THE ISLAMIC TRADITIONS OF AGROECOLOGY: CROSSCULTURAL EXPERIENCE, IDEAS AND INNOVATIONS

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Introduction

The intellectual roots of ecological concepts are not grounded in Graeco-Roman geography, which emphasized 'peoples and places' rather than environmental description or human use of the land. Instead, one must look to the agronomic writings, that begin with Hesiod (*c* 700 BC). By the time of Xenophon (writing *c* 362 BC), epics about rural lifeways had given way to literary works on agricultural economics. Aristotle and Theophrastus subsequently laid the scientific foundations of botany, agroecology, soil science and livestock management. About 160 BC, the Roman statesman Cato wrote the earliest preserved treatise on agriculture, beginning a tradition that culminated with Ibn al-Awwâm in Islamic Spain *c* AD 1160. In fact, until the 1700s, the ecological linkages between climate, plants, soils and human subsistence were primarily studied as part of that agronomic tradition.

To contemporary cultural ecologists, interested in the systemic interactions between people, demography, agrotechnology, and resource management,[1] this will hardly seem surprising. The agronomic tradition was grounded in the experience and understanding of the common farmer, but reflects the coherence, the critical facility, and the capacity to innovate, within a literate segment of society.[2] Its practitioners sought to understand environmental variables, advances in plant taxonomy, or medicobotanical insights for horticulture, in order to weigh the economic prospects of complementary strategies for field agriculture, arboriculture and pastoralism. Many agronomic authors had farm roots, but most were scholars whose higher goals were directed to various forms of economic or social advocacy. It is this array of systematic, ecological and systemic perspectives that places agronomic science within natural history and distinguishes it from agricultural history.

Yet despite all its diversified and challenging subject matter, the agronomic tradition remains largely ignored by historians of science, who have focused on orthodox disciplines. My own interest in the intellectual evolution of the agronomic tradition stems from looking back on my earlier work on prehistoric agriculture, after interacting with a community of farmers during six seasons of a rural microstudy in eastern Spain.[3] I had been impressed by the depth of understanding of all facets of agroecology by many of the more articulate farmers I talked with; they respected experience, constantly weighed options and made decisions within the context of what seemed consonant with cultural values as well as their short- and long-term needs. From this grew an appreciation that agricultural innovation is not a faceless process, but part of an intellectual confrontation with problems and prospects, discussed among individual people in the village bar and in the home. How did actual farmers respond to academic and government writings on agricultural innovation in sixteenth- and eighteenth-century Spain? Could new methods be imposed from above? Why did farmers in some places and at some times practice either conservationist or exploitative agriculture?

Such questions remain central to cultural ecology, but they shift the emphasis from functional to behavioural concerns. This eventually led me to a protracted study of the agronomic authors. Why did they write, for whom, and with what practical experience? Did such writers simply reflect commonplace understanding, or did they innovate and contribute new or important insights? Eventually it became apparent that agronomic scholarship transcended agricultural practices, representing a web of ideas that spanned many generations and even different cultures.

This study complements an earlier examination of the Graeco-Roman or Classical agronomic tradition, and its relationships to the agricultural and scholarly revival of northwestern Europe at the close of the Dark Ages.[4] Its object is to explicate the Islamic counterpart, which emerged in Mesopotamia during the ninth century, and attained its apogee in Andalucia – Islamic Spain – during the twelfth. Despite the fundamental changes in language, society and cultural context, this tradition proves to be grounded in the same Mediterranean agroecology and solidly grafted onto the same intellectual heritage. So much so, that Islamic agronomy represents a renewal and continuation of Classical scholarship, as abstracted in Figure 1. This article first examines the roots of Islamic science, and of agronomy in particular, during the Era of Transmission in the Near East. It continues with the subsequent emergence of a new tradition in Islamic Spain, examining its understanding of soil science in detail. Finally, Islamic agronomy is assessed in its broader intellectual framework.[5]

Transmission, cultural translation and Islamic science

The cultural map of the Mediterranean world was fundamentally changed when a confederacy of Arab tribes, increasingly united by a new religion, emerged to upset the regional power structure after the death of Muhammad in AD 632. The Byzantine or Eastern Roman Empire had been depopulated by bubonic plague and weakened by 50 years of destructive warfare with its archrival, the Neo-Persian or Sasanid kingdom that was based in Mesopotamia and Iran. Within 10 years, the Arabs had wrested the Syrian provinces and Egypt from Byzantium, and by 652 the Sasanid polity was destroyed. By 718, the Arab dominions stretched from the Indus to the Pyrenees, and Constantinople itself was under siege for the second time. The intrusion of a tribal society into the Mediterranean Basin was less than an ideal setting for scholarly activity, yet by 900 the eastern and southern margins of the region represented the stage of a vibrant, Islamic civilization, in which scholarship once again began to flourish as it had during the first century of our era.

Early Islamic civilization was firmly grounded in Hellenistic roots, drawing selectively from the distinctive Byzantine, Sasanid and Indian components of a common heritage, originally given impetus by Alexander the Great. It was an eclectic mix of

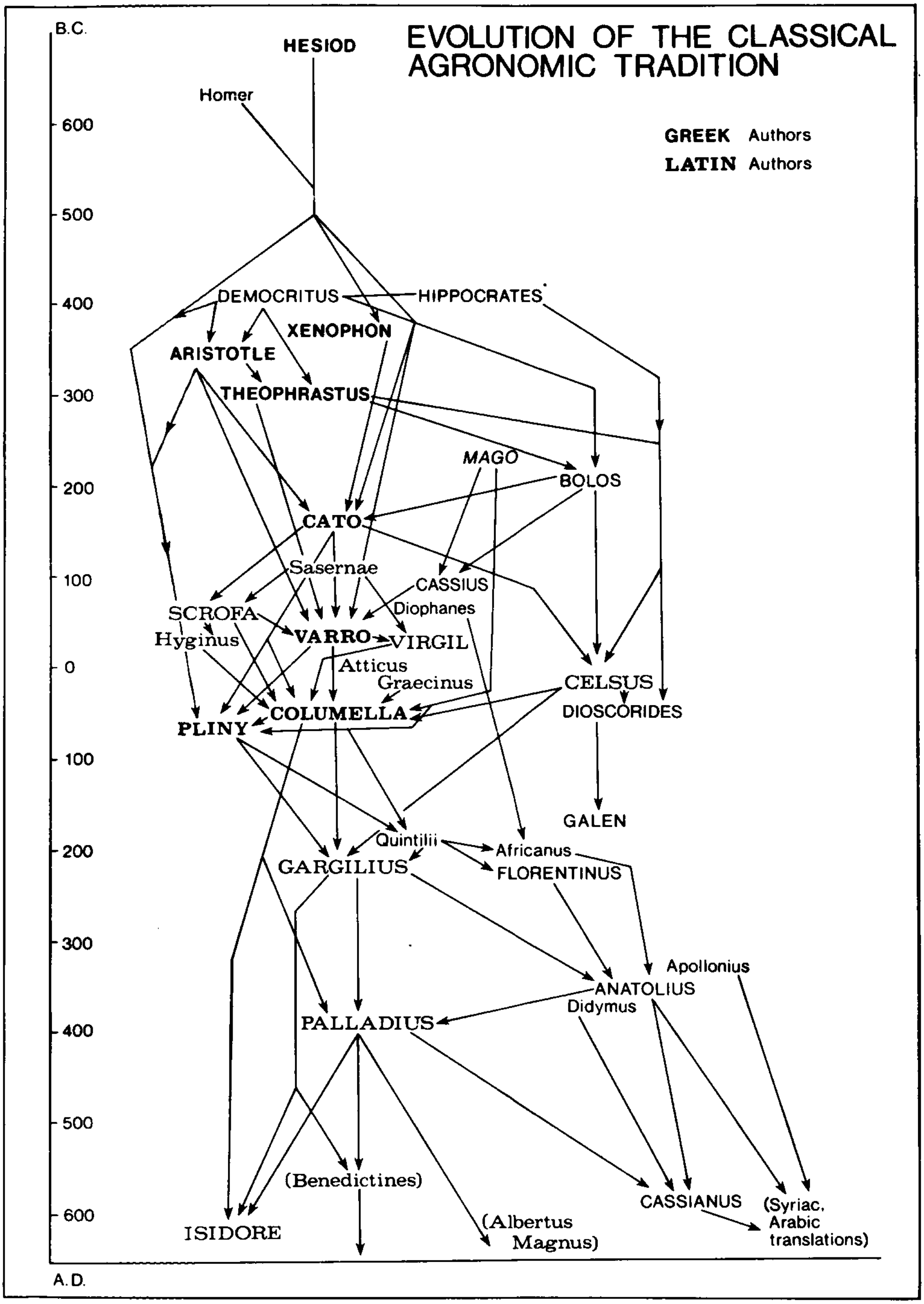

Figure 1 ~ Evolution of the Classical agronomic tradition. The most influential works in Arabic translation were those of Anatolius and Cassianus.

Arab religion and literary culture; Sasanid-Persian art and architecture, as well as political structures; Roman provincial law, transformed by Islamic tenets; and an intricate blend of scholarship, presented within a new Arabic literary framework, but based on Greek, Persian and Indian principles or concepts, ultimately influenced by a common, Hellenistic model.[6] By the tenth century that civilization had firmly established its own identity, at the same time that it began to find fertile, new ground at the extremities of the Islamic dominions, where new centres of cultural activity took root in other historical and intellectual contexts.

For many centuries, Islamic scholars of diverse ethnic origins made excellent contributions to medicine and the sciences, building primarily but by no means exclusively on Greek foundations. Their translations of Greek manuscripts as well as their substantial advances over Greek prototypes eventually filtered through to the Latin West, providing one impetus to the advances of scholastic knowledge in Western Europe during the thirteenth century. But the bulk of the Islamic contributions remained unknown in the West, buried in Near Eastern or North African archival repositories that have been little more than explored during the last 200 years. Even now only a handful of scholars – by some strange irony, mostly Western – are working on this vast corpus of scientific information.

The subsequent development of science in Europe has long rendered the Medieval Islamic efforts technically obsolete, but their continuing interest is more than historical. It is precisely the distillation of Islamic scholarship, from such diverse roots, and in a particular intellectual framework, that remains a challenge as a matter of cultural process – to examine intellectual assimilation, intercultural innovation, and the growth and decline of scholarly traditions. Islamic science provides a superb example to this effect, since the potential documentation is good, and because its evolution can be compared and contrasted with that of contemporary scholarship elsewhere, specifically in Western Europe.

The agronomic tradition offers a convenient sample to explore some of these issues. The extant literature of agronomy is to a large degree accessible in one form or another, and above all it is finite. The latter reflects the low prestige of agriculture, in a society with decidedly urban tastes, and given to illusions about the idealized bedouin way of life.[7] For Islamic scholars, agriculture was more a craft than a science,[8] and writings on the subject tended to be incidental efforts, with some notable exceptions, by physicians or versatile polymaths. Nonetheless, the intellectual history traced here, and amplified by selections from the medicobotanical ('herbal') literature, can probably be considered as a representative microcosm of a much larger and more complex whole.

The early years of Islam were dominated by military activity, and even after the Umayyad dynasty (661–750) had established itself, with a formal residence in Damascus, warfare remained the order of the day.[9] A rudimentary administration for the far-flung empire evolved, and although landmark mosques were built by Byzantine or Sasanid craftsmen, the Umayyads retained a bedouin outlook and initially displayed little interest in scholarship. This changed under the new, Abbâsid dynasty (750–861), established on the banks of the Tigris, where a new residence was laid out in Baghdad (762). The Abbâsids were far more flexible, facilitating the fusion of conquerors and conquered, while themselves displaying great interest in foreign ideas, fostering secular scholarship and inquiry. These were key years of the great transmission of Classical learning, as it is known by historians of science, an era of translations of and commentaries on Greek manuscripts,[10] of sponsorship of scholars of Syrian or Persian origin, and of interest in Indian learning.[11] By about 900, large numbers of distinctive, scientific works began to appear, representing the maturing of Islamic scholarship, but only after the unitary Arab state had disintegrated into a host of regional polities.

Transmission was far more complex and difficult than the notion of 'translation' might suggest. Greek had a large technical and conceptual vocabulary that had no direct counterparts in Arabic. Beyond that, there was the basic problem of cultural translation, of grasping alien thought processes and scientific procedures, that followed an unfamiliar system of logic. Even after a new class of gifted writers in Arabic had emerged, great problems remained to be overcome before the nature and the means of scientific scholarship could be assimilated.

Bicultural intermediaries played a critical role in this process, which began well before Muhammad's early victories in Madîna. In 431 and 451, Christian church councils declared as heresies the beliefs of many local church communities in Syria, northern Mesopotamia, and Egypt. These conflicts and subsequent persecutions took on strong ethnic overtones, since the heterodox Christians represented indigenous, Syriac or Coptic peoples. The consequences had historical significance.

The Nestorians of Edessa (Urfâ) were expelled in 489 and emigrated to the Sasanid realms, where they were welcomed as a competent middle class with a relatively well-educated clergy. Urban communities and monasteries of this diaspora appeared in many areas, gradually spreading to India, Central Asia and even China. Clusters of monasteries sprang up at Harrân, Nisibis and especially Jundîshâpûr (Figure 2),[12]

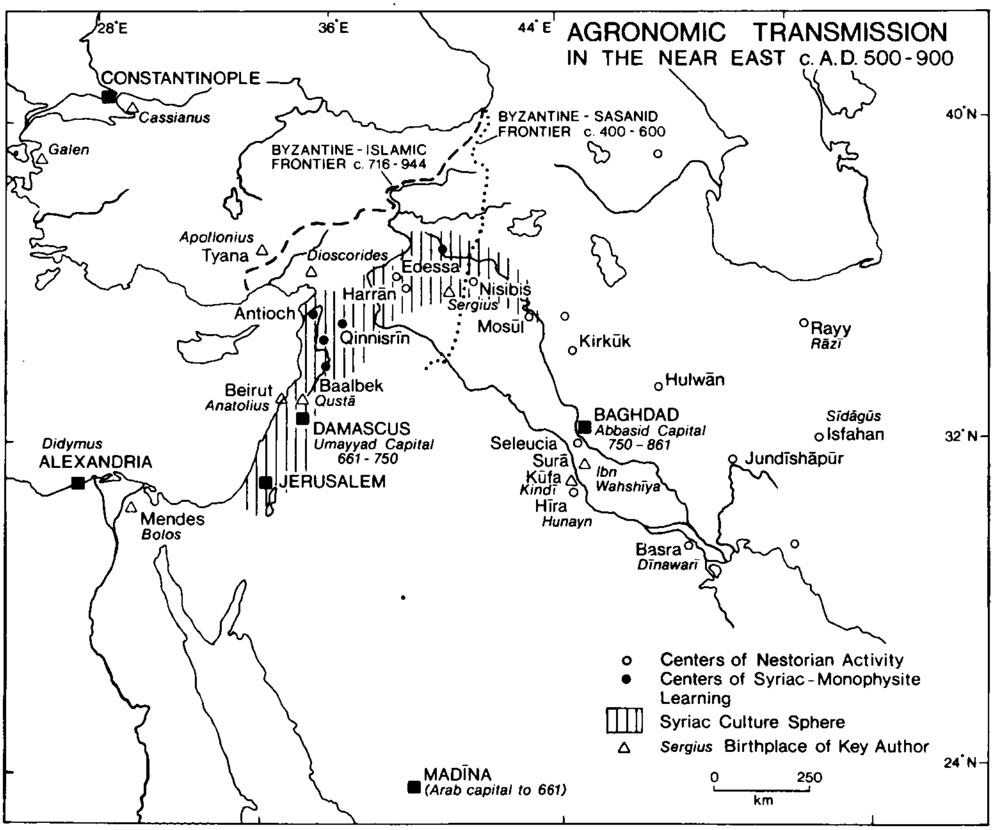

Figure 2 ~ The Near East during the Era of Transmission (to AD 900). Syriac and Nestorian Christians, tapping Late Greek sources of Classical scholarship compiled in the eastern Mediterranean lands, served as critical intermediaries in translation and cultural transmission for Islamic science.

where scholarship was maintained, manuscripts produced and physicians trained. A second wave of Greek ideas came to these centres after 529, when the Neo-Platonic philosophers were driven from Athens. The Sasanid Anûshirwân (531–79) sponsored active learning at the medical school of Jundîshâpûr, which also drew Persian, Indian and Jewish scholars. The degree to which the Babylonian heritage in medicine (including medicinal plants) and other sciences was converted during this period – from oral tradition to manuscripts in Persian or Syriac – remains obscure, although such works are mentioned by later authors in Arabic. The impact of the Nestorian diaspora on education can only be surmised, but leading Islamic-Persian scholars of the ninth to eleventh centuries came mainly from towns with strong Nestorian ('Assyrian') communities.[13]

The heterodox Christians (Jacobite or Coptic) of Syria and Egypt did not emigrate, but Syrian clerical leaders and scholars withdrew to outlying monastic centres, where Greek manuscripts including Aristotle and Ptolemy were being translated into Syriac by 530. In Islamic times, scholars from Syriac families, together with their Nestorian and non-Christian, Sabian counterparts became the key intermediaries between the Greek legacy and Islam.

The critical 'Age of Transmission' or 'Translation Movement' did not therefore begin, but rather resumed, under the Abbâsids or, if legend is to be believed, under the last Umayyads. About 720 what remained of the Great Library of Alexandria was transferred to Antioch, and from there to the various Syriac institutions of Harrân. The caliph set up a translation centre in Baghdad *c.* 830, which served to accelerate a process of transmission and cultural transfer that can be firmly documented since *c.* 760. By the early 900s, the era of acculturation was completed. This brief review suggests that the Near East was an uncharacteristically cosmopolitan place, and that what became known as Islamic science was the product of a long-term and complex, multicultural interchange. An analogous but shorter process of assimilation is recorded in Islamic Spain, as scholars there embarked on an autonomous trajectory of research after 950.

The Greek agronomic sources and their translation

Islamic agronomy was drawn, not directly from the Latin authors, but from the Greek sphere of the eastern Mediterranean world (Figure 1). The oldest source tapped was the text of the Greek-Egyptian physician, Bolos of Mendes (*c.* 200 BC), whose name is enigmatically associated with the older Greek authority, Democritus. It is preserved in an abridged Arabic edition (unpublished) as well as lengthy citations by the twelfth-century agronomist Ibn al-Awwâm.[14] What can now be inferred about its contents suggests that it was the mainstream prototype for both Greek and Islamic agronomy. It did not only deal with those basic agronomic themes elaborated by the Latin authors, but also included advice on plant diseases, methods to protect crops against vermin, food conservation, weeding and hunting. These last themes, based heavily on the assumed magical properties of specific objects or organisms, recur in both the Byzantine and Islamic literature. Bolos-Democritus also used Mago the Carthaginian, an independent Punic tradition that unfortunately cannot be reconstructed.[15]

More immediate is the compilation of Vindanius Anatolius, possibly a physician, active in Beirut (?*c.* AD 360). His work was embedded in later Greek compilations, but was also translated (a) into Syriac, by Sergius of Ras al-'Ayn (d. 536) and thence into

Arabic, as well as (b) directly from Greek into Arabic.[16] Only fragments of the first survive, but it stimulated a commentary by the Islamic physician al-Râzî (Rhazes, *c.* 865–925), and was even translated into Armenian (after 1160). The second translation has recently been discovered in an Iranian manuscript repository. Anatolius's work is a compilation but evidently a good one, that is mainly based on secondary Latin sources and served to bring the systematics of the key Latin authors – Columella and Pliny – into the Greek and Islamic mainstream. The peripheral themes developed by Bolos Democritus play only a subordinate role in an organizational scheme that systematically treats (1) the cultivation of grains and legumes, (2) seasonal agricultural activities, (3) viticulture, (4) conservation of fruits, (5) arboriculture, (6) garden plants, (7) olive cultivation, as well as (8) stockraising, veterinary concerns and bee-keeping. Nonetheless Anatolius was considered as the epitome of Greek agronomy by the last Latin author of stature in the field, Palladius (*c.* AD 400), who referred to Anatolius's work as 'the Greeks'.[17]

The third, central piece is the work of Cassianus Bassus of Bithynia (*c.* 600), a province near Constantinople. A government official and possibly a lawyer, Cassianus rewrote Anatolius and expanded his treatise with materials from another compendium by Didymus, a physician in Alexandria (also *c.* 360). This included astrological, weather prognostication; horse-breeding; omens inferred from animal behaviour; healing and magic; as well as what might be described as household hints.[18] At least part of Didymus's materials seems to have been indirectly derived from Bolos Democritus, either his agricultural work or, more probably, his magicomedical writings. Cassianus's compilation was very influential in various forms. It was translated from Greek to Persian by 600, and subsequently into Arabic; it was also translated directly into Arabic by two Syriac Christians, Sergius al-Rûmî (*c.* 827) and the physician Qustûs Ibn Lûqâ of Baalbek (820–913). Manuscripts of the direct translations are found in Istanbul and Tunis, but one published edition has proved to be abridged and edited, to include tantalizing Persian contributions. Cassianus is called Qustûs or Kasînûs in the different Arabic translations. His book was further reworked in Constantinople *c.* 950, in an inferior but available edition, commonly known as the *Geoponica.*[19]

In addition to these basic, agricultural works, the medicobotanical contributions of the physicians Dioscorides of Anazarbus (Cilicia) (*fl.* AD 40–80) and Galen of Pergamon (AD 129–210),[20] as well as the pseudo-Aristotelian work *de plantis* (attributed to Nicolaus of Damascus, *c.* 64–4 BC),[21] were translated – in part via Syriac – into Arabic and widely used. The key agents in this monumental effort were two Nestorian physicians, Hunain Ibn Ishâq (808–*c.* 873) and Ishâq Ibn Hunain (d. 910), of al-Hîra. This father and son, like Qûsta Ibn Lûqâ, who wrote early commentaries on Galen, were all versatile in Greek, Syriac and Arabic.[22] Even so, many of the Greek plant names had merely been transliterated into Arabic, without identifying appropriate common names.[23]

This inventory only identifies the major works translated into Arabic. It shows that the Islamic authors primarily used proximal sources that were both available and familiar to the translators. It also illustrates how difficult effective, cultural translation was, with almost every work translated or revised several times, not including possible intermediate translations in Syriac or Persian. It also implies that 'good' translations were not easy to obtain and equally difficult to use, by all but a very small, sophisticated élite.

Not surprisingly, the coterie of scholars sponsored by the Abbâsids met increasing opposition from the vast ranks of the religious and legal teachers responsible for Muslim general education.[24] But the conflict ran far deeper than a simplistic division between theologians and rational philosophers – that in reality was far more complex. The rift was about the increasingly entrenched axiom that Islamic culture should be grounded in the legacy of Arabia. Furthermore, the rational scholars, explicitly or not, sought to incorporate the best pre-Islamic thought in a cosmopolitan tradition of 'human science', shared by intellectuals of different faiths, while the opposition, although far from monolithic, insisted on the 'divine science' of revelation.[25] It requires no emphasis that an analogous conflict, but lacking its ethnic overtones, was begun in the Latin West during the thirteenth century, to be rejoined after 1500.

Agronomy and medicobotanical writings during the Age of Transmission

The crosscurrents of these formative decades of Islamic science can best be illuminated by focusing on three scholars, who contributed the seminal works in medical botany and agronomy.

The medicobotanical writings of al-Kindî

The first of these authors is al-Kindî (*c.* 795–870), who shared directly in the intellectual ferment of the transmission era, revising and developing the findings of Greek scholarship. Born in Kûfa as the son of its Yemenite governor, he was educated in Basra, Baghdad and probably also Central Asia.[26] A brilliant but eclectic philosopher at court, he sought to integrate the Greek spirit of inquiry with Islamic beliefs, also contributing a wide array of works that span the range from mathematics to pharmacology. His medicobotanical effort is of particular interest here. It consisted of an alphabetical list of plant remedies, that extended Galen's scheme of the four humours (hot, cold, wet, dry)[27] from simple to compound medicines. The interest of his lists extends beyond the diffusion of cultivated plants, to the new universe of international pharmacopia tapped by the Islamic writers: only 23 per cent of the plant names used are Greek, but 33 per cent are derived from Akkadian (Old Babylonian) lists of botanicals, possibly via oral transmissions; another 31 per cent are Indo-Persian, five per cent Arabic, and three per cent ancient Egyptian.[28] A new, regional and cross-cultural synthesis is apparent here. Yet even with the addition of large numbers of Near Eastern plant remedies, Kindî's total of 319 represents a 30 per cent net loss *vis-à-vis* Galen's 470.[29]

The botany of al-Dînawârî

The second Mesopotamian source is al-Dînawârî (d. 895), born near Basrâ to a Persian family.[30] He was a conscious devotee of the Arabic language, yet he also composed a short history devoted to the pre-Islamic and Islamic history of the Persian realms that almost ignores the Arab Conquest.[31] Dînawârî further wrote an important work for botany that emphasizes not systematics, but instead revels in the linguistic pleasures of plant description; he collected bedouin oral tradition on plants and plant terminologies, to preserve them as he notes, and cites no Greek authors. His method of classification is based on folk taxonomy. The 400 or so entries are initially organized into cultivated and wild plants, and plants with edible fruits. The cultivated plants include (a) grains, legumes and other crops; (b) vines, and (c) dates and other fruit trees. Plants with edible fruits, rather curiously, include cucumbers and gourds, as well as cultigens introduced to Arabia from India. The wild plants are variously subdivided into plants growing in mountains, in rough country, on plains, on sandy surfaces, or near water; annual herbs palatable or unpalatable as fodder; thorny plants; plants that spread out on the ground; trees used for their wood, their parts, or their products; and aromatic plants, dyes, medicinals, resins, or mushrooms. The ecological perspective is fascinating. But there is a different form of logic apparent here, an alternative view of nature that again represents an indigenist statement, implicitly directed against the then-prevailing search for Greek systematics.

Ibn Wahshîya

The third case is the enigmatic persona of Ibn Wahshîya (*fl. c.* 903–30), who possibly travelled widely in the Near East and came from a Syriac family of Sûrâ, near ancient Babylon. A veritable mandrake of divination, he wrote on astrology, alchemy, poisons and the occult. Many of his works were explicitly compiled or translated from Syriac originals. But his lasting contribution is on agriculture, a manuscript translated from Syriac to Arabic *c.* 903 and dictated to his secretary in 930 under the title *Nabataean agriculture.*[32] 'Nabataean' (Arab., *nabat*) referred to the then Syriac-speaking farm populace of Mesopotamia. The work purports to be a compilation from three ancient authors (Sagrît, Yanbûshâd, Qûtâmî), supposedly linked to legendary conflicts between indigenous Mesopotamians and intrusive Syrians, in what is now Iraq, that may relate to a context of the first and second centuries AD. Elsewhere, Ibn Wahshîya extols the cultural legacy of the Syriac and Persian world *vis-à-vis* the Arab conquerors,[33] suggesting that the *Nabataean agriculture* is couched in allegorical terms and represents yet another indigenist statement. The cast of characters appears to represent contributions by several pre-Islamic authors, disguised by pseudonyms. The significant agronomic content of this massive work of almost 650 double folios is made accessible through three, translated segments (on the agricultural calendar and on water and estate management), as well as a very detailed, published summary[34] and over 540 lengthy, almost verbatim citations by Ibn al-Awwâm.[35]

Ibn Wahshîya's agronomic work is exceedingly difficult to interpret as a whole. The embedded sections on astral theology, gnostic theosophy, divinations, and astrological auguries give it an archaic flavour, implying a pre-Islamic date and suggesting a context prior to the influence of Nestorian Christianity in Mesopotamia.[36] The agricultural calendar is equally archaic, unmodified by al-Battâni's astronomical precisions of 882.[37] The inventory of exotic plants – some found only in India or established in Arabia, others specified as introduced from other regions – approximates the data base of Pliny in the first century[38] and includes no materials from al-Dînawârî or his predecessors. These characteristics argue for substantive older components. Yet extended sections of the work are wholly free of theology or magic, and deal with empirical themes quite matter-of-factly, until interrupted by patent digressions that suggest inserted materials. Similarly, most of the empirical material is presented without attribution in a coherent and flowing fashion, while other shorter segments are characterized by multiple citations or excerpts credited to the three central authorities, or to a host of fictive, minor personages called Adam, Noah and so forth. Finally, the 'background' author evidently was widely read and surprisingly current in regard to the latest geographical literature of the time. An allusion to climatic zonation (*klimata*) or comments on the original taste of Nile water derived from the cold Mountains of the Moon suggest familiarity with writings on mathematical geography based on Ptolemy (perhaps Khwarizmi, *c.* 813–46?),[39] while frequent references to comparative phenomena in Tunisia (Ifrîqîyâ), East Africa (Zânj), Kashmir, Ceylon or China are implausible without direct knowledge of the travel compilation *News of China and India* (851) and a geography such as that of Ibn Khurradadhbih (d. *c.* 885).[40] Much maligned in the past, and little appreciated today, this work and its remarkable author merit detailed attention.

The *Nabataean agriculture*

Ecological context and sources

The empirical context of the *Nabataean agriculture* provides another productive insight. References to specific localities cited with respect to weather, health, crops, times of planting, salinization, etc. confirm the author's intimate familiarity with central Mesopotamia, namely the region of Kûfa; information on southern Mesopotamia (Basra district) and the northern reaches, between Baghdad and Mosûl, is implicitly based on other sources, rather than personal observation. There is little to convince the reader that Ibn Wahshîya travelled widely and, if he did, his eye for agricultural landscapes was not particularly keen. Despite the enormous grasp of agronomy in general that is evident in his work, it was as much deductive as it was inductive. His extended treatment of olive cultivation deals mainly with different uses of olive leaves and olive oil, providing minimal information on cultivation. This is consonant with the lack of an Akkadian or Sumerian word for the olive tree, and the limited success of Assyrian and later efforts to grow olives in what is now modern Iraq, where recurrent winter frosts are too severe.[41] But the discussion of vineyards is creditable, and deals with all aspects of cultivation and use (including 24 blank pages on wines and wine-making); that is not surprising since vineyards were well established in Mesopotamia by Early Babylonian times (*c.* 1850 BC), and retained significance to the present day in the Kurdish foothills east of the middle Tigris.[42] The materials on grafting, pruning and vegetative propagation of trees are deficient in empirical understanding, in contrast to the usually good data on planting, transplanting and tending of all manner of fruit trees and crops; the author was familiar enough with normal farm procedures but hazy about exactly those specialized techniques that a life-long urban resident would never have applied directly. Al-Awwâm's conspicuous selection of excerpts (see below)[43] implies a similar evaluation placed on the quality of the *Nabataean agriculture.* In short, Ibn Wahshîya worked with a rich body of source materials on agronomy that he generally understood and about which he was highly articulate. But above all his knowledge of a vast number of plants, their taxonomic characteristics, and their medicinal applications points to a learned practitioner of medical botany.

The fundamental question, then, concerns Ibn Wahshîya's sources for the strictly agronomic materials he presents. His partial dependence on Greek agronomic sources is apparent, but he did not plagiarize or simply paraphrase older authors; in the main part he completely rewrote and perhaps rearranged them. For example, Sagrît with some probability can be identified with Bolos Democritus, described in passing as the author of both agronomic and medical treatises, that were difficult to decipher linguistically,[44] suggesting a poor translation from the Greek and hardly a work in his native Syriac. The sections on management of a farm estate patently have indirect Roman origins and include one on the health of farm workers that clearly is lifted from Cassianus or the *Geoponica*, where it is attributed to Florentinus.[45] These and other examples show that Greek sources were extensively used but deliberately concealed. Perhaps the most telling argument for such borrowing is the nature of Ibn Wahshîya's coverage. A host of Arabic authors document that the most widespread and important commercial crops of Mesopotamia during the ninth and tenth centuries were sugar, rice and cotton;[46] yet sugar is not mentioned by Ibn Wahshîya, while rice and cotton receive only perfunctory attention. Similarly, Jewish Talmudic sources from the Sasanid period indicate that olive oil was locally produced, but scarce and expensive, whereas sesame oil was the most common medium of food preparation;[47] yet Ibn Wahshîya devotes 32 pages to olive cultivation and only one to sesame, mainly dealing with medicinal qualities. The same sources indicate that wine also was expensive, so that beer was the standard drink; again, vineyards receive massive attention (141 pages) while other alcoholic beverages are only mentioned in passing. Plainly, Ibn Wahshîya structured his work around conventional, Greek models, that did not in any way reflect the specific nature of the Mesopotamian agrosystem, which was predicated on irrigation agriculture in a subarid environment, not on Mediterranean dry-farming, despite the over-riding commonalities of cultigens, the agricultural cycle and subsistence strategies.

Agronomic contributions

That much established, the *Nabataean agriculture* is anything but a mediocre, derivative compilation. Its remarkable value is apparent when the superstructure is stripped away and we focus on traditional agriculture in lowland Mesopotamia, and its established links to micromanagement and soil qualities. The work discusses 106 cultivated plants and fruit trees, versus only 70 in the *Geoponica*,[48] with most of the additions being garden vegetables and condiments or medicinals. This serves to emphasize the importance of the kitchen garden in the Near East and its subsequent propagation as a hallmark of Islamic agriculture. Not surprisingly, there is an almost monographic treatment of date palms, a basically new theme in the agronomic literature.

The second category of original contributions is in regard to soil types, which include alluvial, natric, or saline soils as would be found on the Tigris-Euphrates floodplain, red clayey soils as might be found in Syria, and a variety of 'mountain' soils, by which Ibn Wahshîya refers to the Kurdish foothills and Zagros Ranges. The treatment of soils has much to commend it, with notable advances over Graeco-Roman understanding (see below), while the data on fertilizers are generally good and include new ideas. The materials on water, wells and irrigation include a treasure trove of information, ideas and subtle symbolism. The use of sensitive plants and soil conditions for 'water-divining' incorporate data from the *Geoponica*, but go well beyond them. There are explicit instructions how to dig and line wells and canals or how to establish gradients; allusions to the properties of a karstic cavern and deep-seated aquifers; and a remarkable description of the animal-drawn waterwheel or *noria*.[49] Again, Ibn Wahshîya's putative grasp of chemistry – as a pharmacologist – is evident in the treatment of numerous kinds of mineral waters and their medicinal applications.

In sum, Ibn Wahshîya's empirical contributions are substantial and far-ranging, including both agronomic and natural history data unknown in the Classical literature. Beyond his own repertoire of information and understanding, he evidently tapped one or more regional, indigenous sources that remain unknown. Even when overelaborating on marginal themes such as olive cultivation and vineyards, he confines himself to aspects that were familiar, focusing on the medicobotanical applications that he knew best. Contrary to the verdict of several Arabists, who since the 1860s have argued that the *Nabataean agriculture* is a hoax,[50] this is a genuine agronomic work of great value, interest and originality. Indeed, it is a landmark work in agronomy, that establishes the existence of an autochthonous, agronomic tradition in the Near East, probably based primarily on Mesopotamian experience, but informed by Greek models.

Explanation modes

Nonetheless, the organization is perplexing. Some of the digressions are baffling, like an essay on corpses washed out of a cemetery, midway in the treatment of soils. Others express important views, deviating from Aristotelian principles, thus a lengthy explanation of the divergence of plants by means of humour theory and the influences of soils on plant morphology; there appears to be a hint of recognition of opposing, converging and diverging processes, but magical tales are common. Interesting explanations are offered for taste, smell and colour.[51] The remedies for plant diseases are mainly magical and include some bizarre potions (analogues are also found in the *Geoponica*), but others include new empirical views, such as on frost damage. The strong component of magical potions, alchemy and charms is suggestive of borrowings from Apollonius (Balînâs) of Tyana (either *c.* 100 or 360), the author of an unpublished book ostensibly devoted to agriculture, but preoccupied with relating natural phenomena to alchemy or astrology.[52] Equally so, this tendency of the *Nabataean agriculture* recalls the vast body of magical texts known as the *corpus Gabirianum*, written and revised by several authors *c.* 850–1000.[53] The basic premise of such writings is a dynamic of sympathetic and antipathetic forces (Arab., *hawâss*) inherent to organic and inorganic nature.[54] Conceptually, *hawâss* is very much a product of the Age of Transmission, and it goes back to Hellenistic roots, exemplified in the agronomic tradition by Bolos and Didymus. Because of his reliance on 'superstition', Ibn Wahshîya was strongly denounced by Islamic scholars, who supported clerical efforts to root out pagan elements.[55] But the *Nabataean agriculture* continued to serve as a datum for Islamic agronomists, who tended to ignore the magical elements.

Implications of the Nabataean agriculture

In order to compare Ibn Wahshîya's unusual study with more conventional works on agronomy, Table 1 reassembles his materials according to the basic schema of earlier and later authors, specifying the relative length devoted to particular themes. These numerical calculations allow a structural comparison of the different works, beginning with Varro (*c.* 37 BC),[56] Columella (*c.* AD 60),[57] and Pliny (AD 77);[58] continuing with the *Geoponica*,[59] as representative of the Greek-language compilations, and then the extant Arabic works; finally the list is completed by the Italian author Cresentino (writing *c.* 1305)[60] and the Spanish agronomist Herrera (published 1509).[61] At this macrolevel

Table 1 ~ Comparative structure and contents of Classical, Islamic and Medieval works on agronomy.

	Varro	Columella	Pliny	Geo-ponica	Ibn Wahshîya	Ibn Bassâl	Ibn Awwâm	Cresen-tino	Herrera
Soils, fertilizers, irrigation	**10%**	3%	5%	5%	5%	**16%**	**10%**	7%	2%
Arboriculture, fruit trees	2	3	**34**	**18**	**25**	**37**	**44**	14	**28**
Olive cultivation	2	2	3	7	3	1	2	1	3
Vineyards, wine	5	**30**	**15**	**30**	16	4	5	13	**13**
Field agriculture	**10**	11	**16**	6	**18**	9	9	**20**	10
Garden cultivation	—	8	11	**10**	**23**	**32**	**22**	**17**	**16**
Seasonal calendar	4	6	7	4	7	—	1	2	4
Weather almanac	—	—	3	5	2	—	1	—	1
Herding and fodder	**38**	**20**	2	8	—	—	2	**17**	12
Poultry, bee-keeping	**29**	**18**	5	7	—	—	4	10	12

of analysis, Ibn Wahshîya fits within the mainstream of evolving agronomic thought. But, as the preceding discussion shows, Ibn Wahshîya used but did not simply rework his older sources, unlike the derivative *Geoponica*. While emphasizing traditional themes, his treatise was formulated differently on the basis of distinctive, regional and ecological experience. It is an invaluable record of an alternative, and largely independent agronomic tradition – the product of another cultural sphere but for the same, basic agricultural strategies, in an environment that was similar yet different in detail.

Phrased differently, the *Nabataean agriculture* demonstrates the common roots to agronomic understanding in the Mediterranean world and Near East, that transcend entrenched cultural boundaries. As a scientific tradition, Islamic agronomy was indeed stimulated by Greek models and enriched with their information. But we would miss the point if we overlooked that it also was primarily grounded in folk agronomy. This age-old Mediterranean-Near Eastern lifeway was based on a mix of plants and animals, adapted to summer drought and a winter growing season. It was predicated on four complementary strategies that reduced subsistence risk: outfield cultivation of grains and legumes; a package of garden vegetables, condiments and herbals; orchard crops providing wine and fresh or dried fruits and, where viable, olive oil; as well as several options to integrate animal husbandry with agriculture as a source of manure and alternative proteins and fats. The strong integration of horticulture and arboriculture distinguished this Mediterranean-Near Eastern agrosystem from earlier, more generalized types of farming. Irrigation allowed summer cultivation of vegetables in subhumid climates, but was prerequisite to all forms of agriculture in arid settings. Characterized by a diversified yet distinctive cuisine, this lifeway balanced solutions to risk with equally deep-seated cultural values. Thus Table 1 should also be read as a document of cultural continuity, in both time and cultural space.

A Persian tradition?

This now opens the door for discussion of other early Near Eastern agronomic writings. As mentioned above, one Arabic edition of Cassianus adds materials attributed to several, otherwise unknown Persian-surnamed authors. Fortunately, these and others are quoted by al-Awwâm. One of these sources, a Sîdâgûs of Isfahan, is cited in 15 long excerpts that deal with soils, arboriculture, cereal planting, granaries and irrigated gardens[62] – indicating a comprehensive treatise. These materials, perhaps dating to the seventh century, are sound and straightforward, and many appear to be derived from the Greek tradition. Sîdâgûs and other minor authors of this group verified by al-Awwâm acquire further significance in light of our interpretation of the *Nabataean agriculture*; they argue for widespread scholarly interest in agronomy in both the Syriac and Persian spheres, early during the Era of Transmission, probably triggered by Sergius's first translation of Anatolius. The work of Sîdâgûs enters the literature through citations in a treatise by Ibn Hâjjâj (written 1074), that was heavily excerpted by Ibn al-Awwâm; that he was not a minor author becomes apparent from a comment by Ibn Hâjjâj that Sîdâgûs, Anatolius, and Cassianus were *the* three authorities in the field.[63] Whether Ibn Hâjjâj used Sîdâgûs directly or second-hand is another matter; his general dependency on compilations favours the latter possibility. The only lost agronomic works identified from biographical inventories are those of Hunain Ibn Ishâq and of Alî Ibn Rabban, a Nestorian from Merv (Turkmenistan) (*c.* 810–85); Rabban was a pharmacologist with some competence in botany, and a bent for *hawâss*, who also wrote a commentary on Anatolius.[64]

Whoever its authors may have been, it is plausible to suggest the existence of a distinct Syriac-Persian agronomic tradition, inaugurated during late Sasanid times; it appears to have been modelled on Greek works, but explicitly drew from Near Eastern experience in Mediterranean-style agriculture. Ibn Wahshîya deserves credit for preserving a detailed record of a substantial part of that tradition, whatever his seemingly erratic reorganization and manipulation of authorships, in the interest of emphasizing indigenous scholarship – not unlike al-Dînawârî. In fact, Ibn Wahshîya's indigenist agenda adds great interest to his work by illuminating the intellectual and ideological dialectic integral to the process of assimilation.

A new agronomic tradition in Islamic Spain

Another context for Transmission

While pharmacological investigation in the Near East continued to develop until the time of Ibn Sîna (Avicenna, 980–1037) and al-Bîrûnî (Aliboron, 973–1050),[65] another Islamic agronomic tradition took hold in the Far West, in Islamic Spain – al-Andalus.[66] Only after the Andalusian scholars began to move to Egypt, during the course of the Spanish Reconquista, did further writings appear in the Nile Valley (twelfth century), Yemen (thirteenth century) and Near East (fourteenth century).[67]

The Iberian Peninsula was an anomaly within the Islamic world. Although conquered 711–20 and colonized by a warrior-élite of Moroccan Berbers and Yemenite or Syrian Arabs, Islamic rule was only consolidated about 930. Decades of Christian revolts or civil wars between converted, Hispanic indigenists and the new aristocracy delayed the assimilation of the residual Romance population, that probably represented close to 95 per cent of the blood lines of Islamic Spain. As the arabized but Christian Mozarabs of southern Spain were weakened by a slow but sustained emigration of their own élite to the independent mountain kingdoms of the north, most religious conversion took place *c.* 850–1050.[68] But unlike the arabized provinces of Byzantium, southern and eastern Spain had been an integral, even central part of the Roman cultural world. Historical reinterpretations now emphasize the continuity of Classical schooling through the Visigothic period (507–711) and into the late ninth century, with Christian clerics serving as the scribes of a Muslim bureaucracy.[69] Romance remained a viable linguistic component in the Ebro Valley until the Reconquest, and large areas in the south still were bilingual during the early twelfth century, with a strong Jewish minority in addition.[70]

Al-Andalus was, therefore, no less cosmopolitan and multicultural during its period of intellectual ascendance (*c.* 950–1175) than the Islamic Near East during the Age of Transmission. There were lingering elements of scholarship but, perhaps more importantly, some basic educational structures[71] upon which a new scholarly tradition could be grafted. Indeed, Ibn Khaldûn, descended from Spanish Muslim exiles, attributed Andalusian scholarship to a very long tradition of sedentary culture, and to educational methods that combined linguistic skills with instruction in the terminology of scientific norms and in scientific problems.[72] Nonetheless the revival and trajectory of scholarship in al-Andalus was a product of the encounter between West and East, as Hispanoarabs began to study in the Near East, and Near Eastern scholars were attracted to the court at Córdoba.[73] In effect, despite a lag of two centuries, both Andalusian and Near Eastern scholarship grew from older educational roots, facilitated by mediating scholars of diverse ethnicities, and flourishing in the intellectual ferment of early Islamic civilization.

Both the stimulus and response that eventually inaugurated the new tradition of agronomic scholarship on Iberian soil could not have been predicted. In 948 Constantine VII of Byzantium sent a newly transcribed, illuminated copy of Dioscorides to caliph Abd al-Rahmân III (912–61) in Córdoba,[74] setting in train a wave of indigenous scholarship, modelled primarily on Classical rather than Near Eastern sources.[75]

The Calendar of Córdoba

Possibly, but not demonstrably related to this fortuitous event was the compilation of the *Calendar of Córdoba* (presented at the accession of al-Hakam II, 961–76),[76] one of the most complete and accurate agricultural calendars of Ancient or Medieval times. It gave instructions for month-by-month planting and harvesting for a complex sequence of traditional crops, organized around precepts generally familiar from the Classical agronomic writings, but different in both detail and format. The wealth of region-specific information identifies a flourishing tradition of Andalusian agriculture, that includes new food and commercial crops introduced by the Arabs. The hagiography of Palaeochristian saints and Mozarab martyrs identifies the principal author as a Visigothic but arabized Christian, the bishop Recemundus (Rabî Ibn Zayd) of Granada-Elvira, who had served as ambassador to Otto I in Germany and had travelled widely in the Near East. But the accompanying astrological lore and weather-signs (*anwâ*),[77] probably inserted by his Muslim secretary, are based on Arabian precedents; the astronomical structure follows seasonal dates determined by al-Battânî in Mesopotamia in 882,[78] while basic similarities can be noted with a similar, Mesopotamian calendar of *c.* 850[79] and with Egyptian and Yemeni calendars of the late Middle Ages.[80] Yet the weather almanac closely fits the typical evolution of seasonal weather in Andalucia, not that of Egypt or Mesopotamia.

The translation of Dioscorides

The *Calendar of Córdoba* elucidates the sophistication of Andalusian agriculture as a context in which to understand the reception of Dioscorides. Since the caliph, or more probably his cultured crown prince al-Hakam, did not have a scholar sufficiently skilled in Greek to undertake a translation, Constantine obliged by sending one in 952. Eventually, aided by a team of specialists, the earlier translation of Dioscorides made by Hunain and his colleague Stephanos in Mesopotamia was carefully revised, with the insertion of Hispano-Arabic plant names.[81]

One of the members of this team was a boy, Ibn Juljul (944–94), who wrote a commentary on the plant names in Dioscorides in 982, and then a collection of biographies of physicians that included translations from Latin, by Isidore and other Late Period scholars, and finally an original treatise on plant remedies not found in Dioscorides. His plant descriptions were based on personal observation, with notations as to their habitats.[82] Also stimulated by these events was Ibn Samajûn (d. 1002), the personal physician of the caliph al-Mansûr (976–1002) who recommended plant-derived anaesthetics prior to operating. His work on medicinal plants cited Dînawârî and Galen, in addition to Dioscorides.[83] The next court physician, al-Zahrâwi (Abulcasis, 936–1009), is best known for his encyclopaedia of pharmacology and surgery, the latter translated into Latin and a standard work in the Christian West during the later Middle Ages. But al-Zahrâwi also wrote a short treatise of 17 double folios on agronomy, recently discovered, but lamentably still unpublished.[84] The very existence of such a work argues that one or other Near Eastern translation or compilation had found its way to al-Andalus not long after the flurry of activity about Dioscorides.

Ibn Wâfid

This auspicious court school of Córdoba came to an abrupt end with the carnage and destruction unleashed by the Berber military revolt of 1009. The secular books of al-Hakam's famed library were burned, buried, or sold. Córdoba never regained its primacy, and both power and patronage were dispersed to many smaller Islamic centres. The petty king al-Mamûn of Toledo (1043–75) welcomed Ibn Wâfid al-Lakmî (Abenguefith, *c.* 997–1074), reputedly a student of al-Zahrâwi. Previously Ibn Wâfid had been a physician, writing a tract on simple plant remedies, based primarily on Dioscorides and Galen, that was translated into Latin and Catalan and circulated widely. Comprising 105 double folios and including 300 plants,[85] this work probably represents the culmination of the pharmacological tradition of Córdoba.

At Toledo, as vizier, Ibn Wâfid implemented Mamûn's wish for a botanical garden, experimenting with the acclimatization of plants from other regions. He also spent years preparing a short treatise on agriculture (after 1068), only partly preserved (35 of 106 chapters, comprising 16 double folios) in Castilian and Catalan translations.[86] Citations are made to Anatolius, Bolos and al-Kindî. Although some materials also come from Ibn Wahshîya, the organization most closely approximates Cassianus, including themes specific to that work. Fertilizing is emphasized, especially for wheat, with use of the Galenic concepts of hot and cold, moist and dry, to describe soil properties (see below), just as his other work applies them to medicinal plants. Interesting are the (incomplete) sections on wine making and oil pressing, or the

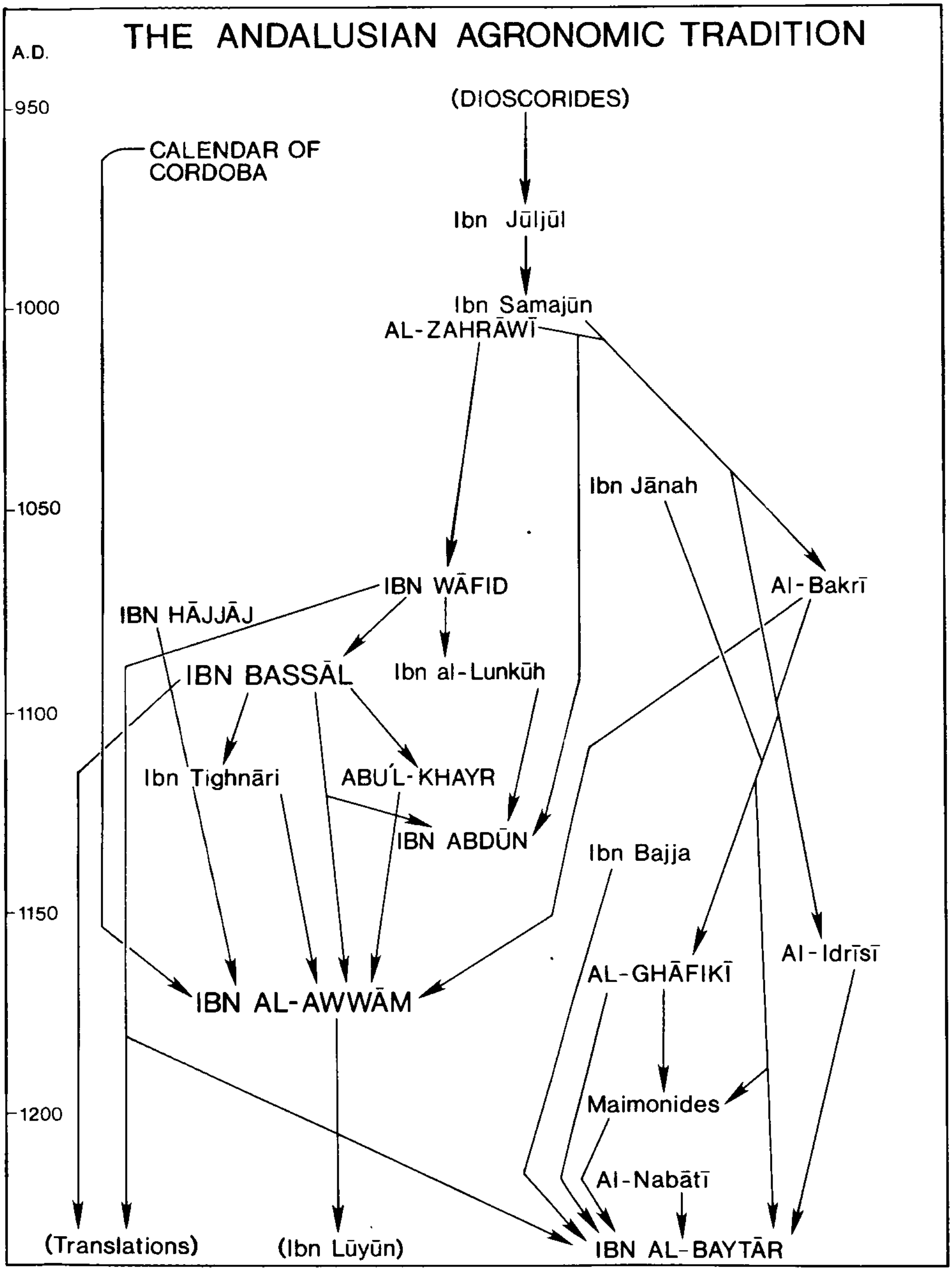

Figure 3 ~ Evolution of the Andalusian segment of the Islamic agronomic tradition. The interconnectivity of the Cordoban, Toledan and Sevillian schools from Ibn Juljul to Ibn al-Awwâm (*c.* 950–1160) was particularly tight. Loosely linked pharmacologists and geographers contributing medicobotanical insights are shown on the right of the diagram.

range of irrigated vegetables and other garden plants discussed. The full coverage of Ibn Wâfid can be estimated from over 100 citations in Herrera,[87] who evidently had access to a complete original. These show that half of the work was devoted to arboriculture, especially to planting, irrigating, grafting and pruning of vines and a wide range of fruit trees. The final 16 chapters, partially preserved, treated a broad range of domesticated birds, and included paragraphs on predators and pests. His discussions are terse but sharply focused.

Ibn Wâfid was at least as important as a catalyst than as an innovator. He presumably followed al-Zahrâwi's agronomic model which, in turn, we must assume, was stimulated by Anatolius or Cassianus or both. But unlike al-Zahrâwi, Ibn Wâfid founded a school of agronomy (Figure 3), and he ensured that this group of more original scholars would build on the roots of the Classical tradition. His influence on thought in Christian Spain during the later Middle Ages is also evident, not only by virtue of three different translations, but also by their utilization in Herrera's treatise, reprinted as late as 1819.

From Toledo to fruition in Sevilla

Ibn Bassâl

A different impression of Andalusian agronomy is derived from Ibn Bassâl, a colleague of Ibn Wâfid, whom he succeeded as caretaker of the botanical gardens of Toledo. All that we know of Ibn Bassâl is that he had travelled in Syria, Arabia, Egypt and Sicily; after the Christian reconquest of Toledo in 1085, he was welcomed at the court of al-Mutamid (1069–92) in Sevilla, where he set up another royal garden.[88] Although his agricultural treatise was completed in Toledo, and dedicated to al-Mamûn (d. 1075), the influence of his agronomic expertise came to bear on the agronomists and botanists already active or then assembling in Sevilla.

The extant work of Ibn Bassâl consists of 70 double folios.[89] Very concise in its formulation, it is far more substantial than the pioneer studies of al-Zahrâwi and Ibn Wâfid. Lacking an introduction and dedication, even this is an abridged edition;[90] some 230 citations to Ibn Bassâl found in the later compendium of Ibn al-Awwâm[91] indicate that the Mediterranean cereals and detail on some vegetables were cut from the abridgement. But the tight organization, of both subject matter and detailed presentation, must have also characterized the original edition, and stands in contrast to Ibn Wahshîya, comparing well with that of the best Classical agronomists. Tangential issues such as medicinal applications or bread-making are not included, recalling Varro's resolve to exclude materials without direct bearing on agriculture.[92] Neither are animal husbandry nor a seasonal calendar included, a striking difference from Classical prototypes.

The work is deceptive in that it appears to be entirely empirical, based on first-hand information and experience, with no Classical or Islamic authors cited or demonstrably used. In this regard, Ibn Bassâl recalls Cato, but the organization more closely follows Columella, except in the omission of domesticated animals, while it adapts to Pliny and Ibn Wahshîya in extensively covering plants grown in kitchen gardens. Economic plants are treated in the Classical sequence: (a) fruit trees, (b) wild trees with food products, (c) legumes, oil and fibre plants, (d) spices, (e) gourd plants, (f) bulbs and tubers, (g) green vegetables, and (h) aromatic plants and flowers. That is a departure from Ibn Wahshîya, and this organization remained the model for subsequent Andalusian agronomists. Ibn Bassâl demonstrates a strong sense of scientific method, as borne out by his systematic treatment of each tree or crop, presenting in sequence the appropriate soil type and manure, plowing, planting, tending, irrigation and harvesting. His discussion of the relative merits of abandoned land, fallow tracts and permanent cultivation, as mitigated by periodic grazing on stubble,[93] offers a novel explication of fallow systems. His tightly organized chapter on soils, classified on the basis of texture, colour and the Galenic humours, and organized into 10 types,[94] has no precedent among the Classical authors.

Ibn Bassâl's erudition in the Classical and Near Eastern sources is mainly implicit, but the evidence is everywhere, subtly interwoven in either the thematic organization or minor details. For example, part of his information on soils, much like his sequential tending of plants, echoes materials or procedures in Ibn Wahshîya. His utilization of the theory of humours derives from Ibn Wâfid. Another striking example is given by his outline of the seven *klimata*,[95] introduced in the context of advice for grafting in different environments.[96] The first of these zones is characterized by low latitudes, intense heat and drought. Here only trees with large rooting systems survive, while plants demand constant manuring. The second zone is a little less hot and dry; here a wider range of trees, including dûm palms and acacias, do well, while date palms thrive with irrigation. The third zone is still hot, but better watered, allowing citrus trees and similar perennial broadleafed genera, as well as pomegranates, figs and plums to flourish, with or without irrigation. These examples, presumably drawn from Ibn Bassâl's own observations in Arabia, Egypt and Syria respectively, illustrate his ability to confirm available theory with practical experience. Such objective criteria for delimination of the *klimata* mark a major advance with respect to the Greeks, one unrivalled until the Age of Discovery.[97]

In other words, the work of Ibn Bassâl subsumes excellent scholarship and is presented in an uncharacteristically direct and critical, modern fashion, without citing and commenting on extended excerpts of earlier authors as was the Medieval norm in East and West. It can be argued that Ibn Bassâl represents a revival of the Classical tradition of empirical inquiry. Ibn Bassâl had a major impact on Andalusian agronomy, and much of his manuscript was translated into Castilian *c.* 1300.[98]

Ibn Hâjjâj

Strictly speaking, the first author of the Sevillian agronomic school was Ibn Hâjjâj, who completed an agricultural work in 1074.[99] Its scope and basic content can be inferred from some 125 excerpts cited in the later compendium of Ibn al-Awwâm,[100] while the style and quality can be sampled from a partial translation of a surviving segment of manuscript.[101] Ibn Hâjjâj is important because he helped introduce the contents of Classical agronomy to Andalusian scholarship, giving long paraphrases in the traditional style, followed by his own comments, criticism, or additions. His main sources were several versions of Arabic translations from Anatolius and Cassianus, and he probably had a copy of Bolos. One of his editions of Cassianus included a number of Greek, Arabic and Persian authors who are otherwise unknown.[102] In particular, some notable observations are attributed by Ibn Hâjjâj to a Solon (Sûlûn), possibly the lost work of a doctor of that name, from Smyrna, as cited by Pliny in regard to kitchen and medicinal plants.[103] Important Near Eastern sources included the Persians – Sîdâgûs and Sâdhamis – and the *Nabataean agriculture.*

The surviving fragments of Ibn Hâjjâj's work deal mainly with olive, vine and fig cultivation, but the excerpts in Ibn al-Awwâm also include important observations on soil properties and cereal cultivation, based on Ibn Hâjjâj's personal experience in the region of Sevilla (Aljarafe, Carmona, Ecíja). Notable points include contrasts between heavy, cracking soils and light soils; intercropping of olives and figs, only found to be productive on heavy soils; and differences in soils and productivity between mountain slopes and adjacent plains, as a result of erosion and deposition respectively. Ibn Hâjjâj was an astute observer, more aware of natural processes than Ibn Bassâl, and some of his insights on soils stimulated Ibn al-Awwâm to broader reflection. At the same time, his presentation of Classical arboriculture, although setting a new standard, contains little that is novel. Ibn Hâjjâj differs from all the other Islamic agronomists in giving little attention to fertilizers, irrigation, legumes, garden vegetables, or condiments, possibly reflecting his excessive use of Greek authors as a model.

Abu'l-Khayr

Abu'l-Khayr of Sevilla[104] probably was a disciple of Ibn Bassâl. Substantial manuscript fragments of some 87 double folios have recently been published and his major agricultural treatise can be basically reconstructed from Ibn al-Awwâm,[105] whose extracts include some 230 citations; these parallel and follow citations from Ibn Bassâl, and some of them even incorporate references to Ibn Bassâl. Abu'l-Khayr evidently built directly upon his mentor, although he includes personal observations from the Aljarafe; his contribution to soils appears to have been more refined. But he also introduces Near Eastern *hawâss*, as well as materials on domesticated birds and bees, or animal pests.[106] He emphasized aboriculture and irrigation, dealing extensively with grafting, olives, fig plantings, palm groves and other fruit trees. His inventory included bananas and sugar cane, and he suggested a multiyear crop sequence, with flax followed by beans, then barley and finally wheat – a nonfallow rotation. He had good data on soils and fertilizers, recommended crossploughing in alternate years, described how to dig wells and operate norias, and urged springtime irrigation of orchards. Abu'l-Khayr at least travelled in Syria, according to Ibn al-Awwâm. His sources were Bolos, Anatolius and Cassianus, probably derivative, as well as Ibn Wahshîya and al-Dînawârî; but like his prototype, Ibn Bassâl, it is mainly a technical manual. He wrote in vernacular, Andalusian Arabic, and like Ibn Bassâl and Ibn Abdûn, used the Julian (solar) calendar.

Ibn al-Tighnâri

Ibn al-Tighnâri (Hajj al-Gharnâti) *fl.* 1075–1118) was a contemporary of Abu'l-Khayr, and a disciple of Ibn Bassâl, studying in Sevilla *c.* 1101.[107] A poet and agronomist, he had made the pilgrimage to Mecca. Some 60 folios survive of his treatise, sponsored by the governor of Granada; the 68 citations in Ibn al-Awwâm[108] suggest that his work was less comprehensive than the norm, offering little or nothing on vegetables and condiments. Al-Tighnâri determined soil quality by colour and taste, discussed the effects of different fertilizers on plants, and recommended grazing of livestock on stubble to increase the productivity of wheat and sugar. His observations on grafting and food preparation are good. His sources included Bolos and Cassianus, as well as Ibn Wahshîya.

Ibn Abdûn

One of the most interesting documents of Islamic Andalusia is the multilingual lexicon of plants attributed to an 'Anonymous botanist of Sevilla',[109] widely believed to have been a certain Ibn Abdûn,[110] probably the same Ibn Abdûn who oversaw the markets and drug-vendors of Sevilla under al-Mutamid (d. 1092).[111] He tells us that he was a medical student under Ibn al-Lûnkuh (Luengo), a disciple of Ibn Wâfid, who moved to Sevilla in 1094 and died in Córdoba 1105; he also was a disciple of Ibn Bassâl, for whom he is the best biographic source (see Figure 3). Ibn Abdûn was bilingual in Arabic and Romance, distinguishing several dialects of the latter as spoken in the south or north of Spain. He also was an avid field botanist in southern Spain, and intimately familiar with Spanish vegetation, giving good site descriptions for many of his plants (Figure 4), for which he provides a folk as well as formal taxonomy. The botanical knowledge, precision and accuracy of his plant descriptions remained unrivalled in Medieval times.[112] His lists expand Dioscorides' inventory by 200 new plant species, including numerous Indian forms or exotic plants acclimatized in Spain, as well as the times of year when particular species should be planted or collected. A summary of the original 243 double folios has been published;[113] a complete presentation would give access to a wealth of both environmental and dietary information.

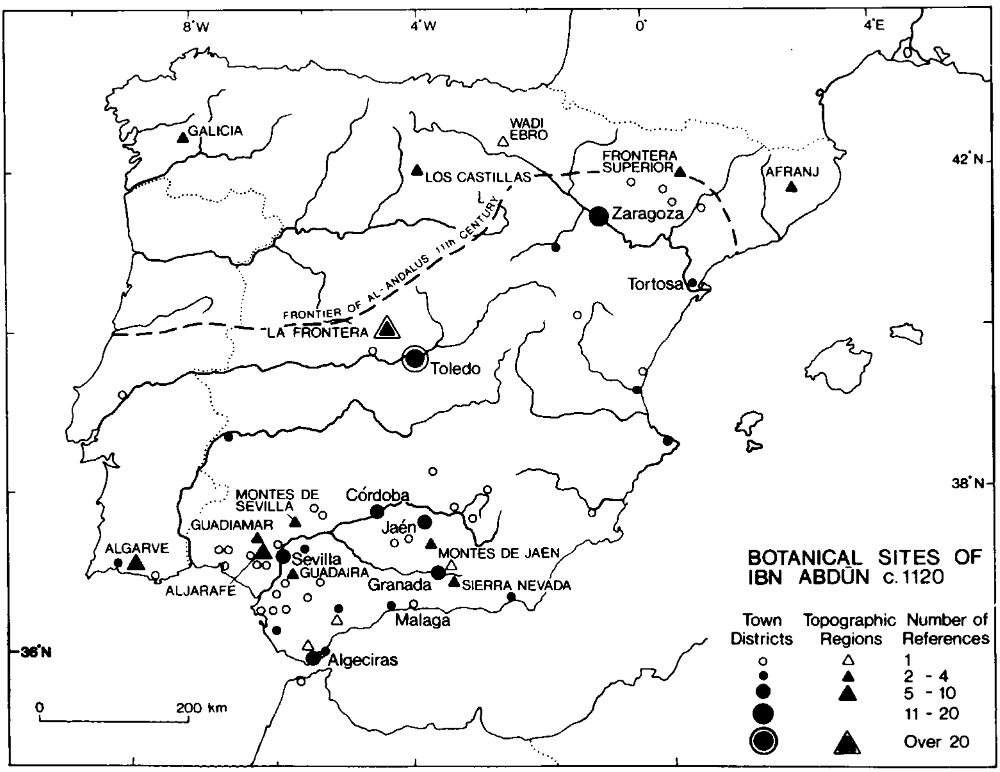

Figure 4 ~ The botanical locations of Ibn Abdûn on the Iberian Peninsula during the early 1100s. The map shows his personal field-collection sites in Andalucia, that describe habitat ecology, as well as other locations from which he obtained plants indirectly.

Ibn Abdûn cites the opinions of Ibn Juljul, Ibn Samajûn, al-Zahrâwi, and Ibn Wâfid – all his direct antecedents; the Andalusian physician, geographer, and botanist Ibn Ubayd al-Bakrî (d. 1094); as well as Dioscorides, Galen, al-Dînawârî, and the Persian physician al-Râzi (d. 925). Ibn Abdûn must have studied medicine under Ibn al-Lûnkuh *after* his position as market-overseer, but no works younger than the 1090s are mentioned; however, his versatile lexicon suggests a mature work, probably written after his diplomatic mission to Marrâkesh in 1147,[114] which would explain the absence of crossreferences to Ibn Adbûn by any of the Sevillian agronomists.

Ibn al-Awwân

The culmination of the Andalusian agronomic tradition is to be found in the treatise of Ibn al-Awwân of Sevilla, indirectly dated by his fond dedication to the deceased Ibn Hâjjâj, and by several references to the physician Ibn Zuhr (Avenzoar, 1092–1162),[115] to the mid-twelfth century. Of all the Islamic writings on agronomy, this work is fully intact, so that its basic arrangement, as shown in Table 1, is unambiguous. The macro-organization is systematic, similar to that used by Pliny, who places arboriculture before the cereals and garden plants, while his relegation of livestock to the end follows earlier Roman agronomists and later Greek compilations.

Ibn al-Awwâm was closely linked to and heavily dependent on materials from Ibn Bassâl, Abu'l-Khayr, Ibn Hâjjâj and Ibn al-Tighnâri (Figure 3). Equally extensive use was made of the *Nabataean agriculture*, the components of which are cited individually and at length. Other Near Eastern sources such as Bolos Democritus, al-Dînawârî, al-Râzi, Ibn Sîna and the Persian agronomists discussed above were evidently taken second-hand from Ibn Hâjjâj. The compilations of Anatolius and Cassianus are his major sources for Graeco-Roman materials; in the first half of his work these were cited after Ibn Hâjjâj, but subsequently they are not, suggesting that Ibn al-Awwâm was eventually able to obtain copies of his own. Certain quotations from Aristotle's *Historia animalium* on veterinary medicine are fairly close to the original,[116] but are more likely to have come from one of many Arabic commentaries. In effect, Ibn al-Awwâm basically assembled his work by direct and extensive transcription from a limited number of sources. He did not have access to a large library and his dependency on Ibn Hâjjâj was enormous, which probably explains his reverential attitude to him as the master. Nonetheless, Ibn al-Awwâm's compilation is of excellent quality, through judicious use of sources and meticulous citation, his rich nuances reflecting an author of immense experience with his subject matter. Citations are commonly followed by amplifications or subtle corrections, although the author expresses diffidence at doing so, and only if his own views have been demonstrated by repeated experience.[117] It is then an unusual work, overwhelmingly a compilation, but one directed by professional experience, empirical observation and an inductive approach. Some of his expositions are rambling and repetitive, but he seems concerned that readers can draw their own conclusions from divergent views. If so, he has been vindicated in that his citations have long been used to reconstruct the content of lost works.[118]

Seen as a whole, Ibn al-Awwâm's work rivals Columella's in comprehensiveness and sophistication, and superseded it – and his Andalusian predecessors – on subjects such as grafting and hybridization, vine cultivation, soils (see below), composts and micro-irrigation. The alidade he used to establish acceptable gradients for canals probably was much the same as the simplified astrolabe developed by the Andalusian astronomer al-Zarkâli (Azarquiel, d. *c.* 1100),[119] a colleague of Ibn Bassâl's at Toledo.

His experimental work in the Aljarafe developed new strains of mountain olives for growing on the plains, and tested the suitability of the area for rice; he also was a proponent of safran cultivation and irrigation in the Sierra Morena. All this argues for royal patronage, probably by the new Almohad (Moroccan) dynasty. Ibn al-Awwâm emphasized the need to verify experimentally every precept he offered, and he downplayed astrological and magical components. The importance of fallow, and the role of legumes and cereal alternation for annual cultivation on good soils are mentioned repeatedly.[120] When the *Principles of tillage and vegetation* of the British agricultural innovator Jethroe Tull (1674–1741) were translated into Spanish in 1751, two chapters from Ibn al-Awwâm (on ploughing and seeding) were appended.[121] The drawing and description of a harrow by Ibn al-Awwâm[122] are noteworthy.

The major difference between the Roman and Andalusian agronomists is in regard to stockraising. Ibn al-Awwâm gives cattle, sheep and goats no more than cursory and unsatisfactory attention, based almost exclusively on Aristotle, while devoting a monograph to horses. Merino sheep, a major economic factor of the later Middle Ages, are not mentioned. But his fellow agronomists barely even discuss livestock (see Table 1), and both the *Calendar of Córdoba*[123] and a later counterpart from Granada[124] leave no doubt that *intensive* stockraising, other than horse-breeding, was not integral to Andalusian commercial agriculture. This matches the general setting of extensive, and frequently mobile stockraising in al-Andalus.[125] Nonetheless, the importance of grazing livestock on stubble for soil fertility, or the use of different types of animal manure, are emphasized.

Ibn al-Awwâm marks the culmination of Mediterranean and Near Eastern agronomic understanding, drawn from several major traditions, representing two millennia of explicit, primarily empirical observation. His role and significance for Islamic agronomy (Figure 2) can be compared with that of Pliny in the Classical tradition[126] – a scholarly encyclopaedist, but also a remarkably cognizant observer, who fully understood the significance of the details that he reproduced.

Classical versus Islamic pedology

This study has, to this point, emphasized the temporal trajectory of Islamic agronomic scholarship and the sparse biographical information that helps illuminate and interrelate the various authors. It is now possible to examine the history of ideas more comprehensively, by focusing on an exemplary theme and tracing it back to possible Classical roots. One such theme is soil science, which combines agronomic experience, field observation, inductive explanation and putative synthesis.

Classical pedology

The groundwork for understanding pedology was laid by the Roman scholar Varro (*c.* 37 BC), who acknowledged the insight of his partner Tremelius Scrofa (*fl.* 71–45 BC), with whom he had distributed agricultural land for veteran settlements.[127] Varro's appreciation of soils was sufficiently good that he presented an organizational scheme with deductive overtones.[128] His framework included topography, specific soil properties and the suitability of terrain and soils for particular kinds of land use. Four types of relief were identified: plains, hills, mountains and combinations thereof – an arrangement relevant to climate, natural vegetation and suitability for different crops and fruit trees. Basic soil components included rock, sand, loam, clay, chalk, (volcanic) ash, dust and red ochre, so that a soil could be described according to its major attribute, for example, as clayey or stony, or finer distinctions drawn as to slight, moderate, or excessive stoniness. Additional criteria were provided by moisture, texture ('rich' vs. 'poor' soils) and consistency (light, crumbly, hard, or ashy). Alluvial soils of the Tiber River were considered as particularly versatile, and white, black and red soils were mentioned, but without reference to their properties and no hint at classification. Varro noted that soils determined land quality, but that farming adapted to such differences by selecting different land-use types, e.g., watered gardens, meadow pastures, grain fields, orchards or vineyards, woodland pastures, or wood lots.

Subsequent Roman contributions were incremental and no one attempted to characterize 'the endless varieties of soil'.[129] A lost agronomic work by Julius Graecinus (d. AD 39) drew attention to excessive qualities that were undesirable: plants rot in soils that are too wet; they remain undernourished in soils that are too dry; overly 'compact' soils are impermeable, poorly aerated, and prone to cracking during the dry season; incohesive soils have excessive permeability and are prone to drought; heavy soils are too difficult to work.[130] Graecinus is to be credited with the first explicit application of the theory of humours, with the argument that the best soils have 'balanced properties of the hot and the cold, the moist and the dry, the compact and the loose'.[131] This is clarified by Varro who had already noted that heavy soils are 'warm', thin soils 'cold'.[132]

The important Roman agronomist, Columella (*fl.* AD 41–65), recognized that the relative age of a soil was unimportant because in its natural habitat it would be nourished by leaves and herbage, whereas it would grow 'lean' with extended cultivation and no manure.[133] Most of the Classical agronomists discussed fertilizers, such as different kinds of dung or mineral soil,[134] as well as restorative legumes and crop rotation.[135] Columella[136] and Pliny[137] were in agreement that soil colour was no foolproof criterion of quality, each citing various counter-examples. Pliny summed up a century of discussion with the less-than-surprising verdict that the best soils were moderately clayey, soft and easily worked, and neither waterlogged nor parched.[138]

Mesopotamian pedology

Except for the deductive elements of Varro's scheme, almost all of these points[139] can be found in the *Nabataean agriculture*, as well as among the Andalusian authors, of whom Ibn Hâjjâj and Ibn al-Awwâm explicitly acknowledge the Classical sources. It is therefore probable that Ibn Wahshîya or his semi-mythical sources already had access to similar information. For example, it is hardly fortuitous that Scrofa noted that the clays quarried to make pottery (typically mined from sterile Tertiary claystones) are unsuitable for agriculture,[140] while the *Nabataean agriculture* says that pottery clays form surface aggregates of the consistency and colour of pottery during the heat of summer,[141] and Abu'l-Khayr lists bluish pottery clays among his poor soils.[142] What is of interest is the degree to which the *Nabataean agriculture* goes beyond this older datum, and the specific, novel insights that can be identified:[143]

(a) It is explicated that good (alluvial) soils are enriched by the deposition of silt after prolonged inundation with 'sweet' waters.
(b) Cold is introduced as a factor in soil response, since heavy soils might also crack as

a result of great cold, while frost would build up a hard surface layer (needle ice?) on excessively wet soils.

(c) Distinctive stony 'mountain' soils are recognized, as found in the 'coldest parts of Babylonia' (the Zagros Mountains); these consist of a superficial, vegetal horizon on top of a subsoil that could be either soft or hard and stony, i.e., rendzinas or lithosols.

(d) Reduced (gley) soils are identified, by their fetid smell (sulfide), their bad acid taste (jarosite), or their affinity for black, violet, or dark green micro-organisms when immersed in water for several weeks.

(e) Alkaline or saline soils are recognized, with surface efflorescences and a brackish or bitter taste as diagnostic criteria; amelioration is suggested via thorough, persistent irrigation, the planting of specific crops that help remove salts, by manuring, or by mixing vine leaves and oil dregs into the soil. Such problematic soils are either coal-black or ashen white, i.e., the black and white alkalis of the early US classifications.

(f) Hardpan soils with white, chalky substrates are first introduced to the literature, i.e., petrocalcic horizons; they can possibly be ameliorated by frequent ploughing, trampling by animals and manuring.

(g) Dark clayey soils are evaluated according to whether they crack in hot or cold weather, absorb water without becoming too sticky, and pass tests for possible gley properties; another useful criterion is that the soil aggregates (peds) should crush easily in any weather.

(h) Red, sticky or clayey soils are recognized – either from old alluvial surfaces in the Zagros foothills or from Syria, where terra rossas (Rhodoxeralfs) are more common.

Although the presentation in the *Nabataean agriculture* is poorly organized, it is readily apparent that great strides had been made not only in understanding soil properties, but also in developing criteria to identify specific soil types and in suggesting particular crops or trees best suited to each type. Some 10 generic soils are identified *de facto*: red and black clay soils; thin, organic mountain soils; sandy desert soils; dark alluvial soils; fetid gley soils; black and white alkaline soils; saline soils; and chalky hardpan soils. The level of detail given varies considerably.

Andalusian pedology

Ibn Bassâl presents 10 major soil types in systematic fashion, organized according to the four humours,[144] following the precedent of al-Wâfid. But preoccupied with agronomic applications, his rudimentary, descriptive data commonly are inadequate to identify the type. The materials excerpted by Ibn al-Awwâm suggest these descriptions may have been abbreviated, and Ibn al-Awwâm adds complementary data, such as permeability or porosity, as well as taxonomic refinements by Abu'l-Khayr.[145] Even so, ambiguities remain, but combining the information directly included in Ibn Bassâl with the indirect citations from Ibn Bassâl and Abu'l-Khayr does provide a view of the soils of the Iberian Peninsula. For example, heavy cracking vertisols are readily identified, and five types of red soils are distinguished: red clays; soft (mollic) and brown clayey variants; slightly sandy red soils; and 'lean', sandy, reddish organic soils. This suite of red soils is suggestive of the regional rhodoxeralfs (terra rossas), haploxerolls (chestnut soils), haploxeralfs (brown Mediterranean soils), xerochrepts (reddish-brown Mediterranean soils), and rendolls (reddish-brown mountain soils or rendzinas).[146] A clear distinction is made between stony lithosols found in the mountains and the gravels or thick coarse sands (regosols) deposited by torrential runoff in the lowlands, while the different aptitudes of coarse and fine sands are distinguished.[147] Petrocalcic soils are called *al-qadan*, or 'pumiceous' – a porous but rock-like horizon near the surface, becoming more earthy at depth. Black, fetid gley soils are characterized as saline, suggestive of the halaquepts of the estuarine marsh of the lower Guadalquivir River.

This, then, is a first approximation of a soil classification, but one where the criteria of organization are fairly rigidly defined by the bipolar dichotomies of hot vs. cold, and moist vs. dry. Figure 5 represents an attempt to organize the soil types of Ibn Bassâl and Abu'l-Khayr according to Galenic humour theory, with the best soils placed toward the centre of the circle, and poor soils outside it. Such a framework provides no coherent logic for remedial ploughing or application of organic fertilizers, which Ibn Bassâl recommends on essentially empirical grounds.

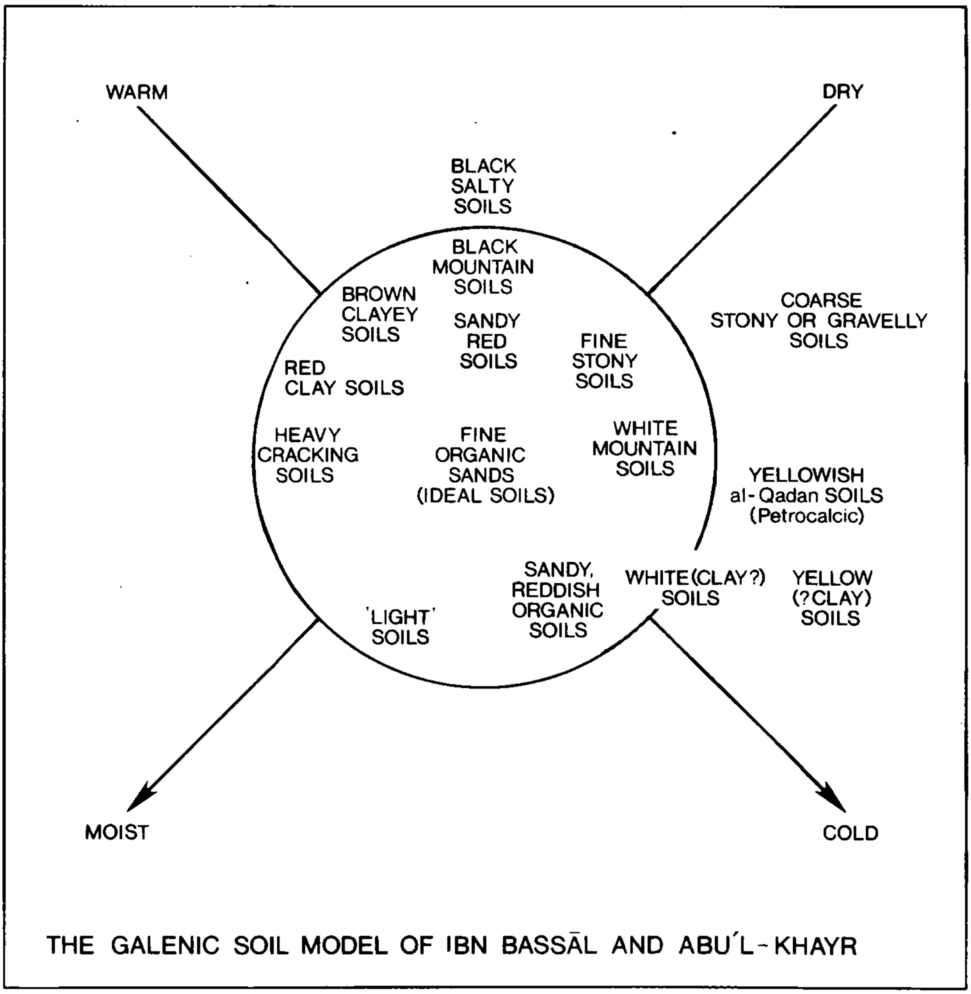

Figure 5 ~ Informal soil categories, described and organized according to Galenic attributes by Ibn Bassâl and Abu'l-Khayr (*c.* 1075–1120). See text.

At first sight, a classification of soils according to a speculative medicinal theory of humours, i.e., body fluids, seems far fetched. Humour theory was long attributed to the Greek physician Hippocrates (469–390 BC), but no authenticated works of his survive. Lacking biochemical understanding, the ancients used its concepts as a pseudo-explanation of human temperaments (hence the modern meaning of 'humour'), of pathologies due to physiological imbalances, and of the remedial actions of plant, animal and mineral drugs. As a comprehensive theory, it was explicated by Galen (AD 129–210). These humours are shown in Figure 6 as equivalent elements and colours, defined by 'active' faculties (hot to cold) and 'passive' faculties (dry to moist) on a bipolar graph.[148] Thus 'earth' is the element, 'black' the colour, and 'melancholia' the temperament for the humour 'black bile' with its cold and dry 'faculty'. As a mixture of elements, drugs potentially had two types of action on the body – warming or cooling, and drying or moistening.[149] The goal was to balance the attributes of the body fluids to achieve good health.

The transfer to soils probably was suggested by the fact that mineral remedies were a standard part of the ancient pharmaceutical repertoire. Drying and wetting posed no problems, but warming and cooling represented an enigmatic black-box theory, impossible to define or test. Exactly what is a 'warm' soil? As noted already, Varro in the first century BC was the first agronomist on record to invoke this theory, and elements of it appear in the *Nabataean agriculture*, particularly in parts attributed to its earliest, semi-mythical authors. As a basic, deductive explanation, it was introduced by Ibn Wâfid and Ibn Bassâl, but the idea that 'balanced' soil properties are ideal recurs from Graecinus to Ibn al-Awwâm. It evidently appeared useful as an organizational

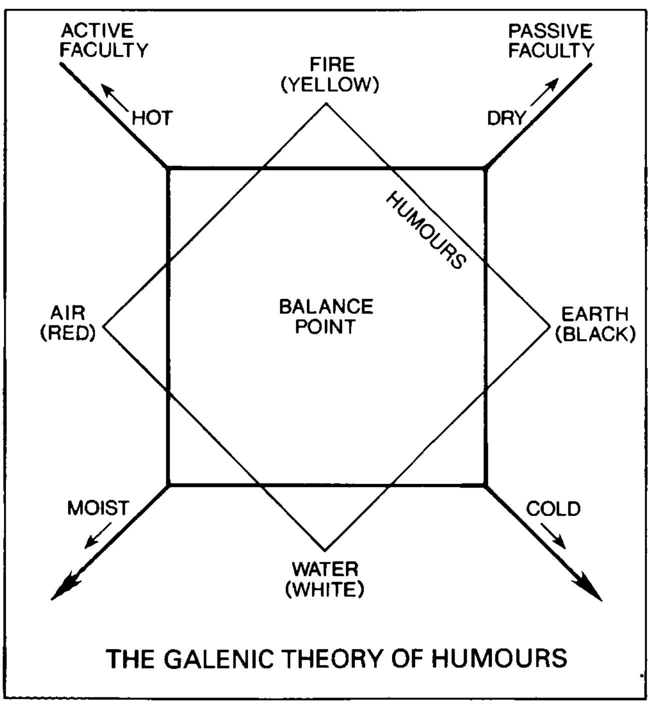

Figure 6 ~ The Galenic theory of humours.

scheme to classify soil types, but was counterproductive in obscuring more objective soil properties.

It is to the credit of Ibn al-Awwâm that, while respecting the popular theory, he injected genuine soil properties into his characterization of types and devised specific amelioration techniques to remedy the excess or deficit of these qualities. He recognized two major variables – organic content and permeability, and one minor variable – special chemical properties, particularly salts. The ideal soil was moderately rich in organic matter, and reasonably permeable and water retentive (primarily reflecting soil texture). A relatively sterile soil could be enhanced by the addition of organic fertilizer, while an excessively organic soil (as he saw it) could be moderated by mixing in fine sand or ash as a temper. An excessively permeable soil might be compensated by regular irrigation, while an impermeable soil could be mitigated by repeated ploughing (increasing aeration) and the addition of sand as a temper (reducing the clay content and enhancing porosity with a less homogenous soil mass). My own interpretation of his conception of soils, which he arrived at inductively – but as an implicit substitute for the humour model, is shown in Figure 7. Ibn al-Awwâm devoted a modicum of lip service to the traditional model, but given his empirical bent, it is not surprising that he recognized contraditions between his approach and that illustrated by Figure 5, giving precedence to the facts as he saw them.

Ibn al-Awwâm's conception represents the first *scientific* classification of soil types, whatever its weaknesses. Although it remained unknown in the Latin West, and was not understood or even appreciated by contemporary or subsequent Islamic scholarship, nothing better was offered until the Russian innovations in soil science during the late nineteenth century. The primary purpose of Figure 7 is to illustrate Ibn al-Awwâm system, rather than to identify his specific soil types. Just exactly which soils he thought were important is impossible to say, since he attempted to conflate the soil types of the *Nabataean agriculture* and of Ibn Bassâl and Abu'l-Khayr into a comprehensive list, expressing minimal critical judgement. Selecting the soils shown in Figure 7 therefore is a matter of personal judgement; to me they appeared to represent major categories, and were reasonably well defined, so that they could be placed within the bipolar graph. In order not to hazard unwarranted identifications, the types are presented as a mix of descriptive categories, including both older (and more general) classes and modern taxonomic terms. I believe the overall scheme will be comprehensible to nonspecialists, and that must serve in lieu of a homogeneous taxonomy. Allowing for the deficient soil definition of Ibn Bassâl and Abu'l-Khayr, it is noteworthy to compare the graphic positions of the various taxa in Figures 5 and 7: Ibn al-Awwâm's empirical criteria lead to some substantial rearrangements, primarily because the Galenic model was inherently arbitrary.

The perspective of Andalusian pharmacology

The Andalusian agronomists represented a distinctive school, that derived from the Cordoban pharmacologists (*c.* 950–1013), and emerged with Ibn Wâfid in Toledo (*c.* 1068), terminating with Ibn al-Awwâm in Sevilla (*c.* 1160). There was, however, another school of Andalusian pharmacology, also derived from the original group at Córdoba, but evolving separately and eventually continuing in the Near East. It has been traced by M. Meyerhof[150] and C. E. Dubler,[151] and is summarized here (see Figure 3) for the perspectives it provides on the decline of Andalusian science. This

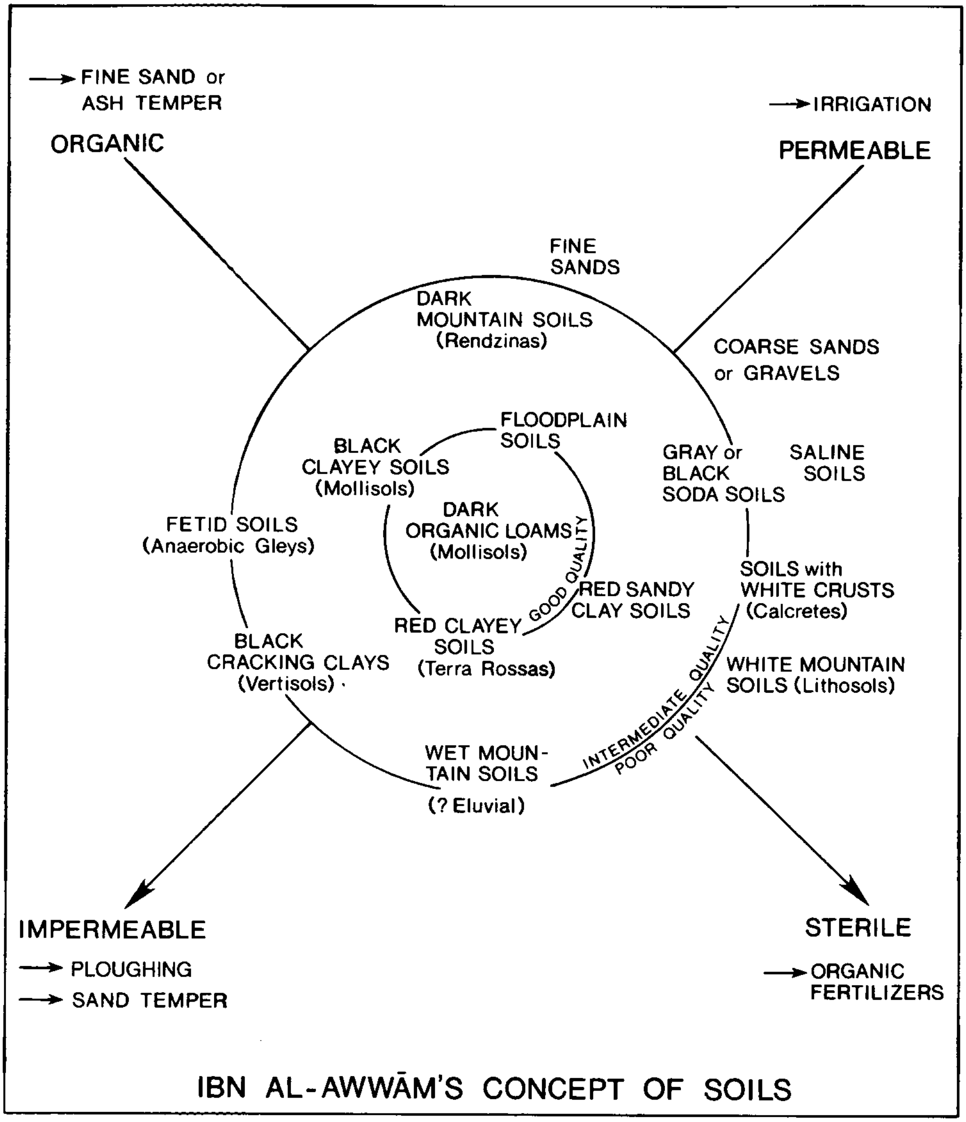

Figure 7 ~ Ibn al-Awwâm's concept of soils, as conditioned by organic content and permeability, with methods proposed for amelioration (*c.* 1160). See text.

particular tradition comes into focus a little before 1130, after a break of a century that may be bridged by the Jewish scholar, Ibn Jânah (Jona Marinus, *c.* 995–1050) of Zaragoza, and by Ibn Sîda (1007–66) of Murcia.[152]

One of the key authors was the philosopher, physician, and astronomer, Ibn Bajja (Avempace, d. 1138) of Zaragoza.[153] He was a colleague of Abû'l-'Alâ Zuhr (d. 1131, father of the famed Avenzoar) of Sevilla, also a physician and pharmacologist. Better known as a botanist was al-Ghâfikî of Córdoba (d. 1166) – who drew on the Cordoban and Persian schools, on Ibn Jânah, as well as on Dioscorides and Galen, using first-hand sources with meticulous care and adding rich original observations on Spanish botanicals. He is considered as a truly scientific botanist, and was a contemporary not only of Ibn Abdûn but also of the great Andalusian geographer, physician and naturalist, al-Idrîsî (1100–66), whose less important herbal drew on the Cordoban group, on Ibn Wâfid, as well as on Dioscorides and the *Nabataean agriculture.*

In the next generation there is Ibn Maymûn or Maimonides (1135–1204), the noted Jewish physician and philosopher from Córdoba, whose pharmacopia drew on the Cordobans and Near Eastern sources.[154] The link to the final generation of Andalusian botanical scholarship is provided by Abû'l-Abbâ-'al-Nabâtî (*c.* 1165–1239) of Sevilla, who collected plants together with his disciple Ibn al-Baytâr (d. 1248), of Malaga. Al-Baytâr later assembled the whole tradition of Islamic pharmacology in encyclopaedic form,[155] using al-Ghâfikî and Ibn Bajja liberally, but also integrating the Cordobans, Ibn Wâfid, Ibn Jânah, al-Bakrî, al-Idrîsî, Maimonides, Dioscorides and Galen, in addition to other Near Eastern sources.

It is readily apparent that the maturation of the Andalusian agronomic school, from Ibn Bassâl to Ibn al-Awwâm, coincides with the apogee of Islamic pharmacology (al-Ghâfikî), medicine (Ibn Zuhr), astronomy (al-Zarkâli), physics (Ibn Bajja), geography (al-Idrîsî) and logic (Ibn Rushd or Averroes, 1126–98) in the Far West.[156] Most of these rational scholars, and other Andalusians of the period as well, were destined to have a significant impact on Western Europe, well into the Renaissance. The question inevitably remains why this intellectual ferment collapsed so abruptly during the subsequent century. Among matters that directly relate to al-Andalus, rather than Islamic scholarship in general,[157] are the changing sociopolitical context and the gathering momentum of the Reconquista.

During this period Sevilla fell to the Moroccan Almohad dynasty (AD 1147), representing a fundamentalist sect with seemingly little sympathy for empirical or inductive inquiry. These new rulers severely restricted the scope of cultural expression, and would hardly be expected to support either experimental research or heterodox reflection. Ironically, some of the finest work was produced during the generation after 1147, and scholarly interaction between al-Andalus and Morocco increased markedly until 1200.[158] Almohad 'literalness' was more complex than the fundamentalist label might suggest; it was directed against the authority of the powerful legal schools that had emerged in the Islamic East, and it gave support to the growing Andalusian attitude of self-assertion, even nationalism.[159] The Almohad ruler Abû Yaqûb (1163–84) consequently supported the Aristotelian rationalism that peaked at this time. But more orthodox jurists triumphed under his successor, and scholarly emigration began.

At the same time, al-Andalus was disintegrating militarily and economically; Zaragoza fell to the Christian armies in 1118, Sevilla in 1248. Cumulatively, the two processes created a 'brain drain' from the Iberian Peninsula, that did not bode well for generational replacement of prime scholars. Ibn Bajja emigrated to Morocco after the loss of Zaragoza, and died in Fez. Idrîsî left Morocco during the 1130s for the more liberal court environment of Christian Sicily. The Jewish family of Maimonides fled from al-Andalus in 1158 because of religious intolerance, eventually settling in Cairo. Ibn Rushd was banished for his heterodox views in 1195 and, like the son of Ibn Zuhr, died in Marrakesh; his protégé, the mystic Ibn al-Arabî, abandoned al-Andalus shortly before, in favour of Damascus. Al-Baytâr emigrated in 1220, moving to Egypt and later Damascus, transplanting the legacy of Andalusian pharmacology to the Near East. Many Moroccan and Tunisian scholars of the fourteenth century (e.g., Ibn Battûta, Ibn Khaldûn, al-Himyâri) also were descendants of immigrant Andalusian families, who prided themselves in their progressive heritage.

During the fourteenth century there was a cultural revival in the Islamic kingdom of Granada. This renewal of scholarship was broadly based,[160] but modest in its achievements. Ibn Luyûn of Almeria (1282–1349)[161] wrote an abridgement of Ibn Bassâl and Ibn al-Tignâri in verse, that lacks professional quality but includes new information from rural informants. At about the same time, Muhammad al-Shâfra, a refugee from Crevillente (Alicante), later to become an able surgeon, first distinguished himself as a botanist, collecting plants on the hillsides of Guadix. But these were only echoes of a more productive era of scholarship that recall the relationship of a Palladius to Classical agronomists such as Columella. The impoverishment of agricultural information can be plainly seen by comparing the fifteenth-century almanac from Granda[162] with the tenth-century *Calendar of Córdoba.*

Contextual discussion of the Islamic tradition

In overview and assessment of Islamic agronomy in general, and Andalusian agronomic science in particular, a number of distinctive features can be identified and discussed.

(1) The Andalusian school of agronomy adhered to the systemic organization and methodology of the Classical tradition, rather than the disorganized precedents set in Mesopotamia by Ibn Wahshîya or the parallel pharmacological work of al-Dînawârî. Although no more free from folk superstitions than were the Greek or Romans, the Andalusians managed to chart new ground in the spirit of rational inquiry. They preferred to rely on first-hand observation, rather than hearsay or blind recompilation, and on experimental verification, rather than deductive arguments. As Bolens[163] emphasizes, this was a Western and Aristotelian, rather than Eastern tradition.

(2) At the same time, the Andalusian agronomists made full use of the expanded range of experience and knowledge available in the Near East. Just as al-Baytâr added 500 medicinal plants to the 1000 of Dioscorides, reflecting the cumulative efforts of Islamic scholarship, the agronomists incorporated the dozens of new plants and fruit trees introduced from India or the Near East into their manuals. They favoured the propagation of new forms of commercial agriculture, and greatly refined the methods of micro-irrigation, which became a central part of their agrostrategies, just as they built on the technological improvements in macro-irrigation characteristic of the Arab dominions. These agronomists were very much a part of the Islamic revival, refinement and expansion of Mediterranean agriculture.[164]

(3) There is a strong indigenous, Hispanic – rather than Near Eastern – flavour to the agronomic tradition of al-Andalus. This is particularly evident in the *Calendar of Córdoba* and the bilingual dictionary of Ibn Abdûn. The translation efforts around the Dioscorides text at the court of Córdoba focused on determining Hispano-Arabic synonyms for the plants described by Dioscorides, as fundamental to creating an observational, as well as recompilatory form of scholarship. The pharmacological lists, until the time of Ibn al-Baytâr, provide living testimony to the survival of a Romance vernacular in Andalucia, and botanical collecting or agronomic interviewing in the field were evidently dependent on bilingual skills. The Julian, rather than the Islamic calendar, was used as a matter of course by the Andalusian agronomists, and the patronyms of both Ibn Bassâl and Ibn al-Lûnkuh

were derived from Romance roots. At the same time, however, starting with Recemendus, many if not most of the Andalusian agronomists and pharmacologists had travelled in the East, presumably to profit from more orthodox Islamic learning.

(4) Orientalists tend to insist that the golden age of Islamic science ended in about 1050, and even Vernet[165] succumbs to this view, basing himself on the quantity (rather than quality) of works produced in the Christian vs. the Islamic world. Andalusian agronomy, however, came to full fruition *c.* 1070–1160, and the scientific calibre of Ibn Bassâl, al-Ghâfikî, Ibn Abdûn and Ibn al-Awwâm finds able Andalusian counterparts in other branches of the sciences. Although working in a context of Islamic political and economic decline, such authors represented a quality of scholarship that compares very well with that of Classical Rome or Early Islam.

(5) The growth of the Andalusian agronomic tradition, and the interpersonal relationships of its members, can be traced with some confidence as a web of like-minded scholars, deriving their initial impulse from the text of Dioscorides, and continuing over the generations – in Córdoba, Toledo and, finally, Sevilla – to build upon cumulative experience and understanding (Figure 3).[166] This process of intellectual maturation, across some two centuries, first involved some 120 years of translation, commentary, and compilation, during which there is little evidence of original observation. Only then, after four generations, did the best people plunge into empirical work and eventually produce works of international calibre, that rank alongside those of Theophrastus and Columella. Although their insights were welcomed in Christian Spain, it is lamentable that they remained unknown beyond the Pyrenees, where Classical prototypes dominated well into the Renaissance.

(6) The motivation of the Andalusian agronomists differed from that of their Roman counterparts.[167] None appear to have been independently wealthy, or retired from military or other government service. Like Theophrastus, they were fully engaged in professional work, of which research was an integral part. Only a few of them, such as Ibn Wâfid and Ibn Abdûn, are known to have played political roles, but all of Ibn Wâfid's successors displayed a measure of advocacy for agricultural development, such as the expansion of olive, sugar, flax, or cotton production in Spain.[168] Although ornamental gardens had a long tradition with Eastern potentates, the botanical gardens set up in Toledo and Sevilla were the first to incorporate an experimental component. Three of the later agronomists were also engaged in research in the olive-growing district of the Aljarafe, west of Sevilla, where there may have been test plots on royal lands. It is quite probable that all the Andalusian agronomists had court appointments, initially as physicians, later as agricultural specialists. Successively linked to the Aljarafe research, Ibn Hajjâj, Ibn Bassâl, Abu'l-Khayr and finally Ibn al-Awwâm probably each served as caretakers of the botanical garden in Sevilla. In effect, the Andalusian agronomists were sponsored by royalty, and their views at least enjoyed the sympathy of their patrons. But they were not official spokespersons for particular policies and, as much as one can imagine Ibn al-Awwâm standing in a trench, alidade in hand, directing construction of a new irrigation canal, he had no palpable social agenda.

(7) As in the case of the Roman agronomic tradition, from Cato to Pliny, the Andalusian agronomists advocated agricultural expansion and greater produc-

tivity to meet the demand of urban populations for foodstuffs or of craft centres for flax or cotton fibre. This seems contradictory in the context of Córdoba's devastation by civil strife in 1009, the fall of Toledo to Castile in 1085, and almost regular Christian raids, that deliberately devastated the rural economy of the Guadalquívir *campiñas* between 1173 and the capitulation of Sevilla in 1248. The Muslims of al-Andalus probably had a blind faith in the invincibility of Moroccan arms, at least until their decisive defeat in 1212. But decentralization after 1013 had a salutary impact in many ways, creating several new, rapidly growing, alternative urban centres, with accelerating agricultural intensification in their hinterlands. In fact, agricultural expansion in the region of Valencia only began about AD 1000, continuing until after 1200,[169] and the great irrigated tracts (*huertas*) from Castellón to Murcia were developed during this period. Defence of the mountainous border marches at least locally involved new rural settlement, anchored in a network of castles and towers.[170] Finally, the resilience of Islamic agriculture, even in retreat, is again documented by the superb, irrigated *vega* of Granada, created with participation of Murcian and Valencian refugees after 1266.

(8) Stockraising, unlike irrigated farming, is conspicuously absent from the Islamic strategies for intensification and commercialization. Sheep were drawn into large-scale transhumance treks, anticipating the later Mesta, while cattle were driven long distances to market.[171] None of the Andalusian authors mention improved breeds of sheep, and evidence for dairying is limited to a few localities.[172] This generalized pastoralism, hinted at by the fifteenth-century *Calendar of Granada*,[173] contrasts with the intensified stockraising characteristic of Rome in its heyday as duly emphasized by its agronomists.

(9) Finally, the degree to which Andalusian agronomy was derivative, original, or innovative must be addressed. The last work of this tradition fortunately is both comprehensive and remarkably well referenced. With the aid of Clément-Mullet's meticulous identification of passages in Ibn al-Awwâm that repeat or parallel earlier writings, almost 1900 direct and indirect citations were identified. Of these, 615 (32.5 per cent) are to Late Greek sources, overwhelmingly to Cassianus, and 585 (31 per cent) to Near Eastern sources, over 85 per cent to the *Nabataean agriculture.* Some 690 (36.5 per cent) are to earlier Andalusian writers of the Sevilla school. But it is the detailed picture that is most interesting, as broken down into different categories of subject matter (Table 2). This shows that Classical arboriculture, even as diluted by the Late Greek compilers, remained the standard, except for grafting and pruning, which were developed to a fine art by the Andalusians. While some special varieties of fruit trees, e.g., the apples, pears and plums, described by Pliny, were ignored by the Islamic agronomists, many new varieties of figs, pomegranates, melons, or cucumbers were emphasized instead. Little was added to Classical methods of ploughing or cereal cultivation, and understanding of improved stockraising and pastoral economics declined. The *Nabataean agriculture* proved critical for a better appreciation of soils, fertilizers, legumes and plant diseases than the Classical writers had, and it spawned a new interest in horticulture (see Table 1). The Andalusian contribution itself was centred on (a) more refined techniques, such as irrigation and grafting; (b) the introduction or expansion of commercial crops; and (c) the unprecedented sophistication of horticultural practices (Table 2).

Table 2 ~ Classical, Near Eastern and Andalusian sources for Ibn al-Awwâm

Sequential subject matter	Classical %	Proportion of sources: Near Eastern %	Andalusian %	Number of references
Soils	20	47	33	103
Fertilizers	20	53	28	87
Irrigation	25	27	48	48
General arboriculture	41	27	32	206
Grafting and pruning	12	33	56	126
Olive cultivation	50	13	38	64
Vineyards	49	36	15	72
Other fruit trees	38	27	35	201
Ploughing and cereals	52	28	20	80
Legumes	11	49	40	81
Fibres and dyes	3	26	72	39
Garden vegetables	17	30	54	175
Condiments and flowers	6	32	62	186
Plant diseases	35	52	13	108
Food preparation	39	31	30	114
Seasonal calendar	25	35	40	84
Animal husbandry*	84	4	3	117
Total	32.5%	30.9%	36.5%	1891

*Excluding horses, but including poultry, beekeeping and animal pests.

The authors of the Andalusian tradition evidently built deliberately on Classical understanding, while examining the Near Eastern materials for new insights, and then proceeded to assemble a more complete corpus, refining the details and, above all, making substantial contributions in selected categories that were either of greater interest or perceived to be deficient. Much as in the other sciences or in the realm of technology, the broader Islamic tradition represented a highly significant evolutionary, rather than revolutionary development, firmly grounded in its Classical roots.

Some conclusions and reflections

Scientific agronomy is based on observations, drawn from the popular practice of agriculture, which in turn is ultimately based on the experience of repeated trial and error over long periods of time. New ideas are tested experimentally, requiring a constant alternation between deductive and inductive study, until a body of knowledge and theory has been articulated. The differences between agronomic science and astronomy or mathematics lie primarily in the first stage of data accumulation, although even here there are some analogues.

Like their Classical counterparts,[174] the two Islamic traditions of agronomy were grounded in a body of empirical understanding that reflected inter-related agrarian strategies, with a similar repertoire of plants and animals, within a common circum-Mediterranean environment. But as an academic medium, they represent a rationalization of folk agriculture by scholars who not only understood its goals and methods, but also mastered writing, argumentation, and the existing corpus of literature.

Both folk agriculture and academic agronomy are subtly shaped by particular cultural contexts, such as food preferences and cuisine, works habits, and the values that permeate all three. These in turn are embedded at a deeper level in a semiotic world of language, symbolism, landscape, religion and philosophy. In other words, both folk and academic information, reflecting historical trajectories and external ideas, pass through different orders of cultural filters, prior to encoding in a complex, conceptual framework.

As the arguments of this article show, Islamic agronomy was the product of linguistic and cultural translation of Greek prototypes, via bicultural intermediaries. The basic agrosystem was and is essentially the same, in terms of crops, methods and strategies. But the cultural filters created interference. At the folk level there are differences in crop emphasis, with the Islamic margins of the circum-Mediterranean region paying more formal attention to small-scale manipulation of irrigated, garden plants and less to dry-farmed grains and legumes. At the academic level there are additional differences in the perception of agricultural goals or the different priorities set by religion, economics, or values.

The transmission of agronomic information during both Preislamic and Islamic times required a new academic medium, to absorb formal understanding and practical precepts from an alien culture, and to fashion these into a form compatible with both regional folk practice and the ideological framework of the emerging Islamic world. Such a cultural reconciliation was only possible after first comprehending and mastering unfamiliar vocabularies, concepts, discursive syntaxes and thought processes. In other words, cultural translation was a prerequisite to construction of a new ontogeny that, in turn, would allow cultural reconciliation and ultimately a fresh burst of creativity. These can also be interpreted as steps in a complex process of cultural adaptation, initially within the élite communities, but with feedbacks for folk agriculture, and further feedback echoes for agronomic scholarship. Unfortunately those feedbacks remain obscure for Early Medieval times.

Islamic scholarship in general, and agronomic science in particular, like all scholarly and educational processes at all times, were mediated by political and economic contexts. Scholars were dependent upon patronage or employment, sought to identify other 'communities' with similar philosophical views, targeted particular audiences in various ways and with different degrees of success, and attempted to deal with complex movements of ideological opposition. Such factors provided opportunities or set constraints to scholarship of whatever kind, in both principle and practice. They imply a measure of sociopolitical or ideological 'steering', that was by no means unique to Islam.

Finally, we can touch upon the growth and decline of scholarly traditions. The stimuli that set in train the agronomic scholarship of Mesopotamia or Andalucia came from books, their translation and digestion, and the responses they provoked. Key individuals served as initial catalysts, to be followed by new generations of experts who revised their empirical understanding in the light of earlier scholarship, evaluating both orthodox views and alternative traditions. When the community of scholars disintegrated, for whatever reason, the tradition of scholarship rapidly became dormant, even as 'informed' agronomic practices continued in use. Periodically, new recompilations appeared, echoing past traditions of scholarship, but their authors had access to few manuscripts and were intellectually isolated from any forum of active interchange. Inevitably there was a loss of information, sophistication and critical facility.

This semi-speculative scenario deserves to be systematically examined for the several European and Near Eastern agronomic traditions, stressing the synchronic and diachronic interconnectivity between clusters of scholars, as well as the stop-go nature of scholarship, crisscrossing cultural boundaries, prior to the invention of the printing press.

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Notes

1 K. W. Butzer, 'The realm of cultural-human ecology: adaptation and change in historical perspective', in B. L. Turner *et. al.*, eds., *The Earth as transformed by human action* (New York, Cambridge University Press, 1990), pp. 685–701.

2 K. W. Butzer, 'The classical tradition of agronomic science: perspectives on Carolingian agriculture and agronomy', in P. L. Butzer and D. Lohrmann, eds., *Science in Western and Eastern civilization in Carolingian times* (Basel, Birkhaeuser, 1993), pp. 539–96.

3 See K. W. Butzer, E. K. Butzer, J. F. Mateu, 'Medieval Muslim communities of the Sierra de Espadán, Kingdom of Valencia', *Viator* **17** (1986), pp. 339–413; Butzer, 'Realm'; K. W. Butzer, 'A human ecosystem framework for archeology', in E. F. Moran, ed., *The Ecosystem approach in anthropology: from concept to practice* (Ann Arbor, University of Michigan Press, 1990), pp. 91–130.

4 Butzer, 'Classical'.

5 In this, the present article differs from the traditional emphasis on the Islamic diffusion of crops and technology, as richly documented by A. M. Watson, *Agricultural innovation in the early Islamic world* (Cambridge, Cambridge University Press, 1983). But Watson over-emphasizes economic forces, in part based on the questionable premise of a general Islamic economic expansion through much of the Middle Ages, in part stimulated by positive changes in land tenure and taxation (Watson, *Agricultural*, pp. 112–16). But regional evidence does not substantiate more enlightened treatment of the farming populace, see P. G. Forand, 'The status of the land and inhabitants of the Sawâd during the first two centuries of Islam', *Journal of the Economic and Social History of the Orient* **13** (1970), pp. 25–37; D. Waines, 'The third century internal crisis of the Abbasids', *Journal of the Economic and Social*

History of the Orient **20** (1977), pp. 282–306; R. H. Collins, *The Arab conquest of Spain, 710–797* (Oxford, Basil Blackwell, 1989), pp. 46–47. Furthermore, in Mesopotamia the Arab irrigation system, as restored after the ravages of the Conquest, represented a major retrenchment with respect to its Sasanid antecedents, and was in patent decay by AD 900, see R. McC. Adams, *Heartland of cities* (Chicago, University of Chicago Press, 1981), pp. 214–28. In Spain the numismatic evidence indicates that a monetary economy was only restored 52 years after the Islamic Conquest, to be again disrupted AD 889–926, see G. C. Miles, *The coinage of the Umayyads of Spain* (New York, American Numismatic Society, 1950), Part 1. Khuzistan only recovered its prosperity about 870, with its irrigation system and towns again laid waste *c.* 1015, see N. M. Pyne, *The impact of the Seljuq invasion on Khuzistan: an inquiry into the historical, geographical, numismatic, and archaeological evidence* (Ann Arbor, MI, University Microfilms International, 1982), ch. 5. Grand generalizations about the early Islamic economy do not therefore stand up to close examination.

6 M. Meyerhof, 'On the transmission of Greek and Indian science to the Arabs', *Islamic Culture* **11** (1937), pp. 17–29; F. Sezgin, *Geschichte des Arabischen Schrifttums:* IV (*Alchemie-Chemie-Botanik-Agrikultur*), V (*Mathematik*), VI (*Astronomie*) and VII (*Astrologie-Meteorologie*) (Leiden, Brill, 1971–79); M. Ullmann, *Die Medizin im Islam (Handbuch der Orientalistik),* I Abt. Ergänzungsband VI, i) (Leiden, Brill, 1970); M. Ullmann, *Die Natur und Geisteswissenschaften im Islam (Handbuch der Orientalistik),* I Abt. Ergänzungsband VI, ii) (Leiden, Brill, 1972); P. Kunitzsch, *Der Almagest: Die Syntaxis Mathematica des Claudius Ptolemäus in arabisch-lateinischer Ueberlieferung* (Wiesbaden, Harrassowitz, 1974); A. J. Sabra, 'The scientific enterprise', in B. Lewis, ed., *Islam and the Arab world* (New York, Knopf, 1976), pp. 181–200; D. A. King, 'Astronomy', in *The Cambridge History of Arabic Literature:* III *Religion, learning and science in the Abbasid period* (Cambridge, Cambridge University Press, 1990), pp. 274–89; H. D. Isaacs, 'Arabic medical literature', in *The Cambridge History of Arabic Literature* III, pp. 342–63; L. E. Goodman, 'The translation of Greek materials into Arabic', in *The Cambridge History of Arabic Literature* III, pp. 477–97.

7 Ibn Khaldûn, *The Muqaddimah: An Introduction to History,* trans. F. Rosenthal (3 vols., Princeton, Princeton University Press, 2nd edn, 1967), I, pp. 253–61, II, pp. 335–36.

8 So, Ibn Khaldûn (1332–1406), *Muqaddimah* III, p. 152: 'There are many books on agriculture. . . . They do not go beyond discussion of the planting and treatment of plants, their preservation from things that might harm them or affect their growth, and all the things connected with that'.

9 The fundamental premises of seventh-century Arab history are almost entirely based on 'tradition' and are due for major revision, see F. M. Donner, Introduction to A. A. Duri, *The rise of historical writing among the Arabs* (Princeton, Princeton University Press, 1983), pp. vii–xvii.

10 J. Vernet, *La cultura hispanoárabe en oriente y occidente* (Barcelona, Ariel, 1978), ch. 3; D. Pingree, 'The Greek influence on early Islamic mathematical astronomy', *Journal of the American Oriental Society* **93** (1973), pp. 32–43; Kunitzsch, *Almagest*; Goodman, 'Translation'.

11 D. Pingree, 'Indian influence on Sassanian and early Islamic astronomy and astrology', *Journal of Oriental Research (Madras)* **34–35** (1964–66), pp. 118–26, and his 'Astronomy and astrology in India and Iran', *Isis* **54** (1963), pp. 229–46.

12 See R. McC. Adams, D. P. Hansen, and N. Abbott, 'Archaeological reconnaissance and soundings in Jundî Shâhpûr' and 'A preliminary historical sketch', *Ars Orientalis* **7** (1968), pp. 53–73.

13 For example, the geographers of the 'formative' era, as analysed by J. F. P. Hopkins, 'Geographical and navigational history', in *The Cambridge History of Arabic Literature* III, pp. 301–27; S. M. Ahmad, 'Djughrâfiyâ (Geography)', in *The Encyclopedia of Islam* II (Leiden, Brill, 2nd edn, 1965), pp. 575–89; A. Miquel, *La géographie humaine du monde musulman jusqu 'au milieu du 11e siècle* (Paris, Mouton, 1967). Syriac, a dialect of Aramaean, was the literary medium of the Nestorian and Jacobite (Monophysite) Christians of Syria and northern Mesopotamia during most of the first millennium AD, see M. G. Morony, *Iraq after the Muslim*

conquest (Princeton, Princeton University Press, 1984), pp. 169–80, 332–83.

14 M. Wellmann, 'Die Georgika des Demokritus', *Abhandlungen, Preussische Akademie der Wissenschaften, Phil.-Hist. Klasse (Berlin)* **4** (1921), pp. 1–59; Ullmann, *Natur,* pp. 428–29; Sezgin, *Geschichte* IV, pp. 310–12; Ibn al-Awwâm, *Le Livre de l'Agriculture d'Ibn el-Awam,* trans. J. J. Clément-Mullet (3 vols., Tunis, Bouslama, 1977).

15 Butzer, 'Classical', p. 546.

16 Ullmann, *Natur,* pp. 429–33; Sezgin, *Geschichte* IV, pp. 314–15. During translation into Syriac, the name 'Vindanius' was garbled to 'Yûniyûs', by which he is cited in Arabic works (Ullmann, *Natur,* pp. 431–32). L. Bolens, *Agronômes andalous du Moyen Age* (Geneva, Université de Gènéve, Etudes et Documents 13, 1981) identifies Yûniyûs with Lucius *Junius* Moderatus Columella, a view supported by T. Fahd, 'Traductions en arabe d'écrits géoponiques', in E. García Sánchez, ed., *Ciencias de la naturaleza en al-Andalus* (Madrid, Consejo Superior de Investigaciones Cientificas, 1992) II, pp. 11–21. Only a full manuscript by Anatolius can resolve this dispute.

17 R. H. Rodgers, *An introduction to Palladius* (London, University of London, Institute of Classical Studies, Bulletin Supplement **35**, 1975), p. 8.

18 Ullmann, *Natur,* pp. 433–37; Sezgin, *Geschichte* IV, pp. 317–18.

19 Cassianus Bassus, *Geoponicorum sive de Re Rustica, Libri XX, ante Constantino Porphyrogenneto,* eds. and trans. P. Needham and J. N. Niclas (2 vols., Leipzig, Fritsch, 1781); E. Fehrle, *Studien zu den griechischen Geoponikern* (Leipzig, Teubner, *Stoicheia* III, 1920), pp. 44–45.

20 J. M. Riddle, *Dioscorides on pharmacy and medicine* (Austin, University of Texas Press, 1985).

21 Ullmann, *Natur,* pp. 71–73; Sezgin, *Geschichte* IV, pp. 312–13.

22 Ullmann, *Medizin,* pp. 115–17, 126–28; Isaacs, 'Arabic', p. 362; Goodman, 'Translation', pp. 487–91.

23 Sabra, 'Scientific', p. 191. Different, technical and conceptual problems plagued the transmission of Ptolemy, see Kunitzsch, *Almagest*: in addition to a Persian translation in the third century and a Syriac version in the sixth, there were four Arabic translations or revisions *c.* 830–900.

24 Khaldûn, *Muqaddimah* III, pp. 143–47, 152–55, also 34–55; Sabra, 'Scientific', pp. 183–84; A. N. Diyâb, 'Al-Ghazâlî', in *The Cambridge History of Arabic Literature* III, pp. 424–45.

25 F. W. Zimmermann, 'Al-Kindî', in *The Cambridge History of Arabic Literature* III, pp. 364–69, especially pp. 366, 368.

26 Zimmermann, 'Al-Kindî'; Ullmann, *Medizin,* pp. 301–302.

27 Riddle, *Dioscorides,* pp. 168–74. See also Figure 6 below.

28 M. Levey, *The medical formulary or Agrabadhîn of al-Kindî* (Madison, University of Wisconsin Press, 1966), pp. 20–23.

29 Riddle, *Dioscorides,* p. 169.

30 B. Lewis ed., *The book of plants of Abû Hanîfa al-Dînawârî* (Uppsala, Uppsala Universitets Arsskrift 10, 1953); also Ullmann, *Natur,* pp. 66–69, 85; Sezgin, *Geschichte* IV, pp. 338–43.

31 C. Cahen, 'History and historians', in *The Cambridge History of Arabic Literature* III, pp. 188–233, especially p. 198.

32 T. Fahd, 'Conduite d'une exploitation agricole d'après "L'agriculture Nabatéenne"', *Studia Islamica* **32** (1970), pp. 109–28; T. Fahd, 'Un traité des eaux dans *al-filâha an-nabatiyya* (Hydrogéologie, hydraulique agricole, hydrologie)', *Atti del convegno internazionale sul tema la Persia nel Medioevo* (Roma, Academia Nazionale dei Lincei, 1971), pp. 277–329; T. Fahd, 'Le calendrier des travaux agricoles d'après *al-Filâha n-nabatîyya*', in J. M. Barral, ed., *Orientalia Hispanica sive Studia F. M. Pareja* (Leiden, Brill, 1974), I, pp. 245–72; T. Fahd, 'L'histoire de l'agriculture en Irak: *Al-filâha an-nabatîyya*', in *Handbuch der Orientalistik,* I Abt., vol. VI, Part 6, i (Leiden, Brill, 1977), pp. 276–377; also Sezgin, *Geschichte* IV, pp. 318–29. For a published transcription of the Arabic text: T. Fahd, ed., *Ibn Wahshiyya: al-Filâha n-nabatiyya* (Damascus, Institut Français d'Etudes Arabes, vol I 1993, vols II and III forthcoming).

33 M. Levey, 'Medieval Arabic toxicology: the book on poisons of Ibn Wahshîya and its relation to early Indian and Greek texts', *Transactions, American Philosophical Society* **56** (1966), pp.

1–131, see p. 20.

34 Fahd, 'Conduite', 'Calendrier', and 'L'histoire'; also H. Q. El-Sâmarrâie, *Agriculture in Iraq during the 3rd Century A.H.* (Beirut, Librairie du Liban, 1972), pp. 24–99.

35 Awwâm, *Libre.*

36 Fahd, 'L'histoire'.

37 Fahd, 'Calendrier'; also J. Vernet, 'La ciencia en el Islam y Occidente', in *L'Occidente e l'Islam nell'Alto Medioevo* (Spoleto, Settimane di Studio del Centro Italiano di Studi sull'Alto Medioevo XII, 1965), pp. 537–72, especially p. 545.

38 The accounts given (see Fahd, 'L'Histoire', pp. 296–99, 304–309, 317–27, 334) of individual plants distinguish those not grown in Mesopotamia or recently adopted there: carobs, lupines, flax, radishes, asparagus and leeks had been introduced from Syria or Egypt; cotton, sorghum and apricots were already considered indigenous; bitter oranges and hemp had recently been brought in via India; limes and bananas were being grown in Syria or Arabia but had not yet been introduced; rice was native to the Indus River but also grown in Mesopotamia, while sugar and indigo are not even mentioned. Since Pliny (*Natural History*, ed. and trans. H. Rackham and W. H. S. Jones (10 vols., London, Loeb Classical Library, 1940–63)) also discusses most of the exotic plants, indicating where they were grown in the Middle East during his time (AD 77), the extent of crop diffusion can be compared. See also Watson, *Agricultural*; and K. W. Butzer, J. F. Mateu, E. K. Butzer, and P. Kraus, 'Irrigation agrosystems in eastern Spain: Roman or Islamic origins?' *Annals, Association of American Geographers* **75** (1985), pp. 495–522, in regard to crop diffusion after the Arab conquest.

39 See E. Honigmann, *Die sieben Klimata: Eine Untersuchung zur Geschichte der Geographie und Astrologie im Altertum und Mittelalter* (Heidelberg, Winter, 1929).

40 See Hopkins, 'Geographical', and Miguel *Géographie.*

41 Levey, *Medical*, p. 278.

42 *Ibid.*, pp. 306–307. For an analysis of wine-making and wines in the Arabic transmission literature, see J. Ruska, 'Weinbau und Wein in den arabischen Bearbeitungen der Geoponika', *Archiv für die Geschichte der Naturwissenschaften und der Technik* **6** (1933), pp. 305–20.

43 Awwâm, *Livre.*

44 Fahd, 'Calendrier', p. 266.

45 See Fahd, 'Conduite', p. 123.

46 See the syntheses of G. LeStrange, *The lands of the Eastern Caliphate* (New York, Cass reprint of 1930 edn, 1966), chs. 2–7, and Pyne, *Impact*, ch. 4.

47 J. Newman, *The agricultural life of the Jews in Babylonia between the years 200 CE and 500 CE* (London: Oxford University Press, 1932), pp. 93–104.

48 Cassianus, *Geoponicorum.*

49 See Fahd, 'Traité', p. 303. For a complementary source on irrigation see C. Cahen, 'Le service de l'irrigation en Iraq au début du XIe siècle', *Bulletin d'Etudes Orientales* **13** (1949), pp. 118–43.

50 Ullmann, *Natur*, pp. 440–42, who even suggests that Ibn Wahshîya may not have existed, his name invented by the translator. However, the elaborate dedication of Ibn Wahshîya's *Book of poisons* to his younger son (Levey, 'Medieval', pp. 20–21) can hardly be considered a hoax, and the direct discussion of the Indian, Persian, Greek and Arabic sources he used for that work suggests, at least to me, that the defamation of Ibn Wahshîya as a dishonest and disreputable author has been somewhat overstated. For example, Meyerhof, 'Transmission', p. 26, claims that the *Nabataean agriculture* used certain Indian authors but suppressed their names; in fact, it uses no Indian materials and the Indian authors, who deal with poisons, are more appropriately, and properly, cited in his *Book of poisons* (Levey, 'Medieval', p. 6).

51 So, for example, T. Fahd, 'Genèse et cause des saveurs d'après l'agriculture Nabatéenne', *Révue de L'Occident Musulman et de la Méditerranée* **13–14** (1973), pp. 319–29, which links four primary tastes (acrid, sweet, tastelessness, and acerbic) with the four Galenic elements so that in various compound variations there are 16 different taste qualities. In regard to colours, again only loosely linked to the thread of an agronomic work, see T. Fahd, 'Genèse et causes

des couleurs d'après l'agriculture Nabatéenne', in R. Grämlich, ed., *Islamwissenschaftliche Abhandlungen* (Wiesbaden, Steiner, 1974), pp. 78–95; Ibn Wahshîya's analysis of colours once more goes beyond Greek understanding.

52 Ullmann, *Natur*, pp. 378–81; Sezgin, *Geschichte* IV, pp. 315–17.

53 *Ibid.*, pp. 198–208.

54 *Ibid.*, pp. 393–401.

55 Thus Ibn Khaldûn, *Muqaddimah*, pp. 151–52: 'The ancients (also) considered plants . . . from the point of view of . . . their relationship to the . . . stars and the great heavenly bodies, which is also used in sorcery. . . . One of the Greek (*sic*) works . . . ascribed to Nabataean scholars . . . contains much information of the type. The Muslims who studied the contents noticed that it was sorcery . . . the study of which is forbidden. Therefore, they restricted themselves to the part of the book dealing with plants from the point of view of planting and treatment . . .'.

56 Varro, *Cato and Varro on agriculture*, ed. and trans. W. D. Hooper and H. B. Ash (London, Loeb Classical Library, 1937).

57 Columella, *On agriculture*, ed. and trans. H. B. Ash, E. S. Forester, and E. H. Heffner (3 vols., London, Loeb Classical Library, 1941–55).

58 Pliny, *Natural.*

59 Cassianus, *Geoponicorum.*

60 P. de Cresentino (Crescenzi), *Liber Ruralium Commodorum Libri XII: Trattato della Agricoltura, Traslatato nella Favella Fiorentina* (3 vols., Milano, Facsimile reprint of Venice edition of 1519, 1805). Whole segments of book II are transcribed verbatim from Albertus Magnus (see *Alberti Magni de vegetabilibus Libri VII, Historia naturalis pars XVIII*, eds. E. Meyer and C. Jensen (Berlin, Reimer, 1867), book VII) and the remainder borrowed extensively from Palladius (*Opus agriculturale de veterinaria medicina, de insitione*, ed. R. H. Rodgers (Leipzig, Teubner, 1975) although there are substantial, fresh materials on outfield agriculture and stockraising.

61 G. A. de Herrera, *Obra de agricultura*, comm. and anthology by T. F. Glick (Valencia, Hispanicae Scientia, Facsimile reprint of 1513 edition, 1979). Herrera compiled from Crescentino and a wide range of authors, mainly Classical but also Arabic; fresh materials are primarily added on arboriculture and stockraising.

62 Awwâm, *Livre*, I, pp. 27, 36, 84, 141, 145–46, 148–50, 186–87, 253, 390, 528, 543–44, II, pp. 24, 30–38, 133, 325. There are 10 citations of high quality to a Sâdhamis, and seven further abstracts from a Sûdiyûn.

63 *Ibid.*, I, p. 153.

64 Sezgin, *Geschichte* IV, pp. 336–39; Ullmann, *Medizin*, pp. 119–21. Whether Ibn Wahshîya might have also drawn directly or indirectly from much older, Sumerian or Babylonian sources, as he implies (e.g., a reference to the agricultural calendar of the Jûhâ district of central Mesopotamia, see Fahd, 'Conduite', pp. 127–28), is a moot point. Sumerian sources include general precepts of management and an agricultural calendar that emphasizes a similar micromanagement, see B. Landsberger, 'Jahreszeiten im Sumerisch-Akkadischen', *Journal of Near Eastern Studies* **8** (1949), pp. 248–97; A Salonen, *Agricultura Mesopotamica* (Helsinki, Annales Academiae Scientarum Fennicae B149, 1968), pp. 202–12.

65 On Ibn Sîna, see Ullmann, *Natur*, pp. 78–79, also in his *Medizin*, pp. 152–56; on al-Bîrûnî: E. Wiedemann, 'Über Gesetzmässigkeiten bei Pflanzen nach al-Bîrûnî', *Biologisches Zentralblatt* **40** (1920), pp. 113–16; G. Saliba, 'Al-Bîrunî and the sciences of his time', in *The Cambridge History of Arabic Literature* III, pp. 405–23; M. Meyerhof, *Un glossaire de matière médicale composé par Maimonide* (Cairo, Mémoire, Institut d'Egypte 41, 1940), p. i.

66 C. S. Colin, I. Habib, H. Inalcik, A. K. S. Lambton, M. al-Shihabi, 'Filâha (Agriculture)', in *The Encyclopedia of Islam* II (Leiden, Brill, 2nd edn, 1965), pp. 899–910.

67 But this should not imply that Near Eastern agronomy was entirely dormant in the interim, see C. Cahen, 'Notes pour une histoire de l'agriculture dans les pays musulmans mediévaux', *Journal Economics and Social History of the Orient* **14** (1971), pp. 63–68; Ullmann, *Natur*, pp.

448–50; D. M. Varisco, 'Medieval agricultural texts from Rasulid Yemen', *Manuscripts of the Middle East* IV (1989), pp. 150–54; D. M. Varisco, *Medieval agriculture and Islamic science: the almanac of a Yemeni Sultan* (Seattle, University of Washington Press, 1993). One of the Yemeni manuscripts (*c.* 1271) is a comprehensive treatise that quotes from Cassianus, Ibn Wahshîya, and the Andalusian agronomists.

68 See R. W. Bulliet, *Conversion to Islam in the Medieval period* (Cambridge, MA, Harvard University Press, 1978), pp. 114–27. On the social context of conversion, see K. B. Wolf, *Christian martyrs in Muslim Spain* (Cambridge, Cambridge University Press, 1988).

69 R. H. Collins, 'Literacy and the laity in early Medieval Spain', in R. McKitterick, ed., *The uses of literacy in early Medieval Europe* (Cambridge, Cambridge University Press, 1990), pp. 109–33, esp. pp. 113–14, 118; Collins, *Arab*, pp. 32, 35–36; also P. Riché, 'L'éducation à l'époque wisigothique: les *Institutionem Disciplinae*', *Anales Toledanos* 3 (1971), pp. 171–80.

70 Meyerhof, *Glossaire*, pp. LXIV–LXV; F. Corriente, *A grammatical sketch of the Spanish Arabic dialect bundle* (Madrid, Instituto Hispano-Arabe de Cultura, 1977), p. 7; K. W. Butzer and E. K. Butzer, 'Historical archaeology of Medieval Muslim communities in the Sierra of eastern Spain', in C. L. Redman, ed., *Medieval archaeology* (Binghamtom, Medieval and Renaissance Texts and Studies 60, 1989), pp. 217–33.

71 Collins, 'Literacy', pp. 114–18; J. Valvé, 'España en el siglo VIII: ejército y sociedad', *Al-Andalus* **43** (1978), pp. 51–112. On the early circulation of Nestorian writings in Islamic Spain, see G. Levi della Vida, 'I Mozarabi tra Occidente e Islam', in *L'Occidente e l'Islam nell'Alto Medioevo* (Spoleto, Settimane di Studio del Centro Italiano di studi sull'Alto Medioevo XII, 1965), pp. 667–95, esp. pp. 677–78.

72 Khaldûn, *Muqaddimah* II, p. 350, III, pp. 301–303.

73 M. Meyerhof, 'Esquisse d'histoire de la pharmacologie et botanique chez les musulmans d'Espagne', *Al-Andalus* 3 (1935), pp. 1–41.

74 C. E. Dubler, 'Die "Materia Medica" unter den Muslimen des Mittelalters', *Sudhoffs Archiv* **48** (1959), pp. 329–50.

75 Bolens, *Agronômes*, pp. 58–87.

76 C. Pellat, ed., *Le calendrier de Cordoue* (Leiden, Brill, 1961).

77 The *anwâ* in preislamic Arabia were originally based on fixed stars such as the Pleiades but subsequently linked (unsuccessfully) to the shifting lunar stations, in an effort to remove preislamic lore, see D. M. Varisco, 'The rain periods in pre-islamic Arabia', *Arabica* **34** (1987), pp. 251–66, and his 'The origin of the *anwâ* in Arab tradition', *Studia Islamica* **74** (1991), pp. 5–28.

78 Vernet, 'Ciencia', p. 545.

79 By Ibn Mâsawaih (786–857), see G. Troupeau, 'Le livre des temps de Jean ibn Mâsawayh', *Arabica* **15** (1968), pp. 113–42.

80 C. Cahen, 'Un traité financier inédit d'époque fatimide-ayyubide', *Journal, Economic and Social History of the Orient* **5** (1962), pp. 139–59, see appendix; D. M. Varisco, 'A royal crop register from Rasulid Yemen', *Journal of the Economic and Social History of the Orient* **34** (1991), pp. 1–22.

81 Dubler, 'Materia'; P. Kahle, 'Ibn Samagûn und sein Drogenbuch', in J. W. Fück, ed., *Documenta inedita Islamica* (Berlin, Akademie Verlag, 1952), pp. 25–44. For a contemporaneous description of the Dioscorides manuscript and its translation, see Vernet, *Cultura*, pp. 69–71.

82 E. H. F. Meyer, *Geschichte der Botanik* (5 vols., Königsberg, Bornträger, 1854–57), III, pp. 173–74; J. Vernet, 'Los médicos andaluces en el "Libro de las generaciones de médicos," de Ibn Yulyul', *Anuario de Estudios Medievales* **5** (1968), pp. 445–68.

83 Kahle, 'Ibn Samagûn'.

84 Ullmann, *Natur*, p. 443, n. 3. For contextual images of the Cordoban school, see D. Fairchild Ruggles, 'Historiography and the rediscovery of Madinât al-Zahrâ', *Islamic Studies* **30** (1991), pp. 129–41.

85 Ibn Wâfid, *El 'Libre de les medicines particulars': versión catalana del texto árabe*, ed. L. Faraudo de

St. Germain (Barcelona, Consejo Superior de Investigationes Científicas, 1943).

[86] J. M. Millás Vallicrosa, 'La traducción castellana del "Tratado de agricultura" de Ibn Wâfid', *Al-Andalus* **8** (1943), pp. 281–332; 'Sobre bibliografía agronómica hispanoarabe', *Al-Andalus* **19** (1954), pp. 129–42.

[87] Herrera, *Obra.* The references that can be crosschecked correspond well.

[88] M. Asín Palacios, *Glosario de voces romances registrados por un botánico anónimo hispano-musulman (Siglos XI–XII)* (Madrid, Consejo Superior de Investigationes Científicas, Escuelas de Estudios Arabes de Madrid y Granada, 1943), p. 13.

[89] Ibn Bassâl, *Libro de agricultura,* ed. and trans. J. M. Millás Vallicrosa and M. Aziman (Tetuán, Instituto Muley el-Hasan, 1955).

[90] Ullmann, *Natur,* p. 445.

[91] Awwâm, *Livre.*

[92] Varro, *Cato,* Book I, p. 10.

[93] Bassâl, *Libro,* p. 64.

[94] *Ibid.,* pp. 45–54.

[95] Honigmann, *Sieben.*

[96] Bassâl, *Libro,* pp. 118–21.

[97] For example, the Hispanoarab geographer al-Idrîsî uses the *klimata* only as a device to organize his regional descriptions, and offers no ecological insight whatsoever; see, for example, the sophisticated summary of Idrîsî by Ibn-Khaldûn, *Muqaddimah* I, pp. 109–66.

[98] J. M. Millás Vallicrosa, 'La traducción castellana del "Tratado de agricultura" de Ibn Bassâl', *Al-Andalus* **13** (1948), pp. 347–430.

[99] J. M. Millás Vallicrosa, 'Aportaciones para el estudio de la obra agronómica de Ibn Hayyay y de Abû-l-Jayr', *Al-Andalus* **20** (1955), pp. 87–101.

[100] Awwâm, *Livre.*

[101] J. M. Millás Vallicrosa and L. Martínez Martín, 'Un capitulo de la obra agronómica de Ibn Hayyay', *Tamuda* **6** (1958), pp. 45–69.

[102] Ullmann, *Natur,* pp. 435–36.

[103] Pliny, *Natural* XX, p. 220. References to a Marsîâl cannot be linked to the epigrammatist Martial, whose writings include none of the materials quoted.

[104] J. M. Carabaza Bravo, *Ahmed b. Muhammad b. Hayyay al-Isbîlî: al-Mugni' fi l-filâha* (Granada, Universidad de Granada, 1988); Millás, 'Aportaciones', pp. 101–105; H. Pérès, 'Abu'l-Khayr al-Ishbîlî', in *The Encyclopedia of Islam* 1 (Leiden, Brill, 2nd edn, 1960), pp. 135–36; Ullmann, *Natur,* pp. 446–47.

[105] Awwâm, *Livre.*

[106] Pérès, 'Abu'l-Khayr'.

[107] J. M. Millás Vallicrosa, 'Sobre bibliografía agronómica hispanoárabe', *Al-Andalus* **19** (1954), pp. 129–37; E. Garcia, 'El tratado agricola del grenadino al-Tignarî,' Quaderni di Studi Arabi (Venice) 5–6 (1987–88) pp. 278–91.

[108] Awwâm, *Livre.*

[109] Asín, *Glosario.*

[110] Ullmann, *Medizin,* p. 274.

[111] E. Lévi-Provençal and E. García Gómez, *Sevilla a comienzos del Siglo XII: el tratado de Ibn 'Abdûn* (Madrid, Moneda y Crédito, 1948).

[112] C. E. Dubler, Review of M. Asín Palacios 'Glosario de voces romances', *Al-Andalus* **10** (1945), pp. 242–52.

[113] Asín, *Glosario.*

[114] Colin *et al.* 'Filâha', p. 901.

[115] Awwâm, *Livre,* cites Ibn Zuhr's 'book on foods' in regard to conserving raisins (I, p. 622) preparing rose-water (II(1), p. 390), and honey (II(2), p. 176). These materials probably come from the recipes appended to Book III of Ibn Zuhr's main work, on therapeutics and dietetics (see Ullmann, *Medizin,* p. 163). This internal evidence is critical, as the youngest citations used, suggesting that Awwâm probably wrote during the 1150s.

116 See various footnotes by Clément-Mullet, the translator, in Awwâm, *Livre* II(2).

117 Awwâm, *Livre* I, p. 9. A critical, comparative reading of Cassianus, *Geoponicorum*, readily demonstrates the difference between a good and a poor compilation. The Byzantine editor of Cassianus did a cut-and-paste job, used little professional discrimination, and had a penchant for bizarre bits of misinformation.

118 For example, Meyer, *Geschichte* III, pp. 260–66.

119 J. M. Millás Vallicrosa, 'Un ejemplar de la azafea árabe de Azarquiel', *Al-Andalus* **9** (1944), pp. 111–19.

120 Awwâm, *Livre*, II(1), pp. 2, 3, 13–15.

121 L. Olson and H. L. Eddy, 'Ibn al-Awam: a soil scientist of Moorish Spain', *Geographical Review* **33** (1943), pp. 100–109.

122 Awwâm, *Livre* II(1), p. 444.

123 Pellat, *Calendrier.*

124 J. Vázquez Ruíz, 'Un calendario anónimo granadino del siglo XV', *Revista del Instituto de Estudios Islámicos en Madrid* **9–10** (1961–62), pp. 23–64.

125 K. W. Butzer, 'Cattle and sheep from old to new Spain: Historical antecedents', *Annals, Association of American Geographers* **78** (1988), pp. 29–56.

126 On Pliny, see Butzer, 'Classical', pp. 549–51. Ibn Khaldûn, *Muqaddimah* III, p. 152, incorrectly thought that Ibn al-Awwâm had simply edited down the *Nabataean agriculture*, but a Turkish translation appeared early, a complete Spanish translation in 1802, a partial German translation in 1842, the French version in 1864–67, an Italian one in 1889–93, and finally an Urdu edition in 1926–32 (Ullmann, *Natur*, p. 447, n. 1).

127 Butzer, 'Classical', pp. 546–47.

128 Varro, *Cato* I.6–7, I.G.

129 Columella, *Agriculture* III.12.1.

130 As cited *Ibid.*, 1–3.

131 *Ibid.*, 3.

132 Varro, *Cato* I.24.1–2.

133 Columella, *Agriculture* II.1.5–7.

134 Varro, *Cato* I.13.4, I.38; Columella, *Agriculture* II.14; Pliny, *Natural* XVII.29–39.

135 Columella, *Agriculture* II10.7, 10.23, 15.5, 17.3; Pliny, *Natural* XVIII.187, 191.

136 Columella, *Agriculture* II2.1–17.

137 Pliny, *Natural* XVII.19–25.

138 *Ibid.*, 37.

139 These are repeated, in simplified form, by Cassianus, *Geoponicorum* II.9–10, II.17, II.23, V.1–2, citing Anatolius, Florentinus, and Varro.

140 Columella, *Agriculture* III.11.9.

141 Awwâm, *Livre* I, pp. 53–54.

142 *Ibid.*, p. 81.

143 *Ibid.*, pp. 39–59.

144 Bassâl, *Libro*, pp. 45–54.

145 Awwâm, *Livre* I, pp. 25–26, 31–32, 67–79.

146 The obscure neo-latinisms or neo-graecisms refer to Soil Conservation Service, *Soil taxonomy* (Washington, US Department of Agriculture, Agriculture Handbook 436, 1975) and its subsequent revisions.

147 Ibn Bassâl, *Libro*, pp. 51–52, introduces the ambiguous terms white and yellow (mountain) soils, concepts which Awwâm, *Livre* I, pp. 71, 502, links to an unidentified agronomist, meaning a 'stranger to Islam', see *Livre* I, p. 8. I have been unable to find anything comparable in the Classical or Medieval sources. This anonymous author provided sophisticated comments on the relative quality of sandy, gravelly and stony soils (Awwâm, *Livre* I, p. 25) that imply intimate familiarity with a semi-arid or arid environment, but there is equally good advice on vines or pomegranates. B. Attié, 'L'ordre chronologique probable des sources directes d'Ibn al-Awwâm', *Al-Qantara* **3** (1982), pp. 299–332, identifies him with

an anonymous Andalusian Christian, author of Paris, ms. no. 4764, and possibly a mentor of Ibn Hâjjaj; that manuscript uses Cassianus heavily. Attié also raises legitimate questions whether the manuscript attributed to Ibn Wâfid may have been authored by another Christian, Nahrāwī. However, Attié's characterization and 're-arrangement' of the other Andalusian agronomists is incompatible with their content and the internal evidence.

148 In part based on Riddle, *Dioscorides*, Figure 4.

149 *Ibid.*, pp. 168–76.

150 'Esquisse'; 'Etudes de pharmacologie arabe tirées de manuscripts inédits', *Bulletin, Institut d'Egypte* **22** (1940), pp. 134–52, **23** (1941), pp. 13–29; Meyerhof, *Glossaire*, pp. i–lxiv.

151 Dubler, 'Materia'. See also C. Villanueva, 'La farmacía árabe y su ambiente histórico', *Miscelanea de estudios Arabes y Hebráicos* **7** (1958), pp. 29–83; J. Vernet, *Historia de la Ciencia Española* (Madrid, Instituto de España, 1975), ch. 3.

152 Lewis, *Book*, p. 8.

153 M. Asín Palacios, 'Avempace botánico', *Al-Andalus* **5** (1940), pp. 255–99; Ullmann, *Natur*, p. 80.

154 Meyerhof, *Glossaire*.

155 Ibn al-Baytâr, *Traité des simples*, trans. L. Leclerc (3 vols., Paris, Maisonneuve, 1877–83).

156 See Dubler, 'Materia'; Vernet, 'Ciencia'; T. Burkhardt, *Moorish culture in Spain* (London, Allen and Unwin, 1972).

157 Ibn Khaldûn, who was aware of both the ongoing political and intellectual decline of the Islamic world *c.* 1400, had interesting views on what had once distinguished scholarship in al-Andalûs. He emphasized its progressive educational methods, in contrast to Morocco, where pupils were simply taught to memorize the Qur'ân (*Muqaddimah* iii, pp. 301–303). Spanish Muslim exiles had created an island of enlightened education in Tunisia (*Muqaddimah* ii, pp. 24, 290, 386–87; iii, p. 302). Implicitly, he saw scholarly education in his day as increasingly isolated, limited to several nuclei.

158 See T. F. Glick, *Islamic and Christian Spain in the Early Middle Ages: comparative perspectives on social and cultural formation* (Princeton, Princeton University Press, 1979), Map 1.

159 J. T. Monroe, *The Shu'ûbiyya in al-Andalus* (Berkeley, University of California Press, 1970), pp.1–22; A. Arjona Castro, *Andalucía Musulmana: estructura política-administrativa* (Córdoba, Caja de Ahorros, 2nd edn, 1982), pp. 93–113; Sabra, 'Scientific', pp. 191–92.

160 R. Arié, *L'Espagne musulmane au temps des Nasrides (1232–1492)* (Paris, Boccard, 1973).

161 Ibn Luyûn, *Tratado de agricultura*, trans. J. Eguaras Ibañez (Granada, Escuela de Estudios Arabes, 1975).

162 Vázquez, 'Calendario'.

163 Bolens, *Agronômes*, pp. 50–81.

164 Watson, *Agricultural*; Butzer *et al.*, 'Irrigation', pp. 500–504.

165 Vernet, 'Ciencia', pp. 566–67.

166 See D. Urvoy, 'Une étude sociologique des mouvements réligieux dans l'Espagne musulmane de la chute du califat au milieu du XIIIe siècle', *Mélanges de la Casa de Velazquez* **8** (1972), pp. 223–94, for similar horizontal and vertical networks of religious scholars in Islamic Spain.

167 Butzer, 'Classical', p. 556.

168 J. M. Millás Vallicrosa, 'El cultivo del agodón en la España árabe', *Boletín, Real Academia de la Historia* **139** (1956), pp. 463–72.

169 K. W. Butzer, J. Miralles, and J. F. Mateu, 'Urban geo-archaeology in Medieval Alzira (Prov. Valencia), Spain', *Journal of Archaeological Science* **10** (1983), pp. 333–49.

170 K. W. Butzer, 'Castles on the Valencian border march', *Bulletin of Middle East Medievalists* **4** (1992), pp. 17–19, 30–31.

171 Butzer, 'Cattle', pp. 37–39.

172 Khaldûn, *Muqaddimah* i, pp. 179–80, emphasizes that Andalusians used olive oil and disdained animal fats.

173 Vázquez, 'Calendario'.