

Origin of agriculture and domestication of plants and animals linked to early Holocene climate amelioration

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Domestication of plants and animals was necessary for the evolution of agriculture, spatial expansion and population increase of humans during the Holocene, which facilitated the evolution of technically innovative societies. The agricultural practices enabled people to establish permanent settlements and expand urban-based societies. Domestication of plants and animals transformed the profession of the early humans from hunting and gathering to selective hunting, herding and settled agriculture. The earliest archaeological evidences, found throughout the tropical and subtropical areas of southwestern and southern Asia, northern and central Africa and Central America, suggest rapid and large-scale domestication of plants and animals ca. 10,000–7000 cal years BP. This interval corresponds to an intense humid phase and equable climates, as observed in numerous paleo records across the regions. I suggest that domestication of plants and animals and subsequent beginning of agriculture were linked to climate amelioration in the early Holocene.

CLIMATE has played a critical role in the evolution of fauna and flora. Proxy data suggest occurrence of widespread repeated, abrupt climate changes throughout the geological record¹. Persistent abrupt changes in climate may alter ecological landscape, leading to faunal adaptation. Human adaptation and migration in response to severe climate changes are known from the paleo records². Recent archaeological findings from Yana River, Siberia, indicate that humans adapted to the harsh, frigid climate of the Arctic during the late Pleistocene about 27,000 year ago³. Likewise, they adapted to arid conditions in the Thar⁴ and Sahara Deserts⁵ in the late Holocene. Although some human societies have adapted to rapid climate changes in the past, there are also examples of civilizational collapse under the persistent influence of climate change. The collapse of the Akkadian, Classic Maya, Mochica and Tiwanaku was related to persistent multi-century shifts in climate^{6,7}. The rise and fall of human civilizations in South Asia have also been climatically mediated⁸. The effect of persistent abrupt climate changes has been equally drastic on the

flora, that brought shifts from one type to another type of vegetation in the past geological records⁹.

The anthropogenic pressures in response to climate change have brought significant changes in fauna and flora. The most significant examples of human impact on the evolution of ecological niches come from domestication of animals and plants. Domestication refers to the process of reciprocation, by which animal and plant species come to depend on humans for survival, while providing humans with numerous benefits in turn. The process of domestication has been markedly important for spatial expansion and population increase of humans during the Holocene. Domesticated plants and animals are of prime importance for agriculture. Without agriculture, the complex, technically innovative societies and large human populations that exist today could not have evolved. Agriculture allowed people to become sedentary (living for a prolonged period in one place), establish permanent villages and towns and develop classified societies that included specialized and dedicated segments such as farmers, artisans, soldiers, religious leaders, teachers and governors. Agriculture is thus defined as the cultivation of domesticated plants and animals for use by the human societies, as many domesticated plants and animals would not survive without human intervention¹⁰.

Early hominids were hunters and gatherers who relied on naturally occurring vegetation, fruits, nuts, carrion and game for subsistence. Hunters and gatherers do not establish permanent settlements such as villages. They move their camps in response to changes in the season and climate. Subsistence by hunting and gathering is still practised by ancient tribes throughout the world. As the climate ameliorated, there was an increase in vegetation and people changed their food habits and lifestyle. Dogs were the first to have been domesticated by early humans (Table 1)¹⁰, which might have been used for hunting of wild animals. Goats and sheep were next to have been domesticated in southern and southwestern Asia during the early Holocene^{8,10,11}. The remains of sheep and goats found at hominid sites that are older than about 10,000 cal years show no evidence of domestication¹⁰, suggesting that hunters were killing the whole population of goats and sheep at that time. However, there was a shift towards greater abundance of skeletons of younger goat and sheep at hominid

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sites after about 10,000 years ago¹⁰. This suggests that immediately after 10,000 cal years, people were keeping herds of these animals and by 9000 cal years, sheep and goat were being kept and raised by people at locations away from the natural realms of wild goats and sheep¹⁰.

Thus, it is believed that human interaction with domesticated herding animals transformed them from hunting to selective hunting and finally to herding. Over the past 10,000 years, many animals have been domesticated in different parts of the world, as known through reasonable archaeological evidences on the early period of domestication (Table 1)¹². For example, pigs and cattle were domesticated in southwestern Asia about 9000–7000 cal years ago. The horse and bactrian camel were domesticated in central Asia between 5000 and 3500 cal years ago, whereas water buffalo was domesticated in India and southeastern Asia ~ 4500 cal years ago¹². In areas such as central Eurasia, parts of the Near East, northern Eurasia and parts of North Africa, human cultures developed, which were organized around herding domesticated animals such as sheep, horses, cattle, camels and reindeer. These people supplemented the meat and milk obtained from their herds with hunting and gathering. The human herders migrated and moved along with their herds during seasonal changes in grazing areas – the so-called pastoral nomadicism¹⁰.

The domestication of plants and animals is believed to have begun in the tropical and subtropical areas in the early half of the Holocene (Figure 1). Tropics provide enough moisture for the growth of vegetation that provides food to both humans and animals. Some of the earliest evidences for the domestication of plants come from southwestern Asia, dating back to the same period as the domestication of goats and sheep. A variety of food plants, including wheat, rye, barley, lentils, chickpeas and peas were all domesticated in the Near East and South Asia about 11,000 to 9000 cal years ago^{10,11}. In southwestern Asia, the archaeological sites with evidence of early plant domestication

occur along an inverted crescent, the *Fertile Crescent* (Figure 1, Table 1), extending from the mouth of Tigris and Euphrates Rivers, north to eastern Turkey and then south to the coastal regions of Lebanon and Israel¹². One of the earliest evidences of domesticated plant cultivation and use comes from a site along the Euphrates River in Iraq. Although numerous important domestic species come from southwestern Asia, people around the world domesticated wild plants¹². For example, corn domestication occurred in Central America and spread to South America. Likewise, domesticated Asian rice is from India and China¹³ and foxtail millet and cabbage came from China¹⁰.

Origin and expansion of agriculture and domestication of animals

Two questions regarding domestication and agriculture expansion have long hounded archaeologists, paleoecologists and paleoclimatologists. These are: (1) why did hunting and gathering people turn to agriculture and domestication of animals? and (2) what was the spatial pattern of agricultural origin and expansion? The cause for people to abandon a hunting and gathering lifestyle and take up agriculture is not that clear. Experiments suggest that it was most likely because of the more energy required for hunting and gathering, than for agricultural practices to obtain the same calories of food energy (e.g. MacDonald¹⁰, p. 357). The external pressure from environmental change and intrinsic dynamics of human populations, particularly in the wake of pressure from population growth, are the other factors proposed to explain how and why hunters and gatherers turned to agriculture¹⁰. But this hypothesis is contradictory, because the early Holocene climate conditions were more conducive with enough rain and river water available throughout the Asian-African region^{5,14–16} that might have caused the origination and expansion of agriculture and not the environmental pressure (Figure 2,

Table 1. Areas and minimum ages for domestication of selected animals and plants around the world (from Simmons¹²; Allchin and Allchin¹¹). For location of areas, please see Figure 1.

Areas with minimum ages	Domesticated plants, animals
Pan Po (3750 BC)	Foxtail millet, cabbage
Indian subcontinent (9000 BC)	Wheat, barley, jujube, sheep, goat (water buffalo: 2500 BC)
Central Asia (3000 BC)	Horse (bactrian camel: 1500 BC)
Ali Kosh (7500 BC)	Sheep, goat? (einkorn, emmer: 7000 BC)
Jarmo (6700 BC)	Einkorn, emmer, barley, lentil, pea
Egypt (3000 BC)	Donkey
Jericho (7000 BC)	Einkorn, emmer, barley, pea, lentil
Palegawra cave (12000 BC)	Dog
Shanidar (9000 BC)	Sheep?
Cayönü (7000 BC)	Einkorn, pea, lentil, sheep, pig, goat?
Catal Hüyük (6500 BC)	Cattle
Franchthi (5000 BC)	Sheep, goat, pig, cattle
Argissa (6500 BC)	Cattle
Ayacucho (6000 BC)	Lima bean, common bean
Tehuacan (6000 BC)	Maize?, squash, gourds (Maize: 5000 BC)
Ocampo Cave (7000 BC)	Squash?, gourd?, scarlet runner bean (Common bean: 4000 BC)
Highland South America (2000 BC)	Guinea pig (llama, alpaca: 1500 BC)

Table 1). I thus suggest that it was climate amelioration during the early Holocene (10,000–7000 cal years BP) and not the environment pressure that triggered the domestication of animals and plants throughout the tropics and subtropics. The favourable climate conditions with enough rains brought significant change in the ecology, leading to the exuberance of vegetation and diversification of the plant community. This hypothesis thus also opposes V. G. Childe’s *Oasis Theory*¹⁷ that envisions a humid phase during the Last Glacial Maximum and a dry phase in the early Holocene.

Evidences indicate that floral taxonomic diversity decreased at the peak of the Last Glacial Maximum (LGM), followed by an increase towards the beginning of the Holocene and a dramatic change in the assemblage during the Holocene¹⁸. As noted earlier, several independent trajectories of subsistence intensification, often leading to agriculture, began during the Holocene. That agriculture did not start during the Pleistocene can be explained from the fact that last glacial climates were extremely unfavourable to agriculture¹⁹, being dry, low in atmospheric CO₂, and extremely variable on short time scales. As the climate ameliorated, domestication followed. Indeed, in the Holocene, agriculture may have become necessary for the expansion of humans¹⁹.

The increased greenery and diverse vegetation during the early Holocene enhanced man’s awareness and sensitivity towards nature. Humans became more curious to learn about the traits and usefulness of plants and vegetation for their subsistence. The availability of stone and metal tools helpful in clearing fields and crop harvesting

may have also helped the domestication of wild plants and beginning of agriculture in the early Holocene. Initially, animals like sheep and goats were domesticated for milk, meat and wool. Subsequent domestication of larger animals was probably for their use in agriculture, irrigation and conveyance.

Despite the well-established ability of humans to domesticate plants and animals and to practice agriculture, both archaeological and genetic evidence from crop plants show that certain areas of the world were centres of domestication for the early development of agriculture (Figure 1, Table 1). Other areas either developed agriculture after contact with people and crops from one of these centres or they never practised it at all. Notable centres of initial plant domestication and agricultural development include southwestern Asia, a large part of central Africa, India, eastern Asia and Central and South Americas. People of northern Europe, North America and Australia practised agriculture only after it was brought from elsewhere^{10,12}. The origin of agriculture was linked to the availability of wild plants and animals that were useful for domestication. The Fertile Crescent of southwestern Asia and the Indian subcontinent offered many varieties of wild plants and animals, which were ideal for domestication (Figure 1).

Evidence from the Indian subcontinent

The Indian subcontinent has been one of the earliest centres for animal and plant domestication, owing to suitable climate conditions during the early Holocene. The region

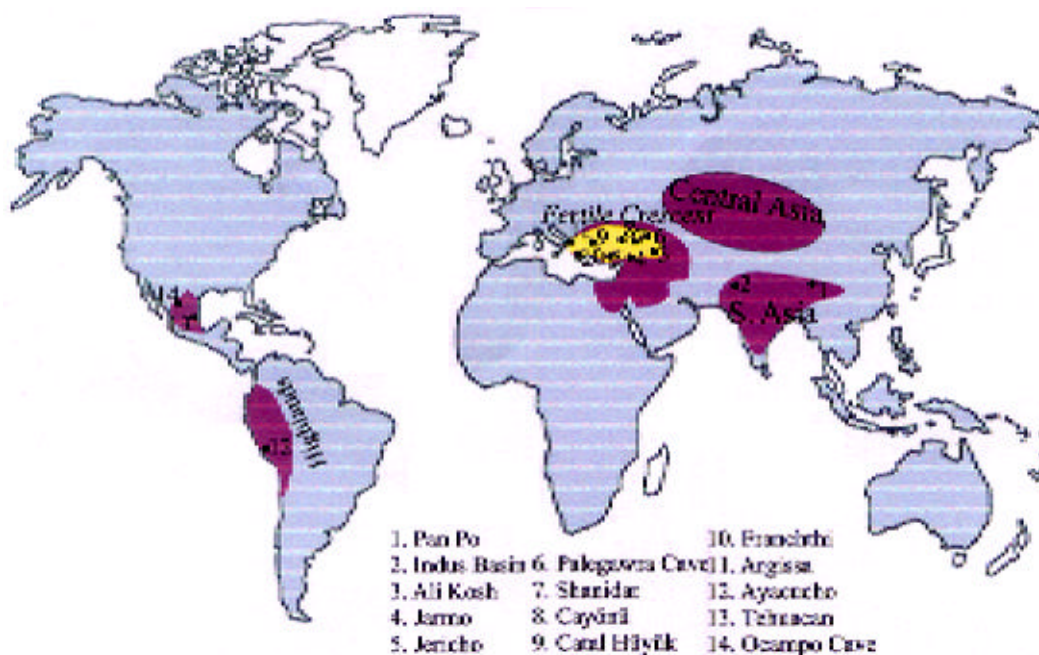


Figure 1. Important centres of domestication and agricultural origins (from Simmons¹²; Table 1). *Fertile Crescent* (yellow-shaded region) and parts of South and Central Asia appear to be the centres of earliest domestication of plants and animals that led to the beginning of agricultural practices.

is characterized by one of the most fascinating climate features of the Earth – the South Asian or Indian Ocean monsoon system that influences the socio-economic life of people of the region^{15,20}. The seasonal changes and decadal to century scale shifts in the monsoon during the Holocene influenced plant population and diversification. For instance, vegetational changes near Gangotri Himalayas have been linked to changes in the monsoonal precipitation during the past 2000 years^{8,21}.

The relation between humans and animals in India has been very friendly and complementary since the beginning of animal domestication, which can be realized from

the fact that many Indian sages turned wild animals as their pets since the *Vedic* times. Worshipping of different components of *nature* (both animals and plants) by Indians since the Vedic times indicates a deep love and awareness of Indians towards nature, which they thought important for their survival. In fact, all ancient civilizations throughout the world were nature worshippers. An excellent example of human–animal relation in India is the domestication of Asian elephant long ago, whereas the African elephant still lives a wild life. The relation between plants and people has been equally intimate for people of India. *Pipal* and *barh* (banyan) – the two sacred trees to Hindus, found throughout the Ganga–Yamuna doab, are some of the oldest wild trees worshipped in India since the ancient times. Vedic Indians realized the importance of plants for subsistence as well as for medicinal use (herbs) that attracted them to undertake exhaustive research on the importance of wild plants in domestic and medicinal use and as a result, the Science of Indian medicine, the Ayurveda, developed. Archaeological evidences from the Indian subcontinent indicate that the domestication of animals and plants began around 10,000–7000 cal years BP in the northwestern part of India, in the region watered by the Indus River and its tributaries¹¹. Paleomonsoon records from marine^{5,15,22–26} and land sequences^{14,16} indicate that the early Holocene (~ 10,000–7000 years BP) was an interval of warmer and wetter conditions with intensified southwest (SW) monsoon (Figure 1). Ganga, Brahmaputra as well as Indus Rivers were flowing in their full strength during this time^{14,27–29}.

Mehrgarh (now in Pakistan) with lush green vegetation was suited to be the centre for early civilization in the Indian subcontinent and for the transformation from hunting and gathering communities to communities with settled agriculture and domesticated animals¹¹. The Bolan valley with abundant vegetation including wild cereals, presence of wild animals and water availability might have attracted the earlier man, even before the evolution of agriculture. The early settlement at Mehrgarh dates back to ~ 9000 cal years BP^{30–31}, which presents the oldest evidence so far for the beginning of agriculture and domestication of animals in the Indus system, coinciding with the humid phase of the SW monsoon^{15,16}. Mehrgarh provides an important evidence for the change from hunting, gathering and pastoralism to a subsistence economy, centered around settled agriculture and the domestication of wild animals¹¹. Agriculture might have allowed people to become sedentary, establish permanent villages and towns and become aware of the social system of the societies. Wheat and barley were cultivated from the very beginning of agriculture and among the fruits, jujube, stones of date palm and grape seeds were first used³². The spread of agriculture thus was essentially the expansion of the highly successful pattern of wheat and barley production and domestication of cattle, sheep and goat that emerged at Mehrgarh area^{11,33}. The increase in rainfall in the Indian subcontinent must have created conditions favourable for

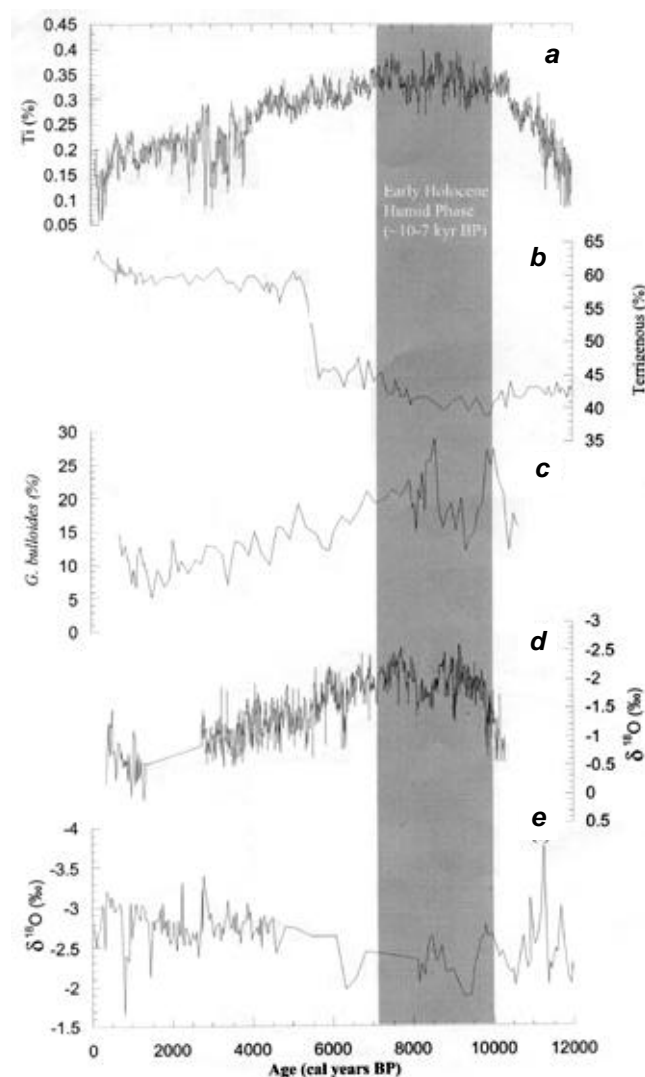


Figure 2. Holocene record of climate variability from different regions of the tropics and subtropics. *a*, Ti (%) from Cariaco Basin²⁵; *b*, Terrigenous flux at ODP Site 658, NW Africa⁵; *c*, *Globigerina bulloides* (%) from ODP Site 723, Arabian Sea¹⁵; *d*, Oxygen isotope record from southern Oman¹⁶; *e*, West Pacific²⁶. Shaded area marks the early Holocene humid phase (~ 10,000–7000 cal yrs BP) corresponding to the beginning of agriculture and domestication of plants and animals in the tropical and subtropical regions.

the expansion of agriculture throughout the Indus Basin and other areas as well. Thus, the early Holocene interval (10,000–7000 cal yrs BP) was marked by a subsistence economy, based on the cultivation of wheat and barley and settled civilization.

It is likely that the summer monsoon season was longer in the early Holocene³⁴ with excess moisture content than what was required for food production. This might have provided enough moisture for the winter monsoon rains needed for winter crops. Since both wheat and barley are winter (*Rabi*) crops, it seems probable that grain production would initially have depended mainly upon winter rains and subsequently, people had developed methods of irrigation and rainwater harvesting as an adaptation to monsoon variability^{2,35}. The cultivation of rice was probably introduced during the early Holocene humid phase in the Ganga–Yamuna Doab (interfluvium)¹¹. The excess summer monsoon rain in the early Holocene probably did not allow early farmers of the Indus region to grow *Kharif* (rainy season) crops like maize, millet (*jawar, bajra*) and a variety of lentils, which were probably introduced later with the beginning of arid phase about 4000 cal years BP^{25,36–37}. In summary, the strong monsoon of the early Holocene appears to have been wet enough for agriculture during the winter season, while the late Holocene (last 4000 years) was drier, coinciding with the appearance of rainy season crops.

Aridity too had considerable influence on the subsequent diversification of crops and their cultivars. The cultivation of millet in southern India may have been in response to aridity. There is evidence that small millets *Brachiaria ramosa* and *Setaria glauca* were domesticated in India. A study by Kimata *et al.*³⁸ suggests that domestication process may have passed through three distinct phases: (i) art associated mimic weed with upland rice and some millets; (ii) a secondary crop mixed with little millet or kodo millet; and (iii) as an independent crop. Indeed, this phased process has been promoted as a means of adaptation to aridity and gave rise to further diversification of the crop pattern.

Evidence from China

China provides significant evidence of climatic effects on humans and their farming systems during the Holocene. Several human-induced changes in vegetation have occurred during the Late Quaternary in the Middle Yangtze River valley, where one stock of rice was domesticated³⁹. Fossil rice phytoliths identified from the late glacial to Holocene sediments in the East China Sea, were probably transported by the Yangtze River. The rice phytoliths are found first in the sequence datable to ~ 13,900 cal yr BP and disappeared during the period of 13,000–10,000 cal yr BP, coinciding with the last glaciation, the so-called ‘Younger Dryas’⁴⁰. The coincident disappearance of domesticated rice phytoliths with cold climate conditions suggests an immense influence of climate on human actions during that

time. Warmer and wetter conditions during the period 13,900 to 13,000 cal yr BP and after 10,000 cal yr BP are most likely to have favoured rice domestication in the area⁴¹.

Climate thus has influenced vegetation and societies throughout the tropics and other regions, leading to the development of different civilizations. The abrupt and dramatic changes in climate during the Holocene caused human migrations in many areas, whereas some societies adapted other means of sustenance. In India’s Thar Desert, people used rainwater harvesting as an adaptation to monsoon failures. The rising global temperature due to increase in greenhouse gases could be a cause of worry for climate modelers, as well as policy planners, because, as the temperature rises, the climate undergoes more dramatic changes with droughts in some areas and floods in other areas.

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Variable Holocene climate conditions have caused cultures to thrive, adapt or fail. The invention of agriculture and the domestication of plants and animals allowed sedentary societies to develop and are the result of the climate becoming warmer after the last glaciation. The subsequent cooling of the Younger Dryas forced humans to concentrate into geographic areas that had an abundant water supply and ultimately favorable conditions for the use of agriculture and widespread domestication of plants and animals. Population densities would have reached a threshold and forced a return to foraging