Title	Sustainable agriculture : the lessons from history
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Citation	SANSAI : An Environmental Journal for the Global Community (2011), 5: 69-81
Issue Date	2011-04-12
URL	http://hdl.handle.net/2433/143607
Right	
Type	Journal Article
Textversion	publisher

Sustainable agriculture: the lessons from history

Yoichiro Sato, Leo Aoi Hosoya, Emi Kimura, Takashi Kurata, Chiaki Muto and Katsunori Tanaka

1. Objectives and overview of the research

In 2006, a diverse group of researchers from the Research Institute for Humanity and Nature (RIHN) in Kyoto and universities and museums across Japan began to collaborate on a five-year project. Its main goal was to study the history of the relationship between agriculture and environment in four Eurasian climatic zones over a period of 10,000 years. This ambitious project proposed to assess how the origins and development of agriculture influenced the surrounding environment and to evaluate the impact of environmental factors on agriculture. By focusing on periods of social crisis (caused by the collapse of agricultural production) and consequent recovery, the project members set out to do two things. First, to challenge the popular perception that the development of agriculture has been linear, progressing from simple agricultural methods to the complex industrialised models we see today and marked by a trajectory of increasing and continual agricultural productivity. Second, to establish a general principle of sustainable agriculture that could inspire future agricultural activity.

The following presents a sample of the results of the five-year activity, drawing upon the strengths of its co-authors, who include three plant geneticists, a historian, a philosopher and an archaeobotanist. The results presented here focus on two case studies. The first was carried out at Ikeshima Fukumanji, Japan, in the so-called "rice zone" (characterised by a monsoon climate), where agricultural production in the pre-modern period experienced several periods of crisis owing to interactions between human activities and environmental impacts. The second was carried out at the Xiaohe tombs in the Taklimakan desert in China in the *mugi* (winter crops) zone, which is characterised by an oceanic, Mediterranean and desert climate. Here, archaeobotanical analyses and wheat cultivation experiments indicated that intensive land use — mainly in the form of irrigation (which caused salinisation) and agriculture — was responsible for the barren land found at the site today. Based on an examination of these case studies, we suggest that the collapse of agricultural production that has often devastated human society has multiple causes and that the intensification of agriculture is a major factor leading to the instability of ecosystems. We conclude with the proposition that the best guarantee for a more sustainable agricultural future may depend on the reintroduction of *shinogi* approaches (traditional and highly flexible contingency planning to revive or improve agricultural activity, cope with agricultural difficulties and avoid agricultural collapse) similar to those of the past, characterised by efforts not to "control" but to "coexist with" nature.

2. Research methodology

The idea of "agricultural zones" is core to the research presented in this field report. Food production systems differ worldwide, depending primarily on natural conditions such as temperature, precipitation, soil condition and topography. For example, the main difference between the rice and *mugi* zones, which form the focus of this study, is found in the pattern of rainfall: the rice zone is associated with summer rain or monsoons, while *mugi* zones are marked by winter precipitation (Figure 1). The establishment of different crop species in these and other agricultural zones depends on a combination of natural and artificial conditions. Traditionally, the major crops in the rice zone are the *japonica* or *indica* rice varieties and millets, such as finger millet (*Eleucine coracana*), foxtail millet (*Setaria italica)* or barnyard millet (*Echinocloa* spp.), all of which are typical summer crops. In contrast, major crops in the *mugi* zone were historically wheat (common wheat and emmer wheat), barley, oats and rye. It is widely accepted that vegetation and fauna also depend largely upon a combination of natural and artificial conditions. Throughout the study, the idea of "agricultural zones" that underpins the research is based on the differences in these and other natural and

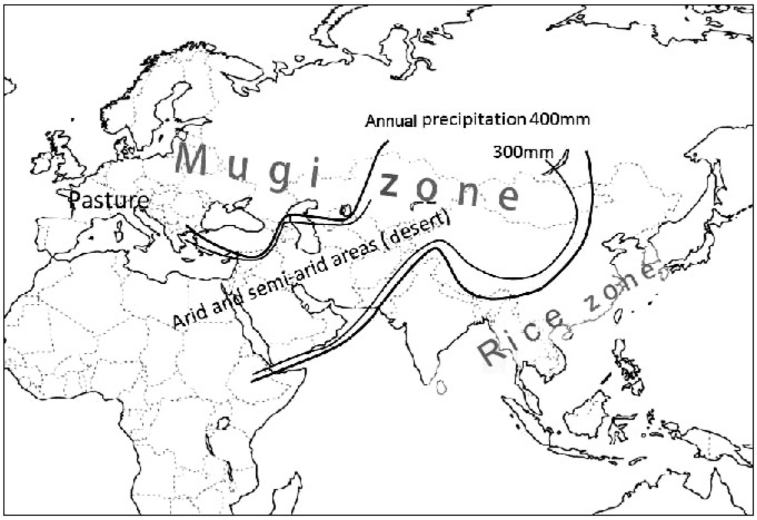

Figure 1. The *mugi* and rice agricultural zones in Eurasia
Source: Worldatlas outline map, adapted by the authors

artificial conditions.

To build up a holistic understanding of the human-nature interaction at the research sites in the agricultural zones outlined above, we performed analyses drawing on the disciplines of archaeology, anthropology, geology, genetics, agronomy and climatology. We collected and analysed organic archaeological remains such as seeds, pollen grains or phytoliths from the sites surveyed and performed dating on them using accelerator mass spectrometry, also known as AMS. Additional data for our study of Japanese *shinogi* techniques was provided by further studies another sites, such as Maekawa, a site dating back to the Yayoi-Heian period (ca. 2100–1100 BP), which is located today in Inakadate village, Aomori prefecture, in Japan's northern Honshu. Written records shed light on the political, economic, cultural and natural conditions of these sites and their neighbouring regions in different periods of history. For example, official records as well as private ones in the Kawachi region (near the Ikeshima Fukumanji site) and historical documents about the age of the Loulan Kingdom in China (ca. 2600–1800 BP or 500 BC–200 AD) all provided essential historical insights for the study. Proxy data such as pollen grains and crop seeds allowed us to reconstruct specific historical agricultural conditions and bolster our research findings.

3. Ikeshima Fukumanji and the sustainability of agricultural production in the rice zone

The rice zone, with its abundant rainfall, is more favorable for agricultural production than the *mugi* zone. Throughout the Asian continent, various millet species — such as foxtail millet (*Setaria italica*), common millet (*Panicum miliaceum*), sorghum (*Sorghum bicolor*) and finger millet (*Eleucinecoracana*) — and pulses, such as soybeans (*Glycine max)*, chickpeas (*Cicer arietinum*), adzuki beans (*Vignaangularis*) and pigeon beans (*Vicia faba*), have been grown historically as supplements to cereal crops. Some of these crops provided starch while others were eaten mainly as sources of protein. Although the former staple cereal crops have been widely replaced by rice and wheat in the rice zone and the *mugi* zone, respectively, minor cereals remain common in the Indian subcontinent and parts of central Asia.

Our research in the rice zone was carried out at Ikeshima Fukumanji, a site located today in Yao city, Osaka prefecture, on Honshu island, western Japan, where it lies in the watershed of the lower basin of the old Yamatogawa River (Figure 2). Dating back to Jomon times, in the early Edo period, rice cultivation is believed to have been sustained at this site for more than 1,500 years since the beginning of the Yayoi era (ca. 2400 BP or 300 BC). This is despite frequent flooding caused by the swell of the old Yamatogawa River that drained into the Yodo River and other extreme weather events that endangered human settlements established in the Kawachi plain in Osaka.

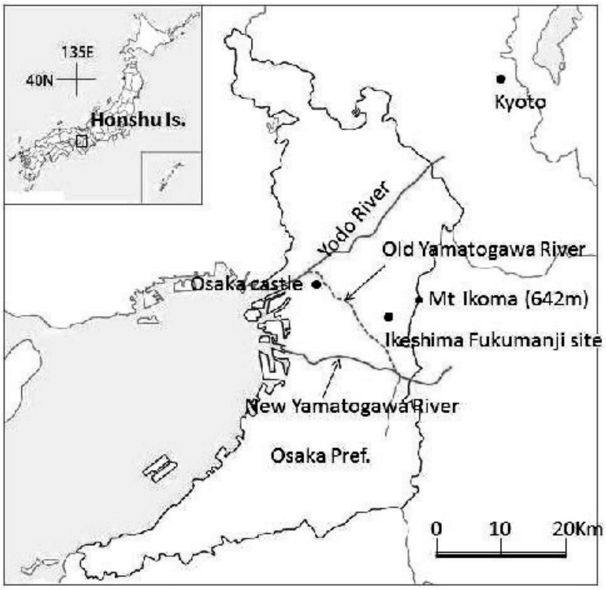

Figure 2. Location of the Ikeshima Fukumanji site
Source: Worldatlas outline map, adapted by the authors

Thick sand layers discovered by archaeologists at the Ikeshima Fukumanji site date to the period from the Yayoi era until the Edo era (ca. first century to 18th century AD) (Figure 3). The total thickness of sand layers exceeded 1.5 metres during the Yayoi era, before dwindling to less than several 10s of centimetres in the latter period. Written records dating from the late 12th century to the late 16th century medieval period as well as from the early Edo era (ca. 1700 AD) reveal that large-scale flooding in the area occurred almost once every two or four years. It is likely that those floods were caused at least partly by human factors. By the time of the final battles between the Tokugawa and Toyotomi clans (early 17th century AD), nearby forest had been cut on a massive scale for use in castle construction or as firewood to feed the burgeoning fuel demands of a growing military. Deforestation on this scale would have reduced the water-retaining ability of the Ikoma mountain range from which the Yamatogawa River flows, and this, in addition to embankment construction that raised the level of riverbeds, is likely to have exacerbated the flood damage.

Figure 3. Sand layers at the Ikeshima Fukumanji site
Source: Y. Sato 2003

How did these early societies adapt themselves to frequent flooding? Excavations have shown that people often abandoned cultivation when floods covered lands with thick layers of sand. This was not the case in Ikeshima Fukumanji, however, where excavations reveal instead that to remove thick layers of sand accumulated by repeated floods, people adopted a new technique of constructing *shima-bata* (literally, "dyke as island"), as seen in old pictures (Figure 4). *Shima-bata* were built from accumulated sand and formed wide and elevated ridges, approximately 5 m to 10 m wide and 20 cm to 30 cm high. As the surface of *shima-bata* tended to be very dry, crops that preferred aridity — such as wheat and barley (winter crops) or cotton (summer crop) — were grown there. The Kawachi area became a famous centre of cotton production from the time when the building of *shima-bata* became widely practiced.[1] Areas from which accumulated sand had been removed were reused as paddy fields for rice. Known as *kakiage-ta*, these recovered lands worked hand-in-hand with *shima-bata*, playing a vital role in maintaining a high level of diversity of crop species in the compromised agro-ecosystem of their day.

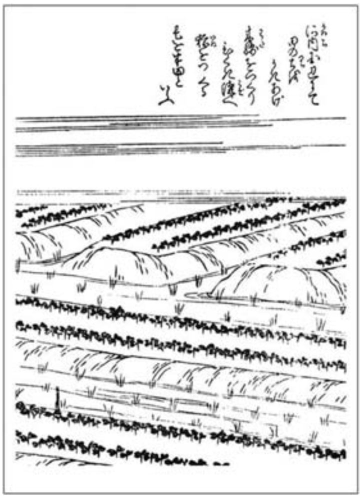

Figure 4. *Shima-bata* and *kakiage-ta* ("ta" meaning field in Japanese) showing young cotton and rice plants
Source: N. Ohkura, mid-19th century

Our excavations showed that other attempts to adjust to flooding in the region or to carry out agriculture were less successful. In 1704, a then new river (the current Yamato River) was diverted to the west, at the northern entrance of the Kawachi region. This diversion dried up the old Yamato river basin — a change in water condition that is suggested by excavations that have revealed many wells in the area, dug out after the opening of the new Yamato River. River activities at Sakai Port, located near the mouth of the new Yamato River, soon declined due to a large amount of inflowing sand.

It might be argued that *shima-bata* and *kakiage-ta* succeeded where river diversion failed because the first two methods — unlike river diversion — were effective examples of *shinogi*. *Shinogi* is a Japanese term that covers a set of agricultural techniques informed by traditional knowledge and characterised by efforts to follow rather than control nature. Phytolith analysis carried out at the Ikeshima Fukumanji site shows that people attempted to adapt their living conditions to natural and/or social changes not only by inventing new agricultural technologies — seen in the *shima-bata* and *kakiage-ta* system — but by introducing various new crops and obtaining different varieties from a crop species. These included new varieties of rice similar to the tropical *japonica* species, suitable for low-input cultivation (Oka 1958; Sato 1987), as well as the aforementioned wheat, barley and cotton. Different varieties of rice plant were thus grown side by side, which suited the varied topography of the Kawachi plain.

Examples of *shinogi* such as these abound in Japanese agricultural history. Before the medieval period (late 12th to late 16th century AD), farmlands were customarily left fallow because of heavy weed growth and/or decreasing soil fertility, regardless of flooding (Sato 2003; Uno 2001). Excavations conducted at Maekawa in Aomori prefecture revealed that the total number of years for which certain blocks of paddy field were used for rice cultivation varied from 50 to 250 years throughout the Heian period (794 AD to late 12th century AD). This suggests that farmland was left fallow for 12 to 64 per cent of the time during the Heian period. Leaving lands fallow would appear to have been common practice in the rice cultivation system of the monsoon zone at that time.

The swidden agricultural practice of burning land and then leaving it fallow to control weed growth and recover soil fertility (Sasaki 1989) is another example of *shinogi*. Although recognised today as providing various ecological services such as fostering the growth of edible wild plants (Kawano 2009), swidden practices are now rarely seen in mountainous regions of Japan. Their disappearance is unfortunate on many counts: the agronomical study of swidden practices clearly indicates that the burning of fields exterminates weeds, pests, insects and micro-organisms that cause disease and makes better use of nitrogen compounds. This is an obvious advantage of swidden farming over modern agriculture methods based on chemical fertilisers and insecticides. It has also been shown that burning fields helps to germinate the seeds of formerly dormant crops. Egashira (2010) points out that the germination ability of turnips in burnt fields was significantly higher than that of turnips in non-burnt fields. This suggests that swidden farming is more efficient in terms of seed germination and plant growth at the juvenile stage.

These findings suggest that a series of phenomena involving both human and natural actions, regardless of their positive or negative effects on human societies, shapes a complex web of human-nature interaction, such as the one shown in Figure 5. Although the rice zone varies in climate and culture, it has one common aspect — throughout the history of rice cultivation, agriculture has not continued in a sustained manner and has not recorded constant increases in productivity per unit area. Instead, it has endured a number of collapses, recovering each time thanks to various *shinogi* techniques.

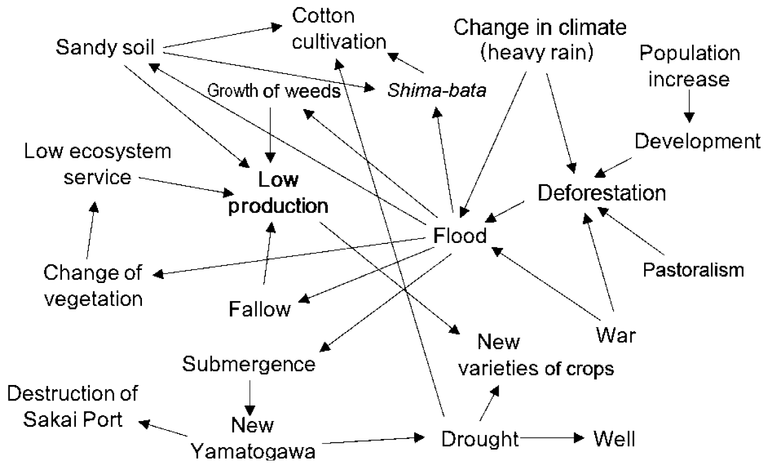

Figure 5. Web of interaction between humans and nature at the Ikeshima Fukumanji site
Source: the authors

4. The Xiaohe tombs and the sustainability of agricultural production in the *mugi* zone

The *mugi* zone stretches over 10,000 km of the Eurasian continent and is characterised by diverse agricultural systems, crop species and varieties. Annual rainfall averages less than 250 mm (400 mm of rainfall being the minimum level necessary for cultivating wheat without irrigation). In such areas, pastoralists have been required to purchase requisite stable cereals from farmers, sometimes at great distance. In semi-arid areas receiving 250–400 mm annual rainfall, subsistence depends on combined systems of crop cultivation and pastoralism.

Our research in the *mugi* zone was carried out at the Xiaohe tombs (ca. 3600–3200 BP or 1500–1100 BC) in the eastern Taklimakan desert in Xinjiang, Uygur autonomous region, China (Figure 6). The Xiaohe tombs site is unique in the sense that various proxy data, such as crop seeds and pollen grains, are available covering the period 3600 BP

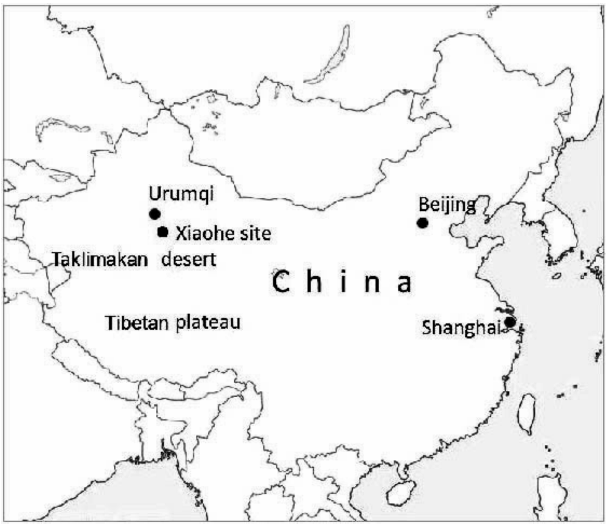

Figure 6. Location of the Xiaohe tombs site
Source: Worldatlas outline map, adapted by the authors

(1500 BC) to the present time. We have analysed pollen samples collected from samples of a dried mud-like substance coating coffins found in the Xiaohe tombs, dating from ca. 3500–3400 BP (1400–1300 BC) and ca. 3400–3200 BP (1300–1100 BC) (Figure 7). We found that:

Figure 7. Xiaohe tombs in the Taklimakan desert, China
Source: Y. Sato 2008

- from 3500–3400 BP (1400–1300 BC), pollen grains of grass species and of plants that prefer wet conditions (e.g. *Sparganium* sp. and *Poaceae*) were predominant;
- from 3400-3200 BP (1300–1100 BC), pollen grains of grass species and of plants that prefer arid and saline conditions (e.g. *Chenopodiaceae*) were predominant.

Grains of wheat were also discovered inside the coffins. Seeds of common wheat (*Tritucum aeativum*) had been put into baskets of approximately 10 cm in diameter and 15–20 cm in height, one of which was placed in every coffin. It is supposed that newly harvested seeds were buried with the deceased person. The length and weight of wheat grains dug out from different coffins showed constant increases between 3500 and 3300 BP. However, between 3300 and 3200 BP, both the length and weight decreased and varied from one coffin to another. The length of grain is a genetic feature, while the weight is determined by conditions of cultivation. The reduction in the weight of wheat grains in the latter stage of the 300-year period suggests that conditions for cultivation had worsened and become less stable by that time.

How does this analysis of pollen and wheat grains (summarised in Figure 8) correlate with other data relating to the study site? It is known that in the area of the Taklimakan desert, after a “humid period” that occurred about 5,000 years ago (Professor Shukuro Manabe, personal communication), water was provided by rivers but not by rainfall. Agricultural activity in the area was supported by irrigation at this time, as is often the case in arid and semi-arid areas, where irrigation is extensively used to supply necessary water to agricultural land (Watanabe and Sato 2009). Irrigation itself is known to cause saline-soil problems: Maekawa (1974) has suggested that salinisation problems caused serious reductions in wheat production at the time of the third Ur dynasty (22^{nd} to 21^{st} century BC), basing his hypothesis on extant records on clay tablets that indicated a quick shift in agriculturists’ preferences from common wheat to barley as the major cereal crop. The description of this shift can be found on a number of tablets dating back to different periods in Mesopotamian history. Although

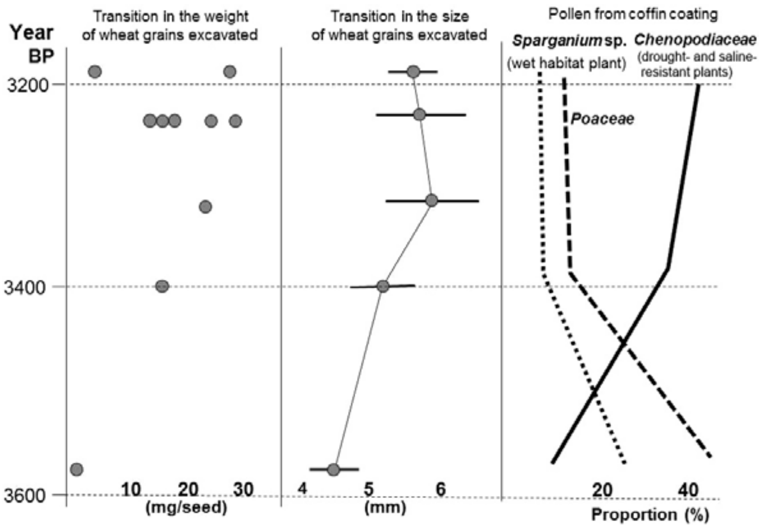

Figure 8. Pollen grain and wheat grain analysis at the Xiaohe tombs site
Source: the authors

no such description is left in the Xiaohe tomb, a thick sediment of salt is observable all over the site, particularly along the old river. It is likely, therefore, that the deterioration of cultivation evident in the different weight of wheat grains analysed in the study was caused by irrigation-induced soil salinisation.

Soil salinisation on an expanded scale might have caused the desertification of the land now known as the Taklimakan desert. It is possible that the salinisation of agricultural land brought about a decline in productivity, which forced people to further expand the area of cultivation. The repetition of this phenomenon could have created a vicious feedback cycle, in which the cause produced an effect that exacerbated the initial cause. Once in motion, such a cycle is difficult to stop.

Archaeological and agronomical research suggests that the Xiaohe area was once rich in vegetation and fauna, which sustained pasture and the cultivation of crops, particularly bread wheat (which requires water). Presumably, at some point in the Xiaohe period (3600–3200 BP or 1500–1100 BC), rainfall in this area decreased to less than 400 mm. Reduced rainfall led to the adoption of irrigation at some time between 3500 and 3400 BP (1400 and 1300 BC). The accelerated degradation of agricultural conditions that came next is conceptualised in the web of human-nature interaction shown in Figure 9, which highlights the complex interactions between human activities and natural events that may well have resulted in the collapse of civilisation in the eastern Taklimakan desert.

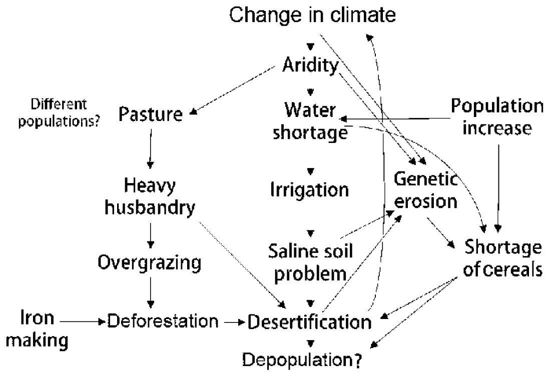

Figure 9. Web of interaction between humans and nature at the Xiaohe tombs site
Source: the authors

5. Discussion

The project findings presented in this paper represent part of the project researchers' efforts to explore two fundamental research questions. First, how has agricultural production by a human population undergone various environmental changes? Second, how have human activities then influenced these environmental changes on different time and spatial scales? These are essential questions to be considered when thinking about sustainable agriculture.

One way to approach these questions is to understand that natural and artificial phenomena form a complex and intricate web of interactions, and that any sudden decrease in agricultural production occurs as a direct result of that network. The case studies presented here show that a sudden decline in agricultural production is rarely attributable to a single factor: rather, it is attributable to the interaction of multiple factors. As we have seen, a decline in agricultural productivity can act as both cause and effect: the vicious cycle that may begin when a natural or man-made cause triggers a slump in agricultural productivity can make the agro-ecosystem in question increasingly unstable and create the risk of agricultural and then social collapse.

How, then, might we put agriculture on a more sustainable footing? In this paper, we advocate the use of *shinogi* techniques to adapt agriculture to dynamic environmental conditions. *Shinogi* could be understood to be similar to adaptation but it is actually a much wider concept, primarily because it also means to minimise damage (to a livelihood system) through the flexible use of difficult conditions. In the Ikeshima Fukumanji case study, a *shinogi*-based approach yielded three important innovations that allowed agricultural productivity to continue in the face of difficult environmental impacts: *shima-bata* and *kakiage-ta* to secure, restore and reuse farmlands immediately after flooding and letting land lie fallow to recover soil fertility. In the Xiaohe tomb site, we saw the opposite — human attempts to use irrigation to overcome natural conditions inadvertently caused the salinisation of the land that led to desertification and, eventually, to agricultural collapse.

Shinogi-style adaptation offers a way to resolve agricultural problems caused by an overdependence on technological innovations. Chemical fertilisers and pesticides in modern agriculture have failed to stop weeds, germs and pests from inflicting damage to agricultural production. Likewise, the best efforts of the so-called "green revolution" to feed a burgeoning world population have exacerbated a decline in genetic diversity (a decline originating from centuries of domestication and selective hybridisation of plant and crop varieties[2]) that may yet trigger collapses of food production on a scale not seen since the Irish potato famine of the mid-19th century. Attempts to control and manipulate natural conditions have never been entirely successful in the past so it is doubtful that such attempts to "control" nature will work in the future. Our findings suggest that "coexisting" symbiotically with nature's more undesirable visitations — be they floods or pests — rather than seeking to "control" them is the best and perhaps only way to make agriculture sustainable.

Notwithstanding the above, the goal of agricultural sustainability should be pursued with caution. Known historical events, including those described in this paper, indicate that agricultural productivity collapses all too often. Such collapses are sometimes caused by humans, for example, when they are closely related to the size of the population. But in other cases, the cause is natural. In some respects, the concept of sustainability is something that could only have been conceived by individuals living in societies that have had the good fortune not to experience a collapse in agricultural production: individuals living in north America, Europe and east Asia in the decades following the second world war, perhaps. Societies should be warned against thinking of the future in terms of personal experience: the risk of agricultural collapse is always present and, at its simplest level, the sustainability of agricultural production means nothing more than the capacity of any given society to lessen the degree of risk that is faced. In fact, the way a society recovers from agricultural collapse is one of the most important subjects in the study of sustainability science.

Acknowledgements

The authors thank Dr Junko Kitagawa of the International Research Centre for Japanese Studies, Kyoto, for her pollen analysis in the Xiaohe tombs and Professor Junko Habu of the University California, Berkeley, for her stylistic comments on the writing of this article.

Notes

[1] Archaeological excavations have traced the existence of *shima-bata* and *kakiage-ta* back as far as the late Heian period (ca. 11th century).

[2] Research into the domestication of rice and wheat species — increasingly backed up by DNA analysis — shows that hybridisation between even distantly related varieties or species can lead to the emergence of derivative species, which grow vigorously but have low seed productivity because of hybrid sterility. This process, along with that of choosing certain seeds and crops over others for cultivation, has resulted in the extinction of species on a tremendous scale and a subsequent loss in agricultural species diversity. Today, humans receive more than 60 per cent of their energy from just three crop species: rice, wheat and corn (Bellwood 2004).

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