

The spread of agriculture in eastern Asia

Archaeological bases for hypothetical farmer/language dispersals

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Abstract

Millets and rice were important for the demographic history of China. This review draws on current archaeobotanical evidence for rice and millets across China, Korea, eastern Russia, Taiwan, Mainland southeast Asia, and Japan, taking a critical approach to dating evidence, evidence for cultivation, and morphological domestication. There is no evidence to suggest that millets and rice were domesticated simultaneously within a single region. Instead, 5 regions of north China are candidates for independent early cultivation of millets that led to domestication, and 3 regions of the Yangtze basin are candidates for separate rice domestication trajectories. The integration of rice and millet into a single agricultural system took place ca. 4000 BC, and after this the spread of agricultural systems and population growth are in evidence. The most striking evidence for agricultural dispersal and population growth took place between 3000 and 2500 BC, which has implications for major language dispersals.

Keywords

East Asian agriculture – millet – rice – archaeobotany – domestication – agricultural dispersal

1 Introduction

The origins and spread of millets and rice, the major staples of ancient China, have implications regarding the development and spread of cultures, language groups and ethnic groups across eastern Asia (Bellwood, 2005; Blench, 2005; Sagart, 2008; Robbeets, 2015). While wet rice agriculture is arguably the most productive form of landuse and has supported dense and growing populations (e.g., Ellis and Wang, 1997), it was millet agriculture that underpinned the rise of the Chinese state in the Yellow River (Liu and Chen, 2012) and is therefore equally significant for studies of past demography. This paper reviews the evidence for the early cultivation, domestication and spread of Chinese millets and rice agriculture from ca. 7000 to 2000 BC. The review is based on the empirical archaeobotanical evidence for plants preserved on archaeological sites, usually by charring; but other plant remains, less diagnostic of domestication, e.g. phytoliths and starch grains, and artefacts indicative of probable cultivation and harvesting activities are also considered. The review draws upon the Asian Crops Archaeobotanical Database (AsCAD, Stevens et al., 2016), expanded from an existing Rice Archaeological Database (Fuller et al., 2011; Silva et al., 2015). A critical approach to dating has been taken and spurious, untrustworthy radiocarbon dates have been rejected. The half-life has been standardized to 5568 before calibration (Stuiver, 1982), as many dates from China reported in the 1980s and 1990s assumed a half-life of 5730, and this has sometimes resulted in miscalibrations in the literature (Lu, 1999: 9). Where radiocarbon dates are not available, dating has been proposed by cultural association to a cultural phase, with a critical approach taken to the radiocarbon dating of that phase on other sites.

There can be no doubt that agriculture, in most instances, supports higher population densities and rates of population growth than foraging. This has led to the observation that agriculture was more or less a necessary requisite for cultural traditions that have survived into the later Holocene (with the exception of extremely marginal environments) (Richardson et al., 2001), and that most linguistic diversity derives from language lineages that were spoken and spread by early farmers (Bellwood, 2005). Binford (1968) introduced the idea that the transition to farming was part of a related set of post-Pleistocene adaptations, in which humans adapted to richer biotic environments and increased demographic pressure through the exploitation of a wider range of lower-value resources, including the ancestors of seed crops, and ultimately agriculture. What has become clear through recent empirical evidence, however, is that the initiation of cultivation occurred much earlier than the domestication of crops and, in its early stage, was disconnected from true agricultural sub-

sistence, in which domesticated taxa came to dominate caloric subsistence (Asouti and Fuller, 2013; Fuller et al., 2014; Maeda et al., 2016). A key implication is that, contrary to the notion of a single rapid Neolithic demographic transition, which has tended to be dated by conflating the start of cultivation and eventual domestication (e.g., Guerrero et al., 2008; Bocquet-Appel, 2011), there rather was a protracted series of developments in the Neolithic that culminated in agriculture, which in turn supported much larger populations. In the current contribution, we decouple the start of cultivation from the transition to major food surpluses that is implied by reliance on agriculture and domesticates. While incipient cultivation undoubtedly supported higher sedentism and some population increase over pure foraging, it was the transition to an agricultural economy and the establishment of true domesticated crops that is likely connected to unprecedented population increase.

The widely discussed language-farming dispersal hypothesis rests on the premise that increased population densities within early farming societies lead to emigration in search of new land for agriculture and settlement, which simultaneously dispersed various languages (Bellwood and Renfrew, 2002; Bellwood, 2005). Over time this led to the distribution of related languages, ultimately the language families of farmers, over wide regions. Robbeets (2017, this volume) argues that the expansion of Transeurasian languages, including the ancestors of Japonic and Koreanic languages, arose from *Panicum miliaceum*-based agricultural societies that developed in northeast China. Meanwhile, speakers of languages ancestral to Old Chinese are inferred to have been present in the Yellow River Valley cultivating millets, especially *Setaria italica*, and some rice. On the basis of similarities in culture and ancestral shared vocabulary for *S. italica* and rice, Sagart (2008; 2011) has suggested that the origins of Austronesian, which dispersed to Taiwan from the East Asian mainland, lie within or near the Shandong peninsula, rather than the Lower Yangtze Region as postulated by Bellwood (2005). Both Hmong-mien and Austroasiatic have been suggested to be connected to rice origins and dispersal from the Yangtze basin (e.g., Bellwood, 2005; Sagart, 2011), but there has been little detailed correlation of the linguistic and archaeobotanical evidence.

2 Method and philosophy: a critical archaeobotany of domestication and early agriculture

The primary approach represented by this paper is a critical assessment of current archaeobotanical evidence, alongside complementary artefactual evidence of cultivation-related tools. This is not a restatement of commonly held

opinions on the Chinese Neolithic, in particular with regards to pre-Yangshao cultures, before 5000 BC. All of these Early Neolithic cultures, which we deal with in this paper, traditionally tend to be regarded as early farming societies (e.g., Liu and Chen, 2012; Underhill, 2013; Shelach and Teng, 2013 and see primary references in Tables S1–S4), but this relies on assigning them agricultural economies more on assertion and assumption rather than on empirical evidence. That such sites were bigger and have more investment in house structures than earlier sites is clear, but this shift towards increased sedentism does not prove year-round occupied villages, nor does it make them farming settlements comparable to those which followed—except by imposing outmoded ethnographic models on the diversity of the pre-agricultural world (see Asouti and Fuller, 2013 for a similar critical perspective on the Near East). Much of this stems from the tendency to equate the presence of domesticated crops, or more precisely, plants undergoing domestication, with fully agricultural societies. This is a recurring problem in many parts of the world and in discussions of agricultural origins (Zeder, 2015; Smith, 2015).

We take as our baseline the clear definitions of cultivation, domestication (a genetic status of a crop), and agriculture from Harris (1989; see more recently Asouti and Fuller, 2013; Harris and Fuller, 2013). Cultivation is seen as an activity of soil preparation, sowing, and harvesting, and in its broadest sense has been widely practiced by many hunter-gatherer societies throughout the Holocene and before, in the sense of *niche construction* (Smith, 2015; Fuller et al., 2014). Agriculture, in contrast, is about economic dependence, encompassing a predominant reliance on cultivation—usually centered on species that are domesticated, e.g. changed genetically from their wild ancestors. Smith (2001) suggests that agriculture means that more than 50% of calories come from cultivated resources, and while precise estimates of past diets are always a challenge, this remains a useful rule of thumb. Taking southwest Asian evidence as an example, the earliest cultivation was established across several sub-regions between 9500 and 9000 BC (if not earlier), but at that period no crops show morphological domestication traits. These do not rise to dominance until after 8000 BC, only becoming fixed in wheat and barley around or after 7000 BC (Fuller et al., 2014). Sites that have produced quantified archaeobotanical assemblages comprising more than 50% cereals do occasionally appear in the Levant by 9000 BC, but on the whole, most early cultivating sites had plant economies dominated by wild foods, with cereal-dominated assemblages only becoming the norm from 7000 BC (Maeda et al., 2016). For the Near East, it is clear that the transition from early cultivation through domestication and agriculture took in excess of 2000 years. Our aim in synthesizing the evidence for China has been to look critically at the available archaeobotanical data and

dating. As was the case in the Near East, we have assumed that the transition from early cultivation to agriculture took a minimum of 2000 years, perhaps longer, and the largest demographic increase came at the end of this process. The interpretations presented below follow this reasoning, and to avoid excessive repetition, we will not continually note where this differs from orthodox treatments of Chinese prehistory.

The pre-domestication cultivation stage represents the transition from the gathering of food plants to preparing the soil and sowing them. Initially these plants are morphologically wild, but during this period, genetic and morphological changes occur which “adapt” the plant to the cultivation regime. These biological changes are defined as domestication. A recent synthesis of many major crops from around the world allowed the start and finish of domestication to be mapped comparatively across species (Fuller et al., 2014). For cereals, this study demonstrated two significant results. Firstly, it showed that domestication occurs over extremely protracted periods of time, ranging from 1500 to over 3000 years. Secondly, it confirmed that grain size increased concurrently with changes in shattering, the transition from wild grain dispersal to reliance on human planting. One implication is that grain size change is a useful proxy for the domestication processes when evidence for seed dispersal is not available, as is the case for the millets. While some size increase is noted for millets from early sites (e.g. Zhao, 2004; Liu and Chen, 2012; Barton, 2009: 174–180; Crawford et al., 2016), what is needed are extended sequences demonstrating directional evolution. What these data tend to indicate, as reviewed below, is that the domestication process for millets continued well into the Yangshao period, and this suggests a need to reconsider when agricultural economies and associated demographic shifts took place.

We also differentiate phases in the spread of crops beyond their initial areas of cultivation. Initially, cultivation technologies emerged where wild cereal stands are prolific, replacing wild harvesting. A second phase sees cultivation spread, along with proto-domesticated cereals still undergoing morphological evolution, into areas within the general ecological limits of the wild ancestor, encroaching on and replacing wild cereal stands. At this stage we might expect increasing human population density. The final stage is the spread of fully domesticated crops, along with cultivation technologies, into areas where wild stands were absent or not widespread enough to have formed a major seasonal staple. This third stage is that posited to have spread the language families of early farmers.

3 Centers of cultivation and domestication of millets

Two species of millet were domesticated in China. Foxtail millet, *Setaria italica*, descended from *Setaria viridis*, is widespread throughout northern/central China, Central Asia and Europe, but appears to have been domesticated in China (Eda et al., 2013). *Panicum miliaceum* was also domesticated within northern China, but the wild progenitor is disputed, although *Panicum miliaceum* subsp. *ruderales* represents one possibility (De Wet, 2000).

Given the general absence of charred archaeobotanical evidence before 6500 BC, the longevity of millet consumption is currently based on conjecture. Shizitan, Shanxi, dated from 12,000 to 9,600 BC, is one of the few sites where charred grains have been identified, along with millet starch associated with grinding stones (Bestel et al., 2014). The use of millets between 9000–7000 BC is also affirmed through millet starch from grindstones at Nanzhuangtou, Hebei and Donghulin (Yang et al., 2012a; 2015). They appear dominated by *Setaria* or *S. italica*-like starch, but given current limitations on reference collections (Yang et al., 2012b), these cannot be accepted as definitive evidence for cultivation or domestication.

Based upon current archaeological evidence, five “centers” of millet cultivation are distinguished (A–E below; see Fig. 1 and Supplementary Materials, Table S1).

A *Peiligang, northern Henan*

The Peiligang culture (excluding Jiahu, which is regarded as peripheral) dates to the 7th millennium BC. Radiocarbon dating suggests that sites with good evidence for charred millets occur no earlier than 6500–6000 cal. BC (Liu and Chen, 2012), the earliest evidence relating predominately to reported foxtail millet (*Setaria viridis/italica*), recovered from three sites to the south of the Yellow River (Fig. 1; Table S1). While other sites in this area, between 6500 and 5000 BC, produced charred remains of wild foods—e.g. walnut, jujube, and acorns—flotation was rarely conducted, so small remains of millet are unlikely to have been recovered. However, many sites did yield evidence for cultivation in the form of sickles, spades and/or hoes (Table S1; Zhu, 2013: Table 9.1; Liu and Chen, 2012: Table 5.3).

Sedentary villages, with increased evidence of cultivation tools, subsequently developed in this region during the Early Yangshao period after 5000 BC (Zhu, 2013). A western Yangshao variant (Early Banpo) and an eastern variant (Hougang period 1) are recognized. Recent archaeobotanical research shows increased grain size for *Setaria* still occurring between the Early and Late Yangshao (Zhao, 2015), suggesting that, while well-established cultivation

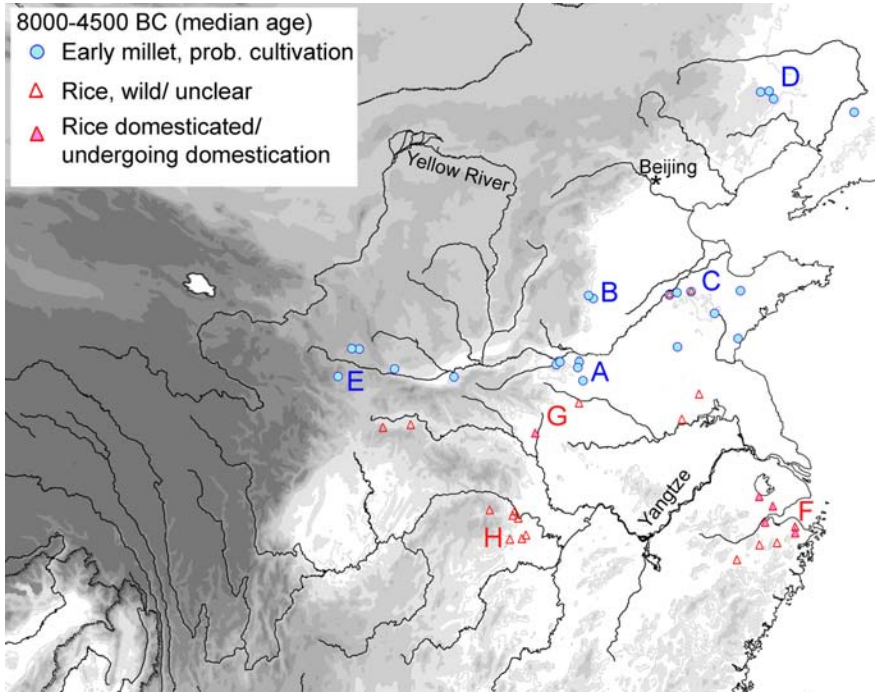


FIGURE 1 Distribution of early sites with archaeobotanical finds of millet and/or rice with median ages between 8000 and 4500 BC. Morphologically wild and domesticated rice differentiated. Regional cultures indicated: A. Peiligang, B. Cishan, C. Houli, D. Xinglongwa, E. Dadiwan, F. Lower Yangtze Neolithic, G. Upper Huai/ Han Neolithic, H. Middle Yangtze Neolithic.

economies were present, the evolution of domestication traits in millets was still ongoing.

B Cishan, southern Hebei

These sites share some cultural affinities with Peiligang sites to the south, although enough differences exist for them to be culturally separated (Zhu, 2013). Currently only Niuwabao and Cishan have reported millet remains, in both cases from rectangular shafts/pits (Ren, 1996). At Cishan, both foxtail and broomcorn millet were identified from phytolith remains (Lu et al., 2009). A critical assessment of radiocarbon dates, along with cultural similarities to the Peiligang culture, places the site in the late 7th/early 6th millennium BC (e.g., Chang, 1986; Cohen, 2011; Zhang and Hung, 2013; Zhao, 2011) and therefore renders it broadly contemporary with millet cultivating sites to the south. The high levels of *de facto* refuse and caches at sites such as Beifudi, and possibly also Cishan, might also indicate some degree of seasonal mobility, perhaps

associated with the collection of acorns (Liu and Chen, 2012: 137). Bettinger and colleagues (2010a) also argue that cache pits like those at Cishan are “typical” of seasonally mobile hunter-gatherers. Cishan culture can also be regarded as a precursor to the early Yangshao (Hougang period 1), when sedentary farming villages became more widespread in this and the Peiligang area (Zhu, 2013, and see above).

c *Houli culture sites, West Shandong*

The Houli culture sites of Yuezhuang and Xihe, near Jinan, have remains of fox-tail and broomcorn millet, along with rice, between 6500 and 5000 BC (Crawford et al., 2006, 2016; Jin G. et al., 2014). Staple isotope data from Xiaojingshan, close to Xihe, indicate the consumption of millets, but demonstrate they contributed less than 25% of dietary protein (Hu et al., 2008). The lack of cultivation tools has also been used to argue that cereals contributed little to the diet (Liu and Chen, 2012: 140), and together with the published photographs, which do not suggest fully domesticated grain, raise questions as to the extent of cultivation/cereal management at this date. The recently reported sites of Zhangmatun, with radiocarbon dates of ca. 7000 cal. BC on wild grape pips, also produced small numbers of millet grains, but as grains of wheat occurred that must be intrusive, the security of these millets must be questioned as well (Wu W. et al., 2014).

The rice grains from these early Shandong sites are also ambiguous. Although there remains some debate over grain size criteria (Liu et al., 2007; Crawford, 2012; Gross and Zhao, 2014), there is no clear case for these grains being regarded as domesticated, and no spikelet bases have been found to assess grain shattering. The Xihe rice is indicated to be morphologically wild (Jin G. et al., 2014), and based on our current understanding of grain size change during domestication (e.g., Fuller et al., 2010, 2014; Deng et al., 2015; Castillo et al., 2016), these finds can indeed be placed at the wild end of the trajectory; hence, this rice is just as likely to be wild gathered as cultivated. Wild rice probably occurred in this region into historic times (Fuller et al., 2010), but, given the lack of continuity of rice into later periods (D'Alpoim Guedes et al., 2015), Houli is a likely dead-end trajectory in early rice cultivation and hence probably played no role in the subsequent development and early spread of rice agriculture. Given Houli rice appears to have been wild, it cannot be ruled out that millets, too, were a largely gathered resource. However, the later Beixin culture (ca. 5500–4000 BC) in Shandong does have limited evidence for millets and finds of harvest knives, and increasing settlement density. Stone spades and unambiguous sedentism dates to the subsequent Dawenkou culture after 4000 BC (Liu and Chen, 2012: 184).

D *Xinglongwa, Manchuria*

The site of Xinglonggou in Inner Mongolia produced a few contexts with large quantities of predominately broomcorn millet and small amounts of foxtail millet, directly radiocarbon-dated to between 6200 and 5400 cal. BC (Zhao, 2011). This material is only a few centuries later than Cishan or the earlier Peiligang, but appears culturally independent. Xinglongwa, the type site for this culture, had no direct botanical evidence, but isotope analysis of the bones revealed some C⁴ plant consumption by the site inhabitants, most likely millets (Zhang X. et al., 2003; Shelach and Teng, 2013). However, millets probably contributed only 15 % of dietary protein, with high N¹⁵ values signifying consumption of hunted animals that consumed C⁴ plants (Hu et al., 2008). The continued presence of cultivation tools through to Zhaobaogu (5400–4500 BC) suggests continuity of a cultivation tradition (Shelach and Teng, 2013). Xinglonggou *Panicum* grains were small (Liu and Chen, 2012: 85), consistent with an early pre-domestication cultivation stage, not domestication.

E *Dadiwan culture, Gansu*

Two sites, Dadiwan and Qin'an, provided charred archaeobotanical evidence for *Panicum miliaceum* between 6000 and 5400 BC (Table S1). While Dadiwan only produced a single spade, other cultivation tools, mainly spades, are known from Baijia and Lijiacun (Liu and Chen 2012: 150–152). Grain measurements of *Panicum miliaceum* are small, indicating grains closer to the morphologically wild end of the spectrum, including possible immature grains (Barton, 2009: 174–178). Isotopic evidence from Dadiwan suggests a C⁴-rich diet for some dogs, indicating millet cultivation and the feeding of dogs on millet cooking scraps (Barton et al., 2009) and/or human feces containing millet.

While there is a case to be made for an independent start of cultivation by the Dadiwan culture in Gansu, this is plausibly a developmental dead-end. Stratigraphic excavation and radiocarbon dating indicate a hiatus in occupation at Dadiwan of a millennium or more through most of the 5th millennium BC (c. 5400–5300 BC to c. 4000 BC; Bettinger et al., 2010b). After this, the site is occupied by people of the Early Yangshao (Late Banpo type) culture, suggesting an influx of settlers from the east who cultivated both *Panicum* and *Setaria*, probably with domesticated pigs that consumed millet and human feces (Barton et al., 2009). Other Late Banpo era sites, such as Xishanping, Heituya and Gedachuan, also produced mixtures of *Panicum* and *Setaria*. Grain sizes of both millets are bigger in the later Yangshao samples from this region (Barton, 2009: 174–178; Liu and Chen, 2012: 85), indicating the domestication process was ongoing into the 4th millennium BC.

3.1 *The establishment of millet agriculture: a summary*

While a number of cultural zones provide candidates for the cultivation and origins of millet domestication, the establishment of agriculture only becomes evident in the late 5th millennium BC with the onset and spread of the Yangshao and Dawenkou cultural traditions along the Yellow River. Our archaeobotanical database includes around 140 sites of this period, and where quantitative data is available, millet grains dominate charred assemblages (e.g., Lee et al., 2007; Fuller and Zhang, 2007; Song, 2011). This period also witnesses the diversification of agriculture, with widespread evidence for soybean, which had begun to undergo size increase, a sign of domestication, by the mid-3rd millennium BC (Lee et al., 2011; Fuller et al., 2014), as well as plausible cultivation of *Perilla frutescens* and hemp (*Cannabis sativa*). It is also possible that some management or cultivation of fruit trees took place, like Chinese date, *Ziziphus jujuba* (cf. Fuller and Zhang, 2007), apricot and peach (Hosoya et al., 2010; Zheng et al., 2014; Weisskopf and Fuller, 2014). Pigs are also widespread across sites in this period and presumably domesticated (Yuan and Flad, 2002; Flad et al., 2007; Larson et al., 2010). The integration of household pig-keeping with millet farming is indicated by carbon isotopes from pigs, such as at Dadiwan, Kangjia, Xipo and even Longshan Liangchengzhen in Shandong (e.g., Pechenkina et al., 2005; Barton et al., 2009; Lanehart et al., 2011). As we will see, domesticated rice began to be adopted into the millet-based agriculture, but even then millets remained the focus of agriculture at all well-documented sites.

4 Centers of cultivation and domestication of rice

The origins of Asian rice have received considerable archaeological and genetic attention in recent years (e.g., Fuller et al., 2010, 2016; Gross and Zhao, 2014; Castillo et al., 2016; Choi et al., 2017). In this discussion, we concern ourselves only with the origins of subspecies *japonica*, which is unambiguously domesticated from wild populations in eastern Asia. The earliest undisputed sites with remains of rice associated with cultivation can be divided into three regions: the Lower Yangtze (F), the Middle Yangtze (H) and the Lower Hanshui Valley/Upper Huai Valley (G) (Fig. 1; see Supplementary Materials, Table S2). Differences in material culture and the nature of the earliest field systems between the Middle and Lower Yangtze argue independent developments of rice cultivation (Fuller and Qin, 2009; Makibayashi, 2014). The Middle-Lower Huai River in northern Anhui/western Jiangsu and the Lower Hanshui River in southern Henan could also represent distinct centers.

F *Early rice of the Lower Yangtze and Lower Huaihe River*

The evolution of domesticated rice from wild rice is archaeobotanically only well documented for the Lower Yangtze, where large assemblages of spikelet bases have been used to track the domestication process (Fuller et al., 2014). Such empirical evidence is better for the middle and later part of the process (Fuller et al., 2009, 2014; Crawford, 2012). The analysis of the proportion of wild (shattering), domestic (non-shattering) and immature rice spikelet bases from these sites over time provides a clear picture of rice domestication as a nearly linear trend of increasing grain size and increasing proportion of non-shattering spikelet bases between 6000 and 3000 BC (Fig. 2).

The earliest dated sites with good evidence for rice use cluster around 7000 BC and are associated with the Shangshan culture (Table S2). Little evidence from macro-remains is available from these sites, so they might represent the beginnings of cultivation or groups who still subsisted solely on gathered wild rice. However, phytolith studies (Wu Y. et al., 2014) put Shangshan at the beginning of a trend in phytolith metrics that led to increasingly domesticated rice plants in later sites like Kuahuqiao and Tianluoshan.

The Shangshan sites were likely only seasonally occupied, with a high reliance on wild foods, but with increased sedentism seen in later phases (Liu and Chen, 2012: 63; Jiang, 2007). The ensuing Kuahuqiao culture is dated from around 6000–5400 BC, with at least some cultivation tools (ZPIACR, 2004), while rice grains and spikelet bases indicate cereals in an early stage of pre-domestication cultivation (Fuller et al., 2014). Extensive use of wild foods, notably acorns and *Trapa* water chestnuts, is similar to the subsequent Hemudu culture (Fuller and Qin, 2010). Unlike the Shangshan, Kuahuqiao appears fully sedentary (Liu and Chen, 2012: 70–72, 158–160).

By 5000 BC, the major sites of Hemudu and Tianluoshan had appeared in the Yuyao region east of Hangzhou, while the Early Majiabang culture emerged north of Hangzhou Bay. The rice spikelet bases from Tianluoshan fall near the middle of the domestication episode, with a shift to the domesticated type outnumbering the wild form around 4650 BC (Fuller et al., 2009). Majiabang and Hemudu grains were plumper than those of earlier Kuahuqiao but yet to reach the size seen in later sites (Fuller et al., 2010; 2014). Wooden hoes and bone spades from Kuahuqiao and Hemudu were suitable for working softer wetland soils, but later were displaced by stone, suited to harder clays (Xie et al., 2015). By around 4000–3800 BC (Late Majiabang period), the percentage of domestic as opposed to wild spikelet bases at Caoxieshan reached 70–80% in some samples, representative of full domestication. Simultaneously, wild foods like acorns and *Trapa* largely dropped out of the diet from the late Majiabang era onwards (Fuller et al., 2010). Rice agriculture is further indicated by the

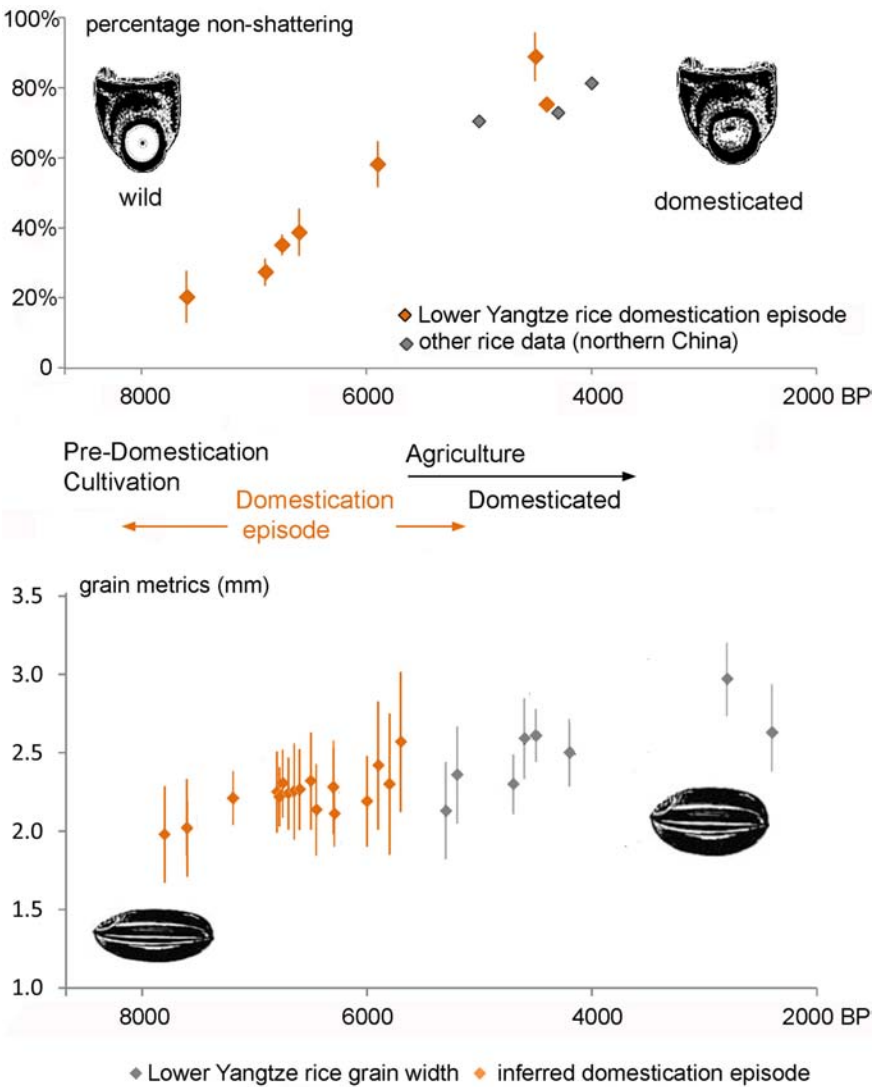


FIGURE 2 Illustration of episodes of evolution of domestication in Lower Yangtze rice, including percentage of non-shattering (top) and grain width (bottom)
AFTER FULLER, 2014

preserved field systems of Caoxieshan, Chuodun and later sites, indicating investment in landscape modification for agricultural systems (Fuller and Qin, 2009). While the Hemudu animal economy focused on deer hunting and fish from fresh water wetlands (Zhang Y., 2014; Nakajima et al., 2010), an age profile shift in pigs suggests ongoing pig domestication during the 5th millennium BC (Zhang Y., 2014).

Parallel processes of early cultivation and domestication of rice can be suggested for societies in the Lower Huai river valley, which joins the lower Yangtze. Slightly predating the Hemudu sites, rice grain impressions, along with stone spades or shovels, are reported from the Houjiazhai culture site of Shuangdun on the Huaihe River in northern Anhui from 5300 to 5050 BC (Zhang and Ren, 2005). Systematic archaeobotanical evidence for assessing domestication status is presently missing. Recently the Shunshanji Neolithic culture, with evidence for rice older than 6000 BC, has been recognized somewhat further north (Nanjing Museum, 2016). However, whether this may come to represent a separate pre-domestication cultivation event or was tied to the spread of cultivation from the Lower Yangtze is presently unclear.

G *The Lower Hanshui and Upper Huai River Basin (Han Basin)*

The earliest good evidence for rice cultivation in China comes from this region. Of the two early rice sites, Jiahu I has a wide range of dates, 6900 BC–5800 BC, but potentially, judging from dates on short-lived fruit stones of 6660–6450 cal. BC (see Table S2), is broadly contemporary with the earliest phase of Baligang, dated 6500–6300 cal. BC by direct radiocarbon dates on rice grains (accelerator, or AMS dates). Both sites show a greater cultural affinity with sites to the north than to the south in their earliest phases, suggesting perhaps a pathway to rice cultivation autonomous from developments in the Middle Yangtze (Zhang and Hung, 2013). It may be noted that high levels of *de facto* refuse and caches at sites such as Jiahu might indicate some degree of seasonal mobility.

Archaeobotanical evidence suggests rice within an early stage of cultivation on both sites (Gross and Zhao, 2014), with grain sizes comparable to Kuahuqiao, suggesting an early stage of evolution in this trait (Fuller et al., 2007; Zhao, 2010a; Deng et al., 2015). Jiahu had bone spades and stone shovels (Chen B. et al., 1995; Zhang and Cui, 2013), but such cultivation tools were not discovered at Baligang (Zhang and Hung, 2013). Both sites produced extensive evidence for wild foods, including *Trapa* and acorns, suggesting a pre-agricultural economy. However, systematic archaeobotany at Baligang produced predominantly domesticated rice spikelet bases, suggesting a pathway to non-shattering panicles evolving in advance of the Lower Yangtze by nearly 2000 years, despite a comparable stage in grain size evolution (Deng et al., 2015). This being said, direct dating of the spikelet bases has not been carried out and intrusion from overlying Yangshao levels cannot entirely be ruled out. A few wild-type *Setaria* and *Panicum* grains were also found here, but these may be wild “weeds” of rice as much as crops. Older literature cites the co-occurrence of millet and rice at Jiahu (e.g., Lu, 2005; Sagart, 2008); however, this appears to be based on the misidentification of *Echinochloa*, a potential wild food or weed of early culti-

vation (see Zhao and Zhang, 2009; 2010a). Further isotope analysis of human skeletons from Jiahu indicated millets were not readily consumed (Hu et al., 2008).

Continuity of these traditions is presently unclear. Baligang has a hiatus of more than a millennium before a clearly agricultural (rice and millet) occupation of the Yangshao culture, Jiahu is abandoned before 5500 BC. Rice impressions in construction debris at Lijiacun and Hejiawan to the west of these sites are broadly dated to the Laoguantai period (c. 5000 BC) and attributed to an early expansion from this region or the Middle Yangtze (Zhu, 2013).

H *The Middle Yangtze—Lishui Valleys (Pengtoushan/Chengbeixi cultures)*

These sites are often cited as beginning around 7000 BC, and therefore contemporary with the sites to the north (Crawford and Shen, 1998; Zhang and Cui, 2013; Pei, 2013). However, a critical assessment and recalibration of radiocarbon dates using the 5568 half-life¹ suggests they potentially post-date both Jiahu and Baligang. Unlike Baligang and Jiahu, where radiocarbon dating upon short-lived species was conducted, radiocarbon dates for the earliest rice use from the Middle Yangtze sites are less reliable, showing wide ranges and being based on charcoal or pottery, the latter of which clearly incorporated old carbon. The two accepted dates from Pengtoushan lie between 6590 and 5670 cal. BC (Hedges et al., 1992), with a median of ca. 6000 cal. BC, with later dates from Bashidang, Zaoshi, Chengbeixi, and Zhicheng (Table S2).

1 Radiocarbon ages are calculated on the basis of the estimated half-life of radioactive ¹⁴C, which was originally estimated as 5568 by the method's originator Willard Libby. However, later measurements suggest that true half-life is closer to 5730 (the Cambridge half-life), and during the 1970s and 1980s some radiocarbon laboratories, including in China, switched to reporting ages based on this half-life. However, it also became clear by the 1970s that ¹⁴C in the atmosphere was not constant and varied over time; therefore, age estimates from the half-life need to be calibrated for variation in ¹⁴C overtime. This has been worked out by dates from tree ring sequences of known age for the past ~10,000 years and corals for older dates. Many laboratories retained the Libby half-life, since the true age is corrected for through calibration programs, and current standards rely on calculations of the radiocarbon age using the 5568 half-life (Stuiver and Polach, 1977; Stuiver, 1982; Millard, 2014). If an age reported based on the Cambridge half-life is entered in a radiocarbon calibration program (such as OxCal), it will return an incorrect and inflated age; such miscalculations are quite common in some published sources on Chinese archaeology. Therefore, throughout this paper, we have corrected original Chinese laboratory reports in the Cambridge half-life to the Libby half-life before calibration.

The status of rice on these Middle Yangtze sites remains enigmatic as no spikelet bases are available, although the small grain size from Bashidang suggests early stages of cultivation. Finds of cultivation tools are rare, with occasional bone and wooden tools present at Bashidang (Pei, 2013: Fig. 24.3) and from the Three Gorges Reservoir area before 5000 BC (Zhu et al., 2008: Table 1). By the Daxi period (4500–4000 BC) rice agriculture seems to be well established, based on the presence of bunded fields at Chengtoushan (Fuller and Qin, 2009), accompanied by a well-established arable weed flora (Nasu et al., 2012) as well as evidence that foxtail millet had been adopted in cultivation alongside rice.

4.1 *Summary on the origins of rice*

On the basis of the present evidence, rice was brought into cultivation within the three outlined areas between 6500 and 5500 BC, but the beginnings of this process and the speed of evolution to domesticated rice and agricultural systems is unclear. Evidence for full domestication presently dates from around 4000 BC in the Lower Yangtze, suggesting a period of 2500 years of pre-domestication cultivation, stretching back to the Shangshan period (around 7000 BC). The Middle Yangtze may have a similar sequence, with domestication in the Daxi period (c. 4500–4000 BC), and incipient cultivation commencing around 6000 BC. In the Upper Han valley, the present evidence from Baligang might suggest domesticated rice much earlier; but given the absence of an *in situ* evolution sequence, this interpretation is unclear, and further investigation and clarification are still needed. Whether the rice cultivators of Jiahu or Baligang persisted or were evolutionary dead-ends also remains unresolved. The early Houli-culture rice found in Shandong remains ambiguous as well, but, as noted above, is more plausibly wild (Fuller, 2011).

5 *The integration of rice and millet agriculture, 4000–3500 BC*

There is no evidence to suggest that millets and rice were domesticated simultaneously within a single region, or brought into pre-domestication cultivation by a single culture. While it is likely that *Setaria italica* and *Panicum miliaceum* became cultivated and domesticated together, the data for the earliest cultivation stages is too incomplete to assess their eventual integration. Only in the case of Shandong's Houli culture might all three have been cultivated together early on, but the dating of cultivation here is based on the least conclusive evidence of any region, with no evidence supporting a full trajectory to domestication continuing from Houli. The empirical archaeobotanical evi-

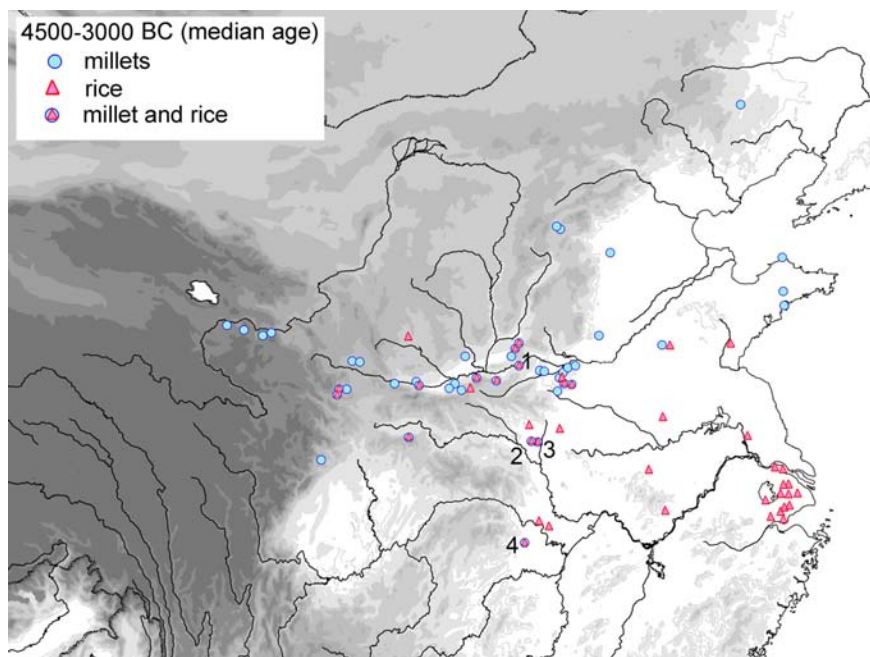


FIGURE 3 *Distribution of sites with archaeobotanical finds of millet and/or rice with median ages between 4500 and 3000 BC. Selected sites with both millet and rice labelled: (1) Nanjiaokou; (2) Baligang; (3) Huitupo; (4) Chengtoushan.*

dence therefore points to distinct separate processes of plant domestication for Chinese millets and rice, and probably in multiple regions. The fragmentary evidence suggests that millet domestication took millennia, as was the case with rice, wheat, barley and other crops (Fuller et al., 2014); millet cultivation was thus not different in terms of the pace of domestication (*contra* Bettinger et al., 2010a). Some of these starts to cultivation may be evolutionary dead-ends, such as Dadiwan millets, Jiahu rice or Houli. In all cases, the earliest part of the process is most obscure, while the tail end, as agricultural dependence and unambiguous sedentism emerged, is better dated.

In the period leading up to 4000 BC, domesticated rice and millets began to spread. In the case of rice, this seems to have been more restricted to intraregional filling in; thus there is an absence of sites south of the Yangtze. By contrast, millet cultivation spread extensively, especially with the expansion of the Early Yangshao cultural tradition.

It is at the end of this first expansionary phase, around 4000 BC, that we find the first evidence for the integration of millet and rice agriculture into the economies of single communities (Fig. 3; see Supplementary Materials, Table S3). Largely this represents the uptake of rice by millet farmers, who

were culturally more expansive, with numerous Yangshao sites having evidence for both millets and rice. The earliest direct AMS date on rice in the core Yangshao area is 4000–3800 cal. BC, at Nanjiaokou, Sanmenxia (western Henan), from an assemblage dominated by foxtail millet (Qin and Fuller, 2009). Other early Yangshao rice finds could date back to 4500 BC, but lack direct dates. The southern expansion of the Yangshao culture, seen at Baligang and nearby Huitupo in the Upper Han River, starts c. 4300 BC with evidence for cultivation of rice, *Setaria* and *Panicum* (Deng et al., 2015; Weisskopf, 2014). Further south in the Middle Yangtze, foxtail millet has been found at Chengtoushan, otherwise dominated by rice agriculture, 4300–4000 BC (Nasu et al., 2012). It is notable that Lower Yangtze agriculture, well documented up to ca. 2000 BC, focused exclusively on rice, without evidence for millets or soybeans.

6 The southern and western spread of domesticated rice and millet agriculture after 3500 BC

By 3500 BC, the spread of rice and millets appears much more rapid, in particular after 3000 BC, when a significant spread of cereals into regions which had previously seen no cultivation of grain crops occurred (Fig. 4). Prior to 3000 BC, *Panicum* and *Setaria* spread beyond Gansu into western Qinghai and south to western Sichuan (D'Alpoim Guedes and Butler, 2014; Chen F. et al., 2015). There is further evidence for rice within Gansu (e.g., An et al., 2010). The first cultivation in western Sichuan, from ca. 3300 BC, is based exclusively on millets and associated with the Majiayao expansion out of Gansu (derived from the Yangshao culture), with rice added after 2700 BC during the Baodun phase, presumably from a separate expansion up the Yangtze (D'Alpoim Guedes, 2011; Fuller et al., 2010; D'Alpoim Guedes et al., 2013). Further finds of millet from the Tibetan Plateau, Qamdo Karuo, start from c. 2800 BC, but are inferred as traded from a lower elevation (D'Alpoim Guedes and Butler, 2014; D'Alpoim Guedes et al., 2014), although it should be noted this site has stone sickles indicative of harvesting (CPAM, 1985).

The Baodun culture is the ultimate source of the spread of mixed rice and millet agriculture into Yunnan from around 2500 BC onwards (D'Alpoim Guedes et al., 2013). Rice, foxtail millet and broomcorn millet are found on Neolithic sites at Baiyangcun dating between 2500 and 1750 BC (Stevens/Fuller, unpublished data) and later at Haimenkou from 1700 BC (Xue, 2010), Dadunzi (Jin H. et al., 2014) and Shifodong (Zhao, 2010b), both dating from 1500 to 1000 BC (see Table S4).

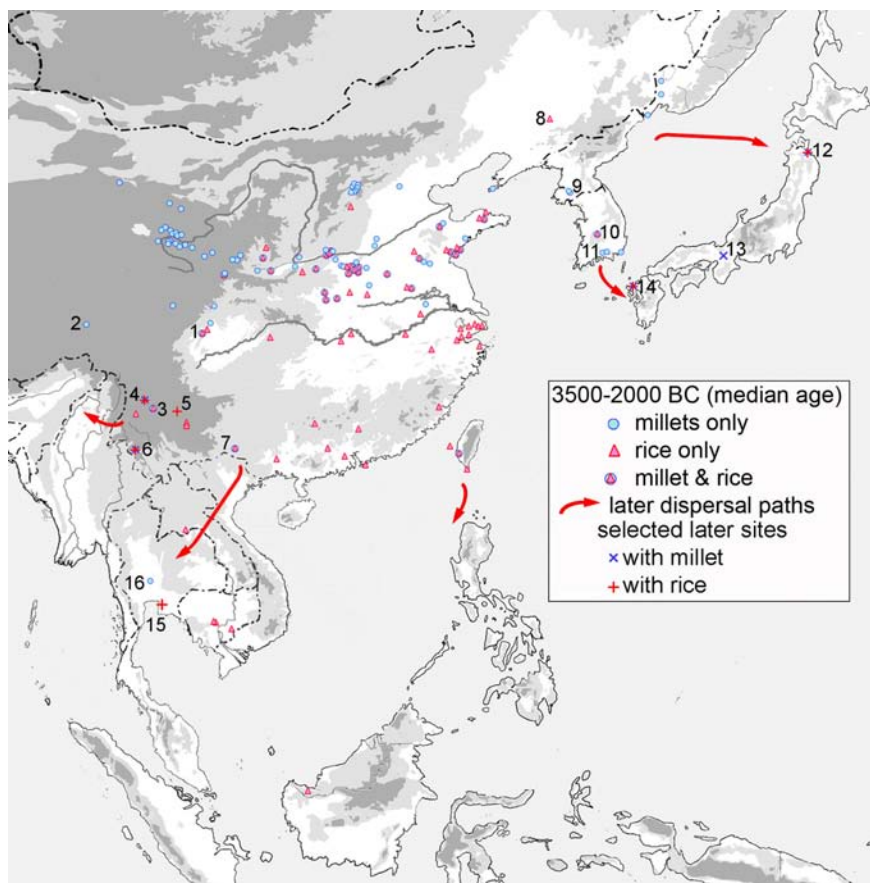


FIGURE 4 Distribution of sites with archaeobotanical finds of millet and/or rice with median ages between 3500 and 2000 BC. Selected sites labelled: (1) Baodun, (2) Qamdo Karuo, (3) Baiyangcun, (4) Haimenkou, (5) Dadunzi, (6) Shifodong, (7) Gantuoyan, (8) Wenjiatun, (9) Jitap-ri and Masan-ri, (10) Daechonri [problematic], (11) Oun and Sangchon B, (12) Kazahari, (13) Ryugasaki, (14) Nabatake (ca. 850 BC), (15) Khok Phanom Di, (16) Non Pa Wai.

As for south of the Yangtze, much of the limited evidence relates to the arrival of rice, at a few sites in Guangdong and Fujian dating generally from around 2500 BC (Table S4; Fuller et al., 2010; Zhang and Hung, 2010). Early populations in these areas focused on nuts (acorns, *Canarium*) and vegicultural plants, like palm pith starch, wild bananas and Chinese arrowroot (Yang et al., 2013; Yang, pers. comm.). In Guangxi, foxtail millet and rice co-occur at Gantuoyan, probably dating to the 2nd millennium BC (D'Alpoim Guedes et al., 2013).

The other significant movements of rice and millet(s) were to Taiwan and perhaps coastal southern China via maritime routes. Given the absence of

millet cultivation in the Lower Yangtze, it is likely that the first cereals in Taiwan derive from further north, such as the Shandong Peninsula, and were carried with the dispersal of maritime-focused groups, whose presence in Shandong is seen through marine shell midden sites from the Dawenkou through Longshan periods (Yuan et al., 2002). This hypothesis is further supported by shared customs like tooth evulsion seen in burials (Sagart, 2008). The earliest finds of foxtail millet and rice from lowland sites in western and northern Taiwan date from between c. 2700 and 2300 BC (Tsang, 2005; Hsieh et al., 2011; and see Supplementary Materials, Table S4). *Panicum miliaceum* may also have been present, given its later importance amongst highland Formosan tribes (Fogg, 1983). In addition to cereals, Taiwanese pigs are genetically derived from central China, unlike pigs further south or in the Pacific (Larson et al., 2010). Maritime cultures, perhaps from Shandong, carrying Chinese cereals to Taiwan may also have transmitted farming among the coastally focused fisher-hunter-gatherers of Fujian and eastern Guangdong, which have strong cultural links to each other and to Taiwan (Jiao, 2007), and later perhaps onwards through parts of island and mainland southeast Asia (Bellwood, 2011; Higham, 2014).

This dispersal of rice and millet together into the tropical far south of China provided the passage for cereal agriculture, predominately rice with some foxtail millet, into mainland southeast Asia, perhaps as early as 2500–2000 BC (Weber et al., 2010), but most notably after 2000 BC (Table S4). Likewise, the spread of millets into northern Gansu resulted in their eventual dispersal into Central Asia by at least 2000 BC (Frachetti et al., 2010; Spengler et al., 2014; Table S4). The movement of wheat and barley (along with sheep and cattle) into China is of a likely similar date (Dodson et al., 2013; Barton and An, 2014).

7 The eastern spread of domesticated rice and millet agriculture after 3500 BC

The migration of agriculture out of northeast China brought the cultivation of millets to south-eastern Siberia, just beyond Jilin and Heilongjiang, by 3500–3400 BC (Sergusheva and Vostresov, 2009), millets to the Korean peninsula in the Middle Chulmun period by 3500–3000 BC (Crawford and Lee, 2003; Lee, 2011) followed by rice around 1500 BC (Ahn, 2010), and after some delay both crops to Japan after 700–600 BC.

The movement of foxtail and broomcorn millet into Korea has only a few direct radiocarbon determinations on grains from South Korean sites, suggesting their introduction between 3500 and 3000 cal. BC (Crawford and Lee, 2003; Lee, 2011; Table S4). Early North Korean sites, between 3500 and 2000 BC,

include Jitap-ri and Masan-ri where only *Setaria italica* was found, but identifications may be unreliable (Lee, 2011; Kim, 2014). The date of the arrival of rice in Korea is less easy to establish. Early finds from Daechon-ri associated with the arrival of millet are uncharred and hence possibly more recent (Lee, 2011). Other early sites like Oun-1 or grains found in peat also have dating problems or include the possibility that the rice may be wild (Crawford and Lee, 2003; Ahn, 2010). Currently, much of the earliest evidence seems to center around the late 2nd millennium BC, the earliest dates being around 1300–1000 BC (Table s4) when agricultural settlements, stone harvesting knives, wooden tillage and pounding tools are recovered from archaeological sites (Ahn, 2010).

The arrival of foxtail and broomcorn millet, shortly after 3500 BC, was probably either across the sea or around the coast via Liaoning into North Korea, as suggested by Ahn (2010). An earlier dispersal of just millets from north-east China would be congruent with the posited language expansion of Proto-Japano-Koreanic (Robbeets, 2015). Ahn (2010) also suggests that rice entered Korea along a similar northern route via the Liaodong Peninsula, and while to date there is only one site recorded with rice, Wenjiatun 3000–2600 BC in Liaoning (Miyamoto, 2009), this route has stronger archaeological support.

The final spread of millets and rice into Japan is particularly poorly dated. The earliest two direct dates, both on rice grains from Kazahari, place the introduction of rice agriculture between 980 and 380 cal. BC (Table s4; D'Andrea et al., 1995), but have wide error margins and are in poor agreement with each other. The younger suggests a date of between 780 and 380 cal. BC, and it might be noted that direct dates of 810–550 cal. BC from Ryugasaki on *Panicum miliaceum* (Miyata et al., 2007) suggest a similar introduction date for millets.

8 The demographic and environmental impact of rice and millet farming (3500–2000 BC)

The evidence reviewed above indicates that agricultural economies based on millets in northern China and rice in the Yangtze basin were well established by the start of the 4th millennium BC. In many parts of the Yellow River Basin, rice was also grown by millet farmers, but appears to be a minor component of agriculture in the Yangshao culture (e.g., Lee et al., 2007; Fuller and Zhang, 2007). While the protracted domestication process began probably prior to 6000 BC for both millets and rice, and plausibly independently across as many as 8 regions, the impact of early cultivation on human economies and demography appears minimal initially. Where evidence is available, wild foods largely outranked early cultivated rice (e.g., Fuller et al., 2009; Fuller and Qin 2010;

Zhao, 2010a; Deng et al. 2015). The drivers of population growth and expansion through migration must be sought in the period when domesticated cereals and agriculture became established between 4500 BC and 3000 BC. There are two aspects of population expansion that should be considered: internal packing, as sites became larger and denser with more of the available land between them colonized for agriculture, and external expansion, the migration of farmers in search of new land in new regions.

The internal packing of growing populations is demonstrated in the distribution of archaeological sites and by evidence for deforestation, implying acquisition of land for agriculture. As a visual comparison, the distribution of millet-growing sites indicates that the total geographical spread of millet only expanded slightly after 4500 BC and only a little more after 3000 BC (Figs 1, 3, 4; Stevens et al., 2016), but that the total number of sites increased. This pattern is even more striking in comprehensive maps based on survey data (Liu, 2004; Li et al., 2009; Wagner et al., 2013). The other indication is massive and sustained reduction in forest cover, estimated from palynological evidence compiled across the region (Ren, 2007). Pollen-derived estimates of forest cover for the Yangtze basin (including the Huai River) and the Yellow River Basin (Middle and Lower) show that forest cover rose through the early Holocene, presumably due to warmer and wetter climate, with peaks reached around 6000 BC, when forest cover was around 90% for the Yangtze and 50% for the Yellow River. Subsequently, there is a marked and sustained reduction in forest (Fig 5A). After 4000 BC, deforestation stopped in the Yangtze basin, but became more pronounced across north China. While there might be some climatic influence, as northern China was more adversely affected by increased aridification (especially 3500–2000 BC), we would argue that differences in agricultural practices between the two regions were more important. Millet production can be most readily raised by colonizing new land, whereas rice output can be increased by intensification of practices within the same unit of land, which has been seen within archaeological and archaeobotanical data in both the Middle and Lower Yangtze regions (Fuller and Qin, 2009; Weisskopf, 2014; Weisskopf et al., 2015).

Population growth is evident from the increase in the density of archaeological sites in the landscape and their size range. Several studies of the substantial published archaeological surveys in central and northern China indicate rising site numbers and the growth of larger sites during the course of the Chinese Neolithic (Li et al., 2009; Wagner et al., 2013). The largest compilation across northern China (Yellow River, Inner Mongolia and northeast China) demonstrates a massive increase in total site counts between 8000 and 2000 BC (Fig. 5B). In order to explore this data on a more regional scale, site counts have been averaged per century to account for the different timespans

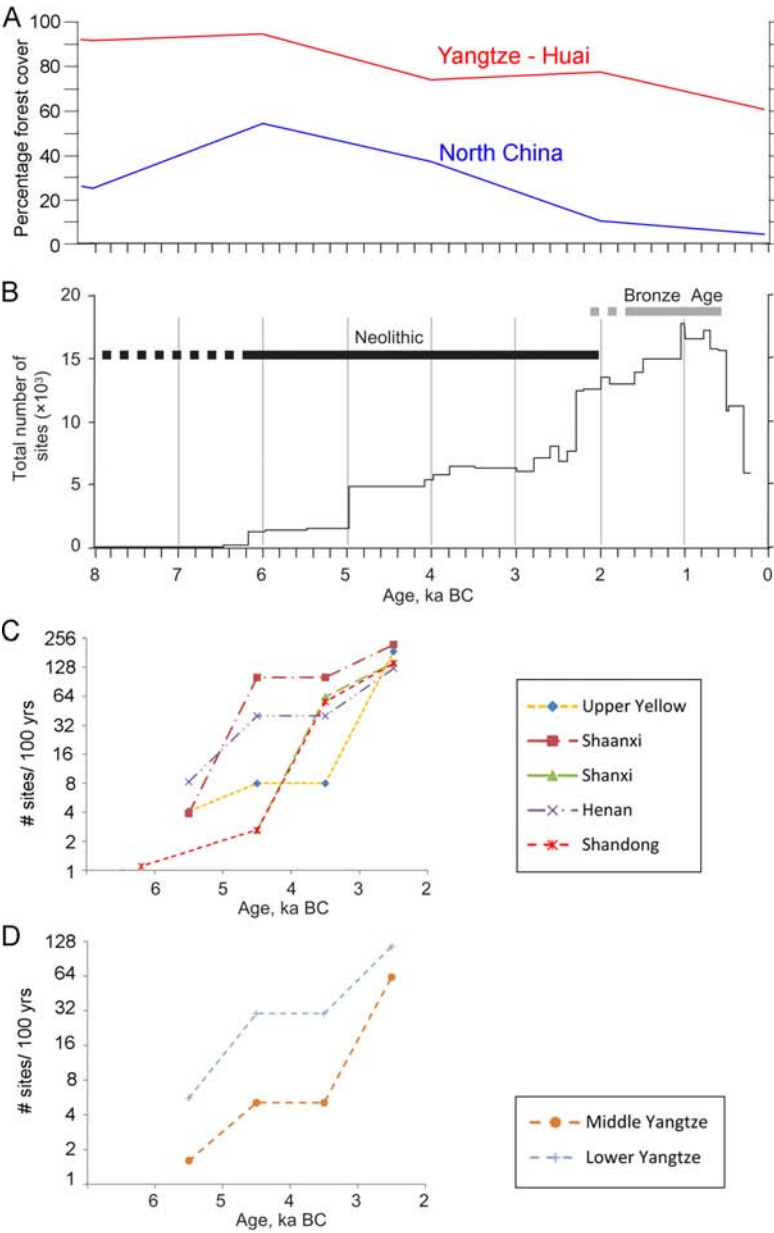


FIGURE 5 Proxies for demographic change: (A) deforestation trends estimated from regional pollen databases (after Ren, 2007); (B) total increase in recorded archaeological sites across north China (after Wagner et al., 2013); (C) regional site counts per century, geometric scale (Upper Yellow River data from Li et al., 2009; others from Wagner et al., 2013); (D) regional site counts per century, geometric scale (data from Li et al., 2009)

of cultural phases (Fig. 5C–5D). Note that the site count (vertical axis) is a geometric scale, and thus the overall slope of the trends represents approximate geometric (exponential) growth in site number.

In addition to an increasing number of sites, the sites themselves got bigger. While data is not systematically available across all of China, central Henan may be taken as an exemplar (after Liu, 2004). In the Peiligang period (7th millennium BC), the largest site was around 6 hectares, while the median site size was 1 ha. During the Yangshao period (5000–3000 BC), the median site size rose to around 5 ha, the largest being around 40 ha. In the Longshan period (2500–1900 BC) the largest was c. 55 ha, but during the Erlitou period, Erlitou itself reached 300 ha (ca. 1700 BC), with several sites attaining sizes between 30 and 75 ha, although the median was around 3 ha. Thus, the growth of population led to an increased number of village sites, the growth of some urban centers, and agricultural expansion through deforestation.

It is in this context that we need to consider the pressures that promoted the expansion of farming via colonization of new regions, the prime mover that underpins the expansion of farmers and their languages (Bellwood, 2005). As both millet and rice farming populations expanded simultaneously, expansion between millet- and rice-focused regions was constrained. A northward expansion of millet farming was limited by climate, as rainfall and the number of growing days became inadequate for millet farming; these climatic constraints likely intensified with increased aridification leading up to 2000 BC. Thus the main outlets for the migratory expansion of millet farmers was to the west and south (along the edge of the Tibet-Qinghai highlands), and eastwards into the Korean Peninsula, far eastern Russia, and potentially, by maritime links, to Taiwan and non-agricultural southeast China. These archaeologically appear as the main areas of expansion, especially during the 3rd millennium BC. Presumably, the initial pulse in population growth early in the Yangshao-Dawenkou era (4th millennium BC) was focused on internal expansion and deforestation, with the second pulse increasingly leading to external migration.

Rice farming was less expansive initially. The ability to intensify wet rice agriculture in the Yangtze basin and its tributaries potentially absorbed considerable population growth through intra-regional population packing. Additionally, the high labor costs of wet rice agriculture probably made its translocation by small frontier populations formidable, and potentially also reduced the attraction of adopting such systems to other societies, creating friction to its dispersal (Fuller and Qin, 2009). Instead, rice only spread to southeast Asia once less labor-demanding rainfed (dry) rice systems evolved (Fuller et al., 2011; Castillo et al., 2016).

9 Concluding remarks: implications for language dispersal

Early cultivation practices are unlikely to have caused major shifts in the distribution of population and, by association, culture or language. Rather, the archaeological evidence for the development of agriculture in China argues for major demographic expansions, which can be expected to have spread major language families geographically, to have taken place from the end of the domestication process. These dispersal processes took place out of the central plains of China, including the middle and lower basin of the Yangtze and lower basin of the Yellow River. Two major demographic pulses are identified that are associated with the establishment of agriculture; the first began around 4000 BC, intensifying between 3000–2500 BC. The first pulse witnessed the spread of millets westward and eastward, while the second pulse saw major expansions of rice and millet southwards by three major routes (Yunnan, Guangdong, and to the southeast). Thus, we have five geographical trajectories of agricultural spread, and perhaps it is no coincidence that five language families have been postulated as having experienced agriculturally based expansions out of greater China (Sino-Tibetan, Austronesian, Austroasiatic, Hmong-Mein and Japonic). Alternative theories purporting to explain geographical derivations from Sino-Tibetan, such as the highly diverse Tibeto-Burman language zone of Northeastern India through Yunnan (e.g., van Driem, 2012), should be rejected, as they are clearly contravened by the archaeological evidence (for an explicit quantitative test of fit with rice data, see Silva et al., 2015). Nevertheless, there is much work to be done to tie together the linguistic evidence for proto-language farming vocabularies, or other associated material culture, and the archaeological geographies of early farming. What the archaeobotanical evidence can provide is a map, in time and space, of subsistence systems, where cultivation began, domestication evolved and agriculture became established as part of demographic expansion.

Supplementary materials

Table s1 lists sites with archaeobotanical evidence for millet and/or evidence for cultivation and dating. Table s2 shows sites with rice. Table s3 lists earliest sites with co-occurrence of millets and rice. Table s4 lists sites with rice and/or millets from Western China, Tibet, Central Asia, Korea and Japan.

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