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From ecological opportunism to multi-cropping: Mapping food globalisation in prehistory

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ABSTRACT

Many of today's major food crops are distributed worldwide. While much of this 'food globalisation' has resulted from modern trade networks, it has its roots in prehistory. In this paper, we examine cereal crops that moved long distances across the Old World between 5000 and 1500 BC. Drawing together recent archaeological evidence, we are now able to construct a new chronology and biogeography of prehistoric food globalisation. Here we rationalize the evidence for this process within three successive episodes: pre-5000 BC, between 5000 and 2500 BC, and between 2500 and 1500 BC. Each episode can be characterized by distinct biogeographical patterns, social drivers of the crop movements, and ecological constraints upon the crop plants. By 1500 BC, this process of food globalisation had brought together previously isolated agricultural systems, to constitute a new kind of agriculture in which the bringing together of local and exotic crops enables a new form of intensification.

1. Introduction

Since Theodore Levitt (1983) brought the term 'globalisation' to economic studies, it has been employed in different ways in different fields (e.g. Held et al., 1999; James, 2005; Steger and James, 2013). Here, we return to Levitt's original usage, to describe the phenomenon of the same resources being consumed across many different cultures in different parts of the world. Levitt's interest was in the modern era and such items as cigarettes, digital watches and Coca-Cola. Our interest in is a much deeper history and the world's many staple crops.

The trans-regional movement of a number of these crops occurred within a series of transformative processes of food globalisation, each of substantial magnitude, but separated in time. The 'Columbian Exchange' involved the transfer of crops between the New World and the Old in the centuries post-dating 1492 AD (Crosby, 2003). Another example is the 'Islamic Agricultural Revolution', which transformed the global agricultural system between the 8th to 13th Century AD (Watson, 1983). Several millennia prior to these, a 'Trans-Eurasian Exchange' took place and this has been discussed by various archaeologists. It involved the exchange of crops between the eastern and western parts of Eurasia and also north Africa (Fuller et al., 2011a; Jones et al., 2011b, 2016b). This earlier exchange, elements of which are first discerned prior to 5000 BC and which attains a very complete form around 1500 BC, brought previously isolated cultivation systems, human

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populations, and ideas from different regions into contact with each other, across the entangled network of the prehistoric Old World.

Early conversations on the ancient interactions between east and west of Eurasia focus on issues such as language, urbanization, pastoralism and analyses of material culture (Bellwood and Renfrew, 2002; Boyle et al., 2002; Wilkinson et al., 2011). Sherratt (2006), for example, observed that two cultural traditions of the East and the West, separated by the Pamir Mountains in the center of the Eurasian Continent, were characterized by their use of ornamental stones in the contrasting colors of blue and green, that is lazurite and jade. This separation began to break down around 1500 BC, through the dispersal of various material traditions across the region, and especially metallurgical technologies (Mei, 2003; Sherratt, 2006). Recent discussions have moved beyond the evidence of material culture alone, to include that of crop plant remains, and put forward the case that the middle of the second millennium BC marks not the threshold, but rather the culmination of an episode of food globalisation in prehistory (Jones et al., 2011b).

In recent years, the gathering of new archaeobotanical evidence from across Eurasia has intensified, allowing a richer and more detailed picture to emerge (e.g. Barton and An, 2014; Betts et al., 2014; Bogaard, 2004; Boivin et al., 2014; Chen et al., 2015; Colledge and Conolly, 2007; Frachetti, 2012; Fuller et al., 2011a; Fuller et al., 2010; Hunt et al., 2008; Jones et al., 2016a; Lightfoot et al., 2013; Lister and Jones, 2012; Liu and Jones, 2014; Miller et al., 2016; Motuzaite Matuzeviciute et al., 2013; Spengler et al., 2014; Stevens et al., 2016; van der Veen, 2010; Zhao, 2011; Zohary et al., 2012). In this paper, we shift the focus to the evidence of the crop plants that moved, and work towards a new framework of chronology and biogeography. On the basis of the chronology and biogeography of crop movement, we organize the evidence into three episodes. Before 5000 BC, crop dispersals are generally to neighboring regions that are broadly compatible in terms of climate and seasonality, for example, in the East the monsoonal belt, and in the West, the mid-latitude belt subject to westerlies. Between 5000 and 2500 BC, various crops extended to the edges of those weather systems contained within and separated by the principal mountain systems and in particular, those associated with the Tibetan Plateau and the Tianshan Mountains. Between 2500 and 1500 BC, a number of crops crossed those boundaries. That crossing of boundaries brought well-established local and recently introduced exotic crops together, both of which had to adapt to varied environments and a new type of human-dominated ecological niche. This in turn allowed for the establishment of a new kind of Old World agriculture, with a focus upon multi cropping (Jones et al., 2016b).

2. Scope and materials

At the core of this process of globalisation is the movement of several principal staples. Free threshing wheat (*Triticum* cf. *aestivum*) and barley (*Hordeum vulgare*) moved from southwest Asia to Europe, India and China, while broomcorn millet (*Panicum miliaceum*) and foxtail millet (*Setaria italica*) moved in the other direction: from China to the West, via Central and South Asia; rice (*Oryza sativa*) travelled across East, South and Southeast Asia; and African millets (*Pennisetum glaucum* and *Eleusine coracana*) and sorghum (*Sorghum bicolor*) moved across sub-Saharan regions and ultimately across the Indian Ocean to South Asia. Other economic important plant taxa, including pulses and fruits, as well as domesticated animals, also spanned across the Old World in various episodes of prehistory.

Prior to 5000 BC, the cropping systems that had come into being around distinct centres of domestication remained relatively isolated from each other. By *c.* 1500 BC, this situation had changed dramatically, with numerous crops grown all over the Eurasia and in parts of Africa. The rapidly amassing body of archaeobotanical evidence has here been rationalized into three distinct periods, illustrated in maps in Figs. 2–4. Locations of representative key sites are indicated in Fig. 1. Site information and associated

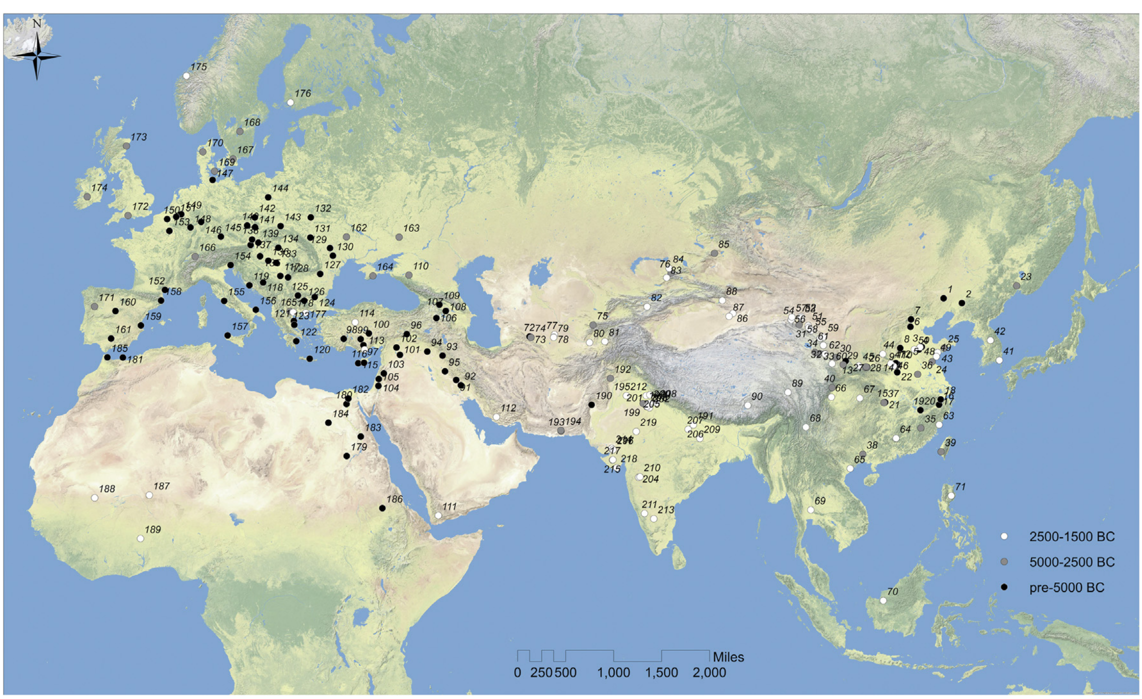

Fig. 1. Locations of representative key sites with early evidence for domestication and translocation of wheat and barley, broomcorn millet, foxtail millet, rice, sorghum and African millets (all maps are generated by ArcMap v. 10.2). Sites information is detailed in Supplementary Table S1. Black circles indicate sites older than 5000 BC; grey circles indicate archaeological sites dated between 5000 and 2500 BC; white circles indicate sites dated between 2500 and 1500 BC.

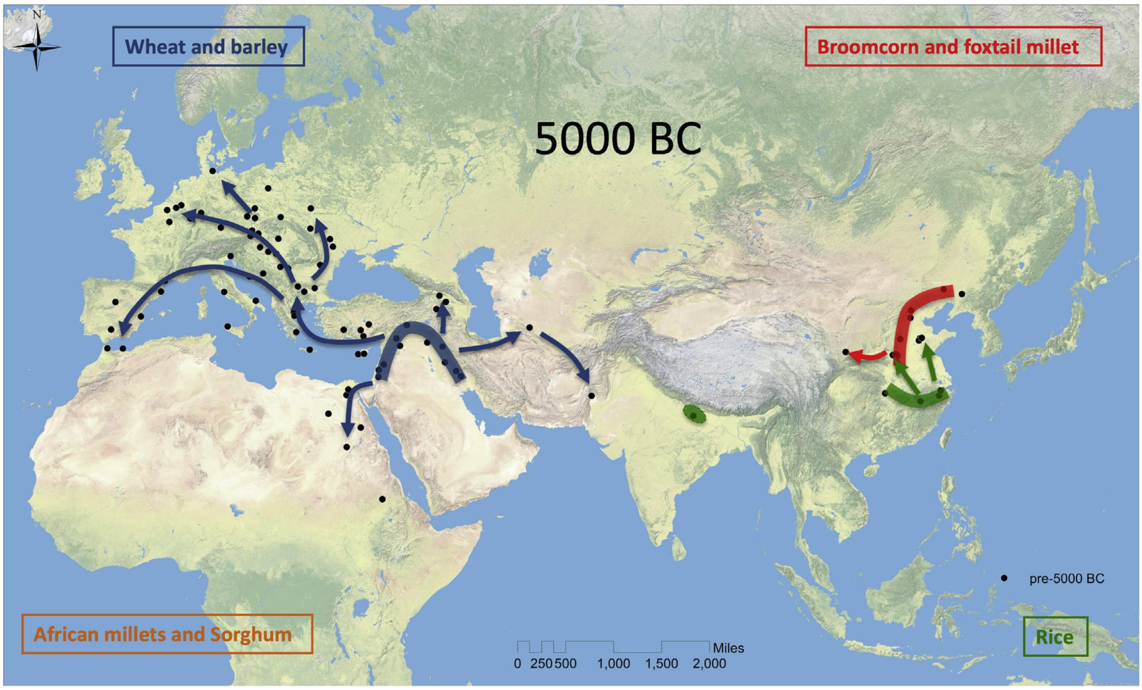

Fig. 2. Map showing hypothesized dispersals of major cereal crops by 5000 BC.

archaeobotanical data are detailed in Supplementary Table S1. This table is drawn from a number of key reviews of crop evidence for different sectors of the Old World. The European and West Asian sites included in this study are largely derived from the fourth edition of *Domestication of Plants in the Old World* (Zohary et al., 2012), and Colledge and Conolly's (2007) edited volume. The Central Asian sites discussed incorporate Spengler (2015), Spengler et al. (2014, 2016) and Motuzaite Matuzevicute and colleagues' (2018) recent reviews, among other sources. The South Asian data draws together various sources of evidence, including Fuller (2006; 2011a), Fuller et al. (2008), Weber (1998, 2003), Stevens et al. (2016) and Pokharia et al. (2014), among others. The East Asian list of sites has been sourced from reviews by Zhao (2010c; 2011), Liu et al. (2015), Ren et al. (2016), Barton and An. (2014), Dong et al. (2017) and d'Alpoim Guedes and Butler (2014), d'Alpoim Guedes et al., (2013), among others. We have sourced the original publications for each site.

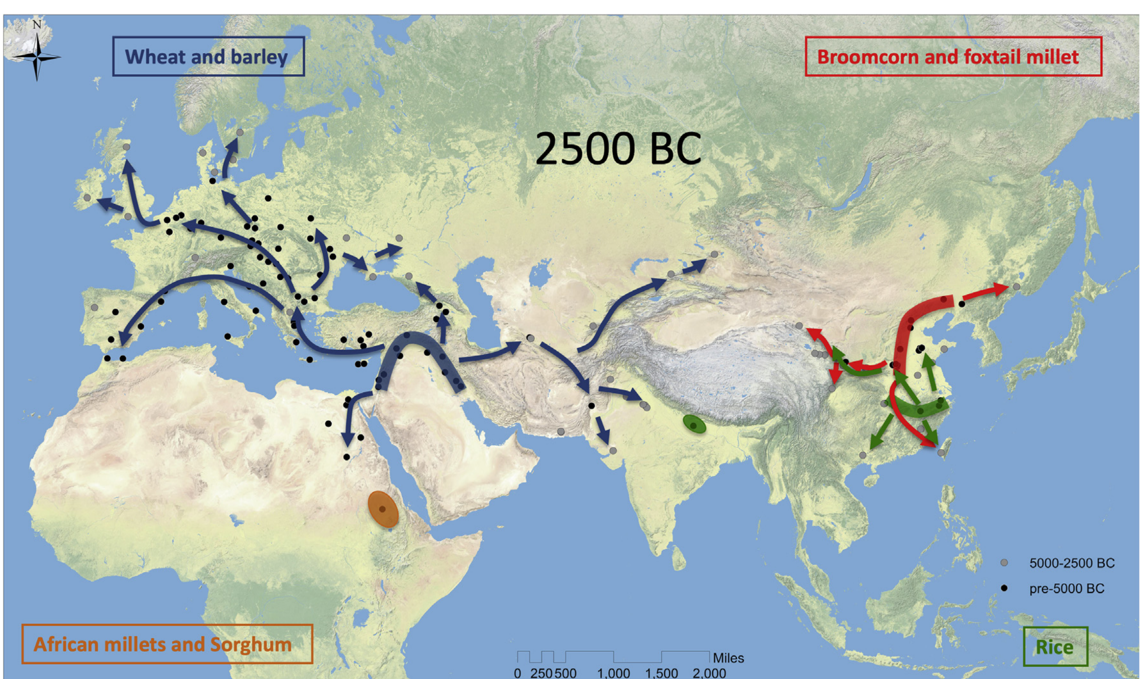

Fig. 3. Map showing hypothesized dispersals of major cereal crops by 2500 BC.

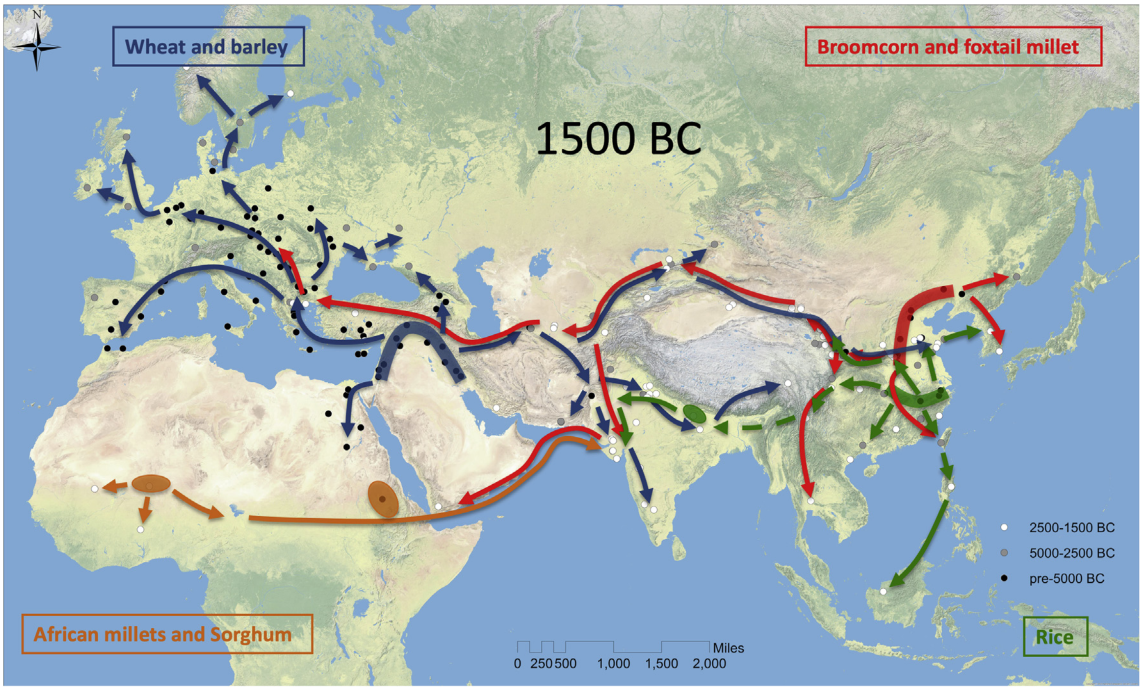

Fig. 4. Map showing hypothesized dispersals of major cereal crops by 1500 BC. Solid line: parsimonious inference from botanical evidence from dated archaeological contexts (the density of which varies greatly across Eurasia). Broken line: hypothetical hybridization occurring during rice dispersal.

3. What is moving and to where?

3.1. Pre-5000 BC (Fig. 2)

The dispersal of the southwest Asian crops in the millennia preceding 5000 BC was more extensive than that of the East Asian crops. A number of wheat and barley taxa had spread from the southwest Asian Fertile Crescent westwards across central and eastern Europe and along northern regions of the Mediterranean (Colledge and Conolly, 2007; Zohary et al., 2012). To the east, various types of wheat and barley are recorded in Turkmenistan and Pakistan before 5000 BC (Harris, 2010; Meadow, 1996; Petrie, 2015). In China, broomcorn and foxtail millet were first cultivated along a series of foothill locations adjacent to the eastern edge of the Loess Plateau, around (and probably prior to) 6000 BC (Liu et al., 2009, 2015; Yang et al., 2012). By 5000 BC, these millets are also found in sites in the Wei River valley (Bestel et al., 2017; Liu et al., 2004), and in the eastern province of Shandong (Crawford et al., 2006). The middle and lower reaches of the Yangtze have been established as the centres of Asian rice domestication (Fuller et al., 2009; Gross and Zhao, 2013), although different *Oryza* spp. were independently domesticated in West Africa and Amazonia, respectively, during the middle to late Holocene (Hilbert et al., 2017). By 5000 BC, Asian rice (*Oryza sativa*) remains are reported in the reaches of the Huai and the lower Yellow rivers (Bestel et al., 2017; Crawford et al., 2006; Zhao, 2010b). By 5000 BC, a separate center of possible utilization of wild rice has been documented in the Ganges region (Fuller, 2006; Tewari et al., 2008).

3.2. 5000–2500 BC (Fig. 3)

Between 5000 and 2500 BC, wheat and barley cultivation expanded into eastern Central Asia and South Asia. While both hulled and naked forms of wheat and barley are reported from South Asia, in Central Asia, the expansion of these species seems restricted to free-threshing/naked forms (Motuzaite Matuzeviciute et al., 2018; Spengler, 2015). By 2500 BC, these crops are present in eastern Kazakhstan (Doumani et al., 2015; Frachetti et al., 2010), the Indus region and in the upper Ganges (Fuller, 2011a; Weber, 1999). A recent study reports that wheat grains recovered from the Altai Mountains are directly dated to c. 3000-1500 cal. BC (Yu et al., 2018). During the same period, morphologically domesticated sorghum is found in eastern Sudan (dated to the fourth millennium BC) (Winchell et al., 2017).

The same period sees the further expansion of millets and rice in East Asia. Broomcorn millet is reported from Primorye in the Russian Far East at c. 3000 BC (Sergusheva, 2006). Foxtail millet cultivation reached Taiwan in the late third millennium BC (Tsang, 2012), and both millets are reported in eastern Qinghai and Gansu c. 3000 BC (Chen et al., 2015; Dong et al., 2017; Jia et al., 2012). From there the cultivation of these crops moved southward and reached the mountainous region of western Sichuan by c. 2500 BC (Zhao and Chen, 2011). Rice cultivation reached the full range of the Yangtze and Yellow River catchments, as well as Guangxi and Taiwan (Fuller et al., 2010; Tsang, 2012; Zhao, 2010a). In South Asia, evidence for rice cultivation appears from c. 2500 BC in both the Indus and the Ganges, although clear morphological evidence of domesticated spikelet, in the form of non-shattering panicles, is not seen until the next episode (Fuller et al., 2011b; Saraswat, 2004).

3.3. 2500–1500 BC (Fig. 4)

Between 2500 and 1500 BC, the Fertile Crescent crops wheat and barley were introduced to eastern China and southern India. Wheat grains in Shandong have been directly dated to between c. 2500 and 2000 cal. BC (Jin et al., 2008; Long et al., 2018). This raises the question of whether wheat was first introduced to China via a maritime route (Zhao, 2009). More substantial movements of wheat and barley took place after 2000 BC across land (Liu et al., 2016a). The spreads of free threshing wheat and naked barley into China appear to be distinct in both space and time (Liu et al., 2017a), via several possible different routes (Lister et al., 2018).

These crops appeared in central China during the second and the first millennium BC, respectively (though note the early dates of wheat in eastern province of Shandong discussed above) (Liu et al., 2017a). Wheat cultivation moved to central China along a series of mountain corridors to the north of the Tibetan Plateau. Barley, on the other hand, could have spread into China from South Asia via Tibet, and this model best fits the available radiocarbon dates.

Broomcorn and foxtail millet spread beyond China, westwards into Central Asia and southwestwards into South Asia (Pokharia et al., 2014; Spengler et al., 2014). Broomcorn millet is reported from eastern Kazakhstan in the late third millennium BC. Foxtail millet appeared in the same region about a millennium later c. 1500 BC (Spengler et al., 2014). During the second millennium BC, broomcorn millet appeared in Afghanistan, Turkmenistan, Turkey and Greece (Miller et al., 2016; Spengler, 2015; Valamoti, 2013; Willcox, 1991). The issue of early broomcorn millet in Europe is not yet fully resolved. The oldest direct dates for broomcorn millet grains in Europe are c. 1600 BC in Hungary (Motuzaite Matuzeviciute et al., 2013). A series of much older, indirect dates of millet remains have been called into question (and could be intrusions of younger seeds into Neolithic layers) (Hunt et al., 2008; Jones, 2004; Liu et al., 2018b; Motuzaite Matuzeviciute et al., 2013). There is also a series of early indirect dates from grain impressions in Neolithic pottery from eastern Europe. These are reliant on the security of identification of casts from impressions, which were largely conducted and published prior to the widespread use in archaeobotany of electron microscopy. Recent study draws attention to features that could be useful for future SEM examination (An et al., 2018). In South Asia, both broomcorn and foxtail millet are common in late Harappan sites at least from the early second millennium BC (Pokharia et al., 2014; Stevens et al., 2016; Weber, 1998). Broomcorn millet is also reported in Yemen dated to the mid-second millennium BC and there is evidence for its spread into Sudan before the mid-second millennium BC (Boivin and Fuller, 2009b; Fuller et al., 2011a). In Southeast Asia, foxtail millet is reported from Thailand at around c. 2000 BC (Weber et al., 2010).

By this period, rice cultivation was fully developed in East, South and Southeast Asia (Fuller, 2011b; Fuller et al., 2010; Zhao, 2010a). There is clear evidence of domesticated rice across northern India at least from 2000 BC (Bates et al., 2016; Fuller, 2006). Genetic evidence indicates substantial hybridization between *japonica* and *indica* forms during the dispersal of Asian rice (McNally et al., 2009; Sang and Ge, 2007; Vaughan et al., 2008). Fuller et al. (2010) suggest that hybridization initially occurred during the centuries after 2000 BC when domesticated *japonica* rice diffused from China to South Asia. African millets and sorghum appear in Indus sites during this period, in the context of a network of resource movement across the Indian Ocean (Boivin et al., 2014; Boivin and Fuller, 2009a; Fuller et al., 2011a).

4. Discussion

Drivers of the food globalisation process include seasonal, culinary and cultural differences among different sectors of the Old World. We have considered elsewhere the context in which agricultural/dietary innovations arose and what agents were involved (Liu and Jones, 2014; Liu et al., 2014, 2016a, 2016b, 2017b, 2018a). These studies emphasize the role played by the primary agents of agricultural production, the ordinary farming communities, and elucidate that the cultural and culinary choices facilitate not only the adoption of some crops but also the rejection of others. Given the biogeographic focus of this paper, nonetheless, the following discussion primarily considers the topographical and environmental context of each movement. The movement of Neolithic and Early Bronze Age communities in the Old World was constrained by a series of major topographical features. Prominent among those features were the Tibetan Plateau and the mountain ranges of Central Asia, separating the east from the west, and the north from the south. The Himalayan uplift and its associated plateau separate the warm, semitropical and tropical lowlands of South Asia from the seasonal and arid temperate regions of Central Asia. It also separates the monsoonal regions of East Asia from non-monsoonal southwest Asia. Once pathways of movement and communication around deserts and mountains had been established, crops could be moved extensively from their regions of origin.

4.1. Pre-5000 BC: ecological opportunism

Not only was the distribution of early farming sites restricted, it was also topographically selective. In comparison with cultivation today, farmers utilized a smaller fraction of the land. The earliest farming settlements in southwest Asia and China appeared along elevated locations at the edge of river catchments, sometimes at a considerable distance from the main river channel. A recurrent theme in both regions is that the earliest farming sites were situated along hilly flanks (Braidwood et al., 1969; Liu et al., 2009; Ren et al., 2016). The choice of sites appears to be associated with certain environments and situations: foothills, alluvial fans and lake edges with high groundwater levels are repeatedly chosen by early Holocene farmers/foragers in both the Near East and in China. We can infer from these site locations that early agriculturalists occupied a narrow zone of maximum productivity, in an essentially small-scale though locally intensive system of cultivation (Liu et al., 2009; Sherratt, 2005; Vita-Finzi, 1969).

Crop expansion in this period is everywhere constrained within these topographic locales. We may understand such expansions in the context of increasing needs for connectivity, such as the seeking of new lands, marriage partners and other resources. Before 5000 BC, the association of settlements with foothills is observed in both the west, along the ‘Hilly Flanks’ of southwest Asia towards the Iranian Plateau, and in the east, along the edge of a series of low mountains east of the Loess Plateau.

4.2. 5000–2500 BC: the filling of familiar environmental niches

Between 5000 and 2500 BC, three agricultural systems (characterized by: wheat and barley; broomcorn and foxtail millets; and Asian rice) expanded substantially. However the distribution of sites remained relatively ecologically constrained: as in the previous period, sites were located along the chains of foothills along various river catchments that connect with the Central Eurasian mountain system (Frachetti, 2012). The preferred sites were often at nodal points on routes of inter-regional contact, where populations might congregate for social engagement, the exchange of goods or seasonal herding (Frachetti et al., 2017). In other words, during this episode, a series of choices of environmental niches favoured by earlier generations of farmers are rolled out across similar conditions in other parts of the Old World.

4.3. 2500–1500 BC: movement, disassembly and reassembly

Between 2500 and 1500 BC the ecological and geographical boundaries so constraining in previous periods were crossed. In this third phase, the predominantly winter sown crops wheat and barley spread to east China, where the indigenous crops such as broomcorn, foxtail millet and rice are mostly sown in the spring and summer. Conversely, the predominantly spring sown crops broomcorn and foxtail millet spread to southwest Asia and Europe, where the indigenous cereals are originally winter sown. Recent research indicates that the adaptation of crops to novel seasonal conditions may have played a role in facilitating the expansion of particular crops, for example wheat and barley into the northern latitudes of Europe and higher altitudes of Asia (Jones et al., 2011a, 2012, 2016a; Liu et al., 2017a). These crop translocations brought their cultivation into different thermal and hydrological contexts, requiring a different mode of engagement between farming cycles and crops with different seasonalities, in sometimes challenging environments.

While consideration of a map of Eurasia primarily draws our attention to the possibilities of movement across horizontal space, the prehistoric communities with both indigenous and exotic crops would have been acutely aware of the vertical dimension of their journeys, for example towards the high altitudes of the Himalayan uplift. Beneath them were the lowlands, characterized by hydrological extremes, from large un-tamed rivers to barren deserts. Above these farmers were the highlands, characterized by high winds, low temperatures and bare rock. In between these extremes were the habitable altitudes, with sufficient soil depth, and a year-round flow of water within modest, manageable streams. As they moved into new landscapes, they would have been sometimes attracted to higher altitudes to reach a more reliable source of water, and at other times descended to warmer conditions at lower altitudes.

During these movements, we see some of the familiar crop clusters unpacked, with individual crops displaying distinct patterns of movement. The eastern expansion of wheat and barley are distinct in both time and space, as are possibly the movements of broomcorn and foxtail millet westward. These patterns reflect a range of choices that different communities made, sometimes driven by ecological expediency in novel environments, sometimes by culinary conservatism (e.g. Fuller and Castillo, 2016; Liu et al., 2016a; Liu et al., 2016b). Such unpacking and separate movement was followed by reassembly into novel combinations and clusters. These crops with different biogeographic and ecological histories, could be grown in different seasons, enabling multi-cropping and the fuller use of the agricultural year. These novel attributes in turn facilitated the full use of the lowlands beneath them. If the large rivers could be managed, controlled and made safe, then we suggest that their larger volumes of water could have been used to meet the greater demands of novel agricultural systems, comprising the cultivation of both local and exotic cereals.

Such a bringing together of local and exotic crops, that came together to form various multicropping systems around the Old World, is documented not only in the archaeobotanical evidence of this period, but also in the early textual records from China and Mesopotamia (e.g. Postgate, 1984; Qiu, 1989; Waetzoldt, 1985). After 1500 BC, the previously isolated Eurasian agricultural systems had established contact, dissembled and reassembled, to constitute a series of new forms of agriculture. Social changes that took place in central China, the Indus, Mesopotamia and Mediterranean in this period may be understood in this context.

5. Conclusion

In the Neolithic and Early Bronze Age, the various Eurasian and African farming centres were relatively separate from each other, and generally exploited local resources. After 1500 BC, previously isolated agricultural systems were brought together, dissembled and reassembled, to constitute a new kind of agriculture with the possibility of multiple cropping. In previous discussions on the cultural and social drivers underlying food globalisation in prehistory, a contrast has been drawn between the perpetual needs of the poor with the more ephemeral cultural choices of the powerful (Liu and Jones, 2014). The fact that the globalisation process spanned several millennia, while it does not exclude a cultural choice as a trigger, indicates that more lengthy drivers had sustained the gradual dispersals of staple crops discussed in this paper. In this paper we argue this process can be understood in the context of three successive episodes: before 5000 BC, between 5000 and 2500 BC, and between 2500 and 1500 BC.

1. Before 5000 BC, farming communities living in different parts of Eurasia took advantage of local environmental and biotic resources, utilizing foothill, alluvial and catchment locations.
2. Between 5000 and 2500 BC, the translocation of various cereal crops and associated agricultural knowledge spanned considerable distances. These translocations, nonetheless, remained ecologically and geographically constrained. Prominent in those geographical constraints were the Tibetan Plateau and the monsoonal zone, separating the east from the west, and the north from the south.
3. Between 2500 and 1500 BC, a number of crops crossed significant geographical boundaries. For example, the Near Eastern crops wheat and barley were introduced into India and China, and the Chinese crops broomcorn and foxtail millet appeared in sites in Central Asia and Europe during the same period. Each translocation brought crop cultivation to novel thermal and hydrologic contexts, with profound consequences for subsequent modes of agricultural production.

Data availability

All data analysed during this study are included in this manuscript and its supplementary information files.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2018.12.017.

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