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RESEARCH UPDATE

Comparing Pathways to Agriculture

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Introduction: a used planet

The transition from foraging systems to agricultural dependence is a persistent focus of archaeological research, and the focus of a major research project supported by the European Research Council (ERC grant no. 323842, 'ComPAg'). Gordon Childe, director of the Institute of Archaeology 1947–1957, influentially defined the Neolithic revolution as that which instigated a series of changes in human societies towards sedentism (settling in one place), larger populations, food production based on domesticated plants and animals, transformed cosmologies and the dawn of new malleable technologies such as ceramics and textiles (Childe 1936).

With hindsight the development of agriculture was a revolutionary leap in the history of human societies and economies, but archaeology now indicates that it was a drawn-out episode rather than a true revolution. Agriculture had important and long-lasting impacts on human demography and genetic variation (e.g. Pinhasi et al 2012), and profound long-term impacts on culture and the earth's environments. Agriculture facilitated a nearly global shift to more sedentary lifestyles, a massive increase in human population levels, urbanism, state formation and with it the support of specialized crafts, leading to the diversification of material technologies, including ceramics, later metals and the modern proliferation of compounds and plastics that we see today. The increased population densities of humans and livestock, clearance of forests for agriculture, and the transformation of soils means that the world we live in has become increasingly affected by human activity over the past few 1000 years (Ellis et al. 2013; Ruddiman et al. 2015). Unlike Pleistocene hunter-gatherers, farming societies have transformed the surface of the earth, its atmospheric composition (increasing greenhouse gases), and impacted the genomes and geographies of many other species, especially domesticated ones. Understanding the origins of agriculture is thus paramount to understanding our species and its place in the global ecosystem. At the base of ecosystems are plants, that convert water and sunlight into energy, and therefore how we have harnessed the power of plants by cultivation is fundamental to the human story.

An empirical archaeobotany of early agriculture

The Comparative Pathways to Agriculture (ComPAg) project began in June 2013, funded by the European Research Council, as an Advanced Investigator Grant awarded

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to Dorian Fuller. This research project seeks to examine the changing relationships between humans and plants that has led to parallel pathways towards the evolution of domesticated crops and agricultural systems across the globe. Agriculture is the outcome of convergent cultural evolution of food production based on different species in different regional environmental and cultural traditions. Crops themselves share many parallel adaptations, which botanists have long recognized as convergent biological evolution of a 'domestication syndrome' (Fuller 2007). This project aims to look at both aspects of convergent evolution, cultural and botanical, by synthesizing, expanding and comparing archaeobotanical evidence from around the world, but with particular emphasis on Asia and Africa in the Old World. While archaeologists have long had an interest in the 'Neolithic revolution' (Childe 1936), the availability of larger archaeobotanical datasets to document plant domestication for most parts of the world is quite recent. The ComPAg research program therefore aims to produce the first global comparative synthesis of the convergent evolution of domesticated plants and early agricultural systems based primarily on empirical archaeobotanical data.

Focusing on the relationships between people and plants allows us to examine both the effects that humans have had on plant behaviour (such as reducing seed shattering or ripening times) and the effects that plants have had on us - such as the move towards sedentism, higher population densities and landscape modifications to favour a comparatively limited number of plant species we call crops. That local wild plants became domesticated crops in multiple areas at different times across the globe suggests that there may be certain recurrent conditions that are relatively common that may lead to plant domestication. The identification of these potential conditions will allow us to achieve new frameworks for examining and possibly explaining the multiple routes from foraging to agriculture on a global scale. In addition to the crop plants themselves we are also considering agricultural weeds, as they represent fellow travellers with crops and farmers that have become especially adapted to the ecological niches made by humans.

ComPAg is pursuing four objectives. First, we are documenting the earliest agricultural packages in each region in terms of the economic components, including crops and major wild food resources. The hope is to escape the established narrative of the origins of agriculture, based on only a single, regional sequence (most-often for the Near East), and to be truly comparative. Second, we aim to reconstruct the earliest ecological systems of cultivation in these regions, including the evidence of weed flora. Third, we are quantifying metric and non-metric traits such as seed length and thickness of crop species to measure the process and rate of domestication. Finally, we aim to compare the circumstances of different crop domestication and regional transitions to agriculture. This we do by considering the archaeobotanical evidence in relation to socioeconomic variables of mobility, pastoralism, ecological zones and other aspects of the economic system.

Existing data, lab work and fieldwork

Archaeobotany provides the most direct dataset for the study of the changing relationships between humans and plants. The ComPAg project is working towards both integration and reanalysis of the considerable, but dispersed, data already out there, as well as generating new data collected in the field. In working with existing data we are taking both a broad-brush and a study-in-depth approach of particular taxa. We have been compiling a georeferenced database of crop evidence across all of Asia and Africa (**Fig. 1**). Such a database allows us to explore patterns in the appearance and spread of crops, and the co-occurrence of crops, but it also highlights regions and periods for which evidence is lacking, thus identifying where further archaeobotanical sampling ought to be targeted. We have the potential to look at other crops, different regions or biomes in terms of the rate and patterns of agriculture development and spread. We have a particular interest in taking better account of under-studied regions, such as India (Fuller and Murphy 2014) and Africa (Stevens et al 2014), which have received less attention in archaeological accounts of the origins of agriculture. From archaeobotanical samples that are already available, both in our lab and in those of collaborators abroad, there is much new data to be compiled on seed size of crops and the composition of different mixes of crops and arable weeds.

In addition to reviewing all the published datasets represented on the map (**Fig. 1**), we are making new measurements in order to track individual crop trajectories of domestication. We are targeting a list of around 30 species for which more data are available and which are drawn from across different work regions and types of crops (cereals, pseudo-cereals, pulses, oilseeds). We are including species whose domestication has never really been studied before, like Indian horsegram or Chinese *Chenopodium,* as well as taking a fresh look at better-studied domestications, such as African sorghum or West Asian flax. The intention is to quantify rates of change and produce more objective comparisons of different domestication episodes.

Some gaps can only be filled with new archaeobotanical sampling in the field on excavations. Therefore, we are collaborating with colleagues in the field in many parts of world. This has taken team members to Bangladesh, Sri Lanka, India, Yunnan in Southwest China and Manchuria, and new sampling is taking place in Benin, the Comoros Islands and Turkey by UCL PhD students working closely with the project. We have also initiated a new fieldwork program at the Neolithic village site of Jarmo, in Iraqi Kurdistan, a representative of the under-studied eastern wing of the Fertile Crescent. This site is known to archaeologists for pioneering interdisciplinary research carried out around 1950, but which could benefit from updated sampling methods and the opportunity provided by current political developments in Kurdistan.

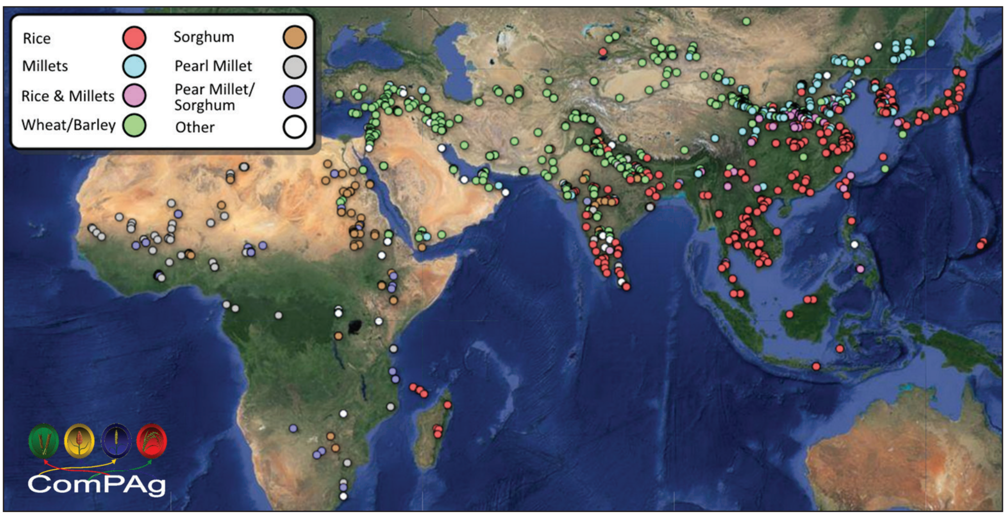

Figure 1: Map of sites with archaeobotanical evidence in Asia and Africa compiled into a database as part of the ComPAg project. This illustrates the geographical range of different early crops and gaps in current knowledge.

A truly global and comparative understanding of agricultural origins requires collaboration and expertise in many archaeological regions. Thus, in addition to our collaboration in various field projects, we are also hosting visiting researchers for short and targeted periods of joint research. So far, we have welcomed visitors from Bangladesh, Ethiopia, the USA, and Italy, who have contributed, amongst other things, new data on pre-domestication cultivation of sorghum in Sudan. More such collaborative visits are planned, to facilitate collaborations with experts on New World crops, European secondary domesticates, like oat and rye, and Chinese millets and oilseeds.

Patterns so far: protracted, parallel and plural

The past couple of decades have seen considerable methodological advances in archaeobotanical identification of domestication traits, and the collection of new data. What analyses indicate is that domestication processes were protracted evolutionary episodes and not rapid 'events'. Not long ago it was inferred from modern experimental observation that human selection of plants during domestication was likely to have been rapid, taking just one, or a few, human generations (Hillman and Davies 1990). However, more recent evidence has drawn that into question (Fuller 2007), and results from our project indicate that domestication episodes typically took around 3000 years, or 150 human generations (Fuller et al 2014). This means that evolution of plants during domestication was not significantly different from evolution in general amongst wild species responding to environmental change. The only difference is that the nature of environmental change during domestication results from the modification of soils by humans

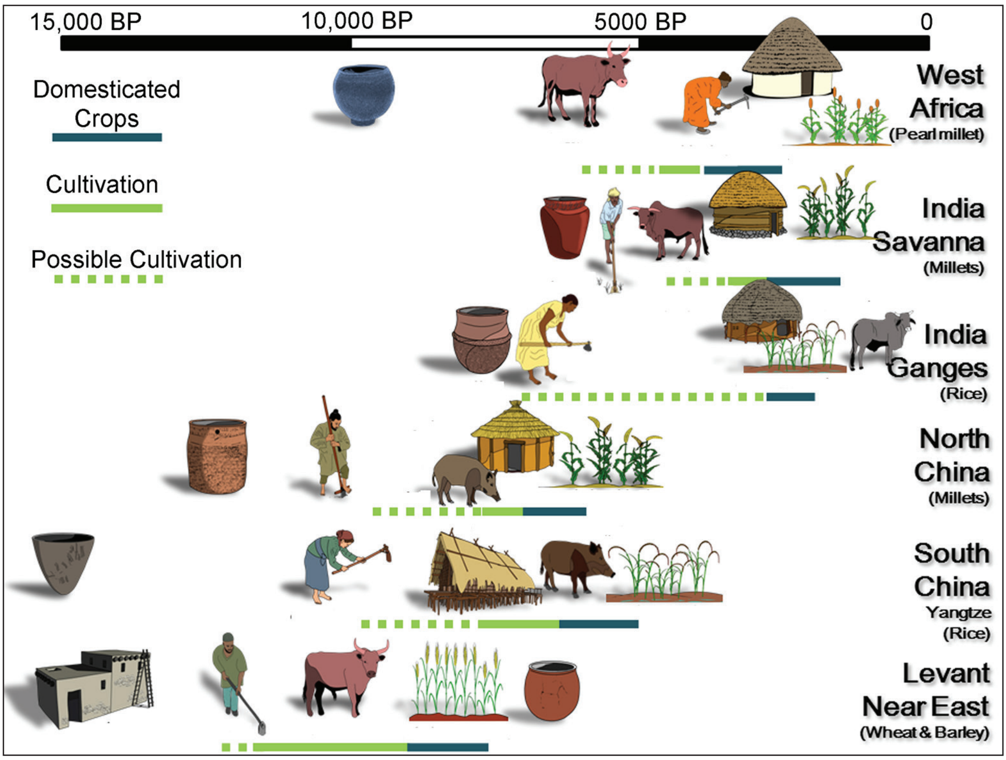

Figure 2: A comparative timeline of pathways to the 'Neolithic', indicating the advent of sedentism (hut icons), ceramics, animal husbandry, cultivation (pre-domestication cultivation), domestication and agricultural economies (indicated by crop icons) for selected regions of the Old World.

and the new seed dispersal mechanism of human sowing. Intriguingly what we have found is the rate of change in domestication traits, for example increase in seed size, was remarkably similar across Near Eastern cereals and legumes, Chinese rice and soybean, Indian mungbean, and North American sunflower. Despite the fact that cultivation began at different times in different cultural environments, the effects of crop evolution were parallel.

Protracted evolutionary processes of individual domestications mean that many more parallel trajectories are likely, both from multiple starting points within a given species or amongst closely related species. This also means that what causes the beginnings of cultivation might differ from what sustained the process across millennia, or brought the domestication process to a close. There is already evidence that domestication in different regions began at different times and with different technologies or economies (**Fig. 2**); some were sedentary, some were not, while some had pottery or livestock, others came upon these things only after crop domestication. As we progress in making the evidence for domestication episodes of different crops comparable, we will be able to return to some of the bigger questions, such as the role of Early Holocene climate change in some regions (north China, the Near East, the Neotropics), sedentism (the Near East, the Yangtze), seasonal mobility (the Americas, north China), or livestock keeping (west Africa, south India) as determining variables in the selection of early crops and the construction of the new societies based around agriculture.

Acknowledgements

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For more information

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