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Impact of agriculture on an oasis landscape during the late Holocene: Palynological evidence from the Xintala site in Xinjiang, NW China

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ABSTRACT

Pollen and charred seeds from the Xintala site within the Yanqi Oasis of Xinjiang in Northwest China were investigated to understand the impact of early agriculture on an oasis landscapes. The data show the original vegetation was meadow steppe dominated by Asteraceae and Poaceae. Wheat-growing agriculture reshaped the landscape by destroying the original vegetation and expanding the farmland area in ca. 3900–3600 cal BP. The high percentage of *Typha* pollen is likely to have resulted from selective harvesting of cattail for domestic uses. Persistent and probably over-irrigation may have led to an increase in soil salinity as evidenced by dramatic increases in Chenopodiaceae and *Nitraria* pollen percentages. The land salinization possibly resulted in the weakening of agricultural activity and later the abandonment of farmland after ca. 3600 cal BP at the Xintala site.

1. Introduction

Agriculture, as one of the most important developments in human history, changed the life style of early humans and promoted an increase in population (Cavalli-Sforza et al., 1993; Bellwood, 2005). It is not an exaggeration to say that agriculture was a major mean for humans to adapt to the environment and also to impact on the environment during the Holocene (Knox, 2001; Ruddiman et al., 2008; Li et al., 2009a; Kaplan et al., 2011). The interactions between the humans and the environments through agricultural activity have attracted persistent interests from archaeological and palaeoenvironmental scientists (Ruddiman, 2003; Willcox et al., 2009).

Archaeobotanical records from archaeological sites have been used to understand the interactions between the humans and the environments through agricultural activity (Dimbleby, 1985; Li et al., 2007, 2008; Lippi et al., 2009). Seeds and pollen have been repeatedly reported to have documented the interactions. Specifically, seeds are normally the evidence of crop cultivation and exploitation and pollen assemblages are normally indicative of the vegetation surrounding archaeological sites (Kirch, 1996; Urban and Buerkert, 2009; Li et al., 2012).

The ecological processes of past human impact on the forest and grassland landscapes have been relatively well documented by pollen assemblages (Chambers, 1993; Oldfield et al., 2003; Li et al., 2008; Zhao et al., 2011). On forest landscapes, five stages of human impact on the landscape were observed and they are primeval vegetation growing, deforestation for farming, cultivation, abandonment of the cultivated land, and recovery of primeval vegetation (Li et al., 2008; Zhao et al., 2011). On grassland landscapes, three stages were observed and they are no grazing, modest grazing, and heavy grazing (Li et al., 2008).

Oases, fragile ecology that is sensitive to climate change and human activities (Yang, 2001), have sustained the development of the local people over thousands of years. However, little is known about the impact of human activities (e.g., agriculture activity) on the landscape in oasis areas. Here, the focus is on the impact of agricultural activity on the oasis landscape based on seed and pollen data from Xintala site, Xinjiang, NW China.

2. Study area

Yanqi Oasis (also known as Yanqi Basin) is located between the Tianshan and Kuruktag Mountains and has a temperate arid climate. The mean annual precipitation and evaporation are 74.4 mm and 1194.7 mm respectively. The mean annual temperature is 8.2 °C. Bosten Lake lies in the northeast of the oasis. The Kaidu River flows into Bosten Lake and then is pumped into the

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Kongque River at the southwest of the lake before finally reaching Lop Nur (Fig. 1).

The vegetation is dominated by dwarf semi-shrubby desert, shrubby and semi-shrubby desert, succulent holophytic dwarf semi-shrubby desert and grass swamp in the basin. The dwarf semi-shrubby desert consists of *Sympema regelii*, *Anabasis aphylla*, *Anabasis brevifolia*, *Reaumuria soongonica*. The shrubby and semi-shrubby desert is composed of *Ephedra przewalskii*, *Iljinia regelii*, *Nitraria sphaerocarpa*, *Calligonum mongolicum* and *Haloxylon ammodendron*. The succulent holophytic dwarf semi-shrubby desert is dominated by *Kalidium foliatum*. *Phragmites australis* and *Carex duriuscula* swamps dominate the floodplain and delta. Some plots with better drainage in the delta have been reclaimed for farmland. Elm and willow shrub are found along the river bank (Xinjiang Expedition Team, 1978) (Fig. 1).

3. Materials and methods

The Xintala site is situated in the north of Yanqi Oasis (Fig. 1). The archaeological site covers an area of approximately 37,000 m^2. Earlier work was conducted at the site in 1979 by archaeologists from the Institute of Xinjiang Archaeology. Pottery, stone artifacts and bronze implements were abundantly unearthed at the site (Institute of Xinjiang Archaeology, 1988).

The Xintala section (42°12′59.1″N, 86°55′51.6″E, 1075 m a.s.l.), a 380 cm thick cultural sediment, is located in the east of the Xintala site. Thirty-eight samples were collected for pollen analysis at 10 cm intervals in the field. Pollen grains were concentrated using a modified acetolysis procedure, including 10%HCL, 5%KOH, 40%HF, acetolysis treatments, and sieving through a 7 um screen to remove clay-sized particles (Faegri and Iversen, 1989). At least 200 pollen grains were counted in most samples. Two samples less than 100 pollen grains were excluded in the pollen diagram. Pollen data from a total of 36 samples were used for vegetation construction in this study. The total pollen sum identified in each pollen spectrum is taken as 100% for calculating the pollen percentages.

Eight samples of 30 kg weight at depths of 50–60 cm, 100–110 cm, 110–120 cm, 150–160 cm, 190–200 cm, 250–260 cm, 290–300 cm and 350–360 cm were treated with the sieving and floating method to extract seeds. The charred seeds were identified under a stereo microscope.

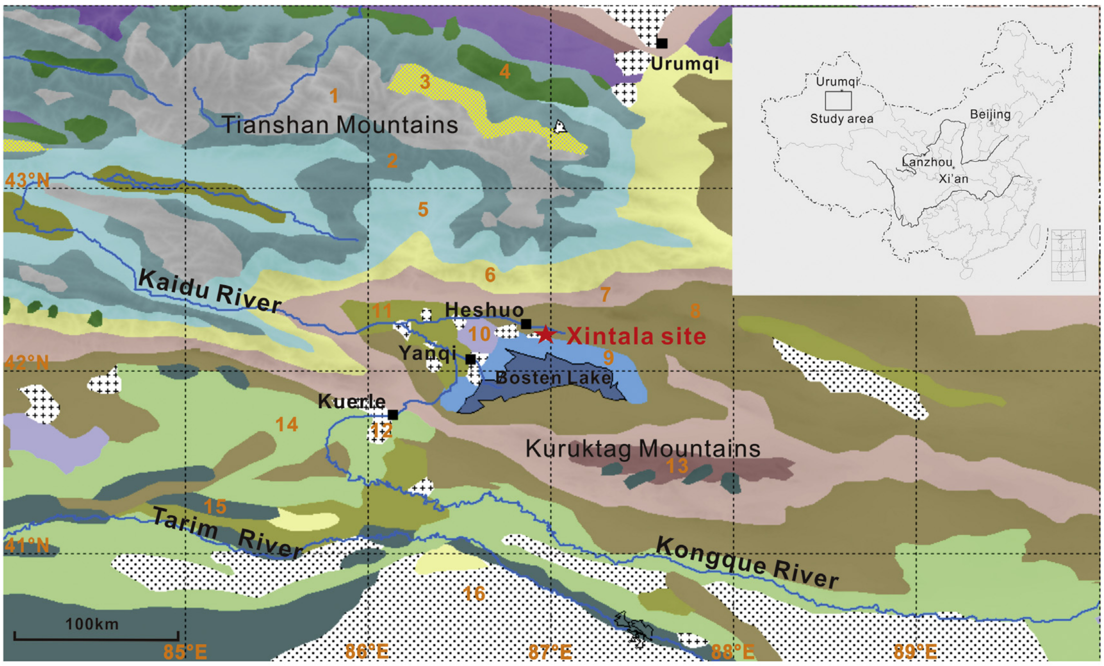
4. Stratigraphy and chronology

4.1. Strata descriptions

The 380 cm section can be divided into six layers according to the changes in color and texture: (1) 0–30 cm, light yellowish silty sand; (2) 30–100 cm, light red silty sand; (3) 100–130 cm, grey silt; (4) 130–240 cm, reddish-brown silt; (5) 240–365 cm, light grey silty sand; and (6) 365–380 cm, light yellow clay. The upper five layers are cultural sediments containing charcoal, and the bottom layer is naturally-deposited sediment (Fig. 2).

4.2. Chronology

Three charcoal and two charred wheat seed samples at depths of 5–10 cm, 80–85 cm, 150–160 cm, 290–300 cm and 350–360 cm were AMS^{14}C dated at the AMS Laboratory at ANSTO, Australia. The radiocarbon dates were calibrated according to Reimer et al. (2009) (Table 1) and the calibrated ages are shown in Fig. 2. All of the five dates from Xintala section fall between ca. 3900 and 3500 cal BP (Fig. 2) and the date at 150–160 cm is unexpectedly younger than the two dates at upper positions. With a full consideration of the uncertainties in radiocarbon dating (including the uncertainties in the calibration), these five dates are similar and four of the five



1 Ice and snow 2 Alpine meadow 3 Alpine cushion vegetation 4 Montane coniferous forest 5 Alpine steppe 6 Semi-arboreal desert 7 Dwarf semi-shrubby desert 8 Shrubby and semi-shrubby desert 9 Grass swamp 10 Succulent holophytic dwarf semi-shrubby desert 11 Montane meadow 12 Farmland 13 Montane dwarf needlegrass, dwarf semi-shrubby desert steppe 14 Broadleaf deciduous shrub 15 Microphyllous deciduous woodland 16 Bare sandy desert and gobi

Fig. 1. The location of Xintala site and vegetation types in the study area (after Institute of Botany, Chinese Academy of Sciences, 1979).

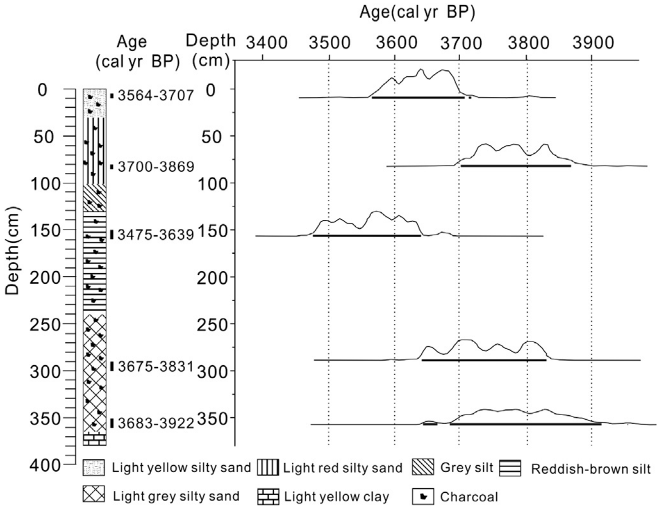


Fig. 2. Xintala section and dating results.

dates with an exception of the date at 150–160 cm are basically identical. This 380-cm thick sediment was deposited approximately between ca. 3900 and 3600 cal BP (Fig. 2) although we are not able to establish a chronological sequence.

Table 1
AMS^{14}C dates from the Xintala section.

Lab code	Depth (cm)	Materials	δ^{13}C (per mil)	^{14}C age (BP)	^{14}C age (cal BP (2σ))
OZM448	5–10	Charcoal	−22.5 ± 0.1	3395 ± 30	3564–3707
OZM449	80–85	Charcoal	−23.4 ± 0.1	3515 ± 30	3700–3869
OZM450	150–160	Charcoal	−9.4 ± 0.1	3335 ± 30	3475–3639
OZM451	290–300	Wheat seed	−22.7 ± 0.1	3460 ± 35	3675–3831
OZL437	350–360	Wheat seed	−22.4 ± 0.1	3515 ± 50	3683–3922

5. Analytical results

A total of 10,197 pollen grains belonging to 43 taxa were identified from the Xintala section. The pollen assemblages are dominated by herbs and shrubs including Poaceae, *Artemisia*, Chenopodiaceae, Asteraceae, *Typha* and *Nitraria*. The section can be palynologically divided into four zones according to the pollen CONISS result (Fig. 3).

Three seed types were identified from 8 floating samples at the site and they are wheat (90 grains), barley (25 grains), and broomcorn millet (22 grains). The charred crop seeds were dominated by wheat grains that were found in all of 8 samples. The barley and broomcorn millet seeds were found in 6 of 8 samples.

Pollen Zone I (380–330 cm): This zone is characterized by high percentages of Asteraceae (2%–42%) and Poaceae (11.6%–20.1%). The Rosaceae and *Humulus* pollen percentages are up to 7.1% and 4.5%, respectively. *Pinus* (2.2%–13.7%), *Quercus* (0.7%–4.5%), Chenopodiaceae (17.7%–39.6%) and *Artemisia* (6.6%–18.7%) also have relatively high percentages. The pollen assemblages indicate that meadow steppe dominated by Asteraceae and Poaceae occupied the area. *Pinus* and *Quercus* plants may have sparsely existed around the site. One charred wheat seed was found in this zone.

Pollen Zone II (330–180 cm): The Asteraceae pollen percentage (0–5.4%) decreases sharply, while the Poaceae pollen percentage (3.9%–63.9%) increases with an average of 34.8%. Tree pollen almost disappeared. The Chenopodiaceae pollen percentage (21.7%–86.5%) is much higher than the underlying zone (i.e., Pollen

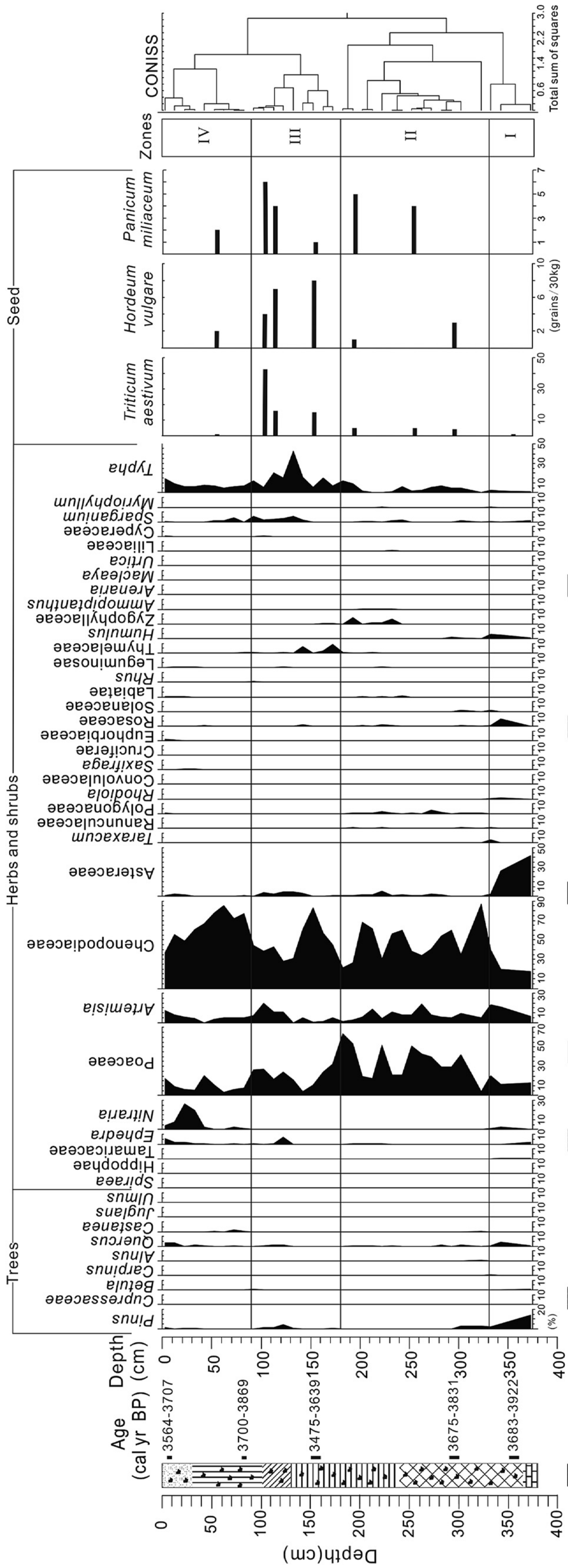


Fig. 3. Diagram of pollen percentage and seed distribution in the Xintala section.

Zone I) with an average of 48%. Fourteen wheat grains, 4 barley grains and 10 millet grains were identified in this zone.

Pollen Zone III (180–90 cm): The Poaceae pollen percentage (4%–32%) decreases and the *Typha* pollen percentage (5.3%–42.3%) increases with an average of 15.4%. The Chenopodiaceae pollen percentage remains the same as that in the underlying zone (i.e., Pollen Zone II). It is notable that the number of charred seeds reaches the maximum in this zone: seventy-four wheat grains, 19 barley grains and 12 millet grains.

Pollen Zone IV (90–0 cm): The Poaceae pollen percentage (3.2%–20.5%) keeps decreasing and the *Typha* pollen percentage drops below 14.1%. The Chenopodiaceae pollen percentages (37.1%–85%) increase dramatically, accompanied by a notable rise in the *Nitraria* pollen percentage. The pollen assemblages show that desert vegetation dominated by Chenopodiaceae and *Nitraria* occupied the study area. One wheat seed and two barley seeds were identified in this zone.

6. Discussion and conclusions

The analytical results reveal that wheat, naked barley and broomcorn millet were cultivated ca. 3900–3600 cal BP at Xintala site, Xinjiang, NW China, lending further supports to the proposition that the ancient people at the site subsisted on an agricultural economy (Wang, 1983; He, 2007). Moreover, the vegetation changes uncovered by the pollen data at the site offer a new perspective on assessing the influence of agricultural activity on the oasis landscape during the late Holocene in arid regions.

The palynological evidence from natural sediments documents the vegetation change caused by natural factors including climate change, natural fire and natural disaster, while the palynological evidence from archaeological sites normally documents the human influence on the landscape (Mercuri, 2008a; Li et al., 2009b). Abnormally high pollen percentages of certain species at an archaeological site may imply that some plants may have selectively preferred to human-altered environments (Mercuri, 2008a).

Studies of modern surface pollen have shown that Poaceae pollen is under-represented and that its percentage is usually less than 10% even in the vegetation community dominated by Poaceae grass family (Li et al., 2000; Xu et al., 2005). If the Poaceae pollen percentage is higher than 20% in the stratigraphic layers of archaeological sites and Poaceae pollen can be used as a substitute index of agricultural activity intensity (Sadori et al., 2004; Mercuri, 2008a; Li et al., 2012).

The vegetation is dominated by Asteraceae, Poaceae, Rosaceae and *Humulus* with few *Pinus* and *Quercus* plants in Pollen Zone I, suggesting that the original vegetation was meadow steppe in the study site. Only one wheat seed was uncovered indicating that the intensity of agricultural activity was still weak or nearly null.

Pollen assemblages are dominated by Poaceae and Chenopodiaceae in Pollen Zone II. The Poaceae pollen percentage reaches a maximum of 63.9% with an average of 34.8%, indicating a dramatic expansion of cultivated area. The original vegetation, such as Asteraceae, Rosaceae and *Quercus*, disappeared suddenly in the pollen spectrum, probably as an indication of land reclamation for cultivation. The rising number of seed grains more firmly suggests that the intensity of agriculture activity increased and cultivated area expanded during that time.

Although the Poaceae pollen percentage decreases in Pollen Zone III compared with that in Pollen Zone II, the percentage is still as high as 32% with an average of 20.1%. It should be particularly noted that the number of seeds in this zone reaches the maximum of the entire section, implying that the cultivation was at its peak in terms of the area extent and of the intensity.

Typha sp. pollen rise with a maximum of 42.3% in the zone may be a result of the selective use of cattail by Xintala ancestors. Archaeological data suggest that cattail stems with flowering spikes were used to make the roofs of huts in the Uan Tabu in the Libyan Sahara (Mercuri, 2008a, 2008b). In the Gumugou tombs (ca. 3800 BP), approximately 200 km southeast of the Xintala site, threads made of *Typha* sp. have been discovered. And, cattail was used for mat making in the Yanghai tombs (ca. 2500 years BP) (Jiang et al., 2013). The *Typha* sp. pollen rise in Pollen Zone III was an indication of intensive *Typha* uses by the Xintala people.

The dramatic increase of Chenopodiaceae and *Nitraria* pollen percentages in Pollen Zone IV is accompanied with a decrease of Poaceae pollen percentage, suggesting a decline of agricultural activities and the associated land degradation. This conclusion is also supported by the decrease of seed grains. Chenopodiaceae is widely distributed in desert, semi-desert and saline land and its pollen percentages often exceed 50% in some extremely dry or salt-affected areas. *Nitraria* is a more salt-tolerant plant whose pollen is adequately represented in modern pollen-plant settings (Xu et al., 2007).

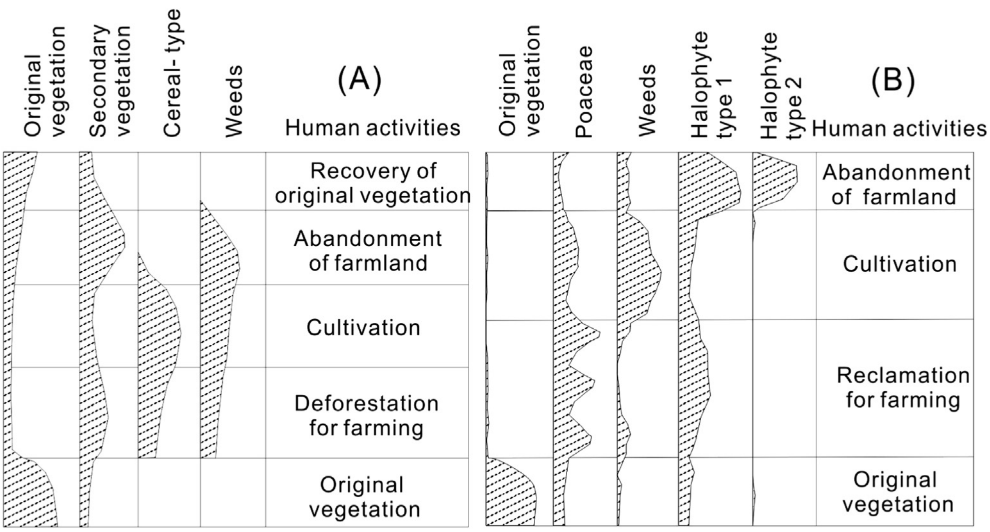


Fig. 4. (A) Patterns of pollen spectra for different stages related to deforestation for farming in a forest region (after Li et al., 2008); (B) Patterns of pollen spectra under cultivation in an oasis area.

The soil salinization in Mesopotamia during 2400–1700 BC had a close relationship with agricultural irrigation (Jacobsen and Adams, 1958). The increases in Chenopodiaceae, Tamaricaceae and Zygophyllaceae pollen percentages at Donghuishan and Huangniangniangtai sites in Hexi Corridor (also called Gansu Corridor) of Northwest China were interpreted to suggest that soil fertility loss was induced by over-irrigation and the associated soil salinization (Zhou et al., 2012). Multi-index records from Bosten Lake reveal that the climate was relatively dry with high evaporation during 3500–4000 cal BP (Mischke and Wünnemann, 2006; Wünnemann et al., 2006). The sustained cultivation and irrigation with high evaporation may have led to the soil fertility loss and the increase of soil salinity at the Xintala site.

Pollen of anthropogenic plants is an ideal indicator of human activities, and different types of human activities may result in different pollen assemblages (Li et al., 2008). In forested landscapes, the occurrence and then an increase of cereal-type pollen, weed pollen and secondary forest pollen characterize the deforestation for farming stage, and cereal-type pollen grains and anthropogenic weeds become quite high in the cultivation stage (Li et al., 2008) (Fig. 4A). But, little is known about the ecological processes of human impact on the oasis landscape.

The pollen record from the Xintala section is one of few available records documenting the ecological processes of agricultural impact on the oasis landscapes. The processes at the Xintala site can be divided into four stages: a period of original vegetation growing, reclamation for farming, cultivation and abandonment of farmland (Fig. 4B). The original vegetation at the Xintala site was meadow steppe dominated by Asteraceae and Poaceae. The subsequent reclamation for farming destroyed the original vegetation and led to the increase of Poaceae (cereal-type) and Chenopodiaceae (halophyte type 1) vegetation. In the cultivation period, the crop cultivation area did not expand. The ancestors began to exploit local weeds for their livelihoods or for building, for example, to make roof and rat using *Typha* sp (weeds). Sustained cultivation probably under high evaporation and over-irrigation conditions may have resulted in soil salinization and abandonment of the farmland. The region was taken over by halophytes, such as Chenopodiaceae and *Nitraria* (halophyte type 2). The recovery of original vegetation is not observed in the pollen record from the Xintala site (Li et al., 2008; Zhao et al., 2011) (Fig. 4), probably suggesting that more time may be needed for recovery after destruction of original vegetation in an oasis region.

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