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The Origin of Submerged-Soil-Based Rice Cultivation with an Emphasis on Archeological Evidences

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1. Abstract

Rice cultivation has long been considered to have originated from seeding of annual types of wild rice somewhere in subtropics, tropics or in the Yangtze River basin. That idea, however, contains a fatal weak point, when we consider the tremendous difficulty for primitive human to seed any cereal crop in the warm and humid climate, where weed thrives all year round. Instead of the accepted view, we have to see a reality that vegetative propagation of edible plants is a dominant form of agriculture in such regions. The possibility is discussed that rice, a major cereal crop unique to the region, may have been developed via vegetative propagation to obtain materials for medicine or herb tea in backyard gardens prior to cereal production. This idea is supported by the fact that rice in temperate regions is still perennial in its growth habit and that such backyard gardens with transplanted taro can still be seen from Yunnan Province of China to Laos. Thanks to detailed survey of wild rice throughout China for 1970-1980, it is now confirmed that a set of clones of wild rice exist in shallow swamps in Jiangxi Province, in an area with severe winter cold. In early summer ancient farmers may have divided the sprouting buds and spread them by transplanting into shallow march. Obviously, such a primitive manner of rice cultivation did include the essential parts of rice farming, i.e., nursery bed, transplanting in submerged-soil-based plots. Transfer from the primitive nursery to true nursery by seed may have later allowed rice cultivation to be extended to northern regions. In thus devised submerged-soil-based cultivation there are a series of unique advantages, i.e.; continuous cropping of rice in a same plot, no soil erosion, slow decline of soil fertility, availability of minerals, and resulted high yield per unit area, which have collectively attained the highly productive cereal cultivation in the warm and humid region. According to archeological reports, it is shown that even the earliest rice cultivation was practiced in submerged plots, and not on upland fields. Rice cultivation in marsh is also favorable to raise fish culture, both of which constituted a nutritionally balanced base. Development of irrigation technology to construct submerged-soil-based plots gave strong bases for stable rice-cultivating societies, which in the end formulated the rise of ancient kingdoms of Yue and Wu in China in BC 6-5th centuries.

3. Introduction

Why rice is planted to submerged-soil-based plots? This is probably a fundamental question to understand the status of East-Asian agriculture. Implication of a 'word "水田" in Chinese language, which implies submerged plots, may be understood for those living in rice-cultivating countries, but explaining it' s implication to those outside of such regions is very difficult. It is not a kind of irrigated field. One of the present authors once published an extensive review with a title of 'The origin of Flooded Rice cultivation '[1], but the term 'flooded' did not seem to be readable to those working in the field of irrigation or water managements. Also, the review was too long as it covered many points of crop improvements and earlier history of China. Therefore, in the present version, while repeating some parts on early agriculture, the authors tried to explain the origin of submerged-soil-based rice cultivation and its advantages. Also, some archeological evidences are

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added here to show that rice cultivation was initiated in the form of submerged plots despite a widely accepted view that earlier rice cultivation was initiated by broad casting the seed on upland.

4.1.Two Types in Domestication of Cereal Crops

Rice cultivation has long been considered to have originated from seeding of annual types of wild rice somewhere in subtropics or tropics. Some authors considered rice might be domesticated as an upland crop in subtropical high land. Other scientists emphasized the implication of annual types which may have differentiated in a climate with alternation of dry and wet season.

They considered a possibility that rice was domesticated in such a climate in the vast range from northern part of Southeast Asia to South China[2]. Such ideas were basically translated from the widely accepted concept about the origin of cereal crops in 'Fertile Crescent' ranging between Mesopotamia and Nile delta, where primitive human had learned to collect grain from plants, scattered the seed nearby their settlement, and gave a basis for primitive agriculture.

In the Mediterranean climate wild cereal plants germinate in early autumn, thrive in humid or rainy season from autumn to winter, and produce a large amount of seed after flowering in early summer. The plants survive hot dry spells in summer by the form of seed which contains adequate carbohydrates as resource. There, far before farming they had acquired the growth habit to bear a large grain on relatively small grass. This is explanation by Diamond[3]for the reason why annual cereal crops were domesticated in the 'Fertile Crescent'. Thus, in the domestication of cereals in the Mediterranean climate, a sustained selection of productive plants would not have been an indispensable preparatory step, because the plant had been pre-adapted to bear heavy grains. On a basis of experimental harvesting from wild cereals, collecting of the grain is supposed to have provided an adequate amount of food for primitive human.

In contrast to the above-mentioned regions there was a unique background for rise of agriculture in Southeast Asia. While some leading scientists are preoccupied by the idea that domestication of cereals was initiated by seeding annual types, as described in a standard text book[4], Sauer[5] was among another group of scientists who recognized the importance of vegetative propagation as a step for primitive agriculture in Southeast Asia, where even today major crops like as sugar cane and banana are propagated via vegetative parts. Sauer indicated the unique position of Southeast Asia, stating 'No other area is equally well situated or equally well furnished for the rise of a fishing-farming culture', and 'this is the world's major center of planting techniques and of amelioration of plants by vegetative reproduction'.

Sauer considered that man learned to plant before he grew crops by seeding, and called our attention to planting and plant selection, by stating that 'the creative curiosity of man in the monsoon lands has operated strongly with asexual plant reproduction, in which, a piece of a plant is set into the ground to make a new plant'. He cited a variety of vegetative propagation, i.e., by an offset or sprout from the parent, by dividing a root stock, by a stem cutting, or by a piece of underground stem or root stock. Thus, an individual plant is divided and multiplied indefinitely. Here we may call this type of farming by a term, vegeculture. The other characteristic feature is the use of wide range of edible plants or vegetable plants ranging from wild to cultivated ones. Today, we see many kinds of wild plants or weed soled as vegetables in markets in the region. He considered that cereal crops were not originated in the agriculture of this region but introduced from the agriculture in which cultivation by plow is dominant.

4.2. Domestication of Two Cereals Originated in Southeast Asia

In discussing the origin of primitive agriculture, we must consider the tremendous difficulty for primitive human to raise the idea of cultivation that may take place of hunting and collecting wild edible plants. With a sharp insight into this point, Sauer came to the idea that propagation with parts of plants may have preceded to seeding and harvesting of seed from cereal crops. In the humid tropics or subtropics, where the dominant agriculture is characterized by vegeculture, two cereal crops were unique to the region, Job's tears and rice.

Job's Tears

Utilization of Job's tears (*Coix lacryma-jobi*) is suggestive of a primitive way of utilizing the plant prior to its use as a food crop. Its edible type (*Coix ma-yuen* Roman) is usually utilized like tea by decocting the grain and sipping it. Domestication of Job's tears was not likely initiated by seeding it for food, because the grain is covered by a very hard glossy layer like glassy shell, although the hard shelled one are reported to be used as food in rare cases[6]. The hard grain is still widely used for making necklace and bracelet in villages in highland of Southeast Asia. Also, roots, stems and leaves of the plants are used for medicine in Thailand, Laos and Vietnam. The wild type must have been widely distributed by women for making accessories in ancient time. In somewhere in the wide range of distribution, they happened to find a mutant which lacked the hard shell. The mutant has only a thin layer and contained perhaps more starch than the wild type. A single mutation may have converted the wild type into the edible Job's tears with soft-skinned grain, because the hard-shell type and thin skin type are proved to segregate at the rate of 3:1 in a test of F_2 generation after hybridizing the two types[7]. The result implies that the soft-skinned is controlled by a single dominant gene.

Initial Domestication of Rice

Asian wild rice is basically perennial, has very small panicles, and does not seem to be adapted to seeding in thriving weed in a warm and humid land. The plant allocates most of synthesized carbohydrate to vegetative parts, i.e., creeping long stems, leaves for growth and to basal stocks for re-growth in next season. Therefore, even if a woman attempted to seed the grain to a small land, she may not have obtained an adequate amount of grain to feed her family, as women might have taken care of a small garden near their housing while raising their children in primitive society. Such busy women may not be so stupid to spend her energy for obtaining only few grains after long sustained works for weeding and protecting the plant against bird and beast.

It is likely that primitive human may have used a small amount of grain of wild rice only for medicine or supplement like tea, propagating it by emerging sprouts in shallow marsh around his housing every early summer. A rich tradition of such ways of plant utilization is still widely found in South China to Indochina peninsula. The habit of sipping tea is perhaps developed in the similar region more for medicinal or tasting use rather than for food. The naming for one of wild species of rice,*Oryza officinalis*, suggests that some of rice species had been utilized for medicinal use, because the word 'officinalis' implies medicinal use. In fact, Indian scientists report some kinds of wild rice are today collected for medicinal use.

4.3. Vegetative Propagation Led Wild Rice into Cultivated One

Selection or improvement of a plant for more productive one must be an indispensable process for the plant to be domesticated, because most of wild cereal plants are far from bearing attractive edible parts except some cereals in the Mediterranean Climate as mentioned before. When a man attempted to take any of them and put them into domestication, only such a plant may be useful, that could have been converted into more productive through its responsiveness to a chain of unconscious improvements. Only a few kinds of plants having an extraordinary responsiveness to human interference must transformed themselves and were domesticated out of many wild plants which primitive human may have tried to grow in his garden.

Genetic Potential of Propagated Plant Via Clone

Many scientists who supposed that primitive farmers might simply have seeded wild cereals in their farm missed a point of variability. If any seed is self-fertilized within a plant, genetic fixation in their progeny will be attained within a few generations. Thus, the original poor wild type cannot show any positive response to human care, except a rare case where a useful mutation takes place.

In contrast to seed-propagation which leads to quick fixation, propagated plants via clone can maintain genetic variability, because they are genetically heterozygote. It is well-known that any seeded plants from an elite fruit tree cannot produce the parental type, because there is a high frequency of genetic recombination in the formation of progeny seed. As understandable from this case, any clone of plant contains a high level of potential to produce diverse genotypes. This principle is greatly significant for primitive farmers who attempted to propagate a set of clones of wild rice to obtain a handful grain from their tiny farm. They were able to obtain a high level of variation among some seed-derived plants from the clones of divided stocks. Such a population may have produced a pool of variation for unconscious selection by human interference. Then, the ancient farmer might be able to choose early maturing types or those with lesser degree of seed dormancy and shattering of seed from panicle.

Primitive Nursery of Rice Via Clone

On the basis discussed above,the authors believe that ancient rice farmers may not have started their rice cultivation simply by seeding, instead, in every spring they had divided sprouting clones from perennial stocks of the semi-wild type. Thanks to detailed survey of wild rice throughout the Chinese continent for 1970-1980[8], it is now clearly confirmed that a set of clones of wild rice exist in shallow swamps in Jiangxi Province at the north latitude of 35˚, where the minimum air temperature in winter goes down below -5^{o}C (**Figure 1**). During winter the rice plants survive the cold by basal stocks with dormant buds which sprout in early spring. Thus, ancient farmers may have divided the sprouting buds and spread them by transplanting them into shallow marsh. Obviously, we see that such a primitive manner of rice cultivation did include the essential parts of rice farming, i.e., nursery bed, transplanting and submerged-soil-based rice cultivation.

Figure 1: Wild rice in Jiangxi Province, China, a type growing in the highest latitude of 35˚.

5. How has a Cereal Crop Been Incorporated into Rise of Agriculture in the Humid Climate?Background of the Primitive Agriculture

For understanding the background of primitive rice cultivation, it is important to see that the propagation of plant via vegetative parts is a prevalent form of cultivation in humid tropics and subtropics. That way of cultivation has been extended to humid temperate zones in south to mid China, together with taro, lotus, bamboo and so on. One can imagine how it is difficult to plow a land and to make seeding in rainy days or in mid of Monsoon season from spring to autumn in Southeast Asia and South China. Propagation of root crops like taro, lotus, sugar cane and banana can better be practiced in rainy or cloudy days. Mostly, divided parts of edible plant are inserted into shallow marsh, which sometimes are very small near or within housing area even today and must have been so in the day of primitive agriculture. As Sauer stated, plants of different kinds, growth habits, and of uses were assembled in the same cultivated patches, not fields but simple gardens. We are still able to see such small marsh like gardens in villages in Yun Nan Province, China and in Laos (**Figure 2**).

Figure 2: Taro grown in a backyard garden in Jinhong, Yunnan Province, China.

From the point of nutritional balance, fish culture in the marsh land must have preceded any cultivation of plants in ancient human life in the humid regions and constituted an essential part of the entire nutrition for human life. Thus, from the time of primitive rice cultivation, rice and fish culture shared the same environmental conditions. As documented in the history of ancient China, development of irrigation system and accompanying fish culture have provided a unique basis for civilization in warm and moist areas.

Advance from Clonal Propagation to Seeding

It was a miracle that the wild rice responded to human handling and converted itself into a productive cereal crop. That is conceivable origin of submerged-soil-based rice cultivation which at last realized a unique cereal production with a very high level of yield and ecological stability.

Transfer from the primitive nursery to true nursery with seeding may have included some intermediate steps. The concept of seeding was not essential for primitive rice cultivation as explained by its origin from dividing sprouting stocks to propagating it in tiny fields. A bunch of panicles instead of seed grain seem to have been used for starting nursery before seeding became routine manner. This assumption is supported by a common practice of placing a set of panicles on a nursery bed in the Mountain Province in the Philippines. Ancient farmers might have seen emerging seedling from panicles in field. It is an easier practice for the farmers to place panicle on nursery bed instead of seeding on it, because they don't need to remove seed from panicles.

Apparently, the transfer from panicle placing to seeding is a break through, by doing so rice cultivation became possible in such a region where no stand of wild rice existed. Rice cultivation with the seeding on nursery beds was extended to northern regions.

6. Advantage of Submerged-Soil-Based Rice Cultivation

To a first glance, rice cultivation in submerged-soil-based plots may seem to be primitive way of agriculture, as farmers cannot easily move in such a field or marsh, pulling his foot out from mud at every step. But the cultivation in submerged-soil-based plots turned out to be a miraculous success in terms of a series of agronomic advantage, once adequate water for submerging field is secured. Such advantages are particularly interesting in the sense that no primitive human might have foreseen the development of submerged-soil-based rice cultivation into the entire East Asia.

First, the submerged-soil-based plots by surrounding levees is free of soil erosion through wind or heavy rain. Not only it is free of such erosion but it is enriched by sedimentation of fertile silt carried by irrigation water. In contrast, if one sees upland farms, an abrupt rainfall sheds fertile surface soil away so often that farms tend to be deteriorated every cropping season. It should be also pointed out that terraces of rice cultivation plots are functioning as a temporary reservoir of water by retaining abrupt rainfall.

Second, in the process of land preparation prior to transplanting, any plant residue from preceding cropping is incorporated into submerged soil and decomposed by anaerobic microbes. In this way, germs or fungi carried over via crop residue are perished. Therefore, continuous cropping of rice is possible without any negative effect of preceding cropping. Without any need for shifting, farmers are encouraged to pay elaborated care to their farm by maintaining canals and levees.

Third, soil fertility is to be kept better by submerged plots, because nitrogen compounds contained in residue of plant and small organism in field are slowly decomposed under submergence due to water as barrier for aerial oxygen. Further, some minerals though in small quantity are supplied from irrigation water. Particularly, potassium required to grow rice can be supplied by irrigation water in many areas in Southeast Asia. The advantages mentioned above have collectively attained the unique and highly productive cereal industry in the world. Because rice can be consecutively planted in a plot, farmers are able to obtain a high level of yield in a limited size of farm, by intensively taking care of a small farm.

Fourth, some nutritional elements like phosphorus, which are often less available to plant due to its fixation to iron or calcium in upland soil, become available in submerged-soil. In other words, submergence of soil changes such nutritional elements into a water-solved state, and to more available forms to plants. Some long-term tests of fertilizer application clearly showed this merit. Without phosphorus application yield levels of upland crops were reduced to a half of the attainable at an adequate fertilizer level, but without phosphorus application the yield level of rice was reduced by 20 % or less under submerged-soil (**Figure 3**).

Finally, fishing as an indirect but significant advantage of sub-

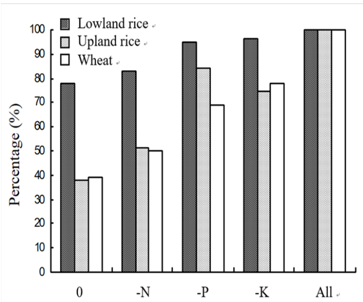

Figure 3 : Relative reduction of yield in the trials without fertilizer(0), no nitrogen(-N), no phosphorus (-P) and no potassium(-K) against the level under complete fertilizer application (All) [9] (Okajima,1976). (The left, center and right column denote lowland rice, upland rice and wheat, respectively. Summarized from a large number of trials).

merged-soil-based cultivation should not be missed here. Fish culture is an essential part of rice and fish system in the sense that they constitute a balanced nutrition. Improvement of irrigation canals and expansion of submerged-soil-based rice terraces can ensure various fishes for their life routes from deep marsh in winter to shallow water where they spawn egg in spring. Therefore, the effort to secure submerged-soil-based rice farms is raising fishes by providing them with a set of good habitats. The effort to ensure life routes of fishes preserved also environment for many other insects and amphibian species which need the water-related habitats. Thus, the way of rice cultivation provided bases for biological diversity, which in return prevented the dominant rice vegetation from potential outbreak of infectious organism.

7. Archeological Evidences for the Initial Cultivation in Submerged-Soil-Based Rice Cultivation

Dongting LakeRegion

Considering the merit of submerged-soil-based rice cultivation discussed above, rice must have been planted in shallow marshes from its primitive cultivation. Even today, we still see tiny marsh-like plots, where taro is cultivated in backyard garden in villages from Southern Yunnan to Laos, as shown (Figure 2).

In the mid of Yangtze River basin, China many plains with networks of rivers and hills are surrounding the vastDongting Lake. In this region, in Li County, Hunan Province, one of the earliest archeological site for submerged-soil-based rice cultivation was found and named 'Remains of Chengtou Mountain' , which was in the mid of neo-lithic age and dated back to BC7000~ BC5000. Detailed explanations were provided by Zhang Chi [10] who have painstakingly edited many original archeological reports into a comprehensive book. One of the archeological sites is cited in (**Figure 4**). According to Zhang, three lines of diches 田埂 with intervals of 2.5~5m and two plots planted to rice (水稻田) were found in the excavated area of 336 m^2 (Three rows of rice plots were visible in Figure 4). According to Zhang's interpretation the longest dich reached to 30m and the area of 'upland' was at least 1.2a. Despite the detailed explanation, there seems to be some interpretative errors in Zhang's explanation in page.50. He interpreted a Chinese word implying levee as ditch, and considered the plots were surrounded by ditches as upland plots. The word interpreted as ditch is levee in South China, according to the reference[11].

In Chinese	Pronunciation	Interpretation (Chinese)	English Word
水稻田	Shui Dao Tian		Plots planted to rice
丘 田	Qiu Tian		Upland
水 田	Shui Tian		Submerged plot
田 埂	Tian Geng	（普通话）溝	Ditch
		（南方方言）「塍」（畔）	Levee
水 坑	Shui Keng		Water hole

Figure 4: Excavated submerged-soil-based plots for rice cultivation, and interpretation of designated Chinese letters (Original from Zhang C. Prehistoric settlement pattern of the mid and lower Yangtze River basin.Beijing: Cultural Relics Press, 2003: pp. 50.)

Following such a widely accepted idea that rice cultivation was initiated by seeding on upland, Zhang explained the rice plots were cultivated by broad-casting of seed. He cited remains of erect stub and root of rice plants buried in soil as evidence for broad casting of seed. But it is true that any rice plant always attains vertical growth with vertical root regardless direct seeding or transplanting. The description that the excavated surface of ancient rice plots was flat and cracked also implies that there were submerged plots, as cracked flat surface of soil can only be seen after submergence of the soil and not in upland. He disregarded these points. In the Figure 4, a small water hole combined with ditches were described, which indicates elaborated structures to maintain water to the cultivation plot.

Excavated Earliest Rice Cultivation of BC 4000 in Jiangsu Province (Majiabang Culture).

One of the earliest cases of submerged-soil-based rice plots was found together with irrigation canals at Remains of Caoxiao Mountain, Jiang Su Province, which is dated back to BC 4000 in the **Majiabang Culture**. The remains of rice-cultivated plots were found at east and west sides of an ancient village cite. The rice-cultivation plots were connected to water pools or wells (**Figure 5**).

At the east site, 33 plots of rice-cultivation, three ditches and six water holes (wells) were found. The six water holes contained a large amount of silica which was characteristic for tissues of rice plants. Those water holes were interpreted as rice cultivation plots [**10**].

According to another detailed report on the same sites [**12**] these plots were constructed on a gentle slope so that each plot was very small. The size of the smallest one was only 0.9 m^2 and the largest one was 12.5 m^2 . The depth of shallow ditches was 0.2~0.5m which were arranged from Southwest to Northeast. In the west side of the village, there were artificially opened two large water pools, eleven plots of rice cultivation, three ditches and four wells. In the west side, all the rice cultivation plots were arranged along the water pool and some plots were connected to the water pool [**12**].

Another archeological site at Kunshan Pier in Jiangsu Province, 24 plots of rice cultivation were found with ditches and water reservoirs [**12**]. The shape of rice plots was round-rectangular or long-striped with the size of 1~16 m^2. Three ditches for drainage were connected to these plots. In addition, four irregularly shaped or round water reservoirs were found. Similarly, from the bottom of a lake in Luzheng district, Chenghu village,Wujiang city of Jiangsu Province, 20 rice cultivation plots were excavated with surrounding water reservoir and irrigation ditches, and water canals were connected to water inlets of rice cultivation plots [**12**].

In these reports of earlier rice cultivation plots, some water holes mentioned as reservoir are often described, while there were ditches or small canal to supply water into rice cultivation plots. Then a question may arise that what is the function of these hole like as shown in (**Figure 5**). To the present authors such holes seem to be nursery to preserve perennial stocks of rice in winter from which sprouting rice were divided for transplanting. At the bottom of the holes a large amount of rice-tissue-derived silica was found.

It should be emphasized here that the number of rice cultivation plots was calculated one by one. That is a strong evidence that the even earliest rice plots were flat and submerged with surrounding levees. If such initial rice cultivation was conducted on upland by broad casting seed, each of such upland plots cannot be separated and counted.

Ancient Village on the Basis of Rice Cultivation

One of striking findings in archeological research is the discovery of ancient rice farming village at Hemudu site near the capital of ancient kingdom of Yue, Kuaiji in Zhejiang Province, China. The site in a marshy topography along a river covers an area of 40000 m^2 with 4-meter thick cultural deposit and 4 superimposed layers. The carbon-14 dating after tree-ring correction is 5000-7000BP. The site was excavated two times in 1973 and 1977. The site is assumed to have been surrounded by dense forests and a vast expanse of lakes and lagoons which provided a good and favorable condition for the growth and production of various animals and plants.

In the process of exploiting the inexhaustible natural resources, the Hemudu inhabitants created a large primitive village which can be the prototype of those found today in Southern China. Together with remains of rice grains, there were over 170 bone spades made of scapula of water buffaloes. The spades are crucial material evidence to prove that rice agriculture at the site was conducted by spade-tillage.

8. Development of Irrigation Technology in Association with Rice Cultivation

Throughout the expansion of primitive rice cultivation by dividing and transplanting of sprouting stocks into small ‘rice plots’, it was essential to keep water over the surface of soil. Thus, from the day of primitive rice cultivation, farmers had to do every effort to keep their farm submerged. Meanwhile farmers may have located a series of tiny plots according to a gradient to supply water from one farm to another.

Although we are not able to see every developmental steps of irrigation system, some huge monumental constructions of canal and dam systems in South or Southwest frontiers of the QinDynasty (ca.200 BC) proves an accomplished technological achievement in hydrology and civil engineering in China (Figure 6). It is said today that some of the delicately calculated overflowing dams cannot be improved anymore even by modern scientists. Summarizing the historical development of rice cultivation, it is important to understand that the submerged-soil-based plot for rice is not such a farm as seen in upland farming but a designed construction or a set of facilities to which water is deliberately supplied from surrounding forests or rivers.

Figure 5: Remains of tiny marsh to which rice was planted in Jiangsu Province, China (4000 BC) [10]].

(Plate 8. In Chang shih: 2003).

Figure 6: Ancient overflow dam and canal constructed in Guangxi, China in BC221. Figure 6: Ancient overflow dam and canal constructed in Guangxi, China in BC221.

The above-mentioned development of submerged-soil-based rice cultivation and accompanied expansion of fish culture formulated a core of agrarian society in humid temperate regions in East Asia. Such characteristics of the society was recognized and depicted by the great historian, Sima Qian (ca.145-ca.86 BC) in China. He traveled through the great empire of Han Dynasty fromnorthern regions in the Yellow River basin to southern frontiers of the empire, and he was in a good position to comparatively review economic status of each region. The last part of his enormous work, *Records of the Grand Historian* (*Shiji*) was allocated to his observation of economic geography, in which he stated that in the southern regions nowhere are people in danger of hungry by planting rice and fishing but at the same time there is no one with infinite wealth. This view implies that in northern regions with the economy of upland farming and developed commercial and industrial activity there were families with infinite wealth together with those at the brink of hunger.

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