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Review

Rice fields and modes of rice cultivation between 5000 and 2500 BC in east China

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ABSTRACT

Recently, rice fields dated between 5000 and 2500 BC were found at the Tianluoshan sit in east China. The early rice fields dated between 5000 and 4500 BC are the oldest rice fields known. The discovery has provided data of recovering reclamation, cultivation, and the ecological system of rice fields in the Neolithic age. People opened up marshes of dense reeds with fire and wooden or bone spades, in order to create rice fields. In the rice fields, there was not only rice, but a lot of weeds as well. The excavations proved that little or even no weeding or irrigation was adopted. However, tilling soil by wooden and bone tools was evidenced. The average yields are estimated to have been about 830 kg for the early period and 950 kg per hectare for the later period. The cultivation system was low-level. Although the Tianluoshan people cultivated rice, they still obtained a great deal of food by gathering and hunting.

1. Introduction

In the Early Holocene epoch, the prologue of cultivation and domestication of rice in China was opened in two core areas, the middle Yangtze basin and the Yangtze delta (Higham and Lu, 1998). In the Yangtze delta, an over 8000-year–old process of cultivation and domestication of rice and a long history of utilization of rice has been demonstrated by morphological research of the short rachillae (spikelet bases) and spikelets (Zheng et al., 2004, 2007). Recent archaeological research indicates that the initial rice cultivation within this area is even earlier, dating back to at least 10000 years ago (Jiang and Liu, 2006; Zheng and Jiang, 2007), much earlier than the appearance of fully domesticated rice (Fuller et al., 2006). This area deserves attention as the birthplace of rice cultivation.

Rice cultivation is a human activity that exerts some selective pressure on the growth and development of rice in specific areas in order to obtain a more stable food supply than the gathering of wild plants. It allows populations to rise or to become sedentary as well. The activities include tilling soil, sowing, fertilizing, irrigating, etc. To understand the origins of rice cultivation, not only archaeological remains of rice but also knowledge of culture and ecology in the Neolithic age is important (Crawford and Shen, 1998). Excavations and research on archaeological sites of rice cultivation can provide better insight into technique, area, yield and environment of rice cultivation. Archaeological and archaeobotanical evidence can be used for estimating the advances in both cultivation and morphological domestication, during the origins of rice agriculture.

In the Yangtze delta, small paddy fields with irrigating ditches and wells of 6000 years ago have been found. They were initial modifications of the natural topography (Fujiwara, 1998; Cao et al., 2006). Older ones have not been found and excavated, although it was inferred that rice paddies with fire and flood management had appeared based on analyzing pollens, diatoms, and charcoal in the occupation area of the Kuahuqiao site between 6000 and 5500 BC (Zong et al., 2007). Recently our recovery of prehistoric rice fields around the wooden pile-dwelling features of the Tianluoshan site has been able to sufficiently answer some preliminary questions of rice cultivation system between 5000 and 2500 BC.

2. Materials and methods

2.1. Brief introduction of archaeological site

The Tianluoshan site (Zhejiang Provincial Institute of Relics and Archaeology et al., 2007) is located at the edge of the Ningshao plain in the Yangtze Delta, and 30–40 km from the east coastline. It is near the piedmont of the Siming Mountain (Fig. 1). Presently the land is

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approximately 2 m above the sea level. The archaeological site was dated between 5000 and 3000 BC, and the lowermost layer lie 310 to 350 cm below the surface. A lot of artifacts recovered from this site include stone, wooden, and bone tools, and pottery. A large number of upright wooden piles indicate that the dwellings were adaptive to wetlands. Due to the good preservation of an anaerobic condition, massive amount of organic remains are recovered. Predominantly wild fauna included animal bones such as buffalo (*Bubalus mephistopheles*), deer (*Cervus nippon*, *Cervus unicolor*, *Elaphurus davidianus*, etc), pig (*Sus* sp.), fish (*Cyprinus carassius*, *Carassius auratus*, *Ophicephalus argus*, etc) and many others. Seed and fruit remains included as rice (*Oryza* sp.), acorns (*Cyclobalanopsis*sp., *Lithocarpus* sp., *Quercus* sp.), hog plum (*Choerospondias axillaries*), peach (*Prunus persica*), mume apricot (*Prunus mume*), water caltrop (*Trapa* sp.), foxnut (*Euryale ferox*), etc. A substantial number of charring or waterlogged rice spikelets and short rachillae (spikelet bases) are morphologically different from wild rice and some spikelets can be characterized as domesticated rice (Zheng et al., 2007; Fuller et al., 2009). These provided evidence of a mixed economy comprised of hunting-gathering and rice cultivation.

2.2. Materials

Sediment cores were taken as 155 locations around the Tianluoshan occupation site with an interval of 20–40 m. According to the textures, colors, and plant remain contents of soil, a coring location was divided into several soil layers and the soil samples were taken from the layers. From results of analysis of phytoliths and seeds for coring samples, the area and hidden depths of prehistoric rice fields were judged. Excavations were done in Location 1 and Location 2 to confirm this (Fig. 4). The areas were 200 and 150 square meter, respectively.

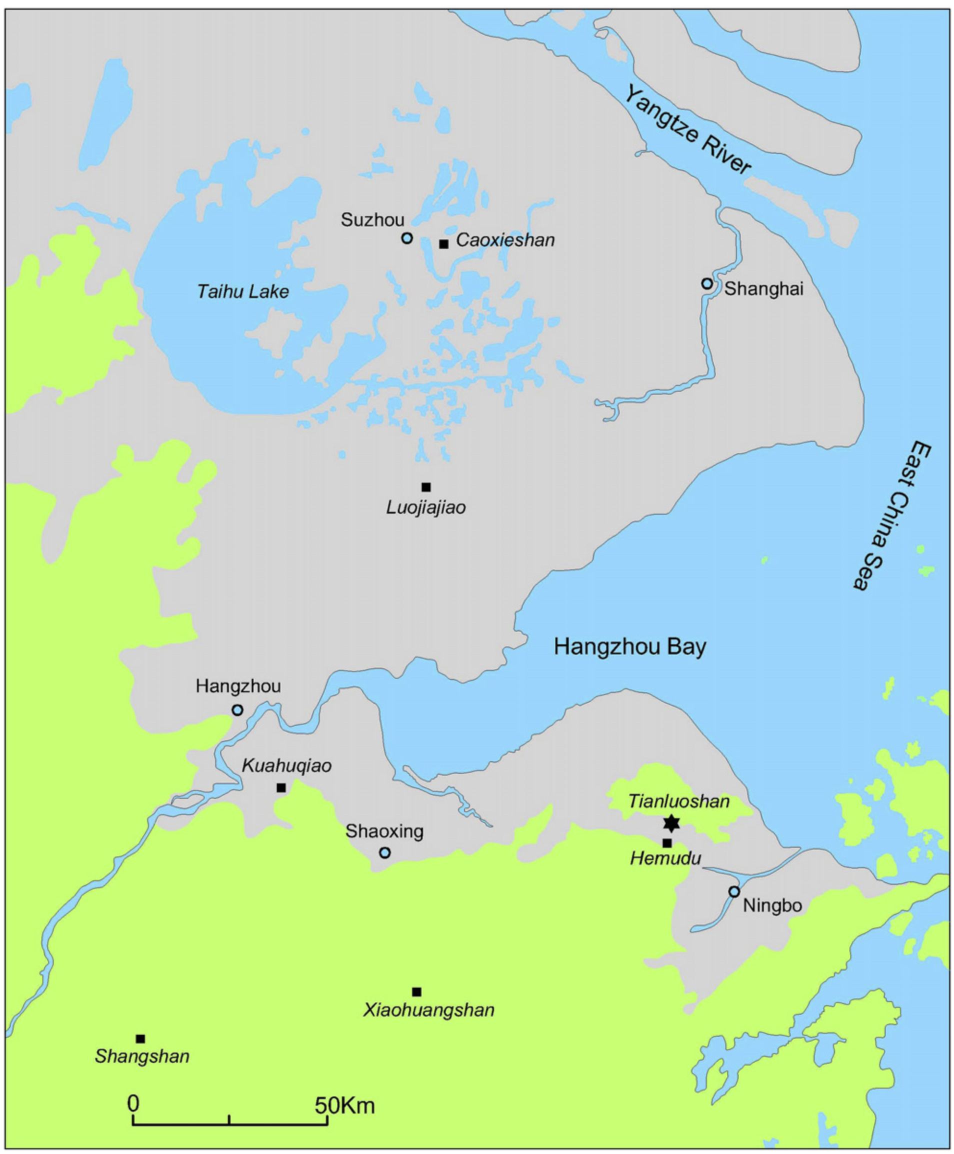

Fig. 1. Location of the Tianluoshan site, and other archaeological sites dated between 9000 and 4000 BC. The Shangshan (Jiang and Liu, 2006) and Xiaohuangshan (Zhang et al., 2005) sites, dated between 9000 and 7000 BC and between 7000 and 6000 BC, respectively, and were located in little basins in mountainous areas. The Kuahuqiao site (Zhejiang Provincial Institute of Relics and Archaeology and Xiaoshan Museum, 2004) dated between 6000 and 5500 BC and the Hemudu (Chekiang Province and Chekiang Provincial Museum, 1978), the Tianluoshan sites dated between 5000 and 3000 BC, and are located at passage from upland valleys to plains. The Lujiajiao site (The work group at the Luojiajiao site, 1981) was dated to 5000 BC. The Caoxieshan site (Fujiwara, 1998) was dates to 4000 BC, in which the Neolithic paddy fields were firstly unearthed in China.

Table 1
Chronology and the radiocarbon dates for the rice fields at the Tianluoshan site with AMS.

Excavation places	Trenches	Depth (cm, below earth's surface)	Number in the lab	Material	^{14}C age (yr BP, $\pm1\delta$)	Calibrated age (yr BC, $\pm1\delta$)
Location 1	T1041	81–86	BA07762	Plant remains	3760 ± 40	2280–2050
		96–101	BA07761	Yagara bulrush seeds (*scirpus distigmaticus*)	4015 ± 45	2575–2475
		106–111	BA07760	Bulrush seeds (*Scirpus triqueter*)	4195 ± 70	2900–2670
		121–126	BA08203	Bulrush seeds (*Scirpus triqueter*)	4470 ± 45	3330–3020
		131–136	BA07758	Yagara bulrush seeds (*Scirpus distigmaticus*)	4765 ± 35	3600–3030
		136–141	BA08895	Yagara bulrush seeds (*Scirpus distigmaticus*)	4830 ± 35	3700–3520
		141–146	BA08894	Yagara bulrush seeds (*Scirpus distigmaticus*)	4965 ± 35	3910–3650
		146–151	BA08893	Yagara bulrush seeds (*Scirpus distigmaticus*)	5040 ± 40	3960–3710
		223–228	BA07764	Flatdstalk bulrush (*Scirpus planiculmis*)	5785 ± 60	4710–4550
		228–233	BA07763	Flatdstalk bulrush (*Scirpus planiculmis*)	6045 ± 45	5010–4850
Location 2	T803	135–140	BA08359	Bulrush seeds (*Scirpus triqueter*)	4250 ± 40	2890–2700
	T803	135–140	BA08355	Bulrush seeds (*Scirpus triqueter*)	4475 ± 35	3330–3090
	T803(Road)	135–140	BA08360	Bulrush seeds (*Scirpus triqueter*)	4705 ± 40	3630–3370
	T705	160–170	BA08526	Bulrush seeds (*Scirpus triqueter*)	4490 ± 40	3340–3090
	T705	280–285	BA08527	Triangular Bulrush seeds (*Scirpus triangulatus*)	5725 ± 40	4650–4490

AMS, accelerator mass spectrometry, Peking University AMS Laboratory, calibrated by Oxcal 3.10 and INTCAL 104.

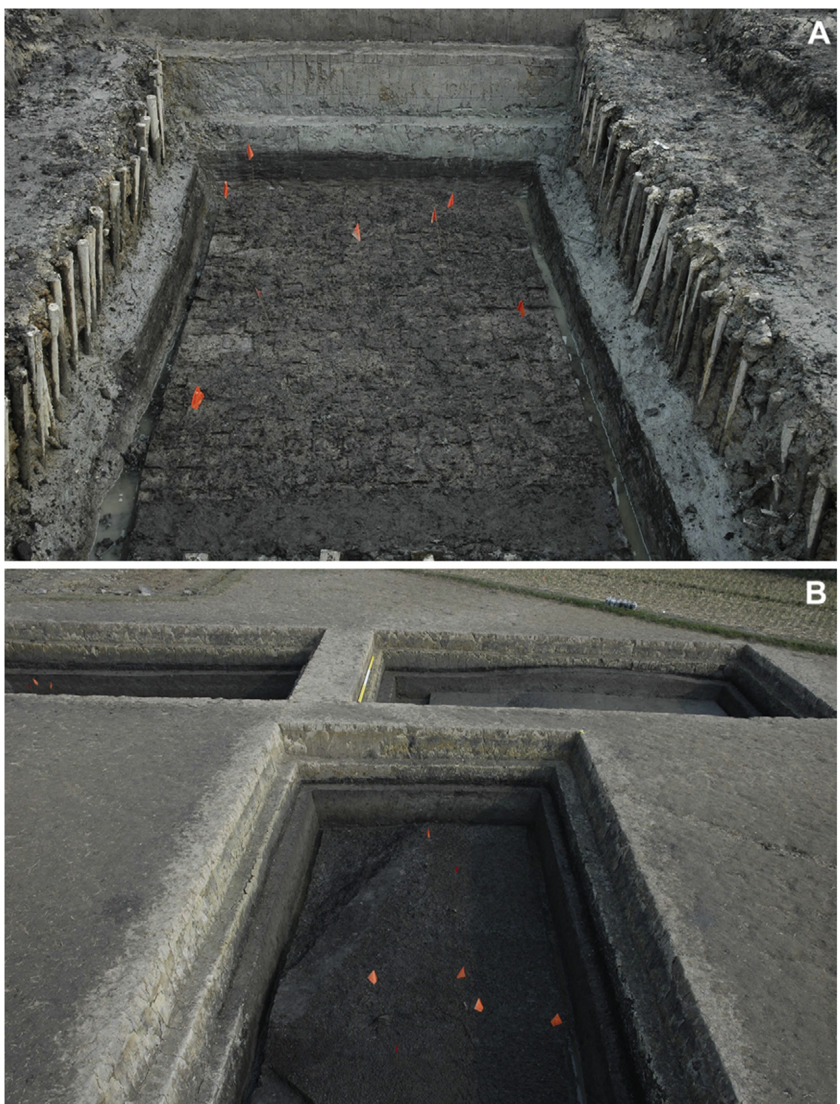

Fig. 2. Parts of the rice field excavated from Location 1. A is early rice fields in T705 trench, lie hidden in about 2.8 m depth below the earth's surface dated between 4650 and 4490 BC. B is later rice fields in T803 and T703 trenches, at about 1.3 m depth below the earth's surface, dated between 3340 and 3090 BC. The places where the pottery sherds were excavated were marked with red flags. The wooden pegs in T705 trench were for preventing the collapse of its walls in the excavation.

40 soil samples for analysis of seeds, phytoliths, pollens, and charcoal were taken from western section of T1041 trench in Location 2, which was about 400 m southwest of the preserved dwellings of the Tianluoshan occupation site. The samples were continuously taken at 5 cm intervals between 45 and 250 cm below the surface. Each sample was about 1500 ml.

2.3. Methods

2.3.1. Analysis of seeds

500 ml sample of soil was moved to 1000 ml beaker, and added 500 ml 5% $NaHCO_3$. The sample was placed in 50 °C water bath for 3 hours, while the sample was stirred well to separate soil particles. Through a sieve (Φ450 μm), the sample was washed until the water is clear. The remained sample was investigated for plant seeds with a stereo microscope.

2.3.2. Analysis of phytoliths

Soil samples were dried in convection oven at 100 °C and then were mechanically crashed. 1 g sample of soil and 300,000 glass beads (Φ40 μm) were moved to 12 ml sample bottle. 10 ml of water and 1 ml of 5% sodium silicate were added, and the sample vibrated in an ultrasonic cleaner (38 Khz, 250 W) for about 20 minutes to separate particles. Using Stokes' Law, the sample was filtered in water to remove particles less than 20 μm, and was dried again. Using EUKITT® mounting medium, the filtered sample was distributed uniformly on microscope slide to facilitate the investigation of densities of phytoliths.

2.3.3. Analysis of pollens

2 cm^3 of sample and 27,637 *Lycopodium* makers were placed in 15 ml polypropylene boiling tube, and 10 ml of 10%KOH was added. The sample was placed in 100 °C water bath for 30 minutes, while the sample was stirred well to break any remaining lumps. Through a sieve (Φ160 μm), the sample was filtered into a polypropylene centrifuge tube. The samples was washed, centrifuged, and decanted until the liquid is clear. 10 ml of 40% HF was added to the sample and it was placed in 100 °C water bath for 30–60 minutes, and it was stirred with polypropylene rod until siliceous material is no longer visible. It was centrifuged and decanted HF. 10 ml of 10% HCL was added, and the sample was placed in 100 °C water both for 15 minutes to remove colloidal silicon dioxide and silicofluorides. It was centrifuged, HCL was decanted, and the sample was rinsed in water. 10 ml of acetolysis mixture (1 ml concentrated H_2SO_4, 9 ml acetic anhydride) was added to the sample, which was placed in a boiling water bath for 3 minutes, with stirring. It was centrifuged, and a few drops 10% NaOH was added to aid dyeing, before decanting and rinsing. Using glycerin jelly, the filtered sample was distributed uniformly on a microscope slide for investigations of pollens.

2.3.4. Analysis of charcoal

20 ml sample of soil was moved to 100 ml beaker, and 20 ml 35% H_2O_2 was added to separate soil particulars. Through a sieve (Φ160 μm), the sample was washed until the water is clear. The remained sample was investigated for charcoals with a stereo microscope.

2.3.5. Radiocarbon dating

Using the accelerator mass spectrometry (AMS) method, the radiocarbon age of samples, mainly seeds, was determined (Table 1). Dates were calibrated with Oxcal 3.10 and INTCAL 104 curve. The radiocarbon dating was carried out in Peking University AMS Laboratory.

Table 2
Artefacts found in the rice fields at the Tianluoshan site.

Artefacts	Trenches	Depth (cm, below earth's surface)	Number	Stratigraphic layers
Pottery sherd	T703	140–150	7	Later rice fields
	T803	140–150	7	Later rice fields
	T705	130–177	22	Later rice fields
	T705	270–290	15	Early rice fields
Wooden handle	T606	115	1	Later rice fields
Wooden dibble	T705	270	2	Early rice fields
Wooden knife	T705	257	1	Early rice fields

3. Results

3.1. Depths and archaeological traces of rice fields

The rice fields associated with the Tianluoshan occupation lie about 1 m below the surface and can be clearly distinguished between early and later periods (Fig. 2). The early rice fields were dated between 5000 and 4500 BC, and the later rice fields were

Fig. 3. Farming tools. The wooden dibble and knife were excavated from the early rice fields, and bone spades were excavated from the occupation site. There are clear frayed traces on the spade edges caused by frequent digging. The scales are 5 cm.

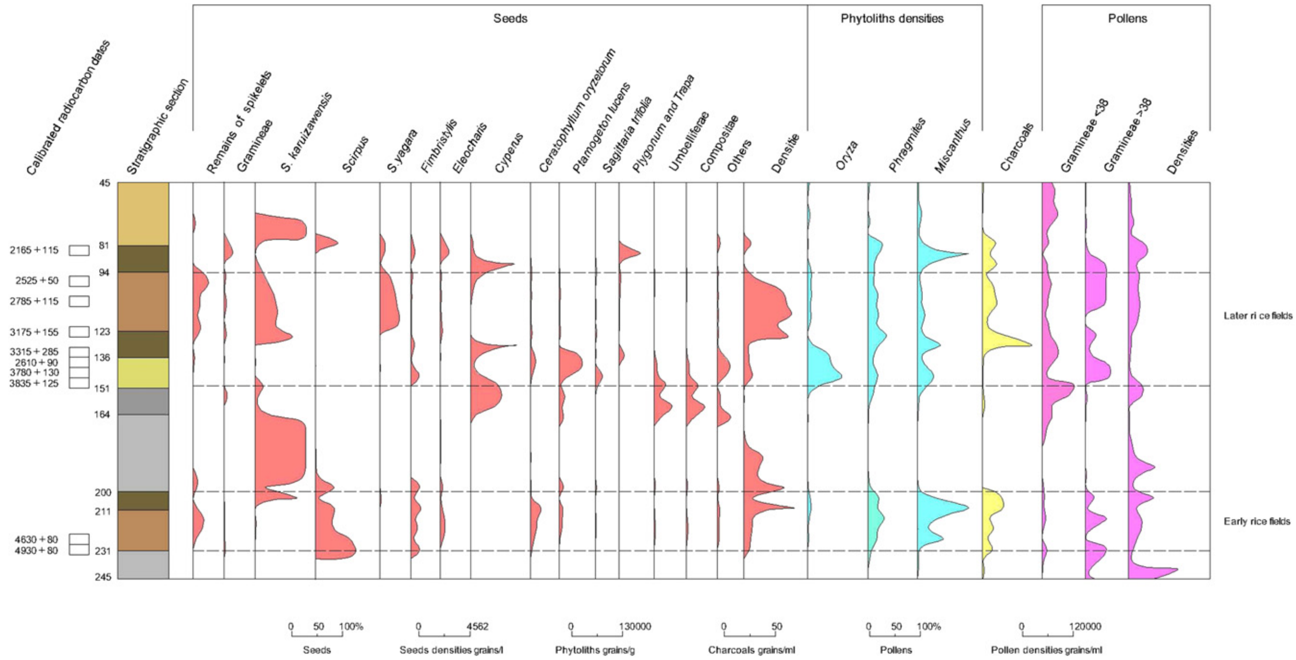

Fig. 4. Integrated palaeoecological data from rice fields dated between 5000 and 2500 BC at the Tianluoshan site. The early and later rice fields at T1041 trench of Location 2 lie hidden in depths between 94 and 140 cm and 200 and 235 cm, respectively. In these layers many husk fragments and spikelet bases of rice, dense bulliform phytoliths derived from motor cells of rice, and a high percentage of grass pollen larger than 38 μm in diameter. High microcharcoal content implies that people used fire in managing these fields.

dated between 4000 and 2500 BC (Table 1, Fig. 4). The early fields lie 200 to 230 cm below the surface at Location 1 (Fig. 4) and 257 to 294 cm below at Location 2. The later fields lie 95 to 150 cm below the surface at Location 1 (Fig. 4) and 93 to 177 cm below at Location 2.

Within the excavated area of 350 sq. meters, a 40 cm wide path was revealed for the later period. This would have made it convenient for people to go into the field and manage the rice stands. In addition, wooden artfefacts and pottery sherds were found. These included two wooden dibble sticks, and one wooden knife from the earlier field layer and one wooden handle of a spade from the later field; many bone and wooden spade remains were also found in the settlement area (Table 2, Fig. 3). However, no evidence of an irrigation system, which should include ditches, field ridges/bunds for controlling drainage and water retention, was found.

3.2. Archaeological remains of rice

There were many plant remains including roots, stems, leaves, seeds and microfossils were found in the strata of rice fields. As showed in Fig. 4, there are also diverse remains of rice in rice fields as well, including high densities of rice spikelets fragments, phytoliths derived from the bulliform cells of rice, and a large number of Gramineae pollens bigger than 38 μm in diameter likely derived from rice. There, however, no carbonized rice spikelets or husked rice were found.

The morphological observation of rice short rachillae and husks suggests that the rice is different from wild rice. Generally, the short rachillae are the best characteristics for discriminating between wild and domestication rice (Crawford and Shen, 1998). Short rachillae were classified into two categories, a smooth wild base, and a non-smooth or attached vestiges of broken stem domesticated base. The short rachillae of domesticated type accounts for 47.1% in the early fields between 5000 and 4500 BC and 59.4% in the later fields between 3600 and 2700 BC, while wild type accounts for 52.9% in the early fields and 40.6% in the later fields. As reported here the domesticated ratios in the early fields appeared significantly larger than that from the occupation site (Fuller et al., 2009), but this is due to a different classification system (of three types) employed in the latter study on the occupation site, in which the estimate of domesticated types was therefore lower. Nevertheless the proportion of wild types is comparable, and direction of trends over time is the same.

3.3. Archaeological remains of weeds

As Summarized in Fig. 4, many plants coexisted with rice in those tilled fields, such as Barnyardgrass (*Echinochloa* sp.), Galingale (*Cyperus* sp.), Bulrush (*Scirpus* sp.), Fimbristylis (*Fimbristylis* sp.), Spikesedge (*Eleocharis* sp.), Sedge (*Carex* sp.), Hornwort (*Ceratophyllum* sp.), Najad (*Najas* sp.), Pondweed (*Potamogeton* sp.). Floatingheart (*Nymphoides* sp.), Arrowhead (*Sagittaria* sp.), Duckleaf Knotweed (*Persicaria* sp.), Yerbadetajo (*Eclipta* sp.), waterchesnut (*Trapa* sp.), reed (*Phragmites* sp.). The habitat of most of these plants is wetlands, such as the banks of rivers and streams, marshes and wasted wetland. These species are also common weeds in rice fields.

3.4. Areas and yields of rice fields

The investigation of stratigraphy, phytoliths and seeds by coring in an area of 14.4 hectares showed that two rice field strata were distributed in the vast area around the occupation. Showed as Fig. 5, the area of rice fields could have covered 6.3 hectares for the early period and over 7.4 hectares for the later period. The depths range from 100 to 200 cm for early rice fields and from 210 to 300 cm for later rice fields. From coring samples of these strata, dense phytoliths derived from the bulliform cells of rice were detected and a lot of remains of rice spikelts were found as well. The densities of rice phytolith for early rice fields range from 1,000 to 90,000 grains/g, average 18,923 grains/g. The densities of rice phytolith for later rice fields range from 2.000 to 34,000 grains/g, average 13,010 grains/g (Table 3).

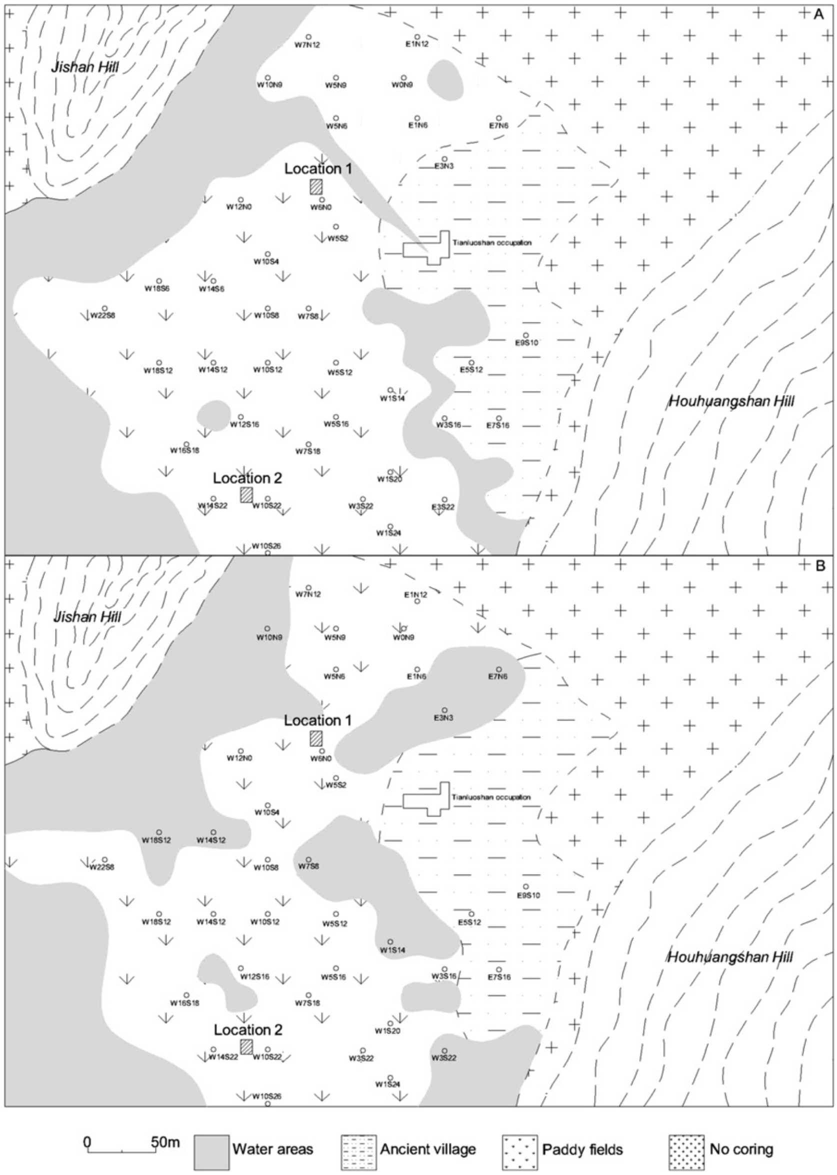

Fig. 5. Distributions of early and later rice fields. A and B show the distribution of later and early rice fields, respectively. The figures were made based on aspects of colors, properties, botanical remains of soil samples taken from the cores sticks. They indicate that the rice fields were located in wetlands with nearby rivers and lakes. The locations of phytolith analysis are indicated by (see Table 2).

4. Discussions

A large number of rice remains with some domesticated characteristics found at the Tianluoshan site (Zhejiang Provincial Institute of Relics and Archaeology et al., 2007) showed that rice was cultivated and was undergoing the domestication process, 7000 years ago. The rice fields associated with the Tianluoshan occupation provided some further evidence of rice cultivation practices at that time, including the environments, area, and methods of field preparation. We have also estimated yields.

High densities of rice spikelet fragments, phytoliths derived from the bulliform cells of rice, and a large number of Gramineae pollens proved the existence of buried rice fields at Tinaluoshan. The coexistence of short rachillae (spikelet bases) of domesticated and wild types indicated that the selective pressure on the morphology of rice had been exerted, but that populations retained some characteristics of wild rice. Nevertheless, these excavated fields could be therefore recognized as the fields for rice production. Although there are some differences in the classification of the short rachillae (spikelet base) (Zheng et al., 2007; Fuller et al., 2009), it is clear that morphological evolution was ongoing and domestication had not been fully reached yet.

The early rice fields associated with the Tianluoshan occupation are the oldest rice fields known. They are 1000 years earlier than the paddy fields revealed at the Caoxieshan and Chuodun sites dated to 4000 BC (Fujiwara, 1998; Cao et al., 2006) in the Yangtze Delta and 3000 years earlier than those of the Zhaojiazhuang site (Jin et al., 2007) in the middle reach of the Yellow River, and also older than ones excavated at the Chengtoushan site (Hunan Provincial Institute of Archaeology and Cultural Relics, 2007) in the middle regions of the Yangtze River. The Tianluoshan evidence confirmed that the people of the Hemudu culture had developed techniques of tilling soil, sowing, and harvesting by wooden and bone tools. This discovery provided important evidence on the processes of rice domestication and changes in economy between 5000 and 2500 BC in east China.

Table 3
Densities of phytoliths derived from bulliform cells of grasses in possible ancient rice field stratums of 37 coring places.

Position	Densities grains/g											
	Depth (cm, below earth's surface)	*Oryza*	*Phragmites*	*Miscanthus*	*Bambusoideae*	*Panicum*	Depth (cm, below earth's surface)	*Oryza*	*Phragmites*	*Miscanthus*	*Bambusoideae*	*Panicum*
E1N6	150–170	33,411	5896	7861	0	0	230–258	9865	22,689	1,61,788	0	0
E1N12	110–141	11,262	938	938	0	0	250–280	29,749	9597	5758	0	0
E3N3	120–162	2,09,976	2890	27,933	0	0						
E3S16	100–118	15,634	10,050	8934	0	0	220–250	2830	6604	5660	0	0
E3S22	90–121	27,784	5954	31,753	0	0						
E5S12	90–112	4,55,766	11,736	22,495	0	0	226–260	1,25,743	4950	13,861	0	0
E7N6	100–153	31,959	2905	28,085	0	0						
E7S16	90–104	78,467	6781	11,625	0	0	212–260	3,73,447	2687	16,120	0	0
E9S10	100–150	2,32,296	3904	16,593	0	0	230–290	1,43,522	2990	6977	0	0
W0N9	142–166	23,684	2733	2733	0	0	248–261	9587	8629	40,266	0	5752
W1S20	75–109	90,064	53,843	70,485	0	0	235–265	34,048	25,293	20,429	0	0
W1S24	93–145	30,160	15,566	12,648	0	0	227–260	6838	34,191	42,983	0	0
W3S22	156–215	13,953	55,814	51,827	0	0	267–300	14,574	58,295	54,131	0	0
W5N6	134–181	12,683	0	906	0	0	270–300	2911	17,466	17,466.	0	0
W5N9	103–120	6329	2713	3617	0	0	220–233	14,408	6724	1921	0	0
W5S2	122–167	20,405	10,688	12,632	0	0	255–277	7504	6566	15,946	0	938
W5S12	93–140	26,826	18,877	37,755	0	0	216–247	28,838	28,838	51,908	0	961
W5S16	105–170	3913	8804	19,565	0	0	222–260	11,650	27,184	70,874	0	971
W6N0	121–166	10,615	2895	2895	0	965						
W7N12	105–150	6816	974	2921	0	0	240–275	8802	36,187	41,078	0	0
W7S8	100–122	48,251	16,832	19,076	0	0						
W7S18	121–140	44,277	48,396	0	0	0	292–300	11,278	18,455	47,164	0	0
W10N9	90–130	1013	0	1013	0	0						
W10S4	100–130	14,074	8444	3753	0	0						
W10S8	95–147	8854.	3935	1,47,575	0	0	212–232	33,458	6506	35,317	0	0
W10S12	132–168	33,151	0	22,682	0	0	206–227	3578	14,310	22,360	0	0
W10S22	100–135	26,500	13,250	45,429	1893	946	240–250	5884	19,613	35,303	0	1961
W10S26	74–120	11,016	12,240	53,858	0	0	210–245	6020	25,083	27,089	1003	0
W12N0	115–151	2766	3688	2766	0	0	248–257	4742	6639	12,330	0	0
W12S16	100–180	5934	10,879	22,746	0	0	211–230	21,667	26,000	59,583	0	2167
W14S6	98–132	5772	2886	8659	0	0						
W14S12	98–192	19,543	37,131	23,451	0	0	212–261	26,464	4,001,881	0	1960	0
W14S22	123–176	2970	56,436	38,614	0	990	202–232	9857	49,285	90,684	0	986
W16S18	95–133	12,596	20,347	63,949	0	0	243–273	1952	18,545	20,497	0	0
W18S6	160–170	10,714	9740	27,273	0	0						
W18S12	100–143	3862	12,552	16,414	0	0	220–237	11,000	20,000	44,000	0	0
W22S8	95–128	7673	10,551	14,388	0	0	280–297	7751	19,378	41,663	0	0
Means		18,923	14,120	24,461	57	88		13,010	1,80,558	38,648	119	549

Table showed densities of phytoliths derived from some grasses in possible ancient rice field strata of 37 coring places. The densities of rice phytoliths of E3N3, E5S12, E7S16, E9S10 places were unconventionally high, and when the coring were carried out, a lot of wooden remains were also found from those areas as well, so there might be many stacking straws of rice in the ancient dwellings. The means were calculated except for above 4 places.

Rice fields can be divided into various types, including paddy fields and unimproved seasonally flooded lands. Paddy fields are lands with ridges for planting rice, and bunds and canals for storing water and moving water. In unimproved fields water derives from rainfall and natural floods and has no irrigation facilities. Appearance of irrigation facilities marks the start of more intensive forms of management and an agricultural technique for increased productivity. Both early and later Tianluoshan rice fields, without irrigation systems, could be suggested that the irrigation of them could have been dependant on rain water and water stored in the marsh. They were different from those recovered from the Caoxieshan and Chuodun sites dated to 4000 BC (Fujiwara, 1998; Cao et al., 2006; Fuller and Qin, 2009). Caoxieshan and Chuodun excavations have revealed the small artificial features of field units, which were connected by channels to some deeply dug reservoir pits dug, which ensured tight control of water levels. The later Tianluoshan rice fields, dated between 4000 and 2500 BC, were well-matched, even much later than ones at Caoxieshan and Chuodun sites in age, suggested that differences between them were perhaps regional, rather than chronological.

The Yangtze Delta is located in a subtropical monsoon climatic zone. Spring is moist and has some rain. In summer, this region is hot and humid due to the control by warm tropical air currents and typhoons. In autumn it is cool and relatively dry. Winter is cold and moist. The seasonal rainfall responsible for annual flooding might satisfy the need of irrigation of rice growth. The markedly abundant micro-charcoals in the deposits of rice fields compared to other strata imply that firing could be applied to rice cultivation. Burning during the dry season might be a common method of field managements in early agriculture for clearing dead twigs and withered leaves of plants in crop fields (Anderson, 2005; Zong et al., 2007; Atahan et al., 2008; Fuller and Qin, 2009).

In the rice field, there are not only rice plants, but a number of wetland plants inferred to be the weeds of ancient rice fields. The analyses of seeds showed that the seed bank could have been 26,000–228,000 individuals/m^2 for the early rice fields and 26,000–184,000 individuals/m^2 for the later rice fields. It is remarkably higher than 9,140–47,452 individuals/m^2 for modern paddy fields nearby wetland and even higher than 83,499–10,9141 individuals/m^2 for secondary wetland (Feng et al., 2008). Generally, the seed bank and species number in paddy fields reclaimed from wetland would decrease. High seed banking and species diversity indicated that little or even no weeding was applied to the management of the rice fields dating between 5000 and 2500 BC. High dense phytoliths and its body remains of reed implied that the rice fields could have been developed from reed-marsh and reed probably intruded into the fields and grew with rice.

Climatic amelioration at the end of the Pleistocene markedly altered the ecology in China and led to changes in human adaptations (Zhao and Piperno, 2000; Lu et al., 2002). The Yangtze Delta witnessed a period of high sea level between 5000 and 4000 BC (Xu and Shen, 1990). During the regression interval, seawater regressed and large areas of land were exposed and left behind a number of lakes. As salinity in soil had fallen, a freshwater environment appeared. Wetland plants flourished and dominated the edge of water habitats. There were also mammals, waterfowl, and freshwater fish. The excavation of occupation provided data for reconstructing resource exploitation. People migrated and settled here 7000 years ago. In addition to planting rice, they lived on gathering wild fruits growing on highlands, such as acorns, peaches, and plums, and nuts in lakes, such as water caltrop and foxnut. They hunted buffalo, deer, and birds and harvested carp, snakehead, crucian, and terrapin in lake. The tools and the ecological analysis of buried rice fields suggest the mode of rice cultivation between 5000 and 2500 BC was based on natural flood recession and seasonal rainfall. Before spring rain, the soil was tilled to a certain extent with wooden and bone spades, and seeding was done with dibble sticks after the ground was cleared by firing. Sprouted rice grew well in wetlands filled by the monsoonal rain while the wetland weeds flourished as well. In the autumn, as the rain decreased, water accumulated in wetland lowered and people later harvested mature rice, perhaps by picking or cutting the base of the inflorescences. The wooden knife, which could be used for cutting ears of rice, implied that the harvest sometime was with the help of some tools. Some time after harvest but before sowing fire was used to clear fields.

The cultivation system was thus a form of low-level food production. According to the ratio of rice phytoliths to spikelets (Fujiwara, 1979) and service life of the rice fields, the rice yields are estimated as 830 kg per hectare for the early period and 950 kg per hectare for the later period. Based on this estimation, the annual yields might have been about 5000 kg for 6.3 hectares of the early period and 7000 kg for 7.4 hectares of the later period. This suggests that the rice could support no more than 30 persons. However, some ethnographic data show that a village living dominantly on hunting-gathering subsistence has 25–100 persons while one involved in agricultural economy has 150–300 persons (Tanter, 1988). Obviously, even though people at Tianluoshan cultivated rice, the production was relatively low-level and hunting-gathering provided a substantial proportion of food in their diet, as indicated by macro-remains of acorns, *Trapa,* and other wild foods from the occupation area (Fuller et al., 2009).

Domestication of crops is not a rapid, but is a protracted process (Allaby et al., 2008). The vast early rice fields combined with the mixed wild and cultigen phenotypes indicate that rice cultivation and domestication had originated earlier. Recent discoveries of rice remains dated between 9000 and 7000 BC in the Yangtze Delta implied that rice cultivation may have originated in some small basins located in mountainous areas as early as 10,000 years ago (Jiang and Liu, 2006; Zheng et al., 2007). The earliest evidence for cultivation of rice in the Yangtze Delta also can be contrasted with the evidence from 1000s of years later in Southeast Asia, indicating that the Yangtze regions are original areas of domesticated rice, and from this area, rice was carried to Southeast Asia (Fuller and Sato, 2008).

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