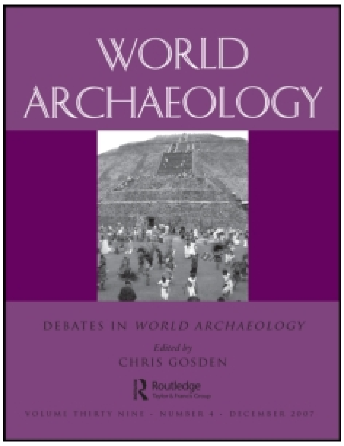


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# Water management and labour in the origins and dispersal of Asian rice

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# Water management and labour in the origins and dispersal of Asian rice

Dorian Q Fuller and Ling Qin


## Abstract

Asian rice occurs in two wild types with differing ecologies that would have necessitated rather different systems of exploitation among early hunter-gatherers and cultivators. The monsoon-adapted ancestors of *indica*-like rice were readily gathered, whether unmanaged or managed through simple burning regimes, and as such might be expected to have long been gathered or cultivated without domestication. By contrast the perennial wetland rice that was ancestral to *japonica* necessitated more intensive forms of management, especially in terms of water regimes, for its productivity to be increased. This encouraged water-management systems that increased in complexity and labour requirements over time and can be linked to the evolution of domestication traits in Yangzte rice between 6000 and 4000 BC. The spread of rice from its Yangzte core seems to have occurred after the development of paddy-field cultivation systems. Meanwhile in India the spread of rice out of the Ganges towards South India, mainly after 1000 BC, may also have occurred only after more intensive irrigated systems of cultivation had developed. These are inferred from the archaeological weed flora of north India to have developed during the Chalcolithic to Iron Age (after 1400 BC). We suggest that the spread of rice, which has played an important role in models of Neolithic population dispersal in Southeast Asia, may have been triggered by the development of more intensive management systems and thus have required certain social changes towards hierarchical societies rather than just rice cultivation *per se*.



## Keywords

*Oryza sativa*; cultivation; domestication; agriculture; India; China.


## Introduction

Rice is a highly productive crop, but this productivity is paid for with labour and water. Rice is the staple crop of the world's most populous countries, India and China, and the most densely populated agricultural regions. For the most part these regions are dominated by rice-paddy agriculture, in which landscapes are modified to retain water in

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which rice can grow and to release water as rice plants come into full maturity. Thus the management of water is central to rice agriculture, and in this paper we will consider the ways in which water management may have been crucial to the domestication of rice, at least in east Asia, and potentially to the delayed domestication elsewhere, such as in South Asia. We will argue that it was the intersection of varying regional ecologies, and their potential for producing wild rice, together with societies that were more or less prepared for major labour investments that structured the process and timing of rice domestication. Once established, the high productivity of rice agriculture may provide the surplus to fuel population growth, and the demographic imperative of rice has been seen as causative to population expansion and migration that shaped the cultural geography of Asia through sequences of migrations, such as the Austronesian dispersal through Island Southeast Asia (Bellwood 1997, 2005), the Austroasiatics through mainland Southeast Asia (Higham 2005; Bellwood 2005), and even the Sino-Tibetans/Sinitic in China and Burma (Van Driem 1998). But we will question whether it was the potential of rice *per se*, or the potential of social systems, with sufficient population already, to mobilize the labour needed for rice production.



## Water in wild rice ecologies and foraging

In recent years traditional morphological taxonomy of the wild members of the sativa-complex has separated annual, more commonly self-pollinating forms adapted to the seasonally drought-prone monsoon regions as *Oryza nivara,* keeping perennial wetland forms as *O. rufipogon sensu stricto* (Vaughan 1994; Plate 1). Some geneticists, however, use *Oryza rufipogon* (*sensu lato*) for both groups. While rice has a complex evolutionary history it is clear that at a whole genome level *indica* and *japonica* are highly diverged

*Plate 1* Examples of wild rice and its habitats: at left, perennial wild rice, *Oryza rufipogon,* growing in permanent pool, central Uttar Pradesh, India (September 2000); at right, annual rice, *Oryza nivara,* growing in seasonal puddles in northern Orissa, India (September 2003).

(Cheng et al. 2003; Garris et al. 2005; Londo et al. 2006; Vaughan et al. 2008). It has been postulated on the basis of such genetic data, as well as archaeological evidence for rice present in human economies by *c.* 7000/6000 BC in both Yangzte China (Lu 2006) and the Ganges, India (Saxena et al. 2006; Saraswat 2005), that separate traditions of rice foraging and early cultivation developed in these two regions (Fuller 2006: 39–46, 2007; Fuller et al. 2007). However, this is complicated by recent data indicating that a few key selected domestication genes, including one of two that control panicle shattering (Li et al 2006; Konishi et al 2006; Onishi et al 2007) and one that causes grains to be white (Sweeney et al. 2007), are shared across *indica* and *japonica,* with plausible origins with or after *japonica* domestication. This can be explained either by separate origins of cultivation and subsequent hybridization of cultivars (preferred by Kovach et al. 2007) or by rapid early geographical dispersal and large-scale introgression from local wild populations in Myanmar and India (Sang and Ge's (2007) 'snowball model'; Vaughan et al. 2008).

The two ecotypes of wild rice are expected to have provided differing opportunities and constraints for foragers and early farmers. *O. nivara*, as an annual grass, is adapted to large-scale seed production, and as such would be an attractive resource for hunter-gatherers. It tends to grow in low-growing clumps and may be widespread on land that is monsoon-inundated and then dried, including around lake edges in the elevations between low-water and high-water shorelines (White 1995: 48). Ethnographically, groups which utilize wild rice in eastern India visit stands when they are green and tie panicles into knots to minimize the loss of grain to shattering; these tied plants can then be harvested by pulling up of tied bundles (into which most early shattered spikelets have fallen), which may or may not involve uprooting (cf. Vaughan et al. 2008: 395). Grain lost to shattering ensures continuity of the wild populations, while harvested grains may be dried and stored. Like the progenitors of the Near Eastern cereals, the annual habit makes these attractive grain sources, and *O. nivara* tends towards self-pollination, which in theory should lend itself to rapid domestication (Zohary 2004), if it were brought into cultivation, especially on new plots of land free of the wild progenitor. On the other hand, the potentially high productivity and predictability of this species in its natural habitat may mean that it could be effectively exploited in its wild state, which may have discouraged intensive cultivation or translocation to new environments (for example, during lower Mesolithic population densities of the early-mid Holocene Ganges). Simple management might have taken the form of the removal of competing vegetation, such as by burning during the dry season after wild rice grains were embedded safely in the soil. In this regard it is worth noting that recent palynological studies in the Ganges plain indicate significant microcharcoal levels that suggest regular anthropogenic burning from the Terminal Pleistocene warm period *c.* 14,500–13,000 BP at Sannai Tal through the early and mid-Holocene, with similar evidence from the end of the Pleistocene at Lahuradewa (Singh 2005; for site locations, Fig. 1). These charcoal levels from the terminal Pleistocene are accompanied by the presence of *Oryza* bulliform phytoliths from *c.* 8000 BC, which show increased levels and morphological diversity from *c.* 7000 BC (Saxena et al. 2006). Whether some of these bulliforms represent cultivated rice, or not, requires further investigation.

By contrast, perennial *Oryza rufipogon* is generally a less prolific seed producer (Vaughan et al. 2008; White 1995: 48). As a perennial that grows in permanently wet soils, this species uses the strategy of perennial growth, through rhizomes and new tillers, to

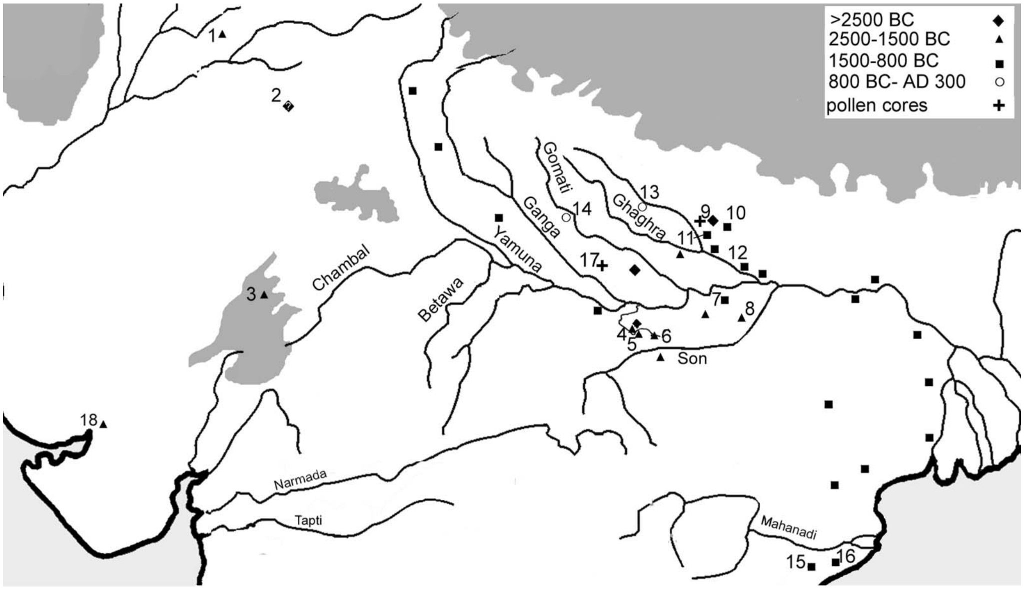


*Figure 1* Map of northern India, showing the locations of archaeological sites with rice, including: 1. Harappa, 2. Kunal, 3. Ojiyana, 4. Mahagara, 5. Koldihwa, 6. Tokwa, 7. Malhar, 8. Senuwar, 9. Lahuradeva, 10. Narhan, 11. Imlidh-Khurd, 12. Manji, 13. Charda, 14. Hulaskhera, 15. Gopalpur, 16. Golbai Sassan, 17. Sannai Tal lake (pollen core), 18. Kanmer.

persist. Grain production is often limited, and may be variable year to year. As such *O. rufipogon* may have provided unreliable wild grain sources, especially when growing in ideal habitats with perennial water. Gathering these populations may have required wading or even approaching them by boat. Under these conditions the natural shedding of mature grain would have presented a particular challenge to foragers as it would not have been easy to gather shed grain from the water or mud. We might expect this rice to have been gathered opportunistically when available in wetland areas that would in any case have been frequented in the late summer/post-monsoon season for gathering other regular foods, such as water chestnuts (*Trapa* spp.) and foxnuts (*Euryale ferox*). An important realization must have been that stands under more water-stressed conditions, where the water table dried back, produced more seeds. This may have encouraged first the planting of rice seeds in more water-stressed conditions, and subsequently the manipulation of water to create and extend such conditions. As White (1995: 58) argues, early rice cultivation was more about management of environment than about individual plants.

Environmental manipulation to produce more rice may have involved several strategies, but water control must have been one of them. We expect such manipulation to have included clearing shallow wetland vegetation and adjacent vegetation, especially shade-producing trees. Burning during the dry season might be one method. Burning would have also facilitated the collection of acorns, by clearing undergrowth, as documented in ethnohistoric sources on aboriginal California (Anderson 2005: 262). It is tempting to see the pollen and microcharcoal evidence adjacent to the Kuahuqiao site as indicating this (Zong et al. 2007), as archaeobotanical evidence indicates that both acorns and rice were consumed (Fuller et al. 2007: table 1). However, as the evidence comes from only a single

*Table 1* A model for the evolution of rice exploitation systems and rice domestication traits in the Lower Yangzte region

| *Mode of subsistence* | *Economic role* | *Ecology of rice* | *Management* | *Harvesting* |
|---|---|---|---|---|
| *From 15,000 BP?* **_Delayed return collecting_** (with storage and post-harvest intensification) | Occasional or secondary resource as available | Wild rice diversification and radiation: populations expanding northwards, local natural bottlenecks (*first finds of rice, e.g. phytoliths in caves and cores)* | N/A | Beating in marshes, possibly even from boats(?). |
| 10,000 BP?–8,000 BP **_Delayed return collecting_** (with diet breadth?; intensive post-harvest technologies) | A important secondary or buffering food resource; major resource dependence on nuts | Natural populations in marshes; with areas prone to stress through fluctuating water-tables producing abundant grain harvests; multiple *Oryza* spp. may be used. | Probable landscape management through burning, but not focused on rice production, but productivity in general and game. | Beating in marshes, possibly even from boats(?). Large-scale seasonal de-husking episodes (*chaff tempered pottery, e.g. Shangshan*) |
| *By 8000–7700 BP* **_Wild plant food production_** (the start of cultivation). Possibly sedentary or with major long-stay sites | A major food resource, reliable and stored, but possibly still secondary to wild gathered nuts. Post-harvest emphasis on boiling, applied to all resources. | Stand management/ landscape manipulation (*anthropogenic burning at Kuahuqiao, Loujiang*). | Clearance through burning, possible water management or careful selection of more fluctuating water environments. | Uprooting? Or beating? Probable multiple pass harvesting, with weak selection for non-shattering. Wild stands possibly harvested alongside cultivated plots. |

(*continued*)

*Table 1* (*Continued*)

| *Mode of subsistence* | *Economic role* | *Ecology of rice* | *Management* | *Harvesting* |
|---|---|---|---|---|
| *By 7000 BP–6300 BP* | | | | |
| ***Pre-domestication cultivation*** (with systematic tillage). Probably sedentary | Becoming a, or the, major staple, together with fish, game and nuts; shift towards more aquatic nuts (e.g. *Trapa*) | ***The development of paddy soils***. Growing in lake margins, in part artificial, on anthroposols | Planting, tillage, some weeding(?); selection of sites which dry during later growth (*Hemudu wooden spades and bone 'spades'*) | Uprooting, possibly with special tools. Reduced/ limited harvesting of wild stands *(Hemudu bone 'spades'?)* |
| *6300–5500 BP* | | | | |
| ***Agriculture*** (domesticated plants in created fields), with first agricultural expansion | The staple food, complementary wild staples continue, and may be cultivated(?); reduction in foraging: dietary narrowing? | ***Start of paddy fields*** (Chinese *tian*). Creation of clearly demarcated artificial cultivation ponds (*Chuodun, Caoxieshan*). | Planting, intensive tillage, field creation and irrigation (wells, chanels). | Uprooting, possibly cutting |
| *By 5500–5000 BP* | | | | |
| ***Intensive agriculture*** (domesticated plants in created fields), with some intensification and expansion | Possible dietary broadening through new crops. | *Spread of paddy fields to central China & Shandong 3000–2500 BC*. Some rice in central China earlier? | Intensive tillage (*introduction of ploughs, continued improvement of harvesting methods)* | Sickling |

sedimentary profile, it is difficult to extrapolate this accurately to a regional scale. Other cores associated with archaeological sites in the region in the region include variable evidence for burning (Atahan et al. 2008; locations indicated in Fig. 2). Thus microcharcoal is consistently high from more than 8000 BC at Loujiang, and from *c.* 4000 BC at Qingpu. At the Guangfulin site low levels of burning are indicated from *c.* 5000 with a marked increase around 2400 BC (the Liangzhu period). Despite variability, this implies a tradition of burning in the region since the early Holocene, and this can be plausibly associated with early wild rice management. A further step would be to manipulate drainage to encourage areas to be flooded during the rainy season and dry out at the end of summer. Such practices would be expected to increase *Oryza rufipogon* grain yields, probably including selection for genes involved with increased grain production and decreased perenniality. One of the major contrasts between *O. rufipogon* and *O. sativa,* is that the cultivar is annual; and this change must have been selected for early in rice management, perhaps even before domestication (in the strict sense).

## Yangzte pre-domestication cultivation and early paddy-fields (to 4000 BC)

It remains problematic how early and how many times this domestication actually took place (Fuller et al. 2007, 2008; Liu et al. 2007). There are a number of issues relating to the status of rice finds, whether wild gathered, morphologically wild but cultivated or obligate cultivars that are morphologically domesticated. Models of domestication have lacked clear support from systematic archaeobotany, either in terms of large sampling programmes with quantitative study or in terms of detailed documentation of domesticated morphology. For example, there have been no analyses of weed floras that might indicate cultivation, as has been documented in the Near East (Colledge 1998; Hillman et al 2001; Willcox et al. 2008). There has also been no systematic study of rice spikelet bases that preserve hard evidence for whether wild-type or domestic-type seed

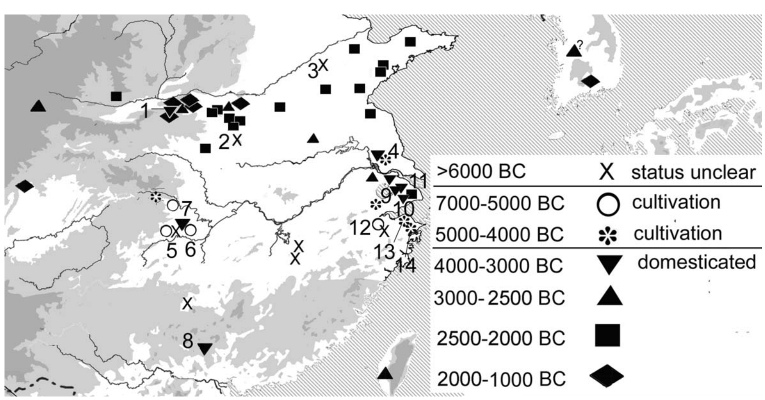


*Figure 2* Map showing representative sites with rice evidence in China including sites mentioned in the text: 1. Nanjiaokuo, 2. Jiahu, 3. Yuezhuang, 4. Longqiuzhuang, 5. Pengtoushan, 6. Bashidang, 7. Chengtoushan, 8. Shixia, 9. Chuodun, Caoxieshan and Chenghu, 10. Qingpu, 11. Guangfulin, 12. Kuahuqiao, 13. Tian Luo Shan, 14. Loujiang and Hemudu.

dispersal was present (for criteria, see Thompson 1996; Fuller and Qin 2008), until recent work in the Lower Yangzte (Zheng et al. 2007; Fuller and Qin 2008; Fuller et al. in press). Less direct sources of evidence, such as changes in grain size/shape and phytolith morphometrics, may nevertheless be taken as indicating directional evolutionary changes in rice, and linked hypothetically to domestication processes. In Table 1, we outline a hypothetical sequence from initial rice use by foragers through intensified use, cultivation, domestication and agricultural intensification, indicating expected archaeological indicators and where available interpret existing archaeological evidence in relation to them, especially for the Lower Yangzte region. As the earliest stages of this, and the shift from foraging to initial cultivation, remain obscure, we focus on the final developments of the domestication process.

This model for the evolution of domesticated rice in this region accepts that the process was completed by *c*. 4000 BC (Fuller et al. 2007; Fuller and Qin 2008). Cultivation had begun already by 6000 BC, indicated by the presence of a minority of domesticated rice spikelet bases at Kuahuqiao (Zheng et al. 2007; but for other spikelet base identification criteria, see Fuller and Qin 2008). Subsistence at this time and through to 4500–4000 BC was still heavily oriented towards wild gathered foods, of which acorns and *Trapa* water chestnuts and foxnuts (*Euryale ferox*) featured prominently (Fuller et al. 2007). Animal subsistence was focused on fishing and hunting, although small numbers of domesticated pigs were kept (Yuan et al. 2008). In addition to these wild resources, however, rice was planted and cultivated, with gradual evolution towards a domesticated state (Fuller et al. in press). Within the Lower Yangtze region there was a marked shift in rice-grain length, but especially the more informative grain width, over time, both within one stratigraphic sequence (at Lonqiuzhuang, with a transition around 4000) and within the Zhejiang/Jiangsu region by contrasting grains from Kuahuqiao (6000–5400) with those from Chuodun (*c*. 4300–4000) (Fuller et al. 2007). This shift in grain size is consistent with morphological change under domestication, but it might also include some shift due to the ability to harvest fully mature rice (with predominantly/wholly non-shattering/domesticated) panicles, on account of domestication. Other lines of evidence, including unfilled spikelets and spikelet morphologies, also suggest that a proportion of the rice, perhaps *c*. 20–30 per cent, was being harvested before the grains had matured. In the same region there was also a trend in the evolution of bulliform phytolith morphometrics, towards larger sizes, with smaller bulliforms disappearing from assemblages after *c*. 4000 (Fuller et al. 2007; cf. Zheng et al. 2004). Although the precise causes of this change in phytolith size are unclear and require research, it can be suggested to include both directional evolution (as by selection during domestication) and change in harvesting practices (such as timing and/or harvest height). Taken together all these data fit with an interpretation in which rice was morphologically wild but under cultivation practices between 6000 and 4500 BC and subsequent to that came to be predominantly of domesticated morphology.

Correlated with these several morphological changes is evidence for an important development in cultural practice: the creation of paddy-field systems. Two sites east of Taihu Lake of the Late Majiabang cultural period (4300–4000) have produced evidence for ancient field systems (Zou et al. 2000; Cao et al. 2006; Li et al. 2007a). First at Ciaoxieshan and later at Chuodun, excavations have revealed the small artificial features of field units and connected canals and reservoirs dug into the natural sterile soil (Fig. 3).

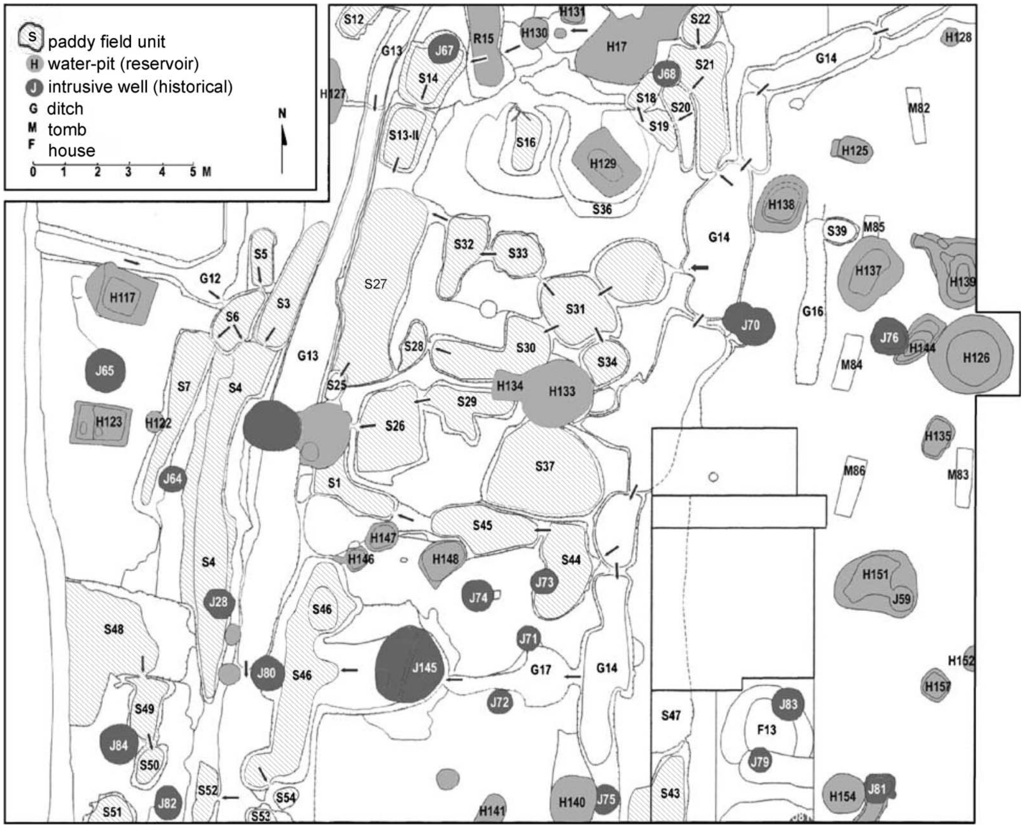


*Figure 3* Paddy-field systems at Chuodun (after Cao et al. 2006).

Analyses on phytoliths, including high densities of rice-leaf bulliforms, and soil chemistry match those expected from rice paddy-fields (Cao et al. 2006; Li et al. 2007a). The field units comprise small dugout features, with variable square or rectangular shapes, ranging in size from roughly 1 square meter to approximately 15 square meters (Chuodun S27). Such fields were then connected by channels to some deeper 'water pits' that are interpreted as reservoirs in which water was retained. Water could be moved from the reservoirs into the field by bucket lifting, and surplus water could be allowed to flow into and out of fields through the interconnecting canals, as can be seen in a photograph from the excavations at Chuodun (Plate 2).

These small fields would have allowed for tight control on water levels in small field units of rice. The layout of the fields appears more organic, rather than centrally planned, and is tied to local topography. The small size of individual units, and excavation evidence indicating that house units were dispersed among the field systems, suggests a non-centralized household unit of production. While manipulation of the water table had probably been important for increasing grain production in *Oryza rufipogon* in earlier periods, the late Majiabang field systems would have ensured tight control of water levels, thereby ensuring productivity. Another potentially important outcome of these field systems would have been the separation of cultivated and partially domesticated

*Plate 2* Photograph showing paddy-field unit and connecting canals at Chuodun (photo courtesy of Professor Ding, Jin-long).



populations from wild stands of rice, reducing cross-pollination and gene flow, and thus speeding up fixation of domestication alleles, such as for non-shattering or thicker grains (Fuller et al. 2007).

Evidence from the Middle Yangzte region suggests a number of parallels with the Lower Yangzte. Although archaeobotanical data are far more limited, grain metrics from Bashidang (7000–6000 BC) show a similar average and range as those from Kuahuqiao (Fuller et al. 2007, 2008), whereas later grains from 4300–3500 show significant proportions of wider and longer grains, including some types at Chengtoushan (Gu 2007) similar to those from Chuodun or from Longqiuzhuang Layer 4. Chengtoushan also provides evidence for apparent rice-field systems from its Tangjiagang Culture (*c*. 4400) and Early Daxi period (*c*. 4300–4000) (Fig. 4; Hunan Provincial Institute of Archaeology 2007: 164–7). This is perhaps slightly earlier than those from the Lower Yangzte area. It is worth noting, however, that the nature of this paddy field is very different from those of the Late Majiabang. Rather than small, agglomerative field units, the Chengtoushan field is a long continuous field for which the ends were not found. It is demarcated on the east and west by linear embankments, with a field width of around 2.7 metres and a length of more than 20 metres (i.e. a field area of more than 54 square metres) (Fig. 4). This suggests involvement of a much larger workgroup and a more communal/centralized organization of field maintenance and cultivation. Its association with a large walled settlement (Hunan Provincial Institute of Archaeology 2007: 164–7; Yasuda et al. 2004) suggests a more centralized social system. The difference from contemporaneous Lower Yangzte field systems may suggest a separate cultural tradition involved in the domestication of rice and the development of rice systems.

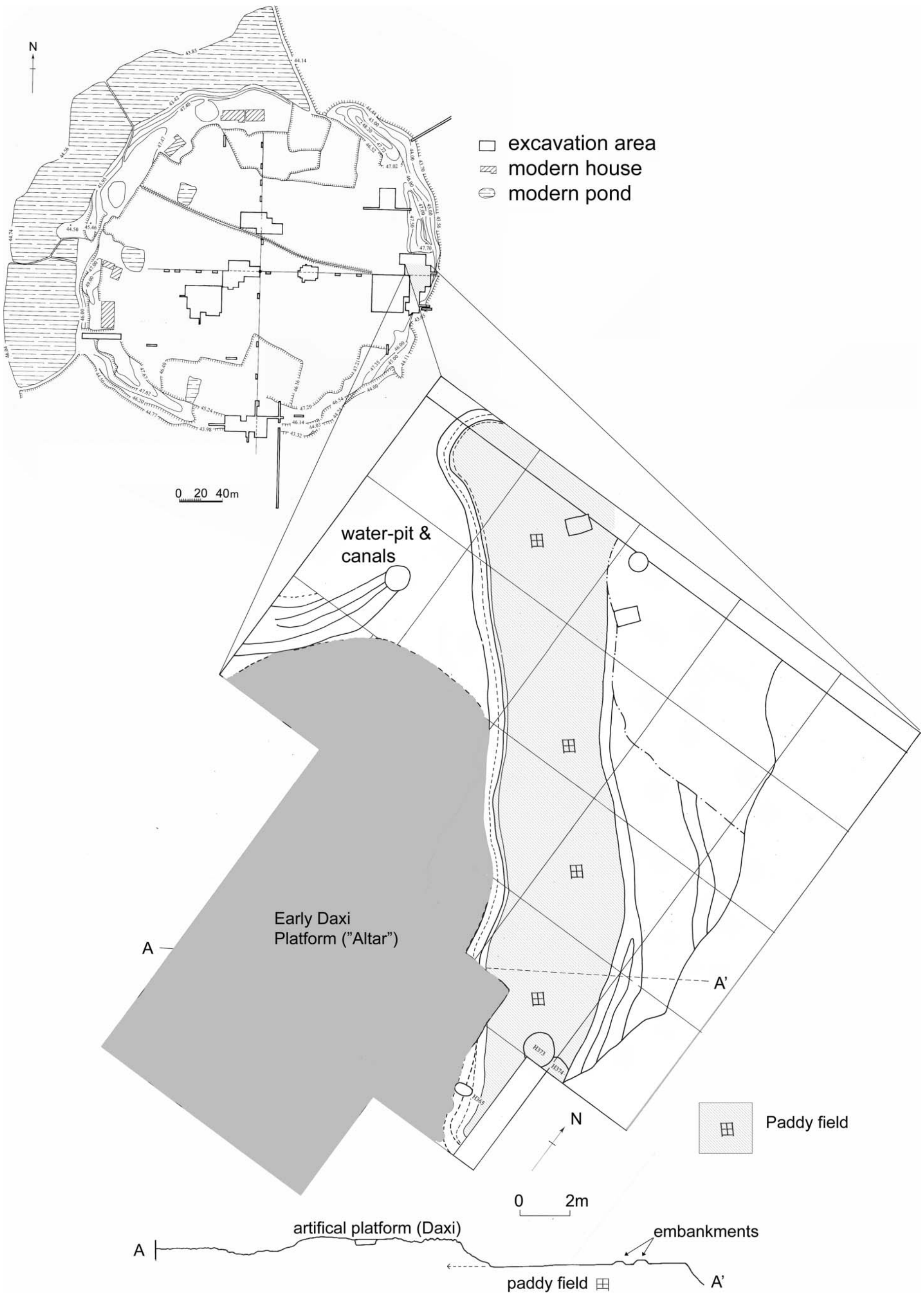


*Figure 4* Plan of the excavated paddy-field area from Chengtoushan, Tangjiagang Culture (pre-Daxi period), *c*. 4400 BC (after Hunan Provincial Institute of Archaeology 2007).

## Social hierarchy, labour mobilization and spread of rice (4000–2200 BC)

In the Lower Yangzte, once rice-field systems were established (before 4000), there is evidence for increasing population growth, craft production and social hierarchy. Site distributional data indicate substantially more sites in the region around Tiahu Lake from the Songze (4000–3300) and then the Liangzhu (3300–2200) periods (e.g. Tao et al. 2006: fig. 10). Cemetery sites indicate changes in social structure (Qin 2000, 2003). While a few graves in the large cemeteries of the Majiabang period include some of the first carved jade in the region, there is little apparent difference in access to such wealth seen between cemeteries or within cemeteries. One exception is the site of Lingjiatan, early Songze period (Anhui Provincial Institute of Archaeology 2000, 2006), which is markedly richer than any other site, and included distinctive jade figurines and ornaments. By the later Songze period (*c.* 3500–3300), however, cemeteries had become smaller, with around 100 graves per cemetery, and within these cemeteries there are recurring patterns of differential access to prestige objects such as jade ornaments and stone axes, and the total number of ceramic vessels deposited in graves (Qin 2003).

Social differentiation became increasingly marked during the course of the Liangzhu period (from 3300), with increasing regional population density and craft specialization, especially evident in the production of prestige jade objects (Qin 2003, 2006). Cemeteries in this period became significantly smaller and more exclusive. Groups of graves generally number between twenty and forty. The cemeteries occur in two types, those dug into specially prepared clay platforms (e.g. Luodun site: see Suzhou Museum 1999) and those dug adjacent to houses (e.g. Puanqiao site: see Archaeology Department of Peking University et al. 1998). By the mid Liangzhu period (3000 BC) it is clear from burial objects that the platform cemeteries have particular access to wealth, including large numbers of jade objects produced by a very limited number of specialized production centres that were probably linked to distinct, and controlled, geological jade sources (e.g. Fanshan Site: see Zhejiang Province Institute of Archaeology 2005a; Qin 2003, 2006). The richest platform cemeteries are clearly located at the key regional centres, much as proto-urban Liangzhu itself (Zhejiang Province Institute of Archaeology 2005b). By this period sites were widely distributed across the landscape, and with quite small habitation structures located on low anthropogenic mounds. This pattern suggests a high density of farmers practising more intensive agriculture, such as by plough.

These social changes are accompanied by evidence for intensification of rice agriculture. In the later Songze period and Liangzhu phase, the first stone plough tips occur, indicating more intensive cultivation methods. The earliest plough tips are from a mid to late Songze period cemeteries (see Administration of Cultural Heritage of Shanghai 1985; Zhejiang Provincial Institute of Cultural Relics and Archaeology 2006). Stone plough tips become more common and larger over the course of the Liangzhu period. Still mysterious is who or what pulled the ploughs, as there remains no clear evidence for domesticated buffalos (cf. Yuan et al. 2008; Yang et al. 2008), and it may be that labouring people pulled these.

There are also later developments towards more effective harvesting methods. The first clear sickles, or harvest knives, in the Lower Yangtze date from the Liangzhu period (Chang 1986: 256–2). Recent excavations at the site of Chenghu (Songze period) also suggest some changes in the construction of individual paddy-fields (Ding 2007). Some field units have become much larger than those from earlier Caoxieshan or Chuodun (nearly 100 square metres), and fields appear to be aligned in a more regular terrace-like fashion (Fig. 5). This may indicate that some agricultural groups were able to mobilize larger workforces for field construction. In this regard is it interesting that some sites start

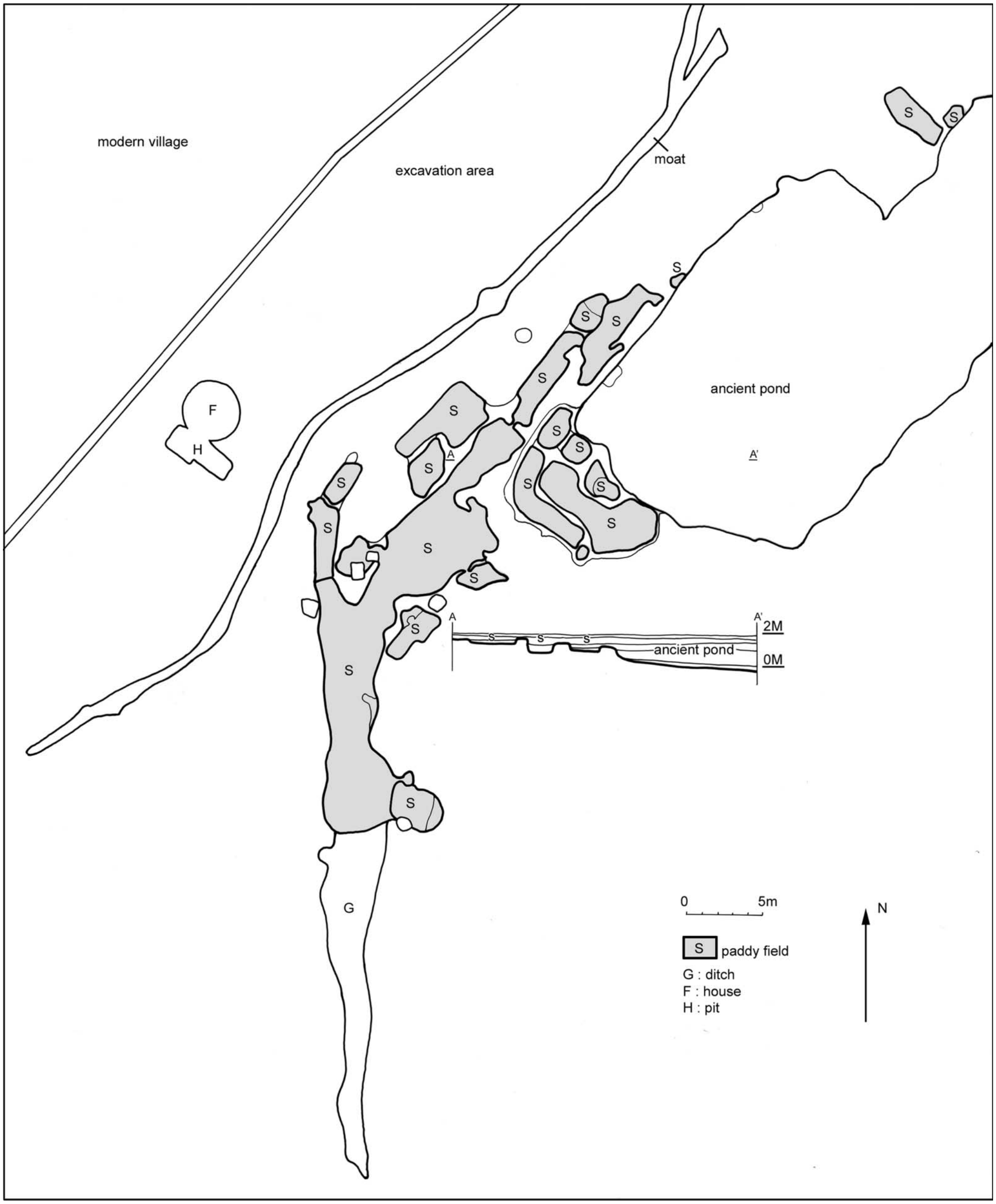


*Figure 5* Plan of excavated paddy-field units from Songze period (4000–3300 BC) Chenghu (after Ding 2007).

to show a predominance of pig remains (Yuan et al. 2008), as pork may well have supported feasting as one means for maintaining solidarity and mobilizing labour.

In the mid Yangtze area, sedentary settlements first appeared during the Pengtoushan period (8000–6000). At the Bashidang site, from the later part of this period, an encircling moat and wall were excavated, as well as living and storage areas, and a cemetery. But there is no evidence for social differentiation within the community or between sites. In the subsequent Daxi period (from *c*. 4300), the difference between the large settlements and regular ones began to be apparent. Chengtoushan and Yinxiangcheng sites are both more than 100,000 square metres, and can be regarded as larger, central sites (Zhang 2003). Chengtoushan site has a wide moat and wall, expanded four times during the occupation. So far the only paddy-field feature in the mid Yangtze area has been found at this site, belonging to pre-Daxi levels beneath the earliest wall, and another possible field from the early Daxi period (Hunan Provincial Institute of Archaeology 2007; Yasuda et al. 2004: 150).

Rapid social change and rearrangement of regional settlement patterns all happened at the next stage, the Qujialing culture. A series of city-sites appeared in this period and continued to be used until the early and mid Shijihe phases (2800–2400 BC), when the sites can be divided into three or four distinct levels (cf. Zhang 2003; Yasuda et al. 2004: 155–6). Shijiahe, a central proto-urban site, is about one million square metres. It produced many figurines and hundreds of thousands of ritual vessels (a red cup type) in one area of the site. This social differentiation continued to intensify from the Qujialing to the early Shijiahe period, similar to contemporary developments of the Liangzhu culture in Lower Yangzte, until these processes were interrupted by the expansion of influence of the late Longshan period (from 2300) of the central plain. At the moment, no direct evidence documents the role of rice agriculture over this period in the middle Yangzte, but it is likely that the increase of population, the development of specialization and the organization of labour for public construction imply rapid development of agricultural societies in this area. This became possible only after the establishment of a rice-paddy system in the earlier Daxi period.

It was only after systematic cultivation of domesticated rice populations was established, perhaps from *c*. 4000, that we find evidence for the spread of rice beyond its Yangzte core (Ruddiman et al. 2008). By, or after, 3000 BC rice as a crop had spread to many sites in the Yellow river basin (Li et al. 2007b; Lee et al 2007; Fuller and Zhang 2007; Jin et al. 2007), Taiwan (Bellwood 2005: 134) and possibly to Korea (Ahn 2004). The earlier finds of this rice dispersal go back into the fourth millennium BC, as at Shixia in Guangdong (Zhang et al. 2006, 2007), South China and Nanjiaokou in Henan (Wei et al. 2000). Although there are a few even earlier finds of rice, older than 6000, at Jiahu and Yuezhuang, these do not seem to form a continuous tradition of cultivation, and have been suggested to be wild (Fuller et al. 2007, 2008). This spread of labour-intensive paddy-field cultivation systems over large areas of East Asia then appears to have occurred rapidly once full domestication and intensive cultivation was established (during the Late Majiabang period). It is probably no coincidence that this spread of paddy-field cultivation correlated with an unexpected rise in global methane levels that started after 3000 BC, and for which rice-paddy agriculture is a likely source (Ruddiman et al. 2008). The long-distance dispersal of rice and farming from Taiwan into Island Southeast Asia (Bellwood 1997) and through the river valleys of mainland Southeast Asia proceeded from this period, reaching central Thailand and Cambodia by *c*. 2000 (Higham 2005). But rather than marking the beginnings of rice cultivation and agriculture *per se* this process seems to happen after the integration of fully domesticated rice and labour-intensive paddy-field systems that relied on increasingly hierarchical labour mobilization strategies.

## State formation and the spread of *indica* rice in South Asia

South Asian archaeologists generally accept that *indica* rice was domesticated in the Ganges plain (e.g. Allchin and Allchin 1997: 94–8; Chakrabarti 1999: 205–7; Possehl 1999: 246–8), although disparities remain as to when and where it was under cultivation and when domesticated (for sites, see Fig. 1). Possehl concluded that cultivation 'preceding the Mature Harappan cannot be supported on current evidence' (1999: 246), while Allchin and Allchin cautioned that 'there may have been long periods when people collected and consumed the seeds of wild rice' (1997: 97). Nevertheless, the possibility of much earlier rice cultivation has been raised again recently based on new, well-dated finds from the site of Lahuradewa (Tewari et al. 2006; Saraswat 2005; Saxena et al. 2006), which include AMS dates on *Oryza* grains back to *c.* 6400 BC and the earliest ceramics in South Asia. It remains uncertain, however, whether this rice was gathered or cultivated, and there is no hard morphological evidence that it is of domesticated type (Fuller 2006, 2007). Tewari et al. (2006: 49) argue that some of the grains resemble domesticated type while others are of weedy/wild types, but more data are needed.

Later evidence from the region, such as Lahuradewa period 1B and Senuwar Period 2 (Saraswat 2005), suggests that rice was a major food resource, probably cultivated, before crops from other regions were adopted, most notably free-threshing wheat and barley adopted in the region between 2400 and 2200. From this period and into the early second millennium BC, agriculture is not in doubt, including both native species and introduced cultivars; after 2000 peninsular Indian cultivars were adopted, such as mung bean and horsegram (Fuller 2006). Earlier cultivation of rice by *c.* 3000–2600 is implied by recent finds beyond its probable wild zone at Early Harappan Kunal (Saraswat and Pokharia 2003), and perhaps the third millennium in the Swat valley of Pakistan (Costantini 1987). The available morphometric evidence for Neolithic Gangetic rice (collected in Harvey 2006) indicates that grains are on the small side, congruent with morphologically wild rice, and perhaps immature grains, being present. All of this evidence could be seen as indicating a long history of cultivation and/or gathering of morphologically wild rice in the Ganges, with the evolution of non-shattering forms occurring quite late after the introduction of domesticated *japonica* rice carrying the key mutations, especially the recessive *sh4* allele, and perhaps the white pericarp *rc* mutation (cf. Kovach et al. 2007; Sweeney and McCouch 2007).

What is striking in the Indian archaeobotanical record, however, is the rapid spread of rice in the second and first millennia BC (see Fuller 2002: 316, fig. 7). In north-western South Asia, including the greater Indus valley, Gujarat and Rajasthan, secure finds of rice date from the Late Harappan period (cf. Fuller 2002; Kharakwal et al. 2007). Based on grain-shape ratios (Costantini 1979, 1987) and bulliform phytoliths (Fujiwara 1993; Sato 2005), however, this rice appears to include *japonica* types, which may indicate diffusion from China via central Asia by this period (also suggested by the occurrence of *Panicum miliaceum, Cannabis* and harvest knives in the Late Neolithic of Kashmir (Fuller 2006: 36)). By the start of the second millennium rice cultivation was also established in Orissa, although better evidence for a mixed agricultural system, including peninsular Indian pulses and rice, dates from the mid-second millennium (Harvey et al. 2006; Harvey 2006).

Further south, in the Deccan, however, rice cultivation takes off in the Iron Age. Earlier finds are few and problematic, including three grains in the Late Jorwe at Inamgaon (Kajale 1988) and plausibly wild grains in low numbers at Hallur in Karnataka (Fuller 2003: 378). However, from Iron Age and Megalithic sites along the eastern peninsula, such as Bhagimohari and Veerapuram, it is clear that rice had been adopted as a major crop (Kajale 1984, 1989), while further south rice-husk-tempered pottery and systematic archaeobotany from sites in southern inland Tamil Nadu indicate the establishment of rice cultivation before the end of the first millennium BC (Cooke et al. 2005; Fuller 2006: 53–5). In central India the spread of rice has been attributed to the spread of elite-supported Buddhist establishments and urbanism, and it is associated with major irrigation works (Shaw and Sutcliffe 2003; Shaw et al. 2007).

Similarly, the spread of rice in the south is associated in the emergence of Tamil city states, around the hinterland of which craft crops like cotton were also cultivated. Cotton had already been adopted into a South Deccan agriculture based on a range of monsoon-adapted savannah millets and pulses. In the case of southern India, rice appears to have been adopted by established, Dravidian-speaking groups (Fuller 2007), and its adoption was connected to new forms of food consumption (Fuller 2005: 769), presumably as rice was a high-status food (Smith 2006). The spread of rice thus indicated the social readiness to deploy more labour-intensive agriculture and the expansion of tank-based irrigation.

The roots of this South Indian rice lay in the earlier Ganges region or Orissa, and evidence from the weed flora suggests that it was the development of irrigated rice that may have been crucial. Table 2 summarizes the archaeobotanical evidence for a selected roster of weed species, including those which are plausibly summer weeds of rice, and indicating a division into those which are typical of wetland or irrigated rice and those which are more likely associated with dry cultivation or upland rice. What can be seen is an overall increase in the number of weed species, but in particular an increasing frequency of occurrence of wetland weeds, while the only species that seem to disappear with time are dryland species (*Silene, Ischaemum*) or the perennial *Coix* (which should decrease with more intensive ploughing). Available data are limited but nevertheless suggest a diversification of cultivation regimes including an increase in irrigated/wetland cultivation.

## Discussion: implications for agricultural dispersal models

Our current understanding of rice domestication suggests key differences from conventional accounts. First the beginnings of rice agriculture were gradual, the domestication process was slow and finished significantly later than often assumed. Over the course of the Chinese Neolithic nut-gatherers switched to being farmers, certainly by 4500–4000 BC. In the Ganges plain groups were also using rice by 7000, but between this time and better evidence for agriculture from 2500–2000, we have little evidence from which to infer cultivation practices or the evolution of rice domestication traits. Once domesticated, rice seems to have spread rapidly, especially through East and Southeast Asia, although it was not merely rice that spread but systems of labour-intensive cultivation. This may indicate that, rather than the beginnings of agriculture *per se*, it was the development of certain

*Table 2* Percentage presence of a select roster of rice weeds across sites from the Ganges and Orissa, in Neolithic, Chalcolithic and Iron Age/Early Historic (from *c.* 800 BC) periods. Columns at right indicate whether they are expected as wet (irrigated/paddy) or dry crop weeds

| *Family* | *Species* | *Neo.* | *Chal.* | *IA/EH* | *Wet* | *Dry* |
|---|---|---|---|---|---|---|
| Commelinaceae | Commelina benghalensis | 20% | 14% | 43% | Wet | Dry |
| Concvolvulaceae | Ipomoea cf. pes-tigridis | 20% | 14% | 14% | Wet | |
| Cyperaceae | Cyperus sp. | 20% | 43% | 86% | Wet | |
| Cyperaceae | Fimbristylis sp. | 0% | 14% | 71% | Wet | Dry |
| Cyperaceae | Scirpus | 20% | 0% | 14% | Wet | |
| Cyperaceae | Scleria | 0% | 0% | 14% | Wet | |
| Cyperaceae | Carex | 0% | 0% | 14% | Wet | |
| Cyperaceae | Eleocharis sp. | 0% | 14% | 57% | Wet | |
| Cyperaceae | Cyperaceae seed indet | 40% | 14% | 14% | Wet | Dry |
| Poaceae | Echinochloa sp. | 0% | 29% | 57% | Wet | Dry |
| Poaceae | Coix lachryma-jobi | 40% | 14% | 0% | Wet | |
| Poaceae | Oryza rufipogon/spontanea | 80% | 14% | 29% | Wet | Dry |
| Polygonaceae | Persicaria/Polygonum (cf. barbata) | 20% | 43% | 43% | Wet | |
| Polygonaceae | Rumex dentatus | 20% | 29% | 14% | Wet | |
| Rubiaceae | Oldenlandia dichotoma | 0% | 29% | 14% | Wet | |
| Aizooaceae | Trianthema portulacastrum | 0% | 29% | 43% | | Dry |
| Amaranthaceae | Amaranthus sp. | 20% | 29% | 14% | | Dry |
| Capparidaceae | Cleome viscosa | 0% | 14% | 14% | | Dry |
| Caryophyllaceae | Silene conoides | 20% | 14% | 0% | | Dry |
| Chenopodiaceae | Chenopodium cf. album | 60% | 43% | 71% | | Dry |
| Chenopodiaceae | Kochia indica | 0% | 0% | 29% | | Dry |
| Fabaceae | Celosia argentea | 0% | 14% | 14% | | Dry |
| Fabaceae | Indigofera sp. | 0% | 57% | 71% | | Dry |
| Lamiaceae | Leonotis nepetifolia | 0% | 14% | 14% | | Dry |
| Malvaceae3 | Sida | 0% | 0% | 29% | | Dry |
| Poaceae | Dactyloctenium aegyptium | 20% | 14% | 43% | | Dry |
| Poaceae | Eleusine indica | 20% | 29% | 29% | | Dry |
| Poaceae | Ischaemum cf. rugosum | 20% | 29% | 0% | | Dry |
| Poaceae | Andropogon sp. | 0% | 29% | 43% | | Dry |
| Poaceae | Cenchrus ciliaris | 0% | 29% | 14% | | Dry |
| Poaceae | Digitaria | 0% | 0% | 14% | | Dry |
| Poaceae | Eragrostis sp. | 20% | 14% | 0% | | Dry |
| Poaceae | Panicum sp. | 60% | 57% | 71% | | Dry |
| Poaceae | Poa sp. | 20% | 29% | 43% | | Dry |
| Solanaceae | Solanum | 0% | 14% | 14% | | Dry |
| | Total weed spp. | 16 | 26 | 31 | | |
| | Wetland spp. | 9 | 12 | 14 | | |
| | Dryland spp. | 12 | 22 | 22 | | |

*Notes*

Numerous weed taxa that are considered winter crop weeds excluded, and total species refers to within this list only. Ecology is derived from Duthie (1960 [1903]), Sarma and Sarkar (2002) and Moody (1989). Presence/absence is tallied on the basis of sites/horizons including, Neolithic (Neo.): Lahuradewa 1B, Imlidh-Khurdh 1, Koldihwa 1, Mahagara, Senuwar 1; Chalcolithic (Chal.): Charda 1, Malhar 1, Narhan 1, Senuwar 2, Imlidh-Khurd 2, Golbai Sassan, Gopalpur; Iron Age/Early Historic (IA/EH): Charda 2, Hulaskhera A/B, Hulaskhera, C/D, Hulaskhera E, Malhar 2, Koldihwa 2, Manji.

social systems that could mobilize labour to create paddy-field systems and/or irrigation works that was the key transition. The creation of these paddy-field systems may also have been a tipping point in the rice domestication process in East Asia. Similarly in South Asia, the period which saw the major spread of rice, during the Iron Age, may be one that was linked to the development and spread of more labour-intensive irrigated rice systems, such as the tank systems documented in central India (Shaw and Sutcliffe 2003; Shaw et al. 2007) and the presumably tank-irrigated rice of the later Iron Age of Tamil Nadu (Cooke et al. 2005). In peninsular India, especially the Dravidian south, it is clear that rice was adopted into existing systems of cultivation and that population movement was not involved in its dispersal; see the linguistic evidence (Fuller 2007).

Labour-intensive forms of rice cultivation would have been highly productive, and can be suggested to have fuelled demographic expansion, but it may well be that it was the social changes towards hierarchy and new means of labour organization that were the turning point in the development and expansion of rice agriculture. Rather than attributing population spread and growth merely to the possession of rice, as implied by Bellwood (2005) or Higham (2005), it is necessary to factor in the social system and how labour was deployed to control and manipulate water. Rice, unlike the cereals of the Near East, followed a trajectory into cultivation and domestication in which the manipulation of water and the deployment of intensive agriculture were central.



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