Rice or Millets: Early Farming Strategies in Prehistoric Central Thailand

Steve Weber[1], Heather Lehman[1], Timothy Barela, Sean Hawks[1] & David Harriman[1]
(1) Department of Anthropology, Washington State University, Vancouver, WA, USA

Steve Weber
Email: webersa@vancouver.wsu.edu

Abstract
Ancient seeds from archaeological sites can provide crucial clues to the understanding and characterization of subsistence strategies. This in turn contributes to our understanding of, and explanations for, the relationship that exists between socio-economic systems and the organization of craft production. This paper will examine the relationship between rice and millets at three copper-producing sites in central Thailand to shed new insights into the subsistence strategy of these communities and to better understand the relationship between these crops and their introduction and use in South East Asia.

Keywords
Agriculture, *Setaria italica*, Foxtail millet, Archaeobotany, Archaeometallurgy, *Japonica*, South East Asia

Introduction

Subsistence strategies based on the use of millets and rice are well documented in modern Southeast Asia. However, these plants were first introduced into this region as domesticated crops between 3000 and 5000 years ago. Yet the relationship of these crops to one another is not well understood. For example, were these crops initially available at the same time? Were they introduced together as part of a package or separately and, if given a choice, why would people select one crop over the other? This paper addresses the occurrence and possible use of these crops at three prehistoric sites in the Khao Wong Prachan Valley in central Thailand, known to be regional center of copper production (Figures 1 & 2). The occupations at Non Pa Wai, Nil Kham Haeng, and Non Mak La span the critical period between the end of the third millennium BCE into the early centuries of the first millennium CE and contain well preserved grains of rice and millets.

Millets and Rice in Southeast Asia

While a variety of foods was in use during the period in question, this paper focuses on just two crops millets and rice. Millets in prehistory are not well understood, are less studied and, unlike rice, include a variety of genera. They are a heterogeneous group of forage grasses known for their small "coarse" grains (Weber and Fuller 2008). They have been recovered from archaeological sites world wide, yet rarely are they found in large quantities or perceived as a primary food source. While there is little current evidence for their use in prehistoric Southeast Asia, they were regularly cultivated in historical times and can easily be seen growing in fields today. In fact, all nine of the common millet genera; *Brachiaria, Digitaria, Echinochloa, Eleusine, Panicum, Paspalum, Pennisetum, Setaria, Sorghum*, are in use today in the region. Of these, only *Setaria* and *Panicum* grains have been recovered in the Southeast Asian archaeological record in any significant numbers. One millet is of particular interest in this paper and that is *Sateria italica (L.) P. Beauv.* or foxtail millet. It was recovered in large numbers from all three sites, like rice, it has its origin in eastern Asia, and it is one of the few millets that, not only has a long history of use, but was used as a primary food crop throughout this region.

Foxtail Millet

Sateria italica is primarily a crop of subtropical and temperate regions of the world. As a warm-weather grass it is quite flexible in adapting to a wide range of temperatures, soils, and elevations. It grows best in areas with between 400 and 700 mm of seasonal rainfall and less than 2000 meters in altitude. Millets, in general, require less rainfall than many of the larger-seeded cereals, and are fairly tolerant of drought due to the fact that they mature fairly quickly. Foxtail millet can be grown in semi-arid environments with rainfall less than 125 mm. Although the millet generally prefers fertile soils with a pH of about 6.5, it can be grown successfully in a wide range of soils; from heavy clays to light sands, and can even grow well on poor or marginal soils. The average annual yield of rain fed foxtail millet is 800-900 kg/ha of grain and 2500 kg/ha of straw, although much higher grain yields can be obtained with irrigation (Brink 2006). Foxtail millet, in general, begins flowering around 60 days after sowing, which lasts about 10-15 days. Total crop duration is usually 80-120 days, although some crops may mature in as little as 60 days. Because it is usually grown as a rain fed crop it takes little management to get a good yield. Crops are maintained by regular weeding, beginning around 2-3 weeks after emergence of the seedlings, and repeat every two or so weeks. Seeds can be broadcast, but they are usually placed in drilled rows. After reaching maturity, the millet is harvested manually by cutting off and threshing the panicles. Before storage, Foxtail millet needs to be dried. Just before processing, the grain is usually husked to prevent insect infestation. Dehusking can be accomplished with a stone roller or wooden mortars (Brink 2006). The grains can be milled, malted or popped. The grain is most commonly cooked and eaten like rice.

Millets have a long history of use and their cultivation in Northern China appears earlier than rice (Lee et al. 2007; Liu et al. 2009). Although issues exist surrounding their exact locus of domestication, and how many times they were domesticated, their origin in China is without doubt. Early evidence of well-documented millet is found at Xinglonggou from ca. 6000 BCE in Eastern Inner Mongolia (Fuller et al. 2007), which may represent an independent development from early millet cultivation found in the Yellow River basin by 5500 BCE (Fuller et al. 2007; Lu 1998; 1999; 2002; Crawford et al. 2005; Crawford 2006). Additional evidence of early domestication of foxtail millet is found at Cishan (Tz'u-shan) in Northern China and dates to around 5500 BCE (Smith 1998). There is also phytolith evidence for *Panicum* use at the same site as early as 8000 BCE (Lu et al. 2009). These early millet farming cultures shared similar social and political structures with their southern rice farming neighbors and differed only in agricultural repertoire due to the dryer climate and unpredictable rainfall.

Evidence for foxtail millet in Southeast Asia, and in Thailand in particular, is much more limited. In fact, there is little evidence for any millet use in this region before 2000 BCE. Whether this is a reflection of its limited use, or a result of its small grain size and issues of preservation or methods of collection, or relatively small number of sites excavated, is difficult to determine. Bellwood (2005) has suggested that the lack of millets in Southeast Asia may be a consequence of the wet, tropical conditions which may not have suited the highly drought-resistant plants. Yet open grass land conditions can be found throughout Southeast Asia. Further, millets are known to grow in a variety of habitats, not just in grass lands (Weber and Fuller 2008). While Thompson found no positively identifiable millet grains at Khok Phanom Di despite an intensive flotation program (Thompson 1996), panicoideae phytolityhs have been identified from archaeological contexts at a number of Southeast Asian sites implying the presence of millet in the Bronze Age (Kealhofer and Piperno 1994; Kealhofer and Grave 2008). Seed evidence presented in this paper clearly demonstrates *Setaria italica* was in use as early as the Neolithic period.

Rice

The origins of *Oryza sativa L.* from its Yangtze core began over 8000 years ago (Fuller and Qin 2009; fuller et al. 2009). The archaeological and genetic evidence for its domestication and spread is well documented and studied (See: Bellwood 2001; Fuller and Qin 2009; Fuller et al. 2007). Rice is often divided into two types, each with a different history and ecology. One, referred to as *japonica*, is associated with more intensive forms of water management (Fuller and Qin 2009). This perennial wetland rice has its origin in East Asia. The second, *indica*, is a dry-land variety that needs little human management. *Indica* is probably the result of a hybridization between japonica and a wild rice found in other regions of Asia. This distinction is important as their ecology and resulting forms of management differ.

Rice can be grown in a great variety of environments ranging from semi-cold zones with little rain to the tropics with thousands of millimeters of rain (Kaida 1991). Rice can be cultivated on mountain slopes to the deltas. In part this is a result of the great diversity of rice varieties. They range from short-maturing varieties which ripen in three months to longer-maturing varieties which ripen in nearly nine months. Further, there are varieties ranging from those that grow best in the pre-monsoon or monsoon season to those that do best in the dry seasons (Kaida 1991). Rice may be grown by broadcast, drilling directly in the field, or may be grown in nurseries and transplanted. Crops management might include weeding, controlling the flow and availability of water and fertilizing (Meertens 2006). Rice grains are often harvested before reaching full maturity, which is usually around 30 days after flowering, or when about 90 percent of the grains are firm and do not display a green tint. While in some areas a small knife is used for harvesting, it was more common for farmers to use sickles to cut the panicles in addition to some or all of the culms (Meertins 2006). The harvested plants are then either allowed to dry in the field or bundled for processing (Meertins 2006). Following harvest, threshing is usually done manually, either by beating the bundles on a stone or drum, or by beating the panicles on a canvas with wooden sticks. Winnowing is often times done by shaking and tossing the grain on a tray with a narrow rim. Like many millets, rice is often stored unhusked, since it is less susceptible to deterioration and loss of quality (Meertins 2006).

While there is a lot of historical evidence for rice use in Southeast Asia, the prehistoric evidence is much more limited. The general consensus is that rice was introduced into this region from China no earlier that 3500 BCE, and more likely after 2500 BCE (Bellwood 2001, 2005; Higham 1989; Glover and Higham 1996; Higham et al. 1998). Most of the earliest evidence of rice is in the form of impressions in ceramics. For example, rice grain casts from ceramics at Ban Chiang in Northeast Thailand date to ca. 2000 BCE (Kealhofer 2002). Rice spikelets and chaff from Khok Phanom Di pottery in southern Thailand date to between 1500 and 2000 BCE (Thompson 1996). Also from Khok Phanom Di are coprolites containing beetles that are common rice pests, suggesting that rice was being stored in large quantities by ca. 1500 BCE (Thompson 1996). While there are rice phytoliths as early as ca. 2500 BCE (Kealhofer 2002), there are few actual rice seeds dating before 1000 BCE Most finds of rice grains date to the Iron Age or later. Many of the early rice dates are based on AMS dating from rice tempered sherds. The accuracy of these dates have been called into question as clays may contain old carbon and give some dates centuries too old (Higham and Higham 2009).

Depending on the variety, rice can be either part of a dry-land farming strategy or one involving permanent paddy fields with water control systems. When wet rice agriculture first occurs in central Thailand is difficult to determine. In fact there is no evidence before the first millennium BCE (Kealhofer and Piperno 1994, 2002; Mudar 1995). Dry-cropped rice can and often is grown in regions where millet cultivation is practiced. In fact, there are examples of rice and foxtail millet being cropped in the same fields at the same time in southern Thailand (Sato 2009, Personnel Communication). When farmers were asked why they grew both together the response was it ensured a good yield (Sato 2009, Personnel Communication). If there was little rain then foxtail millet would thrive, if there was a lot of rain then they would get a good harvest of rice. Whether these plants were cropped together in prehistory is hard to determine and is be addressed in the next section of this paper. While both rice and foxtail millet came from China, it is still debated as to whether they arrived with migrating farmers, as part of a gradual shift in strategy by local gatherers taking advantage of new crops becoming available or if a changing climate was partly responsible for the shift to new crops.

Thailand Archaeometallurgy Project

The Thailand Archaeometallurgy Project (TAP) involved the excavation of a series of ore processing sites in the Khao Wong Prachan Valley in central Thailand (Figure 1 and 2). The goal was to reconstruct the local processes of copper production within the prehistoric technological, ecological, geological and cultural environments. One specific line of research focused on understanding the relationship between subsistence strategies and early copper producing settlements. Specifically, here the project wanted to test the hypothesis that the area was "agriculturally insufficient" and produced copper for subsistence trading to augment an inadequate food supply (Mudar and Pigott 2003; Pigott et al. 2006).

Three sites, Nil Kham Haeng, Non Pa Wai, and Non Mak La, all located near one another were excavated between 1986 and 1994 (see: Pigott et al 1997; Pigott et al. 2006; Kealhofer 2002; Mudar 1995; Mudar and Pigott 2003; O'Reilly 2003; White and Pigott 1996; Pryce 2008). The sites are in an ecologically diverse valley area on the eastern margin of the Central Plain near the modern town of Lopburi in Province. The Khao Wong Prachan Valley is situated on a "fan-terraced complex" that graduates into the hill region east of the Central Plain (Cremaschi et al. 1992). The uplifted, erosion resistant hills (inselbergs) to the east are composed of granites, andesites and limestones. It was from outcrops within these hills that stone, copper and iron ore were mined. The greater Lopburi region is made up of two distinct soil patterns with the valleys being more a limestone and clay-loam and the terraces on the hills being a silty clay rendzina (Mudar1995). This is an important distinction, in that the valleys would be more fertile and suitable for wet-rice agriculture, while the terraces are more porous and would be better suited for dry-land agriculture (Mudar 1995). While in the past the region was a typical tropical savanna, today it represents one of the driest areas of Southeast Asia. Between ca. 2500 BCE and 500 CE, when these three site where occupied, the climate may have been better suited for dry-land farming than wet-rice agriculture (Mudar and Pigott 2003; Kealhofer 2002; Mudar 1995).

The Archaeology and the Sites

At each of the three sites, Nil Kham Haeng, Non Pa Wai, and Non Mak La there was good evidence for ore processing. In fact, the Khao Wong Prachan Valley is known for its concentration of prehistoric mining and smelting sites (Pryce 2008). Smelting was often conducted in large crucibles placed in shallow pits (Pigott et al. 2006). Rudimentary portable furnaces were formed by placing perforated ceramic furnace chimneys on the crucibles (Pigott et al. 2006; Pryce 2008). The result of these activities was heavily disturbed ashy soils with crushed ore fragments and thousands of crucible and casting mold fragments. The ore processing activities in association with subsequent natural and cultural taphonomic processes created problems in constructing the sites chronologies. The lack of tight temporal borders and clearly distinguishable occupations within each site clearly impacts the interpretive value of the archaeobotanical material. New chronologies are being constructed for each site as this paper was being written. Because the chronologies used in this paper are based on existing published sequences for each site (see: Pigott et al. 2006; Pryce 2008), they may need to be redone at some future date.

The site of Non Pa Wai represents one of the earliest occupations in the valley (Figure 2). It was occupied from the Neolithic to the Dvararti and was excavated in 1986 and again in 1992 (Pryce 2008). It was slightly over five hectares and has a depth of around four meters (Pigott et al. 2006). Both smelting and domestic debris was recovered. At least three distinct occupations have been identified (Figure 3). The earliest, Period 1, is Neolithic and dates to between c. 2200/1800 BCE and c. 1500/1400 BCE (Pryce 2008; Rispoli 2007). Period 2 is a Bronze Age occupation lasting to c. 800 BCE (Pigott et al. 2006; Pryce 2008). The last period, NPW3, is heavily disturbed from modern ploughing. This Iron Age occupation ends sometime around 600 CE (Pryce 2008).

The site of Non Mak La, excavated in 1994, is less than 1km from NPW (Figure 2). The size of the site is difficult to determine due to extensive ploughing (Pryce 2008). Neolithic, Bronze Age, Iron Age and historical occupations are all present (Pryce 2008). With 56 primary burials, the presence of domestic ceramics, and with numerous activity areas, including those for adze and stone bracelet production, pottery manufacture, and copper and iron production, NML represents a multi-activity site (Pigott et al. 2006; Pryce 2008).

Nil Kham Haeng is located at the western edge of the Valley and was damaged by the construction of a reservoir (Figure 2). Occupied during both the Bronze Age and Iron Age (Figure 3), NKH represents the latest, shortest, but possible the most permanent habitation of the three sites (Pigott et al. 2006). While work at NKH included three seasons (1986, 1990 and 1992) only four units were excavate.

Archaeobotany

Since subsistence practices, and specifically plant use strategies, were a primary interest of TAP, all three sites were intensively sampled for both macrobotanical remains and phytoliths (see: Pigott et al. 2006). Flotation samples were collected from most strata within each operation, from the fill of features, pits, hearths, ceramic vessels, floors, activity areas, burials and trash dumps. When possible, multiple samples from distinct locations within each culturally meaningful excavation unit were collected in order to try to identify activity. Of the nearly 1000 soil samples collected and floated, 264 have been analyzed. A break down of the distribution of the samples used for this paper can be found in Table 1.

Carbonized seeds have only been minimally recovered from archaeological sites in Southeast Asia. This is partially due to issues of preservation but also a result of few sites being heavily sampled with intensive flotation strategies. While none of the three sites contained large numbers of seeds, carbonized grains were recovered from each. In fact 75 percent of the samples contained seeds (Table 1). On average, seed density was between two and three seeds per liter of soil. Carbonized seeds were most abundant at Non Pa Wai both in terms of ubiquity and density (Table 1). While more samples were collected and analyzed from NKH than from NML or NPW, the distribution of samples within each a given site were relatively equal. Variation in the number of samples analyzed that representing each occupation or Period within each of the three sites was kept to a minimum to avoid biasing the results. While twenty-one different species have been identified, many of the smaller, weedy species still need to be identified. Rice and foxtail millet, the focus of this paper, make up approximately 20 percent of the recovered seeds.

To date, the millet and rice seeds from Nil Kham Haeng, Non Pa Wai, and Non Mak La represent one of the largest collections of carbonized seeds recovered from prehistoric Thailand. Of the 3294 seeds recovered from the TAP sites, millets represent the most common food taxa. The majority of the millets seeds were *Setaria italica*, although grains of *Panicum* (common millet) and *Coix* (Job's Tear) were also identified. Seeds of *S. italica* were identifiable due to their good state of preservation and the presence of lemma and palea on the seed surface (For information on distinguishing millets see: Houyuan et al. 2009). Seed photos presented in Figures 4 and 5 clearly demonstrate the species as *Setaria italica*. In contrast to the hundreds of carbonized foxtail millet seeds, fewer than 50 rice grains were recovered from these sites. The rice grains were all well preserved, fairly wide, and appear more like *japonica* than *indica* (Figure 6). In contrast, *indica* grains are typically long and thin, unlike the TAP seeds. While seed measurements may not be a precise way to identify the type of rice being recovered, it is useful technique that allows researchers to compare grains from different locations. Where tropical *japonica* is long and large, temperate japonica is short and wide. When tabulated, the TAP rice overlaps both categories. While weed seeds may be a better indicator of the ecology associated with the rice, few weeds were recovered with the rice grains. Although sedge (*Scirpus*) seeds were recovered, and are a common weed associated with paddy fields, their numbers were so low as to not be significant. More interestingly, seeds of chenopods, a common dry-land weed, were recovered in significant numbers in samples containing millets, but were rarely found in samples were rice was prominent.

While foxtail millet was recovered from most operations and from a variety of features, rice was found in only limited operations and in few features. Further, whereas millets were recovered in most stratigraphic layers and common in all three sites, rice was mostly from Nil Kham Haeng and was not found in any samples taken from lower levels at any site. Clearly millets were a primary focus at these sites. Given the complexity of stratigraphic contexts at Non Pa Wai and Nil Kham Haeng, and their on-going study by TAP excavators, we chose to submit seed grains themselves to AMS dating 2008. Six independent dates were obtained, two from rice seeds, one from a foxtail millet seed, and three from charcoal (Table 2). Charcoal and seeds from the same sample were dated separately. This should help in determining the value of other seeds that were being dated by association with dated charcoal. It is interesting to note that at NPW the *Setaria* seeds dated were older than the charcoal while at NKH the charcoal slightly predated the rice grains. The seed and charcoal dates either overlap or are close enough to suggest little if any mixing or contamination. These dates confirmed the pattern seen in the stratigraphy, millets were is use long before rice and were the primary cereal crop during the Neolithic and Bronze Age. At each site, rice is only incorporated into the subsistence regime during the Iron Age (Table 3).

The Significance of Rice and Millets

Based on our investigations, Non Pa Wai, Nil Kham Haeng, and Non Mak La, foxtail millet appears to have been in use long before the appearance of rice. While cultural or natural taphonomic processes, issues of preservation and sampling biases could impact the dating process, there is no evidence that this is the case. Rice was consistently absent in the lower occupational layers and independently dated to no earlier than the first millennium BCE. Since rice seeds are larger and are generally processed in a manner similar to millets there is no reason for them to be missing from the earlier occupations if they were in use. Also, as rice first appears at these sites, the density and ubiquity of millet seeds decline suggesting a change in plant food strategy was occurring.

Based on finds at sites like Khok Phanom Di, located on the coast in south, central Thailand, domesticated rice was being used in the region over 1000 years before it appears at Non Pa Wai, Nil Kham Haeng, or Non Mak La (Thompson 1996). This implies that the early inhabitants of the TAP sites either chose not to cultivate or use rice while exclusively using foxtail millets as their primary cereal crop or they never had access to rice. Why then was rice eventually incorporated into the subsistence regime in the Khao Wong Prachan Valley? While it is possible that it was simply a case of increasing availability of rice, it is more likely that some other influencing factors were at work, like climate change or a shift in population dynamics.

Pollen and phytolith studies have demonstrated that an arboreal expansion with higher sea levels 4,000 to 5,000 years ago made agriculture difficult in this area (Pigott et al 2006; Kealhofer 2003). With a decline in forests and an increase in grasses the resulting "tropical savannah" environment became better suited for dry-land agriculture (Kealhofer 2002). As millets have a tendency to do well in dry environments due to their rapid maturation, it is not surprising that foxtail millet was the most prominent crop in the early levels. A continuing decline in arboreal pollen associated with changing proportions of weed seeds and charcoal suggest environmental instability or degradation (Kealhofer 2002; Kealhhofer and Grave 2008). This trend could be seen as either being the result of a response to increasing population and deforestation, or a response to changing climatic patterns such as a weakening of the monsoon (Mudar and Pigott 2003; Cremaschi et al. 1992).

This environmental shift could have had a substantial impact on subsistence strategies and land use (Cremaschi et al. 1992; Kealhofer 2002; White et al. 2003). A change in climatic patterns may have helped to destabilize the local agricultural systems, as well as helping decrease the availability of wild plant and animal resources (Mudar and Pigott 2003; Pigott et al 2006; Kealhofer 2003). Such ecological changes might have encouraged the adoption of more intensive modes of agriculture, such as wet rice agriculture (Mudar and Pigott 2003). While the seed measurements of the TAP rice grains are in the range of tropical *japonica*, it would be inappropriate to conclude that wet rice agriculture was being practiced at any of these sites. Although the decline of millets and chenopods, and a slight increase of sedges does suggest paddy fields may have been in use. A more likely scenario may be that as the ecology was changing and population was growing, people were focusing on a greater variety of crops to lesson the risks from crop failures (Kealhofer 2002; Chang 1970:183). This is supported by the present custom of cropping rice and millets together to ensure a measurable yield. The end result of the inclusion of rice into the subsistence strategy, whether wet-land or dry-land varieties, would likely have increased yield, but at a greater energy cost.

Conclusions

The archaeobotanical data collected from Non Pa Wai, Nil Kham Haeng, and Non Mak La, should encourage more collection and floatation of soil from Southeast Asian sites. As has been demonstrated here, carbonized seeds do preserve and can help in the reconstruction of plant use practices. The presence of a variety of seed crops and an array of weed seeds at all three sites clearly demonstrates that agriculture was being practiced by the late 3rd millennium BCE in the Khao Wong Prachan Valley. The data seems to suggest that the region was not as "agriculturally insufficient" as had been proposed by Mudar and Pigott (2003). While the early AMS dates for *Setaria* needs conformation, it is clear that millets were in use long before the Iron Age.

Initially, rice and millets were not in use at the same time in the Khao Wong Prachan Valley. Dry-land farming, with a focus on foxtail millet, was the primary crop prior to the first millennium BCE. If rice was available at this time it was not in use at any of the TAP sites. A change in the agro-ecosystem occurs in the first millennium BCE. At this point rice is incorporated into the diet, possibly to supplement a subsistence strategy that was no longer capable of supporting the local population. As the popularity of rice increased, foxtail millet declined in importance. This new strategy might have included more intensive forms of water management.

The relationship between rice and millets seen in these sites seems clear. In this region of Thailand, foxtail millet was in use for a long period of time prior to the appearance of rice. Rice overlaps with, but does not predate millet use at the TAP sites. Whether the patterns seen here reflect local processes or have broader implications beyond central Thailand still needs to be determined.

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References

Bellwood P (2001) Early Agriculturist Population Diasporas? Farming, Languages, and Genes Annual Review of Anthropology. 30:181-207.

Bellwood P (2005). First Farmers: The Origins of Agricultural Societies. Oxford: Blackwell Publishing Ltd.

Brink M (2006). Setaria italica (L.) P.Beauv. [Internet] Record from Protabase. Brink M, Belay, G. (Eds). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands.

Chang, K. C. (1970). The Beginnings of Agriculture in the Far East. Antiquity 44:175-185.

Crawford G, Underhill A, Zhao Z, Le GA, Feinman G, Nicholas L, F. Luan, Yu H, Hui F, and Cai F (2005). Late Neolithic Plant Remains from Northern China: Preliminary Results from Liangchengzhen, Shandong. Current Anthropology 46:309-317.

Crawford G. (2006). East Asian Plant Domestication. In: Stark M (ed) Archaeology of Asia. Oxford: Blackwell Publishing, pp. 77-95.

Cremaschi M, Ciarla R and Pigott V (1992). Paleoenvironment and Late Prehistoric Sites in the Lopburi Region of Central Thailand, Southeast Asian Archaeology 1990. In: Glover IC (ed) Proceedings of the Third Conference of the European Association of Southeast Asian. Hull: Centre for South-East Asian Studies, University of Hull, pp. 167-177.

Fuller D, Qin L, Harvey E (2007). A Critical Assessment of Early Agriculture in East Asia, with Emphasis on Lower Yangzte Rice Domestication. Pradghara 2007.

Fuller D, Qin L (2009). Water management and labour in the origins and dispersal of Asian rice. World Archaeology. 41:1,88-111.

Fuller D, Qin L, Zheng Y, Zhao Z, Chen X, Hosoya L, and Sun G (2009). The Domestication Process and Domestication Rate in Rice: Spikelet Bases from the Lower Yangtze. Science. (323):1607-1609.

Glover IC, Higham FW (1996). New Evidence for Early Rice Cultivation in South, Southeast, and East Asia. In: Harris, D (ed). The Origins and Spread of Agriculture and Pastoralism in Eurasia. Washington D.C.: Smithsonian Institution Press.

Higham C (1989). Archaeology of Mainland Southeast Asia: From 10,000 B.C. to the Fall of Angkor. Cambridge. UK: Cambridge University Press.

Higham CFW, Higham TGF (2009) A new chronological framework for prehistoric Southeast Asia based on a Bayesian model from Ban Non Wat. Antiquity 83:125-45.

Higham C, Tracey, Lu LD (1998). The Origins and Dispersal of Rice Cultivation Antiquity 72 (278):867-877.

Houyuan L, Zhang J, Wu N, Lu H, Deke Xu, Quan Li (2009). Phytoliths Analysis for the Discrimination of Foxtail Millet (*Setaria italica*) and Common Millet (*Panicum miliaceum*). PLoS ONE 4(2): e4448. doi:10.1371/journal.pone.0004448.

Kaida Y. (1991). Irrigation Landscapes and Waterscapes in the Rice Land of Tropical Asia. Southeast Asian Studies, Vol. 28, No. 4.

Kealhofer L. (2002). Changing Perceptions of Risk: The Development of Agro-Ecosystems in Southeast Asia. American Anthropologist 104(1):178-194.

Kealhofer L. (2003). Looking into the gap: Land use and the tropical forests of Southern Thailand. Asian Perspectives 42(1):72-95.

Kealhofer L, Piperno D (1994). Early agriculture in Southeast Asia: phytolith evidence from the Bang Pakong Valley, Thailand. Antiquity 68(260): 564-572.

Kealhofer L, Grave P (2008). Land Use, Political Complexity, and Urbanism in Mainland Southeast Asia. American Antiquity 73 (2): 200-225.

Lee GA, Crawford G, Liu L, Chen X (2007) Plants and People from the Early Neolithic to Shang periods in North China. Proceedings of the National Academy of Sciences 104 (3):1087-1092.

Liu X, Hunt HV, Jones MK (2009) River valleys and foothills: changing archaeological perceptions of North China's earliest farms. Antiquity 83:82–95

Lu H, Zhang J, Liub K, Wua N, Lic Y, Zhoua K, Maolin Y, Zhange T, Ahange H, Yangf X, Shene L, Xua D, Lia Q (2009) Earliest domestication of common millet (Panicum miliaceum) in East Asia extended to 10,000 years ago. PNAS.

Lu TLD (1998). Some Botanical Characteristics of Green Foxtail (Setaria viridis) and Harvesting Experiment on the Grass. Antiquity 72: 902-907.

Lu TLD. (1999). The Transition from Foraging to Farming and the Origin of Agriculture in China. Vol. 774. BAR Inernational Series. Oxford: BAR.

Lu, TLD. (2002). A Green Foxtail (Setaria viridis) Cultivation Experiment in the Middle Yellow River Valley and Some Related Issues. Asian Perspectives 41:1-14.

Meertens HCC 2006. Oryza sativa L. [Internet] Record from Protabase. Brink, M. & Belay, G. (Eds). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands.

Mudar KM (1995) Evidence for Prehistoric Dryland Farming in Mainland Southeast Asia: Results of Regional Survey in Lopburi Province, Thailand. Asian Perspectives. 34(2): 157-194.

Mudar KM, Pigott VC (2003) Subsistence Changes and Community-based Craft Production in Prehistoric Central Thailand. Fishbones and Glittering Emblems. In: Karlstrom A, Kallen A (eds) Southeast Asian Archaeology 2002. Ostasiatiska Museet, Museum of Far Eastern Antiquities, Stockholm, Sweden, pp 149-159.

O'Reilly, D. (2003) Further Evidence of Heterarchy in Bronze Age Thailand. Current Anthropology 44(2): 300-306.

Pigott VC, Mudar KM, Kealhofer L, Weber S, Voelker JC(2006) A Program of Analysis of Organic Remains from Prehistoric Copper-producing Settlements in the Khao Wong Prachan Valley, Central Thailand. In: Bacus EA, Glover IC, Pigott VC (eds). Uncovering Southeast Asia's Past. NUSPress: Singapore, pp 154-167.

Pryce TO (2008) Prehistoric Copper Production and Technological Reproduction in the Khao Wong Prachan Valley of central Thailand. PhD Dissertation. UCL Institute of Archaeology. University College London.

Rispoli F (1997) Late Third/Early Second Millennium Bce Pottery Traditions in Central Thailand: Some Preliminary Observations in a Wider Prospective. In Ciarla, R. & Rispoli, F. (Eds.) South-East Asian Archaeology 1992. Proceedings of the Fourth International Conference of the European Association of South-East Asian Archaeologists. Rome, 28th September - 4th October 1992. Rome, Istituto Italiano per l'Africa e l'Oriente. pp 59-67.

Smith B (1998) The Emergence of Agriculture. New York: Scientific American Library.

Thompson GB (1996) The Excavation of Khok Phanom Di: A Prehistoric Site in Central Thailand, Volume IV: Subsistence and Environment: The Botanical Evidence (The Biological Remains, Part II). London: the Society of Antiquaries.

Weber S, Fuller D (2008) Millets and Their Role in Early Agriculture. Pragdhara.Lucknow, India. 18:69-90.

White JC, Pigott VC (1996). From Community Craft to Regional Specialization: Intensification of Copper. Production in Pre-state Thailand. In: Wailes B (ed) University Museum Symposium Series, Volume VI: Craft Specialization And Social Evolution: In Memory of V. Gordon pp 151-175.

Figure 1. Location of TAP study area within South East Asia.

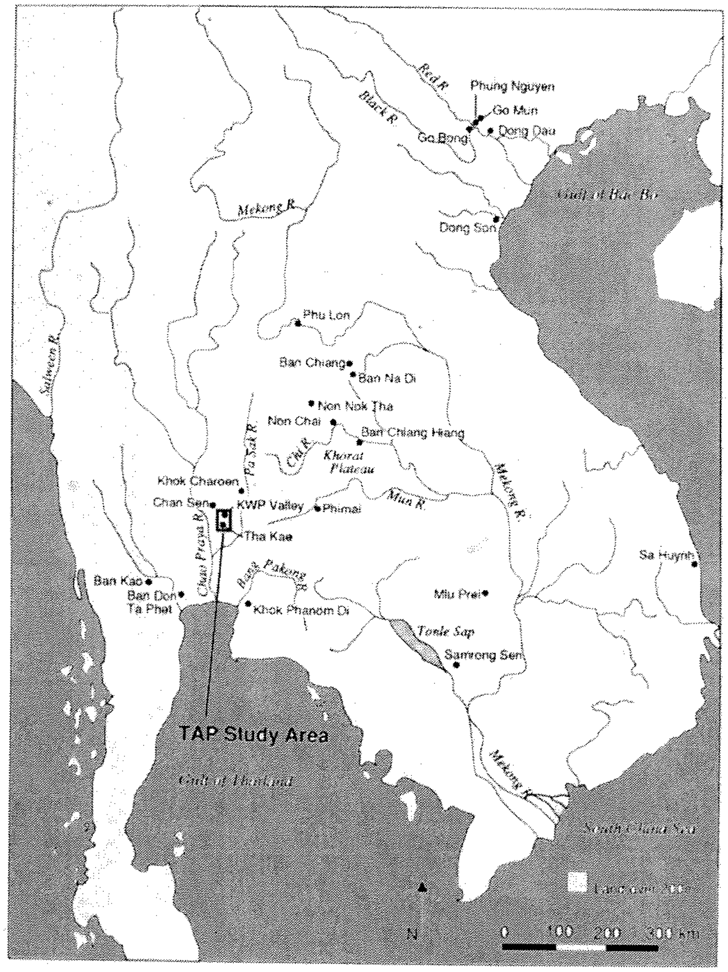

Figure 2. Locations of the Non Pa Wai, Nil Kham Haeng, and Non Mak La within the Khao Wong Prachan Valley in central Thailand.

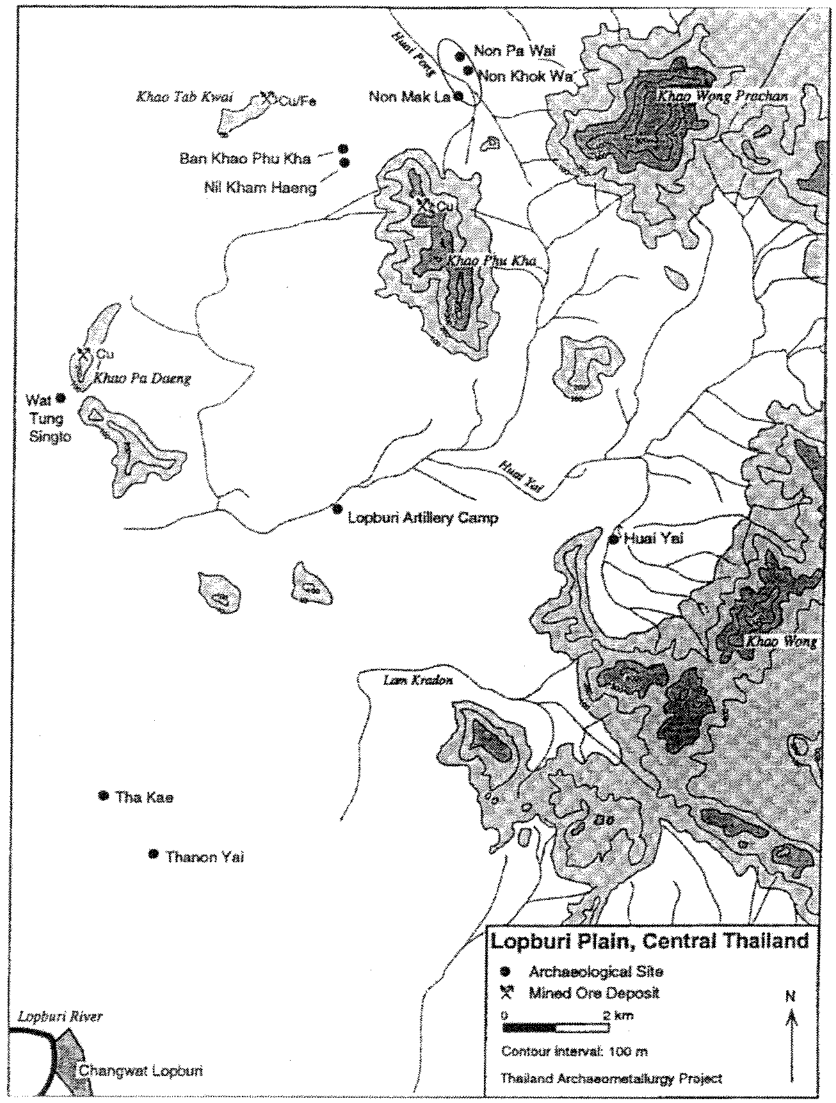

Figure 3. The chronological sequence presented here is based on Pigott et al. 2006. The chronology for these sites may change as more information about these sites becomes available.

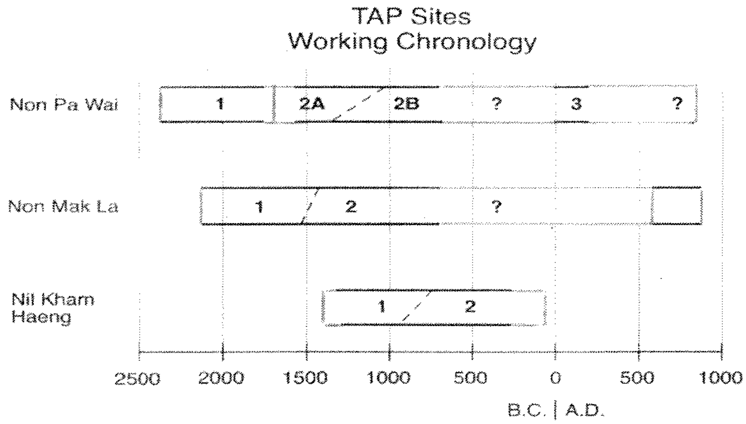

Table 1. Seed recovery chart for TAP sites. Ubiquity refers to the percentage of samples containing seeds, rice or millet grains. Seed density refers to the number of seeds per liter of floated soil. This table demonstrates that while seeds were recovered from all three sites, their numbers were limited.

	NKH	NML	NPW	TOTAL
Samples Analyzed	**160**	**48**	**56**	**264**
Carbonized Seeds	**1542**	**441**	**1311**	**3294**
Number of Taxa	**15**	**18**	**19**	**21**
Seed Density	**1.5**	**10.2**	**18**	**2.7**
Seed Ubiquity	**64**	**89**	**91**	**75**
Rice Ubiquity	**10**	**6**	**3**	**8**
Millet Ubiquity	**12**	**8**	**16**	**12**

Figure 4. Close up Ventral view (hilum visible on the right) of *Setaria italica* grain seen under an electron microscope. This grain, from Non Pa Wai (sample number T11718) is clearly foxtail millet and dates to the Neolithic Period.

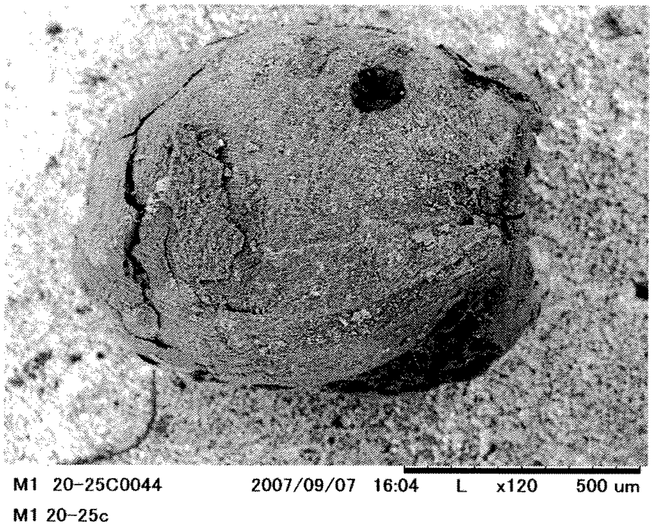

Figure 5. These 24 seeds of *Setaria italica* were recovered from Nil Kham Haeng (sample number T3788) and nicely demonstrate the size range and preservation quality of the recovered foxtail millet seeds. This sample dates to the Iron Age.

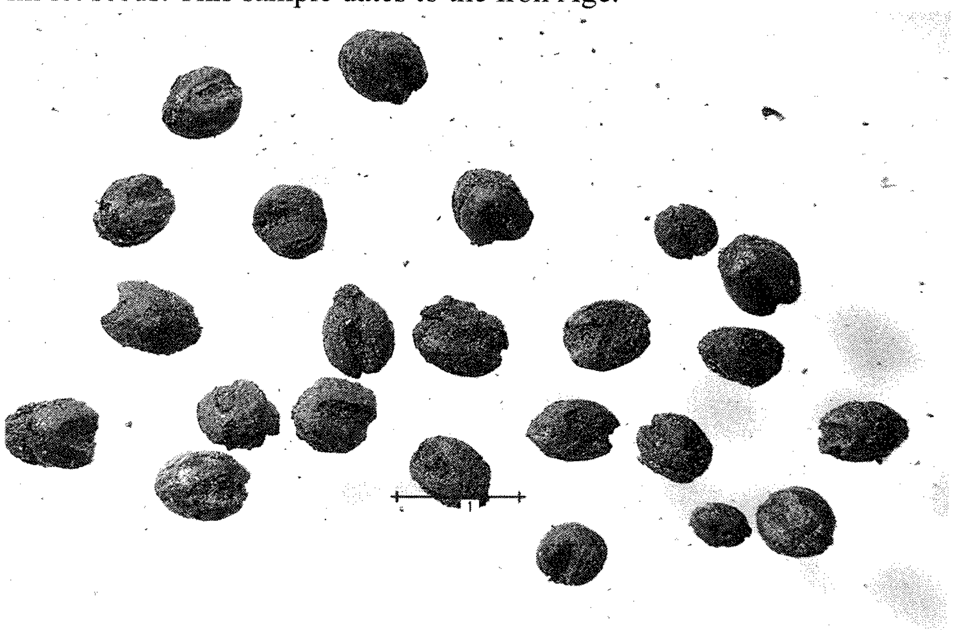

Figure 6. These three examples of *Oryza sativa* were all collected from Nil Kham Haeng (sample number T5084) and date to the Iron Age.

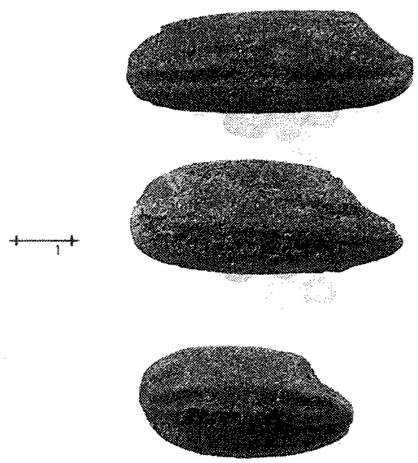

Table 2. Recent AMS dates from seeds and charcoal recovered at TAP.

Site	**Location**	**Source**	**Conventional Age**	**2-Sigma Calibration**
NKH	**Op. 2, L.5**	***Oryza* Grains**	**2490+/-40BP**	**780-410 BCE**
NKH	**Op. 2, L.5**	**Charcoal**	**2520+/-40BP**	**790-520 BCE**
NKH	**Op. 1, L.11**	***Oryza* Grains**	**2550+/-40BP**	**690-540 BCE**
NKH	**Op. 1, L.11**	**Charcoal**	**2490+/-40BP**	**780-410 BCE**
NPW	**Op. 9, L.10**	***Setaria* Grains**	**3870+/-40BP**	**2470-2200 BCE**
NPW	**Op. 9, L.10**	**Charcoal**	**3670+/-40BP**	**2140-1940 BCE**

Table 3. Chronology for rice and Foxtail millet at the TAP sites.

	NKH		**NML**		**NPW**	
	R	**S**	**R**	**S**	**R**	**S**
Iron Age	x	x	x	x	x	x
Bronze Age	-	x	-	x	-	x
Neolithic	-	-	-	-	-	x

R = RICE S = SETARIA