella (2.10.33) erroneously adds *siliqua* (instead of *silicia*) as a synonym for fenugreek, a point corrected by Pliny (18.39). The Linnean name of the carob is *Ceratonia siliqua*. The unsatisfactory and ambiguous references by the Latin authors leaves some doubt that the carob was familiar in Italy or Spain.

[b] The mulberry tree and its fruits were used in the classical Mediterranean, but the related silkworm cultures were not.

[c] Watson (1983, 20ff.) claims hard or *durum* wheat was unknown to the Romans, but Pliny (18.20.89) clearly identifies it by noting its high proportion of bran, its greater cost, its qualities for paper milling, and its use for *similago* flour (Italian: *semolina*). It is distinguished from *siligo* (breadwheat), used for best quality, white bread flour (18.20.85), from *far* (emmer wheat), difficult to thresh (18.20.92, 18.10.56), from "branched" or *centigranium* wheat (? poulard) (18.21.95), and from *trimestrium* ("three month" or spring wheat) (18.12.69–70, 18.65.240; Columella 2.9.8, 11.2.20; Isidore 17.3.8). The best hard wheat was reported to come from "Africa" (Tunisia) (Pliny 18.20.89), which is reasonable because it is a drought-adapted, slow-growing winter crop.

[d] *Panicum miliaceum* (broomcorn millet).

[e] *Setaria italica* (foxtail millet).

[f] A comparative late-comer, and not yet mentioned in tenth-century Spanish Arabic sources.

[g] An Indian plant (Theophrastus 4.4.10; Pliny 15.7.28), possibly familiar in the eastern Mediterranean area in classical times (see the ambiguous reference in Pliny 18.19.81).

[h] For the classical period, Watson (1983, 64–65) believes that only the stalks and leaves, and not the calyx bracts were utilized from unimproved Cinara plants. But one of the key Arabic designations (*qinariya*) derives from the Latin name, and Theophrastus carefully distinguishes the cardoon from the artichoke, the latter with an edible fruit-vessel. The high commercial profits indicated by Pliny are more logically associated with an improved artichoke than an edible thistle.

[j] Theophrastus clearly identifies wild and cultivated forms of safflower, but the plant is never cited by Latin authors.

[k] Used in Arabic and India during the first century A.D. and termed *saccharo* (Pliny 12.17).

[m] Alfalfa was introduced to Greece from Persia during the fifth or fourth century B.C., according to Pliny, and this fodder crop was well established in Italy in Varro's day, in Spain by the time of Isidore. The plant was unknown in Pharaonic Egypt, and appears to have been introduced by the Persians after 525 B.C. The Greek and Latin names (*Medike, Medica*) derive from the Medes.

[n] Noted by Pliny (33.57.163) as "Indian blue."

writings is the current wheel, a feature well known to the Romans. Irrigation was indeed first expanded into some mountainous areas, such as the Sierra de Espadán, in Islamic times. But the vast interior of Spain remained only extensively used by a thin population of Berbers and arabized indigenous folk practicing pastoralism and dry-farming. And examination of the body of literary and archaeological data on Roman and Islamic Spain suggests that it would be difficult to make a case that the population of the eleventh century was significantly greater than that of the second.

The Islamic intensification of agriculture was momentous in that it revived the circum-Mediterranean agrosystem in a measure rivaling and locally surpassing that of the Roman period. A secondary diffusion of technology and cultigens to Christian areas of Spain and Italy was undoubtedly prerequisite to the economic growth that allowed Iberian expansion to the New World or that characterized Renaissance Tuscany and Lombardy and so financed the rapid economic development of temperate Europe in the 50 years prior to the Reformation. Subsequently, on an even larger scale, tertiary diffusion benefited the Americas.

But Islamic intensification was evolutionary, rather than revolutionary. It re-created the Roman agrosystem, and amplified it with methods and cultivars already tested and perfected in India, Persia, Mesopotamia, Syria, and Egypt. Many of the *new* ideas ultimately derived from Indian experience, as Pliny was already basically aware. If there was indeed a revolution, it was the successful incorporation of highly productive tropical cultigens, in India, into a generalized Mediterranean-style economy during the first millennium B.C.

In conclusion, the Spanish irrigation agrosystem was not the product of Islamic civilization, and it is a bad cliché to regard Medieval horticulture in Spain as a re-creation of the desert oasis. Islam contributed significantly to both renewed expansion and further development of Spanish agrosystems. But the Hispano-Romans practiced sophisticated irrigation on a major scale, their basic agrosystem survived intact during the late Roman and Visigothic economic depression, and subsequent re-intensification represented a revival of the Roman system under conditions of demographic and economic growth.

The Hispano-Roman agrosystem was to some degree conservative. Its bearers could afford to be so because they were reasonably successful in long-term maintenance. This paper provides an appreciation of the long-term stability of technology, domesticates, and organizational strategies in the Mediterranean Basin; agrosystems and the three tiers of irrigation provide effective frameworks for this long-term perspective. There was significantly more communication on the vertical axis, over the generations, than there was on the horizontal plane, across the Straits of Gibraltar. There indeed were periods of information flow and increased productivity, as well as structural modifications or elaborations. But this historical case study suggests that diffusion cannot be understood outside the context of adaptation. Diffusion tends to be indirect, complex, and incremental, according to region and period, because new traits must be more efficient or desirable than existing alternatives if they are to be accepted (Denevan 1983).

Whether one is more impressed by basic stability over time, or by the invention or acquisition of some new details, is a matter of one's point of view. In the long term, continuity and change are non-exclusive and complementary, as are adaptation and diffusion. Both aspects of the second dichotomy are essential to understanding the processes of culture change.

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Notes

1. For southeastern Spain, between Almeria and the Segura River, Chapman (1978) has presented and evaluated the substantial evidence for water-storage cisterns and canal irrigation during the Early Bronze Age, c. 2400 B.C. (calibrated radiocarbon dates).
2. In the Eastern Mediterranean Arabic-language area, the Persian wheel is known as a *saqiya*, which is the most common form in English-language literature. The term derives from the same word as the Spanish *acequia*, or canal, and is therefore confusing in a Hispanic context. The Castilian term *noria* (from Arabic *na'ura*) is familiar to Latin Americanists but, at least in Spain, is frequently used to describe both animal-drawn and current-driven waterwheels. We consequently use the Valencian-Catalan designation *cenia*, derived from the Maghrebi Arabic *saniya* (Colin 1932; Griffin 1960, 164).
3. Using the area and population of nineteenth century Egyptian cities of the general size, a population of 400 people per ha seems appropriate (Butzer 1984), although this value should have been lower during periods of early growth or abrupt decline, and higher during times of maximum prosperity. On this basis a population of 25,000 can be tentatively estimated for Valencia c. 100 A.D., as little as 4,000 c. 300 A.D., perhaps 13,500 c. 1075 A.D., and 25,000 shortly before 1238. This interpretation of the changing cityscape of Valencia reflects long hours spent by V. M. Rosselló introducing us to its historical topography. Available estimates of the population of Hispania during the second century A.D. range from 5 to 12 million, for the Visigothic period 3 to 4 million, at least 6 million for c. A.D. 1000, and as much as 9.5 million shortly before the Black Death in 1348 (Russell 1958; Issawi 1981). More satisfactory estimates must (1) incorporate the fact that the walled, fourth-century Roman cities were much smaller than their second-century counterparts; (2) estimate Islamic populations in the context of the regional descriptions provided by the Arabic geographers; and (3) use more realistic figures for urban population densities than the maximum of 250 persons per hectare espoused by Russell (1958, 1972).

4. A *cenia* shaft, in use from the tenth to the fourteenth century, has recently been excavated near Oliva, but the data remain to be fully published (Bazzana 1983).
5. Roman dams were built without buttresses because of their better static balance (Grewe 1985). In Tunisia, Solignac (1953) shows that the Arabs built rectilinear dam walls, without supports, until the mid-ninth century; only thereafter did they begin to build arcuate dams or circular tanks, strengthened by semicircular buttresses, initially on the inside, later on the outside. Such semicircular buttresses are unfamiliar in eastern Spain, but the reservoir feeding the meso-scale irrigation system of Elche, west of Alicante, was still closed by an arcuate dam in the nineteenth century (Markham 1867, 46–47).
6. The significant intraregional differences in water organization in Valencia, Alicante (López 1975), and at Banyalbufar and Palma (Mallorca) (Carbonero 1983; Rosselló 1965) appear to be typical in Morocco as well. There, water rights can be sold in the Rif (Hart 1976, 114) but not in the High Atlas (Geertz, Geertz, and Rosen 1979, 115; Miller 1984, 72); unlike in Spain, downstream users in Morocco do not have equal rights with upstream ones. We agree with T. F. Glick (pers. comm.) that the considerable variability of water allocation methods and measurement encodes significant ecological information and may provide potential cultural markers. But in default of an ethnographic atlas of irrigation in the Islamic world, we would argue for caution in offering paleo-ethnic or macro-cultural interpretations for different water rules without diligent historical research comparable to that of Glick (1970) for Valencia.
7. Columella (2.9.8) and Pliny (18.12.68) indicate that spring wheat was the only type cultivated in the colder environments beyond the Alps, where the Mediterranean agrosystem had been modified and readapted to a primarily summer growing season before 5000 B.C. Spring wheat had explicity been introduced to the Mediterranean not much before Columella's time, but in its new setting was commonly planted very early, in January or February (11.2.20).

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