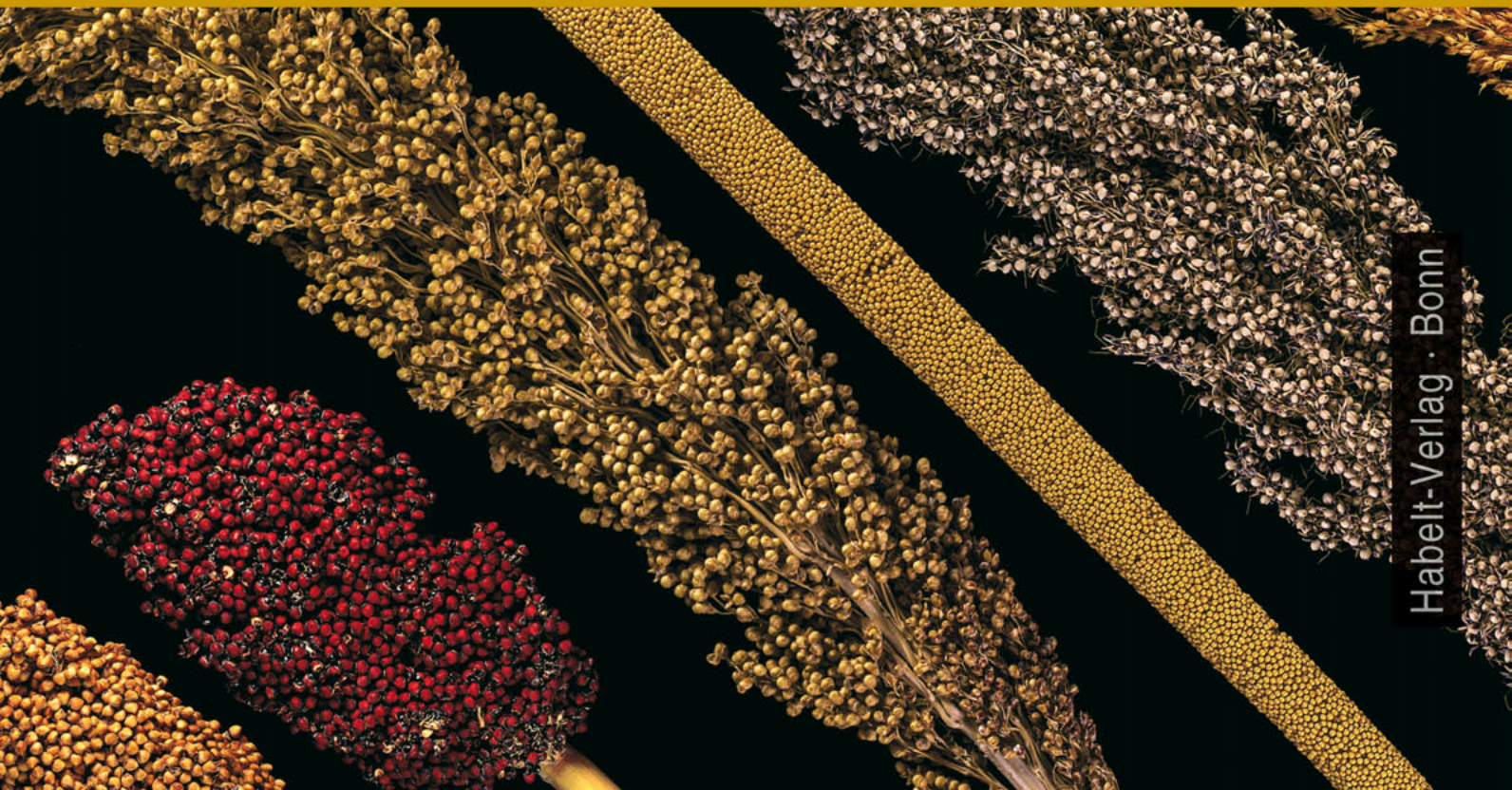


Barbara Eichhorn & Alexa Höhn (eds.)

Trees, Grasses and Crops

People and Plants in
Sub-Saharan Africa and Beyond



Barbara Eichhorn/Alexa Höhn (eds.) · Trees, Grasses and Crops



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Trees, Grasses and Crops

People and Plants in Sub-Saharan Africa and Beyond

edited by

Barbara Eichhorn & Alexa Höhn



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Front cover: Photos by Hans-Peter Wotzka (Baobab, *Adansonia digitata*, Gobnangou region, east of Kantchari, Burkina Faso, 1989) and Jennifer Markwirth (various infructescences of Sorghum, *Sorghum bicolor* and one of pearl millet, *Cenchrus americanus*, syn. *Pennisetum glaucum*).

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Vorwort der Gast-Herausgeberinnen

Wir widmen dieses Buch unserer Mentorin und Lehrerin, unserer Kollegin und Freundin Katharina Neumann zum Anlass ihres 25-jährigen Jubiläums als Leiterin der Arbeitsgruppe für Afrikanische Archäobotanik in der Abteilung Vor- und Frühgeschichte des Instituts für Archäologische Wissenschaften an der Goethe-Universität.

Ein solches Buch ist immer das Werk zahlreicher Beteiligter. Nachdem wir uns entschlossen hatten, eine Festschrift für Katharina herauszugeben, haben wir von vielen Seiten Ermutigung erfahren, zuallererst von der Abteilung Vor- und Frühgeschichte, die dieses Projekt förderte und unterstützte – ideell wie finanziell. Auch das Zentrum für interdisziplinäre Afrikaforschung (ZIAF) sowie Herr Prof. Dr. Hans-Peter Wotzka waren sofort bereit, sich an dem Druck finanziell zu beteiligen. Ohne sie hätte dieses Buch nicht gedruckt werden können! Ganz besonders danken wir natürlich auch den Herausgebern der ‚Frankfurter Archäologischen Schriften‘ dafür, dass wir das Buch in dieser attraktiven Schriftenreihe platzieren durften.

Ganz entscheidend war zudem die Bereitschaft der zahlreichen Autoren, Katharinas wissenschaftliche Arbeit zu würdigen – ohne ihr Engagement hätte es dieses Buch nicht gegeben. Ihnen allen möchten wir danken, auch für ihre Geduld mit uns und dafür, dass sie so lange gegenüber Katharina Stillschweigen bewahrt haben. Ganz besonders hat uns die Bandbreite der Beiträge gefreut, sie sind zahlreich und vielfältig und spiegeln in schönster Weise Katharinas Arbeit und ihre Interessen wider. Sie reflektieren die wissenschaftlichen Fragestellungen, mit denen Katharina sich befasst, genauso wie die Vielfalt der Methoden, mit denen sie an ihrer Beantwortung arbeitet. Aber auch die auf den ersten Blick weniger sichtbaren Voraussetzungen und Grundlagen ihrer und auch unserer wissenschaftlichen Arbeit, wie die reichhaltigen botanischen Sammlungen und frühe, prägende Hochschullehrer und Förderer, werden in den Beiträgen sichtbar. Auch um dieser Vielfalt gerecht zu werden, haben wir auf eine inhaltliche Gliederung verzichtet und stattdessen die Beiträge alphabetisch nach den Namen der Erstautoren angeordnet.

Wir wollten ein buntes Buch im besten Sinn und haben uns deswegen gegen eine wissenschaftliche Begutachtung der einzelnen Beiträge durch Fachkollegen entschieden. Die herausgeberische Arbeit, das Lektorieren und Editieren der Texte haben wir zum größten Teil selbst übernommen, aber sowohl die Beitragenden selbst, wie auch hilfsbereite Kollegen und Kolleginnen unterstützten uns dabei entscheidend. Frau Gabriele Försterling hat die Graphiken hervorragend umgesetzt, beziehungsweise überarbeitet, und darüber hinaus den Umschlag graphisch gestaltet, dessen aussagekräftigen Fotos von Herrn Prof. Dr. Hans-Peter Wotzka und Frau Jennifer Markwirth stammen. Frau Dr. Amy Styring hat uns jederzeit bei der Korrektur und Überarbeitung des Englischen umfangreich und höchsteffektiv unterstützt, auch Frau Dr. Gaby Franke hat uns hierbei geholfen. Zudem lieferten die Herausgeber der Festschrift für Herrn Prof. Dr. Peter Breunig eine wunderbare Vorlage und ersparten uns damit einiges an Arbeit. Darüber hinaus unterstützten sie uns bei allen praktischen Fragen. Frau Dr. Susanne Biegert vom Habelt Verlag hatte eine Engelsgeduld mit uns und unseren Autoren. Unterstützung und Ratschläge erhielten wir darüber hinaus von vielen hier nicht namentlich genannten Kollegen und Kolleginnen. Ihnen allen gilt unser Dank!

Wir hoffen, dass dieses Buch für seine Leser einiges an streng wissenschaftlicher Erkenntnis bereithält, aber dass es auch Freude bringt und überrascht.

Es gilt zwar mit Wilhelm von Humboldt (1767-1835): „Das nachdenkende, betrachtende, forschende Leben ist eigentlich das höchste“, aber es gilt auch mit Johann Wolfgang von Goethe (1749-1832): „Grau, teurer Freund, ist alle Theorie und grün des Lebens goldner Baum“; und so wünschen wir Katharina noch viele Jahre – zum Nachdenken, Betrachten und Forschen, aber auch und vor allem zum Lebensgenuss.

Barbara Eichhorn & Alexa Höhn

Grußwort

Gelebte Interdisziplinarität – so kann man das wissenschaftliche Feld und die Forschungsaktivitäten, denen sich Katharina Neumann seit Jahrzehnten widmet, treffend beschreiben. Als Archäobotanikerin forscht sie seit 1983 über die Beziehungen des prähistorischen Menschen zu seiner pflanzlichen Umwelt. Früh schon in ihrer Karriere spielte dabei Afrika und seine Vegetationsgeschichte eine wichtige Rolle; ein geographischer Fokus, der sie nie mehr losgelassen hat und so kann sie heute als eine der tiefsten Kennerinnen der frühen Entwicklung von Pflanzennutzung und Kulturpflanzen in West- und Zentralafrika gelten.

Die Universitäten Köln und Frankfurt am Main bildeten dabei den Mittelpunkt ihrer wissenschaftlichen Ausbildung. Nach dem Diplom in Botanik an der Universität Frankfurt war sie fünf Jahre wissenschaftliche Mitarbeiterin an der Universität zu Köln, promovierte und habilitierte sich dann an der Goethe-Universität in Frankfurt am Main, wo sie 2008 zur außerplanmäßigen Professorin ernannt wurde.

Im 1988 an der Frankfurter Universität begonnenen Sonderforschungsbereich 268 „Kulturentwicklung und Sprachgeschichte im Naturraum der westafrikanischen Savanne“ forschte sie u.a. als Teilprojektleiterin über die „Vegetationsgeschichte und Archäobotanik in der westafrikanischen Savanne“ und blieb dem SFB bis zu seinem Abschluss 2002 eng verbunden. 1994 wurde Katharina Neumann zur Leiterin der Abteilung für Afrikanische Archäobotanik des Instituts für Archäologische Wissenschaften ernannt. Heute zählt deren Vergleichssammlung mit über 20.000 Früchten, Samen, Pollen und Hölzern aus vielen Regionen Eurasiens und Afrikas zu den weltweit größten ihrer Art.

Zu Katharina Neumanns forscherschem Schwerpunkt der letzten 15 Jahre gehören zwei große Fördervorhaben der Deutschen Forschungsgemeinschaft (DFG), die wiederum ihre enge Beziehung zu Afrika zeigen. Gemeinsam mit den Frankfurter Wissenschaftlern Peter Breunig und Jürgen Runge sowie dem Tübinger Prähistoriker Manfred Eggert forschte sie von 2003 bis 2009 zum Thema des „Environmental and Cultural Change in West and Central Africa“. Das Ziel dieser interdisziplinären Forschungsgruppe aus prähistorischer Archäologie, Archäobotanik und Physischer Geographie war, basierend vor allem auf umfangreichen Feldforschungen in Nigeria und Kamerun, kulturelle Umbrüche im Verlauf der beiden letzten vorchristlichen Jahrtausende und deren Beziehung zum Klima- und Landschaftswandel im subsaharischen Afrika zu untersuchen. Die Ergebnisse dieser Forschungen sind inzwischen in zahlreichen Publikationen dokumentiert.

Wie sehr Katharina Neumann das interdisziplinäre Arbeiten am Herzen liegt, zeigt auch ihr Engagement im 2009 begonnenen, auf 12 Jahre konzipierten und gemeinsam mit Peter Breunig geleiteten DFG-Langfristvorhaben „Development of Complex Societies in Sub-Saharan Africa: The Nigerian Nok Culture“. Zu den Forschungsschwerpunkten gehören neben dem Siedlungswesen dieser bäuerlich-früheisenzeitlichen Kultur auch vielfältige archäobotanische Fragen, wie die Vegetationsentwicklung für die gesamte Dauer der Nok-Kultur von ihrem ersten Auftreten um 1.500 v. Chr. bis zu ihrem Ende um die Zeitenwende. Zu den sichtbarsten und auch beeindruckendsten materiellen Hinterlassenschaften dieser Kultur zählen die um 900 v. Chr. erstmals auftretenden oft lebensgroßen menschen- und tiergestaltigen Terrakotta-Figuren, die wahrscheinlich eine wichtige Funktion im Begräbnis- und Totenritual dieser Kultur spielten. Dank der langjährigen Forschungen von Peter Breunig und Katharina Neumann gehört die Nok-Kultur zu den am besten erforschten archäologischen Kulturen Westafrikas.

Ein ertragreiches wissenschaftliches Arbeiten in fremden Landschaften und Kulturen kann aber nur wirklich erfolgreich sein, wenn es einen intensiven und fruchtbaren Austausch mit den Menschen und Kulturen vor Ort gibt. Auch hier sind Katharina Neumann und Peter Breunig Vorbild. Wissenschaftlicher Austausch auf

Augenhöhe mit afrikanischen Partnerinnen und Partnern ist elementarer Bestandteil ihrer Forschungstätigkeit. Dass ihnen dabei der wissenschaftliche Nachwuchs besonders am Herzen liegt, ist selbstverständlich. Aber auch die breite Öffentlichkeit in Deutschland wie in den Gastländern ihrer Forschungen lassen sie an den spannenden Resultaten ihrer Arbeit teilhaben. Erwähnt sei hier nur die weit über Frankfurt am Main hinaus bekannt gewordene Ausstellung „Nok – Ein Ursprung afrikanischer Skulptur“, die 2013/2014 im dortigen Liebieghaus zahlreiche Besucherinnen und Besucher in ihren Bann zog.

Es bleibt zu wünschen, dass vor allem die häufig schwierigen politischen Rahmenbedingungen in West- und Zentralafrika es Katharina Neumann und ihren Kolleginnen und Kollegen weiterhin erlauben, die hoch interessante, aber auch in vielen Bereichen noch weitgehend unbekannte Geschichte dieses Kontinents zu erforschen. Die breite Palette an wissenschaftlich interdisziplinären Themen, die sich in den Beiträgen dieser Festschrift zeigt, lässt hoffen, dass wir auch in der Zukunft auf neue Forschungsprojekte gespannt sein können.

Hans-Dieter Bienert, Siegburg

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Comparing the tempo of cereal dispersal and the agricultural transition: two African and one West Asian trajectory

Dorian Q Fuller, Louis Champion & Chris Stevens

Archaeobotanical evidence for the timing of grain crop origins over time across the Old World indicates that several grain crop domestications took place in the Early Holocene but many more took place in the later middle Holocene between 5000 and 3000 years BP. Middle Holocene domestications included the major African cereals Sorghum bicolor and Pennisetum glaucum. Rates of domestication followed by dispersal of cereals are assessed for Sorghum, Pennisetum, barley and wheat. Although the African cereal domestications started later than those in Western Asia the rates at which African cereal cultivation spread across Africa was faster. While the climatic changes that lead to the drying of the Sahara were clearly important in the initial domestication and spread of African cereals, the consistently high rate of dispersal after that is suggested to derive in part from inherent differences in productivity of African cereals, setting lower carrying capacity in early African farming as opposed to that in western Asia.

KEY WORDS: cerealization, sorghum, pearl millet, domestication, dispersal

Introduction

The origin of agriculture remains a research focus of great interest in archaeology and quaternary palaeoecology. There is no debate about its transformative impact on vegetation, on human demographic growth, and on social organization (e.g. Diamond 1997; Ellis et al. 2013; Boivin et al. 2016), but there is much debate on how these changes came about, when and where they did, and the extent to which these transitions were similar and different, i.e. about pattern and process. By far the most common archaeological regions considered in discussions of agricultural origins are Southwest Asia and the transfer of agriculture into Europe, i.e. European Neolithization (e.g. Shennan 2018). Katharina Neumann has been one among a small select group of scholars whose research has highlighted distinctive aspects of the transition in Africa, including an apparently late, “African behindhand” (Neumann 2003), non-sedentary, and low crop diversity process which is especially distinct from the “classic” Southwest Asian sequence (also: Kahlheber & Neumann 2007; Garcea 2006). Recent years have seen the steady expansion of empirical evidence in African archaeobotany, including new data on the domestication of pearl millet in western Sahelian Africa (MacDonald et al. 2009; Manning et al. 2011; Manning & Fuller 2014; Burgarella et al. 2018) and sorghum in eastern Sahelian/Savannah Africa, i.e. northern Sudan (Winchell et al. 2017; Fuller & Stevens 2018). In the present paper we pull together these data on morphological changes that index the domestication processes in sorghum and pearl millet and how these compare to documentation on wheat and barley in the Near East. But, beyond domestication, we consider the larger geographical and chronological patterns of cereal agriculture spreading out from centres of origin, and also diversifying, which arguably are the more important process for transforming ecosystems into anthropogenic landscapes and societies into complex, agricultural dependent traditions. Neumann (2005) identified the rapid spread of diversified agriculture throughout Africa in the first millennium BC as a key research problem, and one that is related to the relative rates of dispersal of subsistence systems.

A few words are in order about the methods taken in this study, both with regards to domestication and dispersal. Using current archaeobotanical evidence we have traced, for major Old World grain and grain-legume

Species	Domestication episode if known	Domesticated by (years BP)	Source
West Eurasia			
<i>Vicia faba</i>	11500(?)–10500 BP	10500	Fuller et al. 2012; Caracuta et al. 2016
<i>Triticum monococcum</i>	11500–10500 BP	10500	Fuller et al. 2014; Allaby et al. 2017
<i>Triticum</i> cf. <i>uratu/thaoudar</i> “2-grain einkorn”	11500–10500 BP	10500	Fuller et al. 2012
<i>Hordeum vulgare</i>	11500–10500 BP	10500	Fuller et al. 2014; Allaby et al. 2017
<i>Lens culinaris</i>	11500–10500 BP	10250	Fuller et al. 2014
<i>Pisum sativum</i>	11000–10000 BP	10000	Fuller et al. 2014
<i>Cicer arietinum</i>	11000–10000 BP	10000	Fuller et al. 2014
<i>Triticum diccocon</i>	11500–9500 BP	9500	Fuller et al. 2014; Allaby et al. 2017
<i>Lathyrus sativus</i>		9500	Fuller et al. 2012
<i>Vicia ervilia</i>	11500–9000 BP	9000	Fuller et al. 2012; Zohary et al. 2012
<i>Vicia sativa</i>		9000	Fuller et al. 2012; Zohary et al. 2012
<i>Triticum</i> cf. <i>timopheevi</i> “striate emmeroid”		8500	Fuller et al. 2012; Bogaard et al. 2017
<i>Avena sativa</i>		3000	cf. Zohary et al. 2012
<i>Secale cereale</i>		3000	cf. Zohary et al. 2012
<i>Digitaria sanguinalis</i>		?	
Africa			
<i>Sorghum bicolor</i>	6000–3500 BP	5000	Stevens & Fuller 2018
<i>Pennisetum glaucum</i>		4500	Manning & Fuller 2014
<i>Vigna unguiculata</i>		3750	D’Andrea et al. 2007; Kahlheber & Neumann 2007
<i>Lablab purpureus</i>		3750	Fuller 2003
<i>Vigna subterranea</i>		3500	Kahlheber & Neumann 2007; Kahlheber et al. 2014
<i>Eleusine coracana</i>		3000	Fuller 2003
<i>Eragrostis tef</i>		2500	D’Andrea 2008
<i>Oryza glaberrima</i>		2500	Kahlheber & Neumann 2007; Champion & Fuller 2018
<i>Brachiaria deflexa</i>		2250	Champion & Fuller 2018
<i>Digitaria exilis</i>		2250	Champion & Fuller 2018
<i>Digitaria iburua</i>		?	
<i>Pisum abyssinicum</i>		2000	Author’s guess
<i>Macrotyloma geocarpum</i>		2000	Author’s guess
East Asia			
<i>Panicum miliaceum</i>		7000	Stevens & Fuller 2017
<i>Setaria italica</i>		7000	Stevens & Fuller 2017
<i>Oryza sativa</i> ssp. <i>japonica</i>		8000	Stevens & Fuller 2017
<i>Glycine max</i> (China)		5000	Fuller et al. 2014
<i>Glycine max</i> (Japan)		5000	Nasu 2018
<i>Vigna angularis</i>		5000	Nasu 2018
<i>Echinochloa utilis</i>		4000	Nasu 2018

Table 1. Grain crop domestications in sub-continental regions of origins, and estimated age of full domestication.

Species	Domestication episode if known	Domesticated by (years BP)	Source
<i>Fagopyrum esculentum</i>		3500	Weisskopf & Fuller 2014; Hunt et al. 2018
<i>Chenopodium album/giganteum</i>		3500	cf. D'Alpoim Guedes & Butler 2014
<i>Vigna umbellata</i>		2500	Castillo et al. 2016
<i>Spodiopogon formosanum</i>		?	
<i>Coix lachryma-jobi</i>		?	
<i>Fagopyrum tartaricum</i>		?	
South Asia			
<i>Panicum sumatrense</i>	5500–4500	4500	Fuller 2011; Murphy & Fuller 2017b
<i>Brachiaria ramosa</i>	5000–4000	4000	Fuller 2011; Murphy & Fuller 2017b
<i>Setaria pumila</i>		4000	Fuller 2011; Murphy & Fuller 2017b
<i>Macrotyloma uniflorum</i>		4000	Fuller & Murphy 2018
<i>Vigna aconitifolia</i>		4000	Fuller 2011; Murphy & Fuller 2017b
<i>Vigna mungo</i>		4000	Fuller 2011; Murphy & Fuller 2017b
<i>Echinochloa frumentacea</i>		4000	Murphy & Fuller 2017b
<i>Oryza sativa</i> ssp. <i>indica</i>		3750	Fuller 2011; Fuller et al. 2014
<i>Vigna radiata</i>		3500	Fuller 2011; Fuller et al. 2014
<i>Cajanus cajan</i>		3500	Fuller 2011; Murphy & Fuller 2017b
<i>Paspalum scrobiculatum</i>		2500	Fuller 2011: supplement
<i>Digitaria sanguinalis</i>		?	

Table 1 (cont.). Grain crop domestications in sub-continental regions of origins, and estimated age of full domestication.

species, their earliest stage of domestication, and then tracked the geographical dispersal of a few key species after their domestication from their centre of origin. Our focus is cereals, but our analysis also includes pseudo-cereals and grain legumes. We refer to our maps as approximating cerealization, as they represent when parts of the world became engaged with grain crop cultivation, which does not exclude the possibility that some forms of cultivation, especially based on vegiculture (the cultivation of root and tuber crops), may have occurred equally early or earlier in some regions of tropical-forest zone.

Domestication is here taken to represent the end of a process of selection for adaptation on the part of the plant to cultivation, which is presented by morphological adaptations, especially loss of wild-type seed dispersal mechanisms (Harris & Fuller 2014; Fuller et al. 2014). Empirical evidence for this change is only available for a few species - pearl millet and sorghum in Africa (Manning et al. 2014; Fuller & Stevens 2018), Asian rice in China; and barley, emmer and einkorn wheats in southwest Asia (Fuller et al. 2014; Allaby et al. 2017). Therefore, to move beyond reliance on the identification of loss of shattering in cereals, we have also drawn on other domestication traits, such as seed size increase, that have been demonstrated to evolve over broadly the same period as non-shattering (Fuller et al. 2014), thus providing a reasonable proxy for non-shattering. In pulses, one might ideally look for changes in seed coat anatomy that relate to loss of germination inhibition, but this has presently only been documented in detail for Indian horsegram (Murphy & Fuller 2017a), but once again this appears to occur alongside seed size increase, which therefore is a viable proxy. Where detailed morphological data are not available, a less secure determination of minimal age of domestication has been deduced from the archaeological evidence such as we understand it (Table 1).

A Continental view of the great Holocene transition

Archaeobotanical research over recent decades has revealed that domestication took place in several regions of the Old World at different times, suggesting it was driven by different initial stimuli. As global reviews make clear (e.g. Purugganan & Fuller 2009; Larson et al. 2014; Fuller et al. 2014) many domestications began in the Middle Holocene (after 6200 BC) and were only completed in the Late Holocene (after 2200 BC). Such evidence refutes the theory that the origins of agriculture occurred rapidly and synchronously on a global scale, associated with the Pleistocene-Holocene climatic transition, a notion which gained prominence based on privileging West Asian empirical data alongside a few fragmentary early claims for possible domesticated crops from the Neotropics and China (e.g. Piperno & Pearsall 1998; Zhao 1998; Harris 1998). As Katharina Neumann's own reviews have long made clear, Africa lagged behind such alleged stereotypical Early Holocene models of domestication (e.g. Neumann 2003; 2005; Kahlheber & Neumann 2007), but indeed this African pattern is perhaps more the norm than the exception, with transitions to crop farming across Arabia, the Indian subcontinent and Southeast Asia now placed in the third millennium BC at the end of the Middle Holocene (see Boivin & Fuller 2009; Castillo 2017; Murphy & Fuller 2017b). What this emerging pattern indicates, is that global climatic drivers, such as the Younger Dryas (e.g. Harris 2003), have little relevance to most crops' domestication processes, or to most regional transitions to agriculture. Add to this the observation that domestication processes were protracted (Allaby et al. 2008; 2017; Fuller et al. 2009; 2014; Maeda et al. 2016), and it becomes increasingly difficult to attribute the transition to agriculture to any unitary cause, globally or in any particular case. Instead, a sequence of interacting factors must have played a role in maintaining selection pressures towards domestication in each case (e.g. Zeder 2016; Fuller et al. 2016).

Nevertheless a comparative, intercontinental perspective on domestication may still be informative. Based on a growing archaeobotanical database it is feasible to provide reasonable empirical estimates for the period of domestication for 43 grain crops, including cereals, pseudo-cereals and grain legumes (Table 1). This compilation can be considered chronologically by broad geographical regions as a chart representing the cumulative progress of domestication in terms of domesticated biodiversity (Figure 1). It should be noted that full domestication, once morphological change has been detected archaeologically across ancient crop populations, only came after some centuries or millennia of continuous cultivation and selection. A minimal estimate of this time period is perhaps in the order of 2000 years (e.g. Tanno & Willcox 2012; Fuller et al. 2014), although the period of selection is potentially longer, if the process began with very low levels of selection for domestication traits associated with elements of cultivation that began during the initial exploitation of wild stands (Allaby et al. 2017). Nevertheless, at an Old World level, it can be seen that the eras of domestications cluster into two phases (Figure 1); the first sees a gradual increase in domesticates during the Early Holocene, mostly focused in Southwest Asia; the second, a more rapid increase in domesticates, that are generally more taxonomically diverse, around the Middle to Late Holocene transition which involved a much more diverse set of regions in Asia and Africa. This follows a similar pattern to that of animal domestications. The Early Holocene (9,700-7000 BC) saw the domestication of the major animal domesticates, cattle, sheep, and goat, which followed a prey-pathway, animals first hunted for meat, then managed as herds leading to domestication; and pigs which followed a commensal pathway, in which animals attracted to human settlements became managed and eventually bred (see Zeder 2012). However, the biggest increase in animal domestications was between 6000 and 2000 years ago, including a range of directed domestications, where animals in captivity were deliberately bred to encourage certain traits (e.g. horses, donkeys, camels), as well as more prey animals (Figure 2, top; Larson & Fuller 2014). What is striking is that the pause in new domestications (7000-3000 BC) coincides with the period in which the dispersal of livestock, through agropastoralism or pastoralism, really took off, including the Neolithization of Europe, the Iranian plateau through to Pakistan, and the livestock arrivals throughout the Sahara, Arabia and Central Asian deserts (Figure 2; also, e.g. Boivin & Fuller 2009; Manning et al 2013; Patel & Meadow 2017). The Mid- to Late Holocene surge in new domestications accompanied the major second expansion of pastoralism as it reached out across eastern Eurasia (China, Southeast Asia, Southern India) and sub-Saharan Africa (Fuller et al. 2011a; Liu & Ma 2017; Patel & Meadow 2017).

At an intercontinental scale, African agricultural origins follow a pattern similar to many other regions in terms of later grain crop domestications, post-dating the first expansions of food production out of Western Asia through western Eurasia. The West Asian Neolithic was more or less unique in terms of the diversity of early plant and animal domestications associated with the Early Holocene's moist climatic optimum. Sherratt (1996) offered the

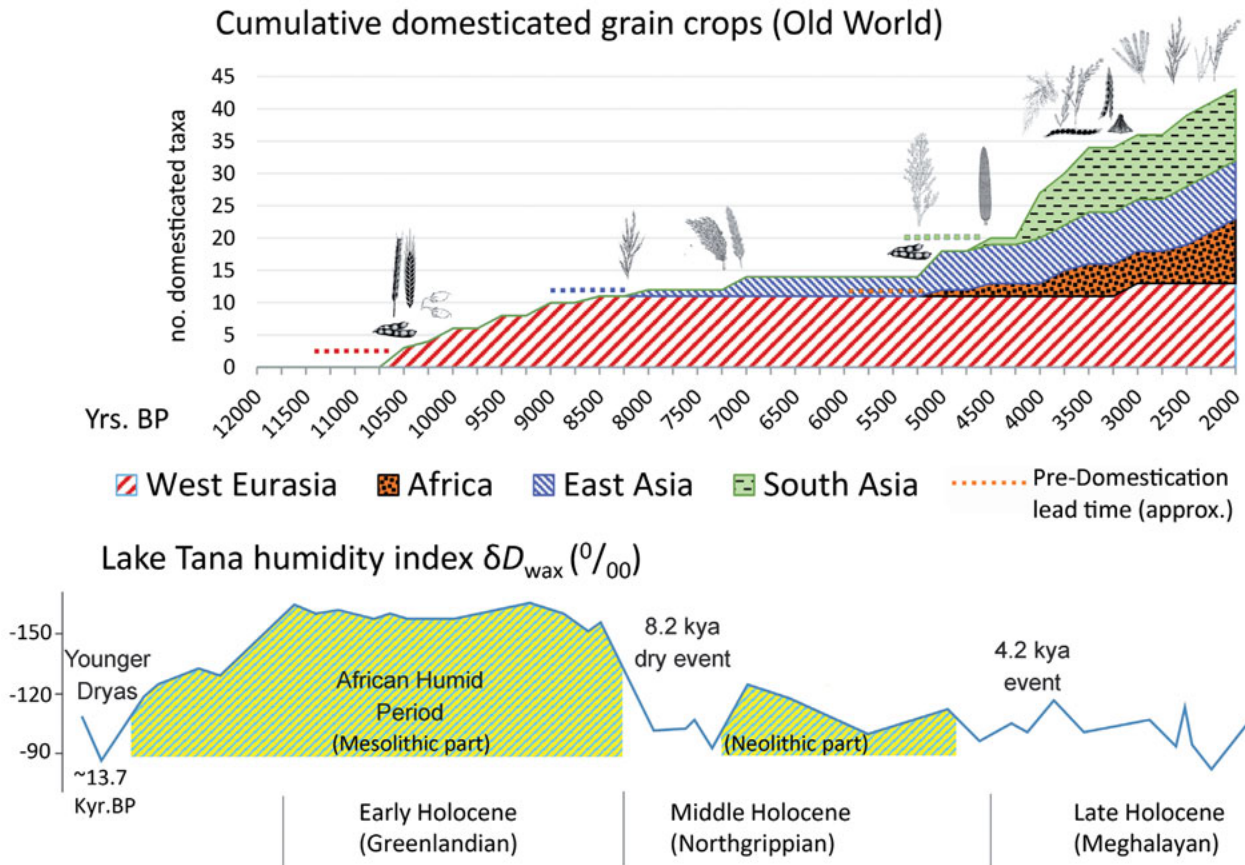
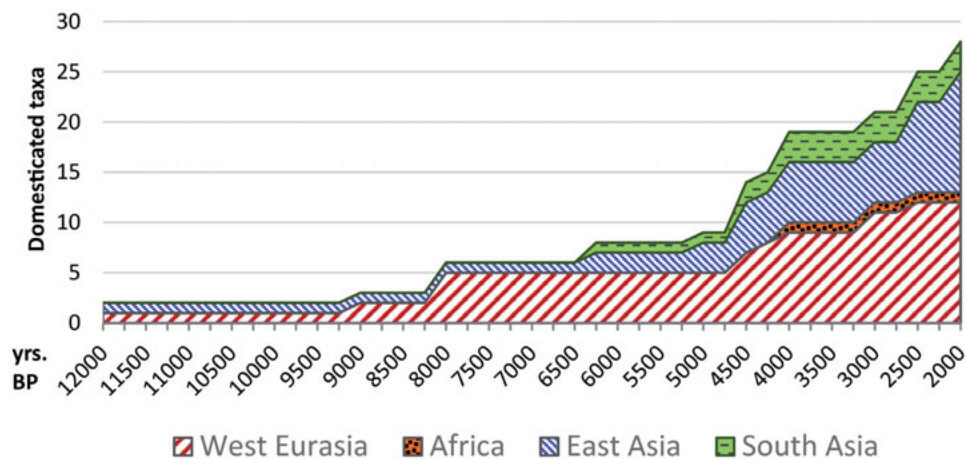


Figure 1. The cumulative sum of domesticated Old World grain crops for which there is archaeological evidence subdivided by continental regions (from Table 1). An estimated 2000 year lead-time (pre-domestication cultivation) is indicated by a dotted line in advance of the earliest domestication in each broad region; representations of selected crops are placed at approximate domestication point. These are compared chronologically with a climatic proxy from Africa (Lake Tana deuterium humidity index: Costa et al 2014), and the broad climatic subdivisions of the Holocene, including interpretation of “Green Sahara” periods and major aridification events.

explanatory framework of a geographical bottleneck, where a spine of mountains and habitable valleys was squeezed by rising sea levels and a desert margin, providing endogenous population pressure. In contrast, the wetter and warmer conditions of the Early Holocene provided an expansive Green Sahara to attract hunter-gatherer-fisher populations (Figure 1, bottom; Drake et al. 2011; Manning & Timpson 2014). Greener conditions continued through the Middle Holocene, after the 8.2 kya dry event, making the environmental conditions conducive to the spread of food production, but especially livestock. These green periods were characterized by increasing vegetation bio-mass within the deserts of the Sahara, Arabia, Central Asia and northwest India. The large-scale expansion of savannah and Sahelian vegetation is readily evident in the transect of wood charcoal assemblages between the Wadi Howar in Sudan and various sites throughout the Western Desert of Egypt (Neumann 1989). In East Asia, some pre-domestication cultivation may have also been underway in this period, but for most of the Old World food production and domestication began as climate settled into drier conditions typical of the Late Holocene. This tends to suggest that new pressures brought about by previous population expansions, such as in the green deserts, and contracting grasslands were a recurrent contributing factor in the origins of agriculture in sub-Saharan Africa as elsewhere. Archaeological evidence suggests that plant domestications in sub-Saharan Africa were few and far between, and although archaeobotanical data is still absent for large areas, the late spread of many African domesticates would presently support a hypothesis that early domestication centres were limited in number and extent. This theory stands in contrast to the diffuse and widespread process that Harlan (1986) once suggested, but restricted to a few locations, indicating that general demographic and climatic factors are unlikely to be sufficient in and of themselves to have driven domestication and the transition to crop agriculture.

Cumulative domesticated animals (Old World)



Maximum extent of pastoralism

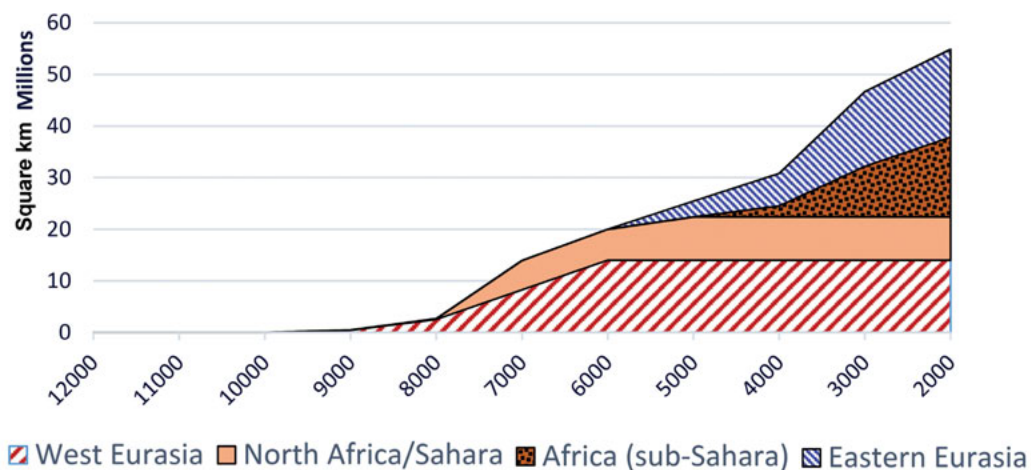


Figure 2. The record of Old World animal domestication and pastoral dispersal. Top: the cumulative sum of domesticated fauna in the Old World subdivided by continental regions (data from Larson & Fuller 2014); this includes two Pleistocene domestications of the dog, two plausible chicken domestications (South and East Asia) and excludes an independent African cattle domestication; bottom: an approximation of the maximum extent of ungulate pastoralism by millennium (based on polygon land area estimates, revised from Fuller et al. 2011).

East Sahelian domestication and dispersal: *Sorghum bicolor*

Africa's most important contribution to global agriculture is sorghum (*Sorghum bicolor* (L.) Moench.), which has long been attributed to domestication somewhere in the eastern Sahelian-Savannah transition zone (Figure 3), within the eastern part of the range of the wild race "aethiopicum" (Harlan & Stemler 1976; Fuller & Stevens 2018). Current genetic data and recent archaeobotanical reports bear this out and point to a domestication process that commenced before 3000 BC and was completed probably after 2000 BC (Winchell et al. 2017; Beldados et al. 2018; Fuller & Stevens 2018). Current evidence, although still limited, points to an intriguing geographical differentiation, between a Nilotic Neolithic known from the alluvial plains near Khartoum and Shendi, dating between 5000 and 3500 BC (Caneva 2005), versus the sequence of cultures in the Southern Atbai, including the Gash Delta, the Upper Atbara River and the zone in between (Winchell 2013; Winchell et al. 2018). In the former, ephemeral settlement occupations have produced remains of sheep, goat and cattle (Caneva & Gauthier 1994) and evidence for wild sorghum alongside other gathered millets in the tempering of ceramics (Stemler 1990; Winchell et al. 2018). A progress of pastoralist diffusion from further north in Nubia is

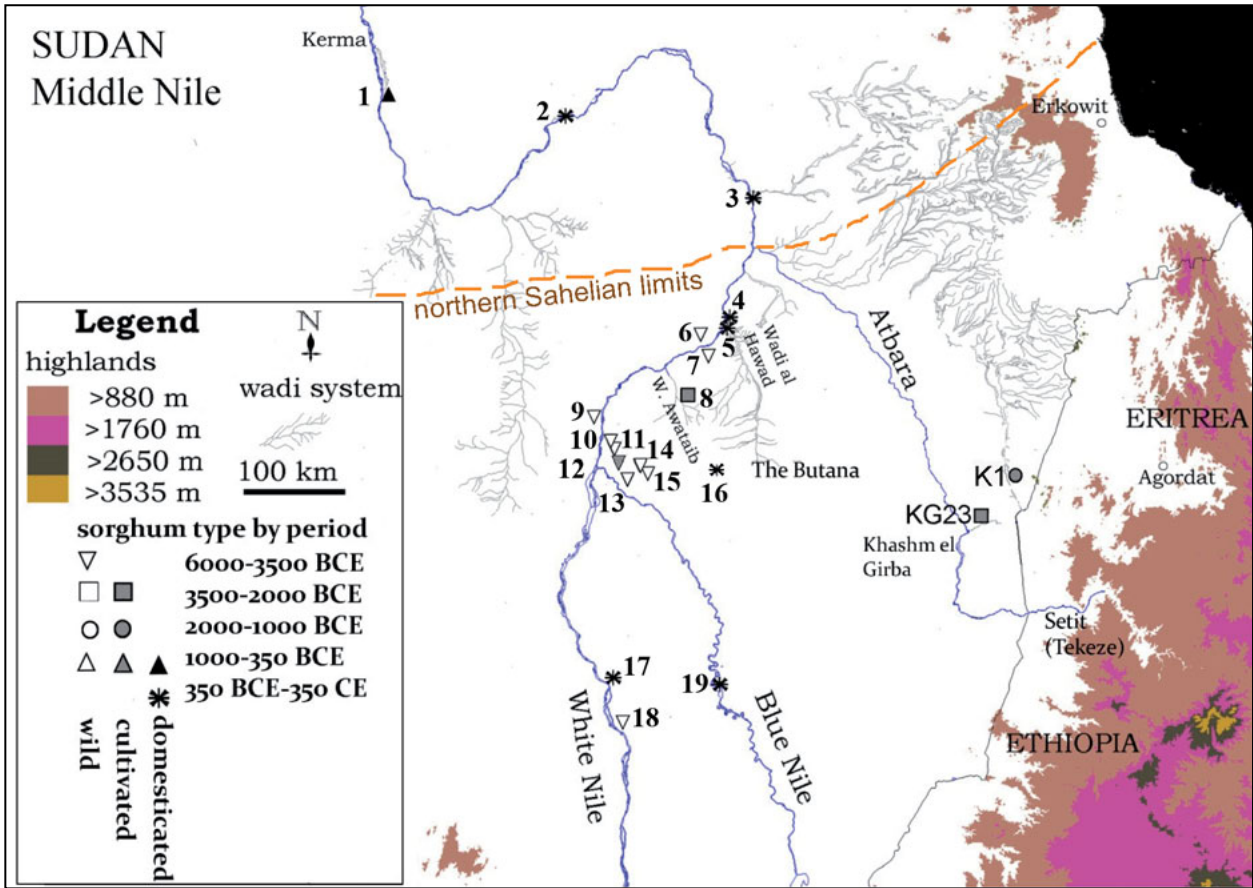


Figure 3. Map of sites with evidence for Sorghum domestication Kasala K1 and KG23, other archaeological sites with sorghum evidence in northern Sudan: 1. Kawa; 2. Umm-Muri; 3. Dangeil; 4. Meroe City; 5. Hamadab; 6. El Kadada; 7. Naqa; 8. Shaqadud; 9. Shaheinab; 10. El Zakiab; 11. Kadero; 12. Umm Direiwa; 13. Sheikh Mustafa; 14. El Mahalab; 15. Sheikh el Amin; 16. Jebel Qeili; 17. Jebel Tomat; 18. Rabak; 19. Abu Geili.

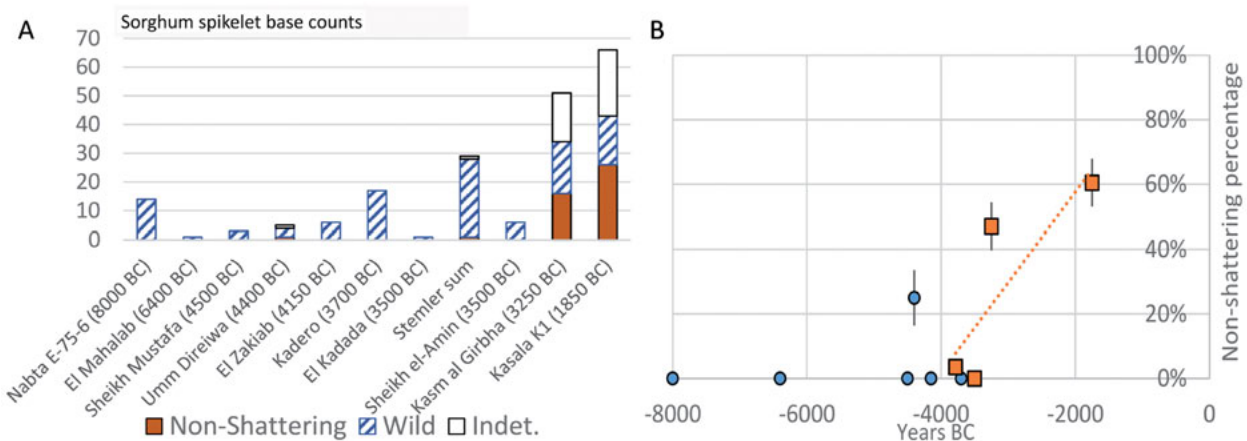


Figure 4. Sorghum domestication timeline: A. Bar graph showing number of determined sorghum spikelet remains from Early-Middle Holocene Egypt and Sudan (data from Stemler 1990; Magid 2003; Winchell et al. 2017; Beldados et al. 2018). B. Sorghum domestication rate estimate as a linear regression (based on combined data in A, including a combined Stemler dataset). Orange squares represent the inferred domestication episode from which the regression is calculated. For comparable data on wheats and barley, see Figure 8 below.

generally inferred, overlaying continuities from the earlier Mesolithic (Haaland 1992; Salvatori & Usai 2016). By contrast, the Butana group in the Southern Atbai (3800-2700 BC) occupied fairly large settlements (from 6 to 12 ha), producing stone tools that included possible picks for cultivation and ceramics tempered with plant remains that were predominantly from sorghum chaff with non-shattering sorghum spikelets, indicative of cultivation, identified from a number of sherds (Winchell et al. 2017, 2018). Faunal remains, however, comprised only hunted mammals, land snails and aquatic resources in the earliest phases with no evidence for pastoralism before ca. 3000 BC, shortly after which the site was abandoned (Peters 1986; Manzo 2017: 25). Thus, contrary to previous hypotheses (e.g. Magid 1989; Haaland 1992), sorghum domestication does not appear to have taken place as a consequence of pastoralism. The eastward spread of pastoralism from the Nile valley is represented by evidence from the late occupation at Shaqadud, in which pastoralists occupied a cave (from ca. 2900 BC) subsequent to perhaps two millennia of hunter-gatherer occupation on a mound outside the cave (see Marks & Mohammed Ali 1991; Winchell et al. 2018). Cultivation at the Late Neolithic site at Shaqadud remains unconfirmed by reliable archaeobotanical evidence (cf. Magid 1989; Winchell et al. 2018).

The domestication process of sorghum itself is still only known from limited data (Figure 4A), but these do provide a basis for estimating the rate of evolution of domestication traits. The proportion of non-shattering versus wild type spikelet bases (Fig. 4A) provides data from Kasm el Girbha (Winchell et al. 2017), Kasala (Beldados et al. 2018), and an earlier Nilotic Neolithic (summed across a few sites from Stemler 1990). These data can be plotted against estimated median age providing a regression line estimate of the domestication episode (Fig. 4B). The slope of this regression provides an estimated average rate of change of 0.03% per year, which is comparable to rates of increase in non-shattering estimated for Asian rice, einkorn wheat, emmer wheat and barley, which all approximate 0.02%-0.03% (Fuller et al. 2014). This suggests that the rate of evolution during sorghum domestication was typical of cereal domestication. It also contradicts the older notion that sorghum domestication was slower than other cereals due to cross-pollination (e.g. Magid 1989; Haaland 1995); indeed cross-pollination has little influence on expected domestication rates when selection coefficients are low (Allaby et al. 2010, 2016). Katharina Neumann (2003, 2005) was the first to criticize the hypothesis that African cereals were harder and slower to domesticate due to their tendency of cross-pollination. Instead, we propose that sorghum domestication began and finished later than the domestication of cereals in both West Asia or in China, but that their domestication occurred at a comparable rate and by a comparable process.

Sorghum spread rapidly as a crop, both within Sudan and beyond, potentially while even still undergoing domestication. As long recognized, sorghum has dispersed via maritime routes from eastern Sudan/Eritrea to western India by the period of 2000-1700 BC (Boivin & Fuller 2009; Fuller & Stevens 2018). The current evidence from Kasala would then imply that dispersal to India occurred before non-shattering was fully fixed in cultivated sorghum populations (Beldados et al. 2018). Subsequent to this, sorghum must have spread too through the savannahs of Africa, although empirical data remains few and far between in second and first millennium BC. Nevertheless, the earliest finds in western Africa (Benin, first millennium BC) and in southeastern Africa (early first millennium AD) provide a basis for charting the spread of this cereal, which we might refer to as a geographical process of *cerealization*. Sorghum had become a widespread grain crop within two millennia of its domestication (Figure 5).

Domestication and dispersal of Pearl Millet

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) was the earliest domesticate of western Sahelian Africa, and provides both parallels and contrasts to processes in sorghum. As with sorghum, domestication can be inferred to have taken place in the later Mid-Holocene, as the Sahara expanded and as pastoralism spread. Data from the Tilemsi Valley in Mali, 2500-2000 BC, and from the Tichitt archaeological tradition in Mauretania, 2000-1300 BC, provide evidence marking the end of the domestication episode in this species (Manning & Fuller 2014; Burgarella et al. 2018). Presumably, cultivation and the evolution of non-shattering had begun some 1000-2000

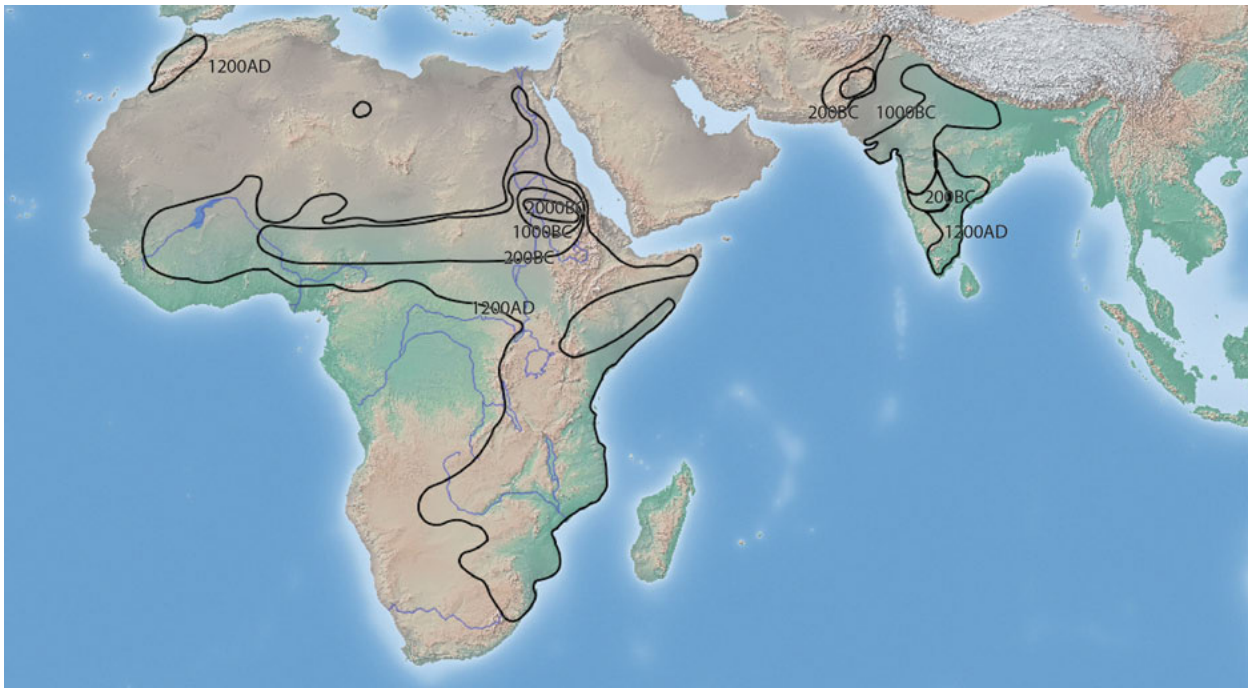


Figure 5. Map of spread of sorghum with isochrones. This is based on the distribution of archaeobotanical evidence reviewed in Fuller & Stevens (2018).

years earlier. This time frame overlaps with an estimated domestication age of 4800 BP from SNP diversity in 20 genes across a panel of 46 wild and domesticated populations (Clotault et al. 2012). Nevertheless, the association of the earliest domesticated finds with pastoralism is clear, and this suggests that pearl millet domestication may have taken place amongst forager-pastoralists. Of potential importance is that pearl millet constitutes a poor forage crop, as growing grass (Van Wyk & Van Oudtshoorn 1999), the grains being protected from grazers by a bristly inflorescence. This represents a contrast to *Sorghum* spp., which makes an excellent, and preferred source of fodder (e.g. Snowden 1955). Thus livestock would have been detrimental to early sorghum cultivation in contrast to pearl millet cultivation that had inherent protection from overgrazing (Winchell et al. 2018). Along similar lines, Mercuri et al. (2018) have suggested that early cultivated millets of the Central Sahara (Libya), such as *Echinochloa colona* and *Panicum laetum*, lent themselves to cultivation because of weedy traits such as resilience to grazing. Thus sorghum and pearl millet, despite similar chronological and climatic circumstances of domestication, appear to have been influenced by differencing socioeconomic ecologies, especially in terms of the compatibility with pastoralism.

Once domesticated, both sorghum and pearl millet were integrated with pastoralism providing a potent economic package for dispersal. Pearl millet's earliest and most rapid spread was perhaps eastwards across the Sahara, reaching eastern Sudan by perhaps 1850 BC (Beldados et al. 2018) and India, via maritime links, by ca. 1700 BC (Boivin & Fuller 2009). The archaeological record is more robust, when it comes to spread within West and Central Africa, where pearl millet made steady progress southwards (Figure 6) into ever wetter and more tropical ecologies, eventually extending into openings within the rainforest zones by ca. 400 BC (Kahlheber et al. 2014; Ozainne et al. 2014). Estimates of the land area covered by the dispersal of sorghum and pearl millet farming over time is remarkably similar (Figure 7), suggesting that similar processes of dispersal, i.e. cerealization, took place by growing agropastoral populations. In addition to early Sahelian dispersal and long-distance translocation to India, both crops spread southwards in Africa cutting across different climatic and vegetation belts at gradually increasing rates.

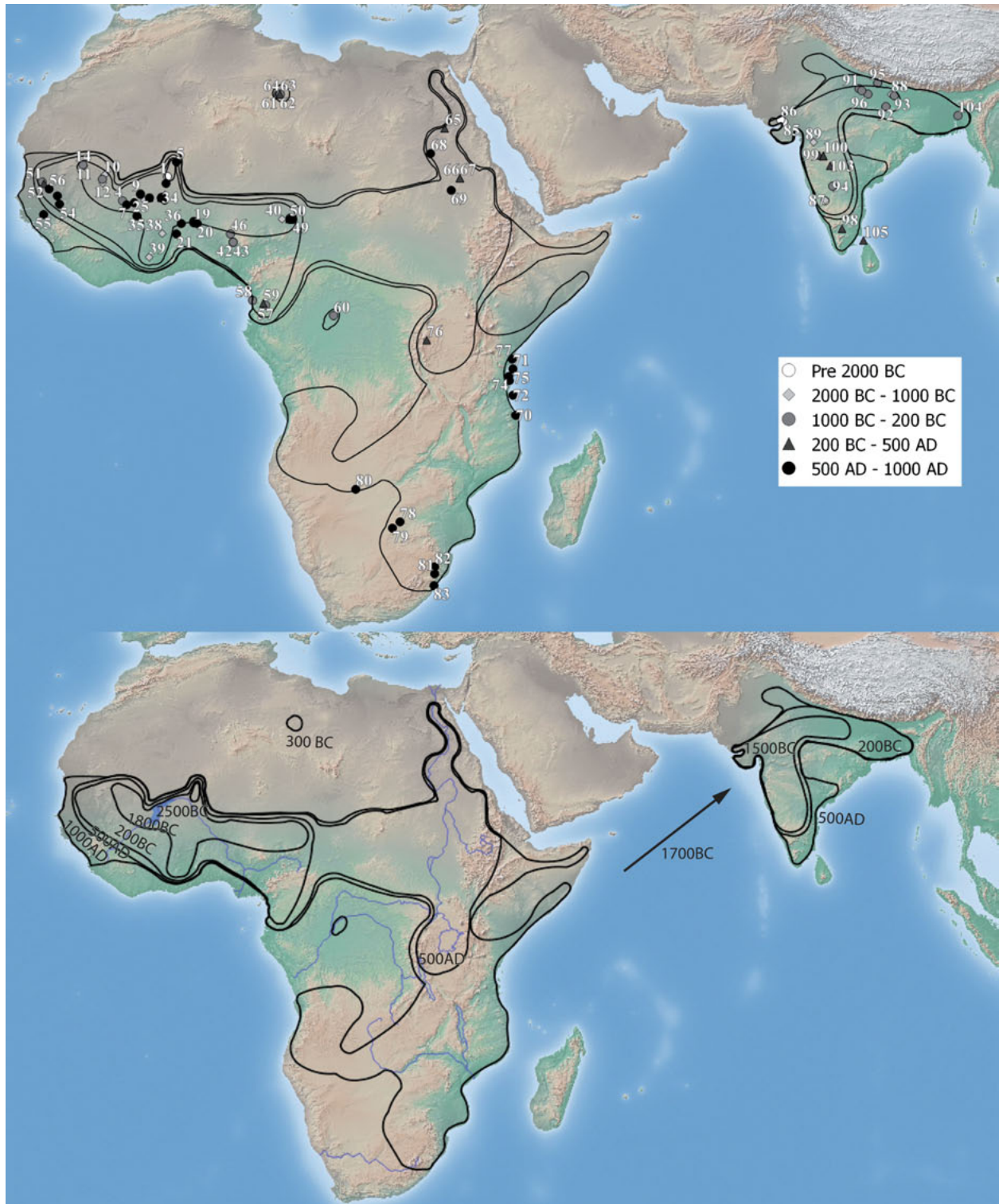


Figure 6. Map of spread of pearl millet with isochrones. Map compiled from recent reviews, including Manning et al. 2011; Crowther et al. 2018; Champion & Fuller 2018. Sites numbered on top map: **In Mali:** (1) Karkarichinkat (2) Winde Koroji (3) Ounjougou (4) Dia–Shoma (5) Essouk (6) Gao (7) Jenne-Jeno (8) Sadia (9) Tongo Maare Diabel. **In Mauritania:** (10) Dhar Oualata (11) Dhar Tichitt (12) Djiganyai (13) Oued Chebbi (14) Dhar Tichitt (15) Oued Bou Khzama. **In Benin:** (16) Alibori SIII (17) Birnin Lafiya (18) Birnin Lafiya (19) Kantoro (20) Madekali Road (21) Yohongu. **In Burkina Faso:** (22) Oursi West (23) Ti-n-Akof (24) Corcoba (25) Kissi 22 (26) Oursi 1 (27) Oursi West (28) Kissi 40 (29) Kissi (30) Kolel Nord (31) Oursi 2/3/4 (32) Oursi hu-beero (33) Oursi Nord (34) Oursi Ost (35) Kirikongo (36) MAS541 (37) Saouga. **In Ghana:** (38) Birimi (39) Boase: B5C. **In Nigeria:** (40) Gajiganna (41) Akura (42) Janjala (43) Janruwa (44) Kursakata (45) Mege (46) Ungwar Kura (47) Kursakata (48) Mege (49) Daima (50) Mege. **In Senegal:** (51) Walade (52) Cubalel (53) Arondo

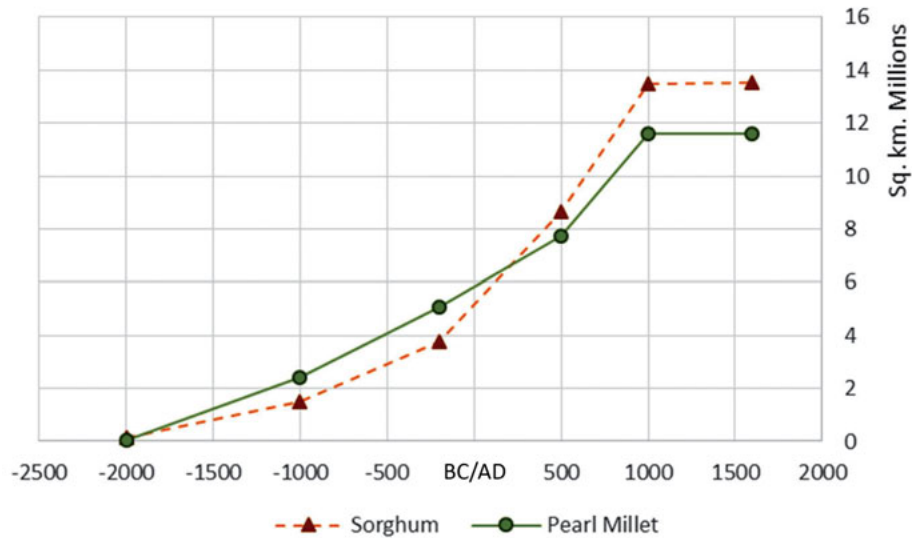


Figure 7. A comparison of the maximal extent of land area covered by the dispersals of sorghum and pearl millet (i.e. extent of “cerealization”).

A West Eurasian head start: domestication, diversification and dispersal tempo

The Early Holocene domestication of grain crops in West Asia provides striking parallels with the processes now known for pearl millet and sorghum in Africa. Domestication processes, as recorded in morphological changes were slow (Figure 8). Protracted periods of change over ~3000 years can be reconstructed for non-shattering ears in barley, emmer and einkorn, in which grain size change may have taken as long as 3500–4000 years. As already noted, the rate of evolution of non-shattering in wheat and barley is very close to that inferred for sorghum. The context in which this occurred was in sedentary villages, typically in the 0.5–4.5 ha site range during the Early to Middle Pre-Pottery Neolithic B (Braidwood et al. 1974; Guerrero et al. 2008). While cultivation may have begun in the absence of domesticated animals (Harris 1998), animal herding and domestication was well underway by 8000 BC, prior to the fixation of domestication traits in cereals and legumes (Fuller et al. 2011; Larson & Fuller 2014).

Once domesticated, wheat and barley also spread, becoming widespread across Eurasia and large parts of northern Africa (Figure 9). As with sorghum and millet, we can see that the extent of land area over which cerealization based on wheat/barley spread, shows a gradually increasing rate of species spread. The geographical reach of this form of agriculture is impressive, expanding from less than 5 million km² at 6000 BC, to around 40 million km² at 1000 BC (Figure 10). The form of the graph of this dispersal process appears similar in wheat/barley and both African cereals, which can be taken to suggest that similar processes underlie these trends, such as demic diffusion processes, often inferred to contribute to agricultural spreads (e.g. Bellwood 2001; Shennan 2018). Nevertheless the actual rate of cerealization by wheat and barley was notably slow for several millennia, advancing perhaps only 100s of km² per year during the Pre-Pottery Neolithic and accelerating to more than 2000 km² per year only with the dispersal across Europe.

← (54)Diouboye (55) Payoungou (56) Sincu Bara. **In Cameroun:** (57) Abang Minko’o (58) Bwambé-Sommet (59) Akoneteye. **In DRC Congo:** (60) Boso-Njafo. **In Libya:** (61)Tinda (62) Zinchecra (63) Jarma (64) Jarma. **In Egypt:** (65) Qasr Ibrim; **In Sudan:** (66) Hamadab (67) Meroe (68) Nauri (69) Soba. **In Tanzania** (70) Mikindani sites (71) Tumbé (72) Ukunja Cave (73) Unguka Ukuu (74) Fukuchani (75) Kimimba. **In Rwanda:** (76) Kibusanze. **In Kenya:** (77) Mgombani. **In Botswana:** (78) Kgaswe (79) Matlhapaneng (80) Nqoma. **In South Africa:** (81) Magogo (82) Ndondonwane (83) Shongweni. **In India:** (84) Hallur (85) Kanmer (86) Surkotada (87)Hallur (88)Imlidh-Khurd (89) Kaothe (90) Narhan (91) Ahirua Rajarampur (92) Magha (93) Narhan (94) Piklihal (95) Pirvitani Sariff (96) Sanchankot/Ramkot (97) Siyapur (98) Kodumanal (99) Nevasa (100) Paithan I (101) Paithan II (102) Paithan III (103) Ter (Thair). **In Bangladesh:** (104) Wari-Bateshwar. **In Sri Lanka:** (105) Kantharodai.

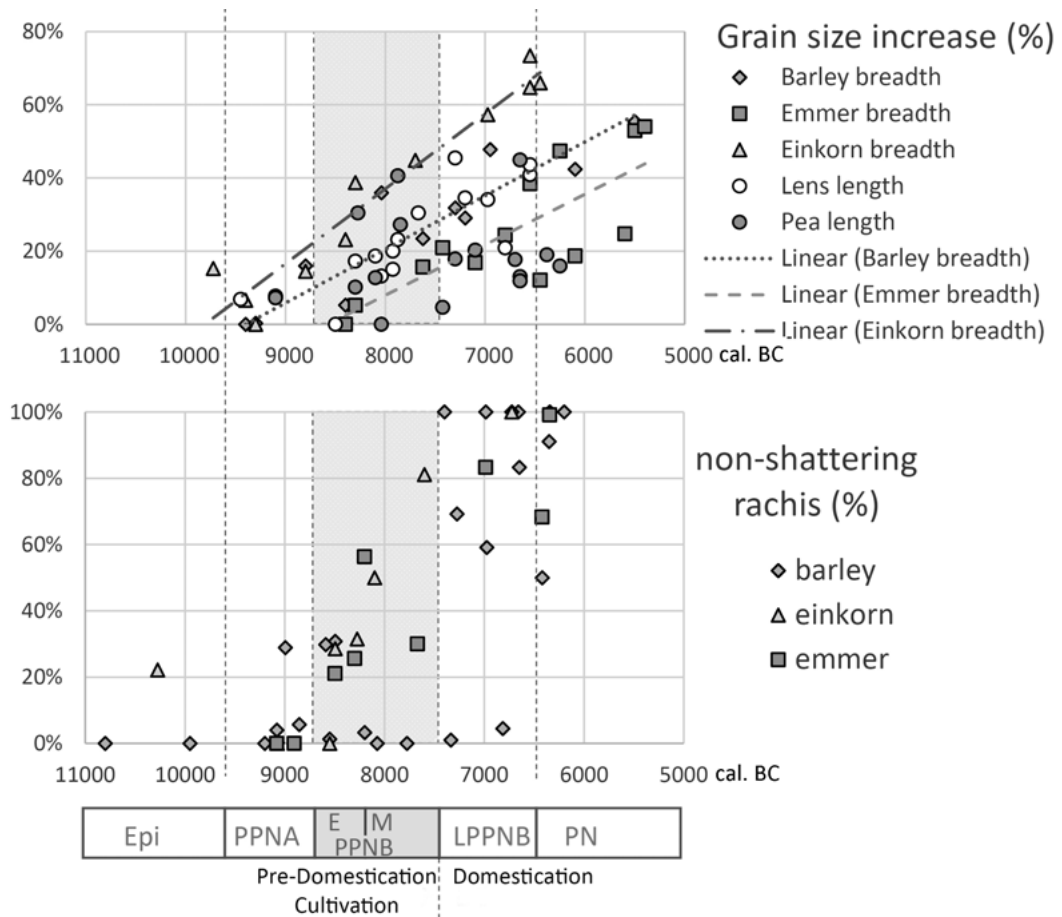


Figure 8. Archaeobotanical data on morphological change in Near Eastern grain legumes and cereals, providing estimates for domestication rates (updated from Fuller et al. 2014; Maeda et al. 2016; dataset online: Lucas & Fuller 2018).

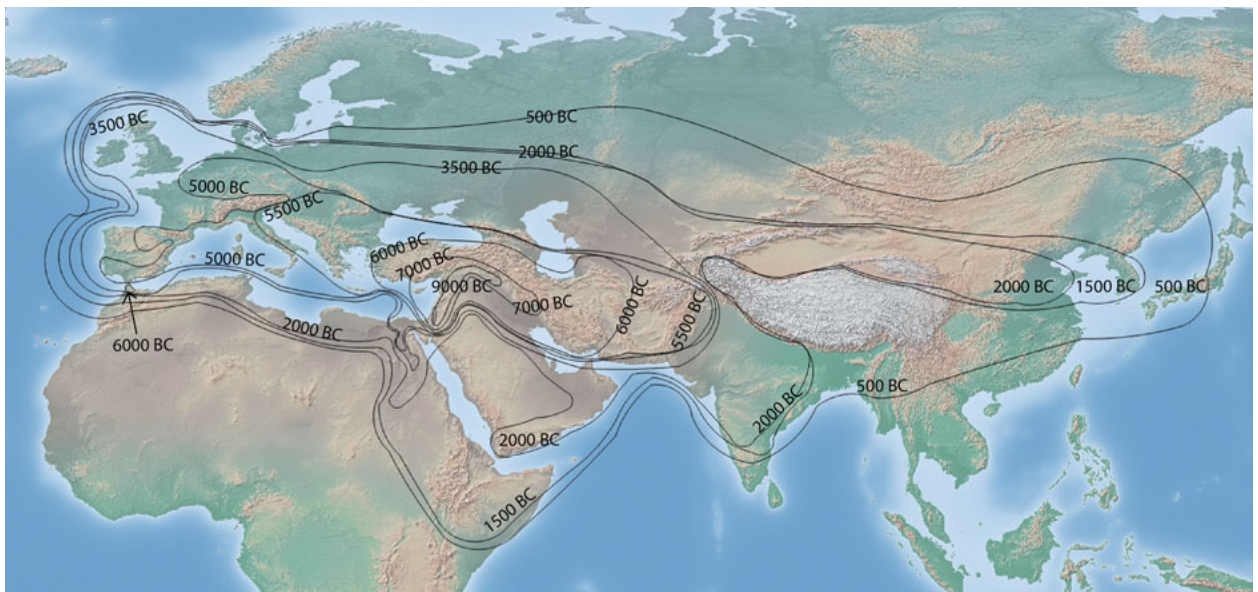


Figure 9. Map of spread of wheat and barley crops with isochrones. Eastward spread after Stevens et al. 2016; Europe is well-known, e.g. Zohary et al. 2012; Shennan 2018.

maximum extent of wheat/barley cerealization

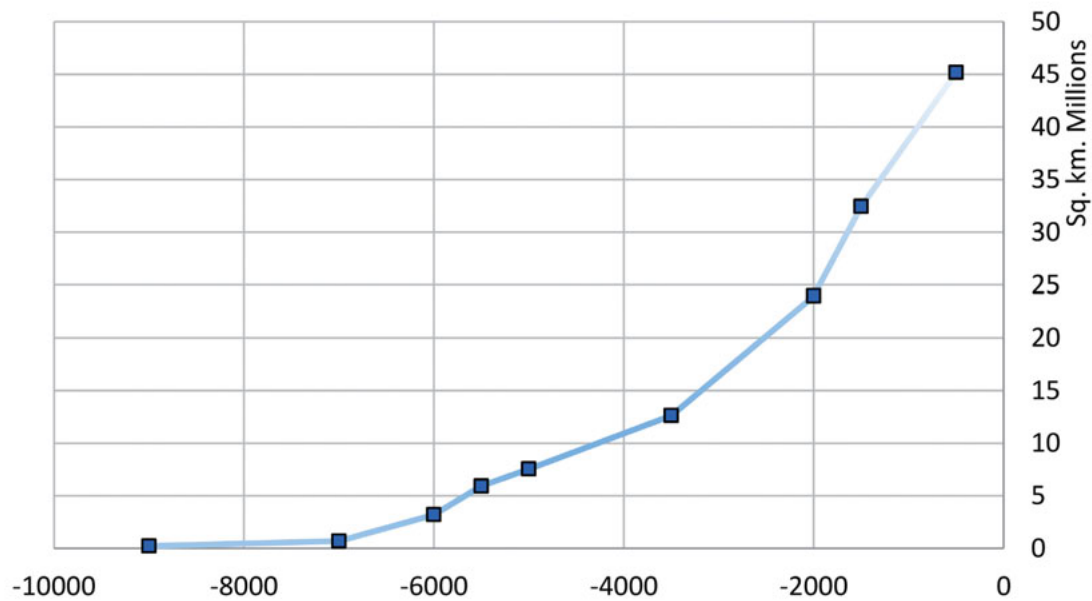


Figure 10. Land area under wheat/barley cerealization over time.

First is not fastest: a tortoise and hare parable for cerealization

The contrast seen between the absolute rates of spread of the African cereals and West Asian crops is significant. This is clear when these rates are plotted on a common timescale adjusted for the years since the beginning of cereal dispersal in each region (i.e. Δ years). Figure 11 illustrates this difference: sorghum and pearl millet are both expanding at $\sim 2000 \text{ km}^2$ per year within a millennium of domestication, accelerating to $\sim 8000 \text{ km}^2$ per year or more by $\Delta 3000$ years. In contrast wheat/barley cerealization only exceeds 2000 km^2 per year around $\Delta 3000$ years after domestication, and hovers below 4000 km^2 per year beyond $\Delta 5000$ years. Indeed the rate of wheat/barley expansion is only seen to accelerate some $\Delta 6000$ years after domestication, represented by the period when these crops broke into East Asia, peninsular India and the Ethiopian plateau. In other words, wheat/barley farming is something of a tortoise phenomenon, gaining more ground by starting early and having longer to disperse. The longer period of cerealization can be expected to have also allowed more time for varietal diversification and local adaptation to a broad range of environments.

The contrast in rates of agricultural dispersal between Africa and Eurasia (Figure 11) runs counter to what is often assumed. Jared Diamond (1997), for example, pointed to the contrast between Eurasian societies and Africa or the Americas (in terms of technological advancement, colonial expansion, economic “success”) as underpinned by geographical differences in the ease of agricultural spread: he reasoned that East-West longitudinal spreads in Eurasia met less ecological resistance than latitudinal spreads in north-south oriented continents like Africa. This claim is contradicted by the empirical archaeological record reviewed here. Instead, domestication in Africa began late, but once it started spread very rapidly through most of the continent, including eventually southwards to South Africa. Katharina Neumann (2003) considered a key feature of African subsistence prehistory its rich savannahs, that provided a “Garden of Eden” in which foraging was a long-lasting successful adaptation. This explanation could equally be extended to the smaller areas of savannahs in South and Southeast Asia, where domestication and agricultural dispersal also began later.

Nevertheless, we are left with the conundrum of why pearl millet and sorghum spread so rapidly once domesticated. We would propose that the general problem of fluctuating yields coupled with the long-term trend of growing population provides a plausible motor for recurrent sequential emigration and dispersal events. Our point is not to deny the importance of an established pastoral lifestyle in the Sahara, which was being pushed southwards out of the Sahara by climatic changes (e.g. Ozainne et al. 2014; Manning and Fuller 2014; Manning

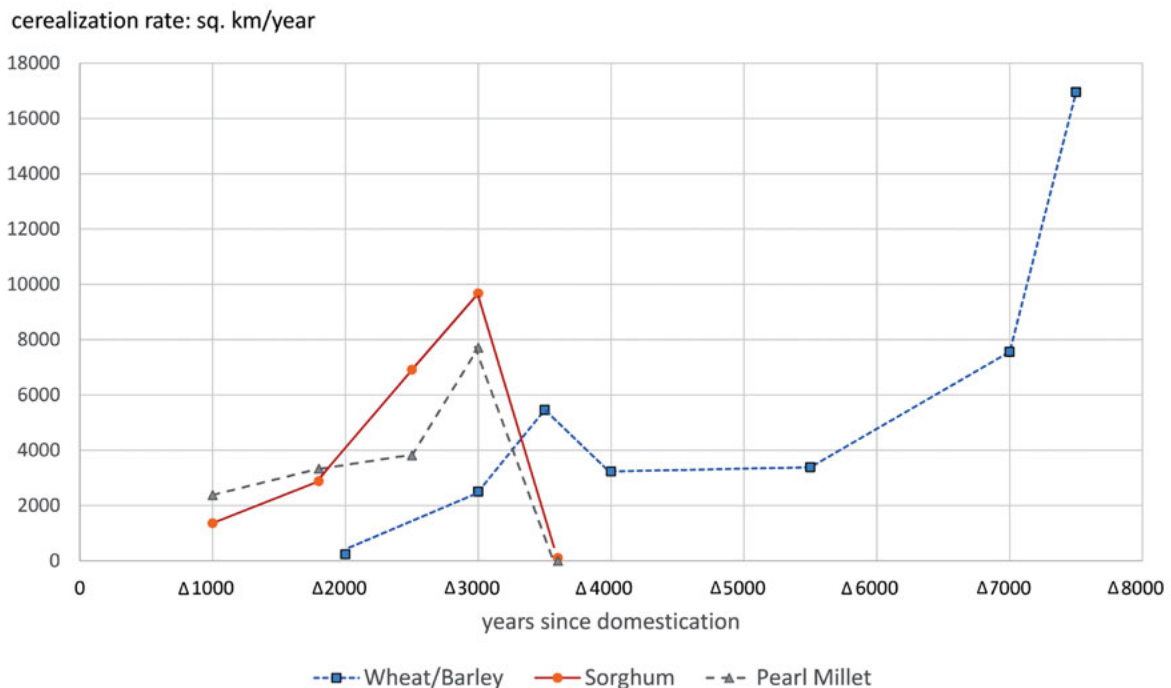


Figure 11. Comparative graph of cerealization rates: indicating the estimated rate of spread (km^2 per year) in wheat/barley, sorghum and pearl millet since the beginning of post-domestication dispersal (i.e. Δ years since domestication), based on data in Figures 7 and 10.

and Timpson 2014), but to highlight an additional factor relating to cultivation that also promoted migration, and would have done so in addition to, or even in the absence of, climate change. This derives from the insight of Rindos (1980) that the carrying capacity of cereals fluctuates above, and sometimes below the average effective carrying capacity, due to vagaries of inter-annual variability (Figure 12A), leading to years or periods of years when low productivity means that the regional carrying capacity falls below the actual population, leaving “excess” population. While under scenarios of complex societies, local shortfalls might be covered by exchange in grain, e.g. from urban stores, in the initial stages of small scale farming societies, we might expect “excess” population to form the basis of emigration. In essence, Rindos (1980) provides a dynamic underpinning of demic diffusion processes that is about more than inexorable population growth but about long term fluctuations in agricultural productivity. While this would be a problem in any agricultural system, there is an inherent yield gap between wheat and barley, on the one hand, and sorghum and pearl millet on the other. Traditional yields, and those inferred from Neolithic wheat and barley suggest yields two to three times higher per cultivated hectare than could be expected from traditional cultivation of sorghum or pearl millet (Figure 12B). There is a problem with the Rindos graphs (Figure 12A), namely the assumption of a continuously increasing effective yield, an assumption of intensification or crop improvement at a near constant rate. Instead more recent thinking suggests cycles of intensification, involution and stagnation (Ellis et al. 2013). Indeed, much of the increase in agricultural production that supported early Mesopotamian urbanism may be down to extensification, through more land and the use of ards, rather than intensification as defined by a productivity increase per unit of land (Styring et al. 2017). Nevertheless, the problem of growing populations outstripping supply in runs of poor years remains the same. The average yields for traditional wheat are ~ 1350 kg/ha (Figure 12B, Table 2), while estimates from pre-pottery Neolithic Syria, based on ^{13}C measurements of charred grain, suggest yields of 1560 kg/ha (Araus et al. 2007); even barley, usually relegated to cultivation on the worse land traditionally averages ~ 970 kg/ha. Compare those estimates to traditional yields in sorghum (~ 610 kg/ha) and pearl millet (~ 450 kg/ha), and there is a clear basis for being able to pack more population into Neolithic settlements in Southwest Asia as opposed to those across sub-Saharan Africa. Indeed, by the end of the Pre-Pottery Neolithic in Southwest Asia “mega-sites” reached sizes like 13 ha (e.g. Çatalhöyük) and even 16 ha (e.g. Abu Hureyra) and estimated populations in excess of perhaps 5000-6000 (Moore et al. 2000: 493-494; During 2007), with populations packed in at levels of

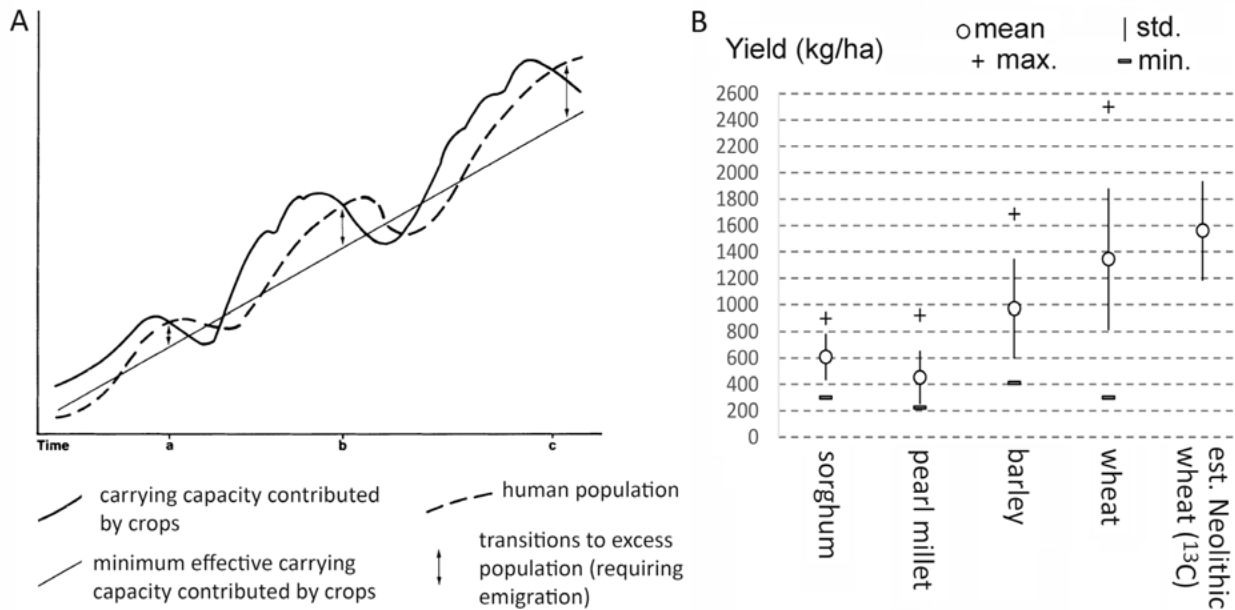


Figure 12. The effect of relative yields and carrying capacity on the expansion rate of cereal farming. A. Hypothetical mode of relationship between fluctuating cereal yields (carrying capacity) and fluctuating human population overtime leading to excess population crises (a, b, c) that require emigration of some population (after Rindos 1980). B. Estimated relative yields (1000kg/ ha) in early cereals, contrasting higher yields in wheat/barley versus African sorghum and pearl millet (based on sources in Table 2).

ca. 375 persons/hectare. The smaller sites associated with established early farming in sub-Saharan Africa were presumably also much less densely occupied.

The lower baseline yields of the African cereals mean that inter-annual fluctuations in yields can be expected to more regularly fall below the poverty line, creating excess population with motivation to move. Cultural traditions too, especially given the importance of pastoralism with its in-built affinity for mobility, can be expected to have constructed motivational patterns of movement—traditions that are presumably reflected in the widespread pattern of an “internal African frontier” (Kopytoff 1987; also Rowlands 2003; Ashley et al. 2016). But it is the inherent contrasts between the African and West Asian grain yields, on top of differing intensities of early cultivation that set up inevitable differences in the dispersal potential of early cereals. West Asian evidence, from arable weed seeds and from grain ^{15}N stable isotopes, point to high intensity cultivation of wheat and barley, including manuring, in the earliest Neolithic and during its initial dispersal (Bogaard 2005; Araus et al. 2007; Bogaard et al. 2013; Halstead 2014: 247-250; Styring et al. 2017): this would have helped to maintain high yields, at the higher end of those in Figure 12B, without the need to shift cultivation plots.

By contrast we might expect more extensive, low labour input cultivation of early pearl millet and sorghum to have been the norm across the Sahel and northern Sahara, requiring shifting of plots to rest soils. Experiments indicate that pearl millet grown on the same soil without added fertilizer reduces in yields 23% in the second year, 43% by the third year, and 75% by the fourth year (Bationo et al. 1993). This was one of the key appeals of later, added domesticates in western Africa, such as *Vigna unguiculata* (cowpea, a nitrogen-fixing legume), domesticated by 1500 BC (D’Andrea et al. 2007), and fonio (*Digitaria exilis*), a low yield (22 kg/ha -322 kg/ha: Aliero & Morakinyo 2001; higher yields can be achieved with modern agronomy and fertilizer: e.g. Sidibe 1998), fast-growing, highly resilient millet often grown in fallow years, or as part of double-cropping regimes, and added to the suite of West African crops by the early centuries AD (Kahlheber & Neumann 2007; Champion & Fuller 2018). In the earlier Neolithic, prior to this crop addition, we might expect fallow periods as long as 7 years (Botiono et al. 1993). As such if plots were cultivated for 2 years and rested for 7, and assuming yields to be $\sim 1/3$ or even $\frac{1}{2}$ those of early wheat/barley, then we can infer around $1/10^{\text{th}}$ to $1/13^{\text{th}}$ the populations of those supported by wheat and barley in West Asia could be supported by the baseline productive capacity of Neolithic African systems. This means that more arable land was needed to support the similar sized farming

Crop	Country/Region/Year	Yield (kg/ha)	Source
<i>Sorghum bicolor</i>	African subsistence sorghum mean (1990s)	700	BSTID 1996: 159
<i>Sorghum bicolor</i>	India (1950s low)	336	Randhawa 1958
<i>Sorghum bicolor</i>	India (1950s high)	448	Randhawa 1958
<i>Sorghum bicolor</i>	India, rainfed, pre-1970	484	BSTID 1996: 162
<i>Sorghum bicolor</i>	Ghana (1930s): manured	841	Nye and Greenland 1960: 132
<i>Sorghum bicolor</i>	Ghana (1930s): no manure	336	Nye and Greenland 1960: 132
<i>Sorghum bicolor</i>	East Africa (rainfed low end of production, 1960s)	550	Acland 1971
<i>Sorghum bicolor</i>	Africa (FAO mean 1976)	704	Hulse et al. 1980: Table 2.1
<i>Sorghum bicolor</i>	Sudan (FAO mean 1976)	692	Hulse et al. 1980: Table 2.1
<i>Sorghum bicolor</i>	Sudan (2009 mean)	600	Rakshit et al. 2014
<i>Sorghum bicolor</i>	Sudan (low 1970–2009)	300	Rakshit et al. 2014
<i>Sorghum bicolor</i>	Sudan (high 1970–2009)	900	Rakshit et al. 2014
<i>Sorghum bicolor</i>	India (FAO mean 1976)	544	Hulse et al. 1980: Table 2.1
<i>Sorghum bicolor</i>	Pakistan (FAO mean 1976)	621	Hulse et al. 1980: Table 2.1
<i>Sorghum bicolor</i>	“developing countries” (FAO 1976 mean)	850	Hulse et al. 1980: Table 2.1
<i>Sorghum bicolor</i>	Sudan: Gezira experiments 1940s (close spacing)	617	Tothill 1948: 485
<i>Sorghum bicolor</i>	Sudan: Gezira experiments 1940s (close spacing)	657	Tothill 1948: 485
<i>Sorghum bicolor</i>	Sudan: Gezira experiments 1940s (normal spacing)	756	Tothill 1948: 485
<i>Pennisetum glaucum</i>	Namibia typical (1990s)	300	BSTID 1996: 108
<i>Pennisetum glaucum</i>	East Africa typical (1960s)	450	Acland 1971
<i>Pennisetum glaucum</i>	Niger (control experiment)	280	Bationo et al. 1993
<i>Pennisetum glaucum</i>	W Africa min (1960s)	270	Irvine 1969
<i>Pennisetum glaucum</i>	W Africa max (1960s)	900	Irvine 1969
<i>Pennisetum glaucum</i>	Nigeria: Kado 1931–35	922	Nye and Greenland 1960: 132
<i>Pennisetum glaucum</i>	Nigeria: Kado 1936–40	455	Nye and Greenland 1960: 132
<i>Pennisetum glaucum</i>	Nigeria: Kado 1941–45	318	Nye and Greenland 1960: 132
<i>Pennisetum glaucum</i>	Nigeria: Kado 1946–1950	546	Nye and Greenland 1960: 132
<i>Pennisetum glaucum</i>	Nigeria: Kado 1951–55	330	Nye and Greenland 1960: 132
<i>Pennisetum glaucum</i>	Experimental control “Sahelian”	690	Winkel et al. 1997
<i>Pennisetum glaucum</i>	“Traditional low”	400	Winkel et al. 1997
<i>Pennisetum glaucum</i>	1950s high	336	Randhawa 1958
<i>Pennisetum glaucum</i>	1950s low	224	Randhawa 1958
Pearl millet (and others)	Sudan “millets” (FAO mean 1976)	375	Hulse et al. 1980: Table 2.1
Pearl millet (and others)	Ghana “millets” (FAO mean 1976)	330	Hulse et al. 1980: Table 2.1
Pearl millet (and others)	India “millets” (FAO mean 1976)	468	Hulse et al. 1980: Table 2.1
Pearl millet (and others)	“developing countries millets” (FAO mean 1976)	558	Hulse et al. 1980: Table 2.1
<i>Digitaria exilis</i>	Nigeria: white mbulus variety	23	Aliero & Morakinyo 2001
<i>Digitaria exilis</i>	Nigeria: Jakashale variety	22	Aliero & Morakinyo 2001
<i>Digitaria exilis</i>	Nigeria: Red dapys variety	47	Aliero & Morakinyo 2001
<i>Digitaria exilis</i>	Nigeria: Wandat variety	219	Aliero & Morakinyo 2001
<i>Digitaria exilis</i>	Nigeria: Biyama variety	244	Aliero & Morakinyo 2001
<i>Digitaria exilis</i>	Nigeria: Cibo variety	138	Aliero & Morakinyo 2001
<i>Digitaria exilis</i>	Nigeria: Wun variety	133	Aliero & Morakinyo 2001
<i>Digitaria exilis</i>	Nigeria: Tsunshalla variety	322	Aliero & Morakinyo 2001
<i>Digitaria iburua</i>	Nigeria: Red iburua variety	248	Aliero & Morakinyo 2001
<i>Digitaria iburua</i>	Nigeria: Black iburua variety	46	Aliero & Morakinyo 2001
<i>Digitaria exilis</i>	Mali 1990/91	457	Sidibe 1998: 18
<i>Digitaria exilis</i>	Mali 1991/92	723	Sidibe 1998: 18
<i>Digitaria exilis</i>	Mali 1992/93	501	Sidibe 1998: 18
<i>Digitaria exilis</i>	Mali 1993/94	700	Sidibe 1998: 18

Table 2. Comparative data on traditional cereal yields for sorghum, pearl millet, fonio, barley and wheat; estimates of Near Eastern Neolithic yields are also included.

Crop	Country/Region/Year	Yield (kg/ha)	Source
<i>Hordeum vulgare</i>	Greece	1200	Halstead 2014: 204-241
<i>Hordeum vulgare</i>	Greece: poor land (from 1000–1300 kg/ha)	1150	Halstead 2014: 204-241
<i>Hordeum vulgare</i>	Germany: Prussia 17th century	700	Braudel 1981: 121
<i>Hordeum vulgare</i>	Germany: Brunswick 18th c	750	Braudel 1981: 121
<i>Hordeum vulgare</i>	Greece: wheat and barley maslin, Kithera (max)	1000	Halstead 2014: 204-241
<i>Hordeum vulgare</i>	Crete, poor land (max)	700	Halstead 2014: 204-241
<i>Hordeum vulgare</i>	Turkey: Asvan (rainfed)	410	Hillman 1973
<i>Hordeum vulgare</i>	Turkey: Asvan (irrigated)	1150	Hillman 1973
<i>Hordeum vulgare</i>	Pharaonic Egypt (ideal)	1687	Eyre 1990
<i>Triticum monococcum</i>	Montana (USA), 1993	1420	Stallknecht et al. 1996
<i>Triticum monococcum</i>	Montana (USA), 1994	2160	Stallknecht et al. 1996
<i>Triticum dicoccon</i>	Montana (USA), 1993	1880	Stallknecht et al. 1996
<i>Triticum dicoccon</i>	Montana (USA), 1994	1540	Stallknecht et al. 1996
<i>Triticum dicoccon</i>	Prehistoric Europe, “long-term guess”	1500	Halstead 2014: 250
<i>Triticum dicoccon</i> / <i>T. spelta</i>	Spain: Austurias (low)	1250	Halstead 2014: 239
<i>Triticum dicoccon</i> / <i>T. spelta</i>	Spain: Austurias (“normal”)	1875	Halstead 2014: 239
<i>Triticum dicoccon</i> / <i>T. spelta</i>	Spain: Austurias (high)	2500	Halstead 2014: 239
<i>Triticum dicoccon</i>	lightly manured (min)	1100	Halstead 2014: 239
<i>Triticum dicoccon</i>	lightly manured (max)	1500	Halstead 2014: 239
<i>Triticum dicoccon</i> / <i>T. spelta</i>	Lowland N. Greece (after fallow)	400	Halstead 2014: 240
<i>Triticum dicoccon</i> / <i>T. spelta</i>	Lowland N. Greece (after fallow)	1600	Halstead 2014: 240
<i>Triticum dicoccon</i> / <i>T. spelta</i>	Lowland N. Greece (on stubble)	300	Halstead 2014: 240
<i>Triticum dicoccon</i> / <i>T. spelta</i>	Crete	1000	Halstead 2014: 204-241
<i>Triticum</i> sp. (wheat)	Crete: Knossos area: good fallowed land (min)	1600	Halstead 2014: 204-241
<i>Triticum</i> sp. (wheat)	Knossos area: good fallowed land (max)	1900	Halstead 2014: 204-241
<i>Triticum</i> sp. (wheat, winter)	Turkey: Asvan (rainfed)	630	Hillman 1973
<i>Triticum</i> sp. (wheat, winter)	Turkey: Asvan (irrigated)	1100	Hillman 1973
<i>Triticum durum</i>	Syria: Breda (experimental)	1469	Araus et al. 2007: Table 4
<i>Triticum aestivum</i>	Syria: Breda (experimental)	1428	Araus et al. 2007: Table 4
<i>Triticum</i> sp. (wheat, rainfed)	Syria: Raqa	1100	Araus et al. 2007: Table 4
<i>Triticum</i> sp. (wheat, rainfed)	Syria: Aleppo	1200	Araus et al. 2007: Table 4
<i>Triticum</i> sp. (wheat)	Germany: Prussia 17th century	870	Braudel 1981: 121
<i>Triticum</i> sp. (wheat)	Germany: Brunswick 18th c	850	Braudel 1981: 121
<i>Triticum</i> sp. (wheat)	France: Artois, 14th c. [Good farmer] (max)	1700	Braudel 1981: 122
<i>Triticum</i> sp. (wheat)	France: Artois, 14th c. [Good farmer] (min)	1200	Braudel 1981: 122
<i>Triticum dicoccon</i>	Pharaonic Egypt (ideal)	2220	Eyre 1990
<i>Triticum monococcum</i>	France: Provence poor land (min)	500	Halstead 2014: 239
<i>Triticum monococcum</i>	France: Provence poor land (max)	1250	Halstead 2014: 239
<i>Triticum aestivum</i> / <i>durum</i>	Syria: Tell Halula (MPPNB), est. from ¹³ C on archaeological grains (n=21)	1752±865	Araus et al. 2007: Table 4
<i>Triticum aestivum</i> / <i>durum</i>	Syria: Tell Halula (LPPNB), est. from ¹³ C on archaeological grains (n=2)	1710±625	Araus et al. 2007: Table 4
<i>Triticum aestivum</i> / <i>durum</i>	Syria: Tell Halula (Pottery Neolithic), est. from ¹³ C on archaeological grains (n=3)	1378±448	Araus et al. 2007: Table 4
<i>Triticum aestivum</i> / <i>durum</i>	Turkey: Akarçay Tepe (MPPNB), est. from ¹³ C on archaeological grains (n=5)	1360±132	Araus et al. 2007: Table 4
<i>Triticum aestivum</i> / <i>durum</i>	Turkey: Akarçay Tepe (LPPNB), est. from ¹³ C on archaeological grains (n=13)	1651±141	Araus et al. 2007: Table 4
<i>Triticum aestivum</i> / <i>durum</i>	Turkey: Akarçay Tepe (Pottery Neolithic), est. from ¹³ C on archaeological grains (n=10)	1509±167	Araus et al. 2007: Table 4

Table 2 (cont.). Comparative data on traditional cereal yields for sorghum, pearl millet, fonio, barley and wheat; estimates of Near Eastern Neolithic yields are also included.

communities in early African farming systems in comparison to those of West Asia. As population grew, the lower carrying-capacities associated with African millets then kept population densities lower than seen in Western Asia. The resulting dynamic was one in which each unit of land was of limited productivity, while human labour needed to work larger land areas was more likely to be limited. From these observations it is not a far leap to see the origins of the cultural pattern of valuing “wealth-in-people” rather than things (Guyer 1995; also Kopytoff 1987: 41; Ashley et al. 2016), which characterised many different societies and historical patterns across sub-Saharan Africa. Thus, to some degree at least cultural traditions of economy in Africa can be seen to fit with a history of early farming that was less productive and more prone to dispersal. How lower population densities, wider geographical networks of shared practice and systems of exogamy and property inheritance may have interacted in different strands of agricultural and population history across Africa would seem to be a ripe field for further research.

Conclusion

Plant domestication was a fundamental component of agricultural origins, which transformed the Earth into a planet of many anthropogenic environments, peopled in most parts by ever denser and differentiated societies. While the African continent was the cradle of the small-scale foraging communities that characterized most of the history of *Homo sapiens*, and it remained a “Garden of Eden” for foragers through much of the Holocene (Neumann 2003), some regions of Africa, on the southwestern and southeastern margins of the Sahara, participated in local plant domestication and agricultural transitions based on pearl millet and sorghum respectively. The differing dynamics of productivity, reliance on pastoralism and impacts of climate set in train differing rates in the spread of food production, with a more rapid spread in-built in the African systems. In Africa this is inferred to have involved at least as much transfer of crops to formerly foraging populations as by migration (e.g. Casey 2005), but this too would have been facilitated by the relatively low density farming populations interacting with the entrenched forager traditions within the savannas, and the low labour input requirements of the African cereals. The spread of agriculture and pastoralism did ultimately support denser populations through the savannah than had more pure foraging. As agricultural crop packages diversified, including nitrogen-fixing legumes, more crops to rotate and potential use of harvested by-products or animal by-products in farming, we might expect yields to have stabilized and fallows reduced somewhat — processes to be associated with diversification in the later first millennium BC (Kahlheber & Neumann 2007). What remains less clear is why domestication took place in the particular parts of the Sahelian belt where it did, and how the crop packages diversified after the first millennium or two of rapid dispersal. This calls for the need for further archaeobotanical sampling across more parts of Africa, as “new data often open the way to surprising insights” (Neumann 2005: 266).

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