# Plants and people from the Early Neolithic to Shang periods in North China

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**An assemblage of charred plant remains collected from 26 sites in the Yiluo valley of North China as part of an archaeological survey spans the period from the sixth millennium to 1300 calibrated calendrical years (cal) B.C. The plant remains document a long sequence of crops, weeds, and other plants in the country. The results also demonstrate the effectiveness of sediment sampling as part of an archaeological survey. Ten accelerator mass spectrometer (AMS) radiocarbon dates on crop remains inform an assessment of the sequence of agricultural development in the region. Foxtail millet (*Setaria italica* subsp. *italica*) was grown during the Early Neolithic period and was the principal crop for at least four millennia. Broomcorn millet (*Panicum miliaceum*) was significantly less important throughout the sequence. Rice (*Oryza sativa*) was introduced by 3000 cal B.C. but apparently was not an important local crop. Wheat became a significant crop between 1600 and 1300 cal B.C. The weed flora diversified through time and were dominated by annual grasses, some of which were probably fodder for domesticated animals. The North China farming tradition that emphasized dry crops (millets, wheat, and legumes) with some rice appears to have been established at the latest by the Early Shang (Erligang; 1600–1300 B.C.) period.**

millet | rice | wheat | Yiluo | Yangshao

Recent paleoethnobotanical research in China is revealing the rich potential for understanding a heretofore poorly known food-production system (1). The poor state of knowledge is at odds with the fact that North China is one of the major regions where agriculture began and is home to one of the longest-lasting, sustained agricultural systems in the world. A patchwork of analyses from around the country confirms a north–south division in agricultural development and that the earliest domesticated plants so far recovered in both regions appear to date between 8000 and 6000 calibrated years (cal) B.C. (1). However, the best plant-remains data for the most part are limited to the Late Neolithic period. Our paleoethnobotanical research is clarifying the process of agricultural development in China by contributing a diachronic and regional perspective to a single region, the Yiluo valley in western Henan province. The valley forms part of the Huanghe (Yellow River) basin in North China and is home to one of the world's earliest primary state-level societies where the Xia, Shang, and Zhou Dynasties developed (2) (Fig. 1). The initial steps in understanding agricultural development in any region require establishing a chronology of directly dated crop remains from defined contexts. This study reports data from China by using crop remains collected during an extensive archaeological survey from 1998 through 2002. Samples are from the Early Neolithic (Peiligang) to the Early Shang (Erligang) periods (for project details, see ref. 3). Direct accelerator mass spectrometer (AMS) radiocarbon dates of crop remains test the cultural associations of the crops and help calibrate the regional chronology (Fig. 2). The project also demonstrates the effectiveness of limited soil sampling as a component of archaeological surveys to facilitate discovery of general patterns of plant use through time. Although this strategy meant taking a limited number of samples from each site, nearly 31,000 seeds from 55 samples were recovered from the 26 sites.

## Results

**Culture History.** A continuous sequence of socioeconomic development, increasing specialization and increasing complexity, began during the Early Neolithic in the Huanghe drainage basin. Details are provided in supporting information (SI) *Text*. Agriculture facilitated these developments. Early Neolithic cultures in North China include Xinglongwa in the north, Peiligang in the central Huanghe basin, Laoguantai in the west (6000–5000 B.C.), and Houli-Beixin (6000?-4300 B.C.) to the east in Shandong province. Technology in all of these cultures includes pottery and a variety of stone tools, including manos and metates. The first records of millets and domesticated animals in North China are from these cultures. However, nearly all Early Neolithic plant remains have been collected by hand rather than systematically collected by flotation. Flotation of sediment from the Houli culture Yuezhuang site and the Xinglongwa culture Xinglonggou site are two notable exceptions (4, 5). Details are summarized in *SI Text*. Broomcorn millet (*Panicum miliaceum*) appears to have been the main crop at both sites, and foxtail millet (*Setaria italica* subsp. *italica*) is barely present. This suggests that broomcorn millet was more significant than foxtail millet in the early stages of food production in North China. In the Yiluo region, Late Peiligang sites are quite small and are the first recorded Neolithic occupations there (Fig. 1).

The Middle Neolithic of the Huanghe basin is represented by the Yangshao culture (5000–2800 B.C.), perhaps best known from the excavations at the Banpo site in the late 1950s. Its contemporaries include the Dawenkou culture (4300–2600 B.C.) in Shandong province. Middle Neolithic people in the region raised domesticated animals and grew crops such as foxtail millet, broomcorn millet, and possibly hemp (*Cannabis sativa*) and canola (rapeseed, *Brassica rapa*). Sites appear to have been occupied for centuries if not longer, although there is some debate regarding whether sites were moved regularly as a result of a shifting agriculture system (6).

The Late Neolithic in the region is synonymous with the Longshan culture, with its seven regional variants (7). Longshan is important because of the nascent characteristics that link it to the subsequent dynastic eras of the Xia, Shang, and Western Zhou. The complexity evident in the Late Longshan continues to develop in subsequent periods. After the late Neolithic is the Erlitou culture, named after the Erlitou site near the modern city of Luoyang. Erlitou covers an area of some 300 ha (8) and was the largest settlement in China at the time, *ca.* 1900–1500 B.C.

**Plant Remains.** The Yiluo samples yielded a minimum of 23 taxa that can be identified at least to the level of plant family (Table 1 and

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Abbreviations: AMS, accelerator mass spectrometer; cal, calibrated years; SNU, Seoul National University.

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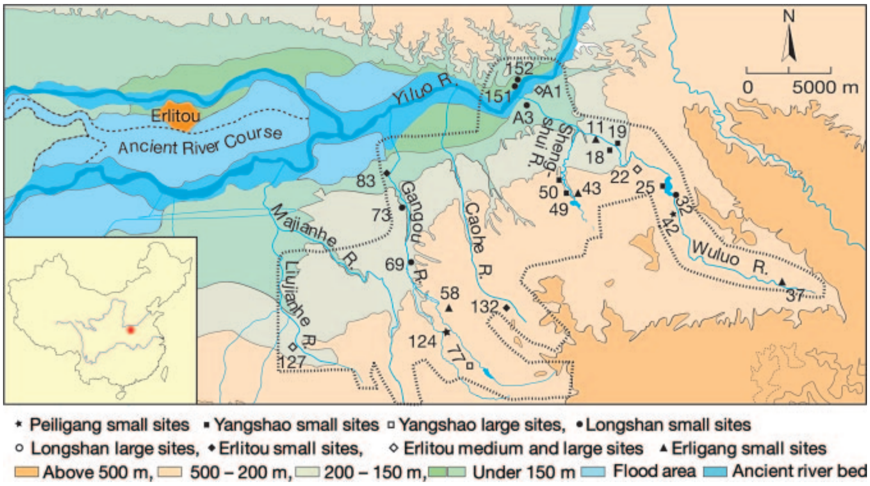


**Fig. 1.** The Yiluo valley survey area and sites from which flotation samples were taken. Site codes and names are listed in Table 1.

SI Table 2). Many types of unknown taxa are represented by small numbers each, and in some cases, the same unknown types are found in different samples. Other plant remains include grass-stem fragments, grass lemma/palea (chaff), as well as tuber and possible pod fragments in negligible quantities. Wood charcoal is in the light fractions at a density of ≈2.0 g/liter.

Four unambiguous crops are present in the samples, and two other plants have ambiguous status as cultigens (Table 1). Foxtail millet is the most common grain, whereas broomcorn millet ranks second throughout most of the sequence in the region, representing ≈2.5% of the millets (SI Fig. 7). In samples with >10 millet grains, none is >4% broomcorn millet. Despite its low representation, broomcorn millet is significantly more common in the Yiluo record than in the regions farther east such as Shandong (9) and the Korean Peninsula (10). Almost no broomcorn millet was recovered from Liangchengzhen, but the millet represents ≈8% of the grain at the extensively sampled Shantaisi site, located not far from the Yiluo valley (analysis in progress). This does not negate the hypothesis that the recent crop-distribution pattern was established by the Middle Neolithic in China. That is, foxtail millet was traditionally more common in the wetter eastern areas, and broomcorn millet was more common in the drier interior areas (9). Foxtail millet grains are typically spherical and sometimes popped because of charring. The earliest examples in our sample are slightly smaller than later millet on average, and the dorsal face is slightly flattened, a trait similar, but not identical, to green foxtail grass (*S. italica* ssp. *viridis*), the ancestor of the crop. Zhao (5) notes that the Early Neolithic broomcorn millet from Xinglongou has similar characteristics. Some small specimens among the Yiluo samples may be grains from immature fruit. Similar grains are common in the Longshan period Shantaisi and Liangchengzhen sites (9).

Rice (*Oryza sativa*; SI Figs. 8 and 9) is a crop native to South China; therefore, it either was grown as an introduced crop or was brought to the Yiluo valley by trade rather than grown there. It is relatively rare in the sequence (Table 1). Its earliest confirmed presence in North China is in the lower Huanghe Early Neolithic Houli culture (4). Rice is also a rare crop at the Longshan period Shantaisi site, but it is relatively common at the Longshan site of Liangchengzhen on the east coast (9). Residue analysis of pottery from Liangchengzhen indicates that rice was used for the preparation of a fermented beverage (11). There is no way to determine what type of rice is in the assemblage because measurements are not particularly diagnostic (SI Fig. 9). If rice was grown in the Yiluo region, we are unable to determine whether it was a wetland or dryland crop. No field remains have been found, nor are there any clear weed indicators of paddy fields such as *Echinochloa crus-gali* var. *oryizicola* (*E. oryzicola*) in the samples.

Bread wheat (*Triticum aestivum*) is found at two sites: Fengzhai NW and Tianposhuiku (Erligang contexts) (Table 1 and SI Figs. 10 and 11). It is an extremely small variety of bread wheat that is the only type documented in the archaeological record of East Asia until very late (10, 12, 13). An AMS date on wheat from Tianposhuiku is consistent with its Erligang context (Fig. 2). Historically, wheat has been a crucial winter crop in the Yiluo region. The historic subsistence pattern that used millets, rice, and wheat appears to date at least to the Erligang period in the Yiluo region,

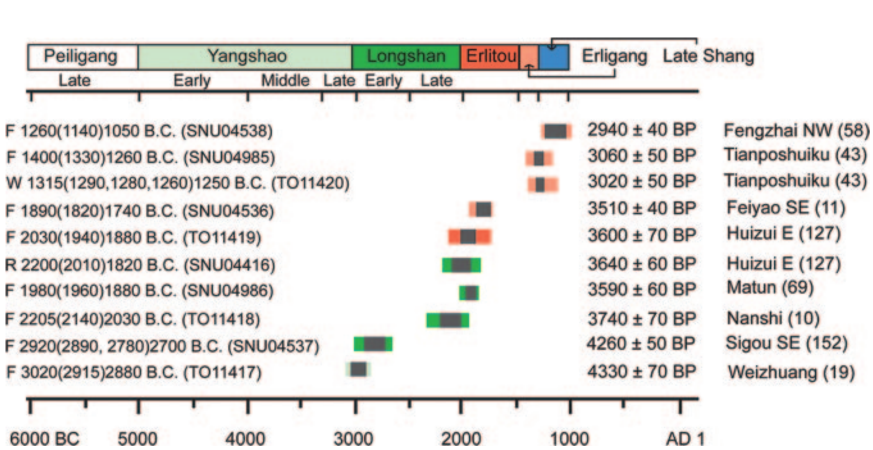


**Fig. 2.** Calibrated AMS dates and Yiluo valley chronology. White box, 2 $\sigma$ range; black box, 1 $\sigma$ range. SNU, Seoul National University; TO, Isotrace, University of Toronto; F, foxtail millet; R, rice; W, wheat.

**Table 1.Numbers of seeds by plant taxa in each site in the Yiluo survey area**

| | LP | | Late Yangshao | | | | | | | | EL | Late Longshan | | | | | | Erlitou | | | | | Erligang NW-58 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site name and code | Fudian E-124 | Wuluoxipo-42 | Wuluoshuiku W-25 | Weizhuang SW-18 | Weizhuang W-19 | Yulinzhuang-50 | Tianpocun-49 | Zhaocheng-77 | Nanwayao-156 | Fu-Xi-Tai | Sigou SE-152 | Matun-69 | Nanshi-A3 | Nianzizhuang NW-73 | Wuluo Nandian-32 | Sigou S-51 | Luokou NE-22 | Huilongwan E-83 | Xinhougou Yaochang E-132 | Huizui-127 | Luokou NE-22 | Shaochai-A1 | Feiyao SE-11 | Shangzhuang-37 | Tianposhuiku-43 | Fengzhal NW-58 |
| Period | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Soil L | 7 | 6 | 15 | 5 | 9 | 8 | 7 | 22 | 10 | 5 | 46 | 11 | 11 | 4 | 15 | 20 | 10 | 7 | 25 | 35 | 8 | 72 | 10 | 10 | 30 | 7 |
| Nut g | - | * | – | 0.1 | 0.4 | 0.1 | – | – | – | – | – | – | – | – | – | * | – | – | – | 0.5 | – | 0.2 | – | – | – | – |
| Cultigen | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Broomcorn millet | – | – | 1 | 1 | 3 | 1 | 1 | – | 7 | – | 60 | 42 | 233 | – | 4 | 5 | 4 | 1 | 48 | 13 | 6 | 39 | – | 3 | 34 | – |
| Foxtail millet | 2 | 2 | 50 | 40 | 152 | 37 | 25 | 83 | 1 | 3 | 3,290 | 482 | 8,957 | 11 | 310 | 319 | 326 | 438 | 888 | 482 | 259 | 1,924 | 338 | 72 | 2,402 | 587 |
| Rice | – | – | – | – | – | – | – | * | – | – | – | – | – | – | – | – | – | – | – | 2 | 1 | 11 | – | 2 | 5 | – |
| Wheat | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 172 | 92 |
| Cultigen | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Soybean | – | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – | – | – | – | – | 2 | 1 | 11 | – | 2 | 9 | – |
| Beefsteak plant | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 2 | – |
| Weeds | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Foxtail grass | – | 2 | 13 | 7 | 14 | 7 | 2 | 11 | – | 1 | 147 | 33 | 291 | 2 | 55 | 34 | 119 | 24 | 225 | 92 | 69 | 451 | 22 | 18 | 345 | 162 |
| Panic, mannagrass | – | 1 | – | – | – | 5 | 1 | – | 1 | – | 11 | 5 | 2 | – | 17 | 2 | 19 | – | 11 | 12 | 1 | 27 | 10 | 12 | 79 | 7 |
| Paniceae | – | – | 3 | – | 54 | 3 | 13 | 10 | – | 5 | 466 | 37 | 214 | – | 179 | 49 | 163 | 30 | 577 | 163 | 200 | 837 | 38 | 16 | 2,315 | 121 |
| Wild bean | – | – | – | – | 2 | – | – | 1 | – | – | 2 | 2 | – | – | – | – | – | – | – | 6 | – | 1 | 9 | – | 9 | – |
| Sedge | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – | – | 1 | – |
| Chenopod | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 9 | – | 11 | – | 20 | 13 | 2 | 115 | 2 | – | 76 | 11 |
| Knotweed | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – | – | – | – | 1 | – |
| Miniature beefsteak plant | – | – | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – | – | – | – | – | – | 1 | – | – | – | – |
| Wild mustard | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – |
| Night-shade | – | – | – | – | – | – | – | – | – | – | 36 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Spurge, borage | – | – | – | – | 1 | – | – | – | – | – | 7 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Fruit | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bramble | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 2 | – |
| Plum | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1 | – |
| Rosaceae or others | – | – | – | – | – | – | – | – | – | – | – | 5 | – | – | – | – | – | 1 | 2 | – | – | 1 | 2 | – | 3 | – |
| Unknown | – | – | – | – | 12 | 5 | 1 | 3 | – | 1 | 15 | 7 | 7 | – | 5 | 1 | 5 | 3 | 11 | 5 | 3 | 36 | 6 | 1 | 35 | 6 |
| Total *n* | 2 | 5 | 67 | 49 | 238 | 57 | 43 | 108 | 9 | 10 | 4,035 | 614 | 9,705 | 14 | 579 | 410 | 648 | 497 | 1,782 | 790 | 533 | 3,455 | 427 | 126 | 5,492 | 986 |
| Density | * | * | 4 | 10 | 26 | 7 | 6 | 5 | 1 | 2 | 89 | 56 | 924 | 4 | 39 | 20 | 65 | 71 | 71 | 23 | 67 | 48 | 43 | 13 | 185 | 141 |

In the category of site sizes, ''S'' and ''L'' stand for small and large, respectively. ''LP'' and ''EL'' stand for Late Peiligang and Early Longshan, respectively. Asterisks indicate weight $<0.1$ g, seed density $<1$ per liter, or seed presence. All densities and weights are rounded.

although it appears to be developing elsewhere in North China by the Longshan period (9). Wheat is rare at Longshan sites such as Liangchengzhen in Shandong, so its absence from pre-Erligang survey samples in the Yiluo valley should not be given much significance. Additional details on the cultigens are provided in *SI Text*.

Soybean (*Glycine* sp.) is evidenced by 26 specimens from the Early Longshan to the Erligang periods (SI Fig. 12). These specimens are significantly smaller than the unquestionable domesticated specimens from the Early Bronze Age (Mumun) sites in Korea that date to 1400–1000 cal B.C. (10). The soybeans from the Erlitou period (*ca.* 1900–1500 B.C.) Zaojiaoshu site are reported to be intermediate between wild (*Glycine soya*) and cultigen (*Glycine max*) on the basis of seed size and thus are classified as the cultigen (14). However, the size difference between the wild and archaeological specimens is insignificant in our view. Soybean seeds have been reported from nearly 30 other sites in China in contexts dating from 7000 B.C. to A.D. 220 (none are AMS-dated). Wild soybean grows throughout north-central China (15). Although seed size can distinguish domesticated from wild soybean in collections postdating 1000 B.C., size should not be the sole distinguishing trait of domesticated soybean (9). Small seeds could be from purposefully managed populations, but they may also be wild. Even if they are wild, their representation in nearly all Chinese sites at which flotation has been conducted suggests that they were a component of anthropogenic plant communities and people exploited them. The Xiaxiaozheng and Shijing texts mention soybean in the middle Huanghe from possibly as early as the Xia Dynasty (*ca.* 2100–1600 B.C.) and refer to soybean as a crop during the Zhou period (*ca.* 1026–226 B.C.) (16), so the crop has a deep history in the region. Nevertheless, we prefer not to classify the Yiluo soybean as either wild or domesticated. Several other types of legumes, all wild, are

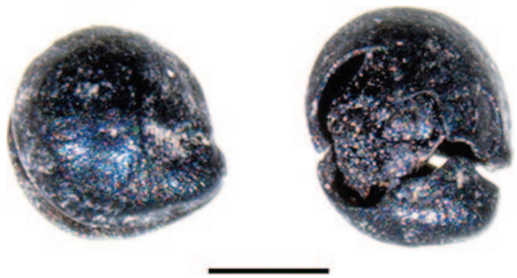

**Fig. 3.** *Chenopodium* from the Late Longshan Loukou NE site. (Scale bar, 1 mm.)

found in our samples. They are similar to Korean clover (*Kummerowia* sp.), sweet clover (*Melilotus* sp.), or lespedeza (*Lespedeza* sp.). They are common in dry fields throughout East Asia and were used as field fertilizer in Northeast China in the early 20th century (17).

The most numerous weedy seeds are probably panicoid (Panicoidea but probably Paniceae) grasses (SI Fig. 13). Seeds in this group are difficult to specifically identify, but at least seven types are distinguishable on the basis of seed length-to-width ratios, overall shape, embryo size and shape, and the surface patterns of hulls attached to grains. Among these types are probable green foxtail (*S. italica* ssp. *viridis*) and panic grass (*Panicum* sp.). One resembles wild *Setaria* but is morphologically quite similar to foxtail millet except for being significantly smaller. Millet-tribe (Paniceae) seeds are found at least from the Late Yangshao period and later. Seeds of this type are thin ($<$0.6 mm) and round (equal length-to-width ratio).

Chenopod (or lambsquarter, *Chenopodium* sp.) is another common annual, weedy plant represented in the samples from the Late Yangshao period onward (Fig. 3). The variation in size and shape of chenopod seeds in our samples indicates that different species are represented. In particular, some seeds have truncated margins, typical of thin testa domesticated chenopod (*C. berlandieri*) in North America (18). Many of the specimens in the Yiluo samples have a distinct cellular pattern on the testa similar to the North American cultigen that is in the Cellulata subsection of *Chenopodium*, so it raises a critical question of the domesticability of this Asian chenopod. Chenopod grows well in disturbed areas and dry fields and is still used in China today as a source of greens and starchy grain. One species, *Chenopodium giganteum*, has apparently been "long cultivated in China" (19). Indeed, highland indigenous people in Taiwan intermixed a chenopod, said to be *Chenopodium album* [note that *C. giganteum* is described as being a "cultivar of the *C. album* aggregate" (19)] as a crop in millet fields for starchy food (20). Additional details on the weeds are provided in *SI Text*.

The 10 AMS dates are generally consistent with the artifact seriation, but three dates vary slightly from expectations (Fig. 2). The Feiyao NE date [SNU04536; Seoul National University (SNU)] of 1890–1740 cal B.C. is several centuries earlier than its expected 1600–1300 B.C. Shang period date, suggesting that there was an Erlitou occupation at Feiyao. One late Longshan date (SNU04537) is approximately a century younger than expected, but a similar date at Liangchengzhen suggests that Longshan ends somewhat later than currently thought. An overlap between the Late Longshan and Erlitou phase I is feasible because the AMS dates on crops from Matun and Huizui indicate that the gap between the two periods was short. One Erligang (Early Shang) foxtail millet sample from Fengzhai NW dates to Late Shang (SNU04538), also suggesting yet-unknown issues with the chronology or disturbance leading to contamination from a later period. It is also possible that the Erligang material culture lasted longer in the Yiluo region than in other areas such as Zhengzhou.

**Trends Through Time.** Two general patterns are noteworthy. First, charred seed density increases through time, particularly if outliers such as Nanshi, where a single rich deposit of millet was found, are excluded (Fig. 4). This pattern is consistent with intensifying agriculture and land use over time. Second, charred seed density is inversely related to site size for all periods combined in the region (Fig. 5). This also holds true for each of the three periods for which sites of varying size have been found (SI Fig. 14). The crop remains primarily influence this pattern. Reasons for this trend are unclear. The small sites may represent mainly residential farming settlements, whereas larger sites have a range of functions, such as administration and craft specialization, with less emphasis on domestic activities that bring charred grains into the archaeological record. More extensive sampling at the larger sites should help resolve this issue.

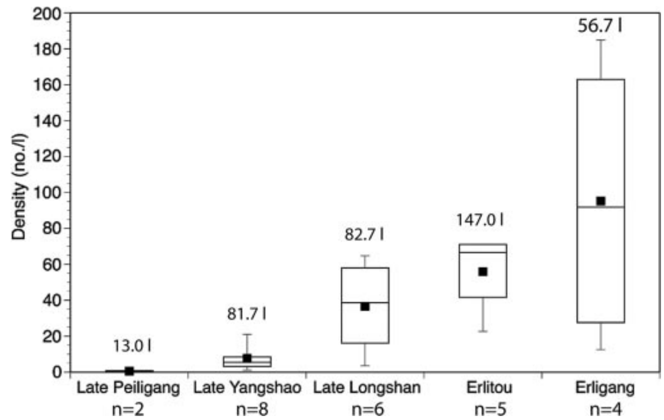


**Fig. 4.** Box plot of charred seed density by period. Two outliers have been removed: the single Early Longshan sample and the Late Longshan Nanshi site sample. *n*, number of sites; the number above the box is the total sediment volume sampled. The lines at the top and bottom are the 10th and 90th percentiles, the box indicates the 25th and 75th percentiles, the line through the box is the median, and the small box is the mean.

**Early Neolithic.** Peiligang sites here are small, and cultural deposits are thin, so their representation in our sample is low. Nevertheless, foxtail millet is part of the plant assemblage at Wuluoxipo and Fudian E, in contrast to the Early Neolithic occupations at Xinglonggou in Inner Mongolia and Yuezhuang in Shandong, where broomcorn millet predominates. Weeds are represented only at Wuluoxipo by probable green foxtail grass. Both broomcorn and foxtail millet are reported from the Peiligang site (6), so the absence of broomcorn millet from the small sample in the Yiluo valley late Peiligang is not necessarily evidence of its absence. The two

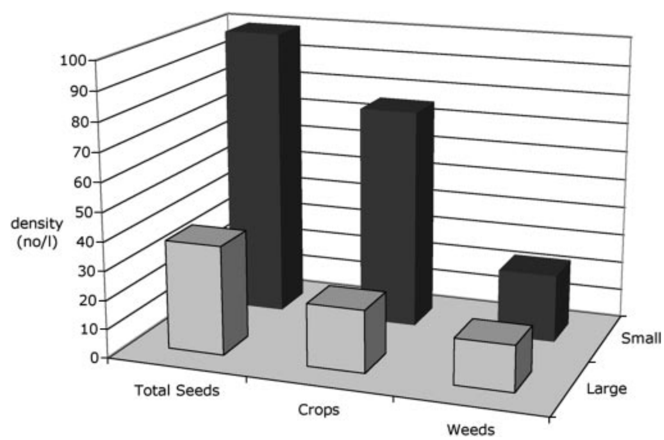


**Fig. 5.** Density of crop and weed seeds by site size.

flotation samples, because they contain millet and annual weeds, are qualitatively similar to the rest of the Yiluo survey samples, although they are among the lowest in density of all of the samples. The low density is suggestive of less-intensive food production, but this suggestion needs to be tested by more comprehensive sampling.

**Middle Neolithic.** Millets are the main crop remains during the Yiluo valley Late Yangshao. Weedy annuals are also quite common. Seed densities are higher at Late Yangshao sites than in the Early Neolithic (Fig. 3), suggesting a greater intensity of crop production and land disturbance by 3500–3000 B.C. Rice phytoliths have been identified at the Yulinzhuang site, situated on the tableland near the Shengshui River (3). Charred rice is in samples that are part of the ongoing analysis of samples from the excavation phase of the Zhaocheng site (Table 1). Subsistence may have been enhanced with the introduction of rice either as a trade item or as a locally grown crop. A possible soybean is in the Zhaocheng sample, but the plant appears to have no more significance there than at other sites in the region. Climatic amelioration and fertile, stable lowlands probably contributed to the success of intensifying agricultural production with two types of millets and possibly rice and soybean being grown. By this time, a two-tiered settlement hierarchy had appeared in the region with the rise of the large center at Zhaocheng (2) in addition to a number of small sites. The other Late Yangshao occupations sampled are the comparatively small ones. The samples, one or two pits from each site, are far too few to provide a comprehensive assessment of hierarchical specialization here. In fact, the evidence for such specialization from the perspective of the plant remains is weak.

**Late Neolithic.** Foxtail millet is still the dominant crop during the Longshan. Broomcorn millet density is higher in both the Early and Late Longshan period compared with other periods. Three sites have relatively dense representation of this millet, the highest for all sampled periods (Table 1). Rice is present at Huizui, and an AMS date on the rice (SNU04416) confirms its Late Longshan association in the Yiluo region (Fig. 2). Rice phytoliths have been found in pit samples at Nanshi and Luokou NE, but charred grains have not been found at either location (3). The majority of weedy grasses appear to be millet-tribe grasses (Paniceae) and exhibit far greater morphological variation than do the grasses from earlier periods. Some specimens may be Panicoideae rather than Paniceae. The mannagrass-type seeds are more common than in preceding periods, suggesting that, if the specimens are mannagrass, aquatic habitats are increasing in local significance. Anthropogenic habitats were far more extensive in the Longshan period, and people may have encouraged the grasses, possibly for fodder. Indeed, the Late Longshan Huizui occupation has significant evidence of livestock, primarily pig, but also cattle, sheep, and goat.

Population density, intensified intergroup conflict, and social stratification all increased during the Longshan in the Huanghe basin. The Late Longshan marked a significant increase in the number of sites compared with the preceding Early Longshan, when there was a significant drop in settlement numbers, perhaps representing a local depopulation. Hierarchically organized societies were well established by this time. Agricultural intensification evidenced by expansion of anthropogenic habitats and higher densities of crops correlates with these developments. Broad interregional interaction such as trade in the Yiluo region is evidenced for the first time. To what extent plants were traded is a question for further research. For example, rice may have been a product brought to the region from the south and east. Increasing land instability and climate deterioration during the third millennium B.C. did not deter agricultural intensification (9). The deterioration clearly did not go beyond the tolerances of productive agriculture.

**Erlitou Period.** The trends noted for the earlier periods continue. Rice is more prevalent in the samples, although it is still rare and restricted to the large sites, particularly Shaochai. The large Erlitou-period sites also have higher weed diversity, but this may well be a factor of the larger sample size from this period. Preliminary animal-bone analysis at Huizui indicates the continuing importance of livestock. Pigs are dominant, followed by cattle, sheep/goats, and dogs. Many of the weeds are potential animal fodder as they may have been earlier in the valley. Stable isotope analyses at the Yangshao period Xipo site in western Henan provide evidence that pigs and dogs consumed substantial quantities of $C_4$ plants, probably domesticated millet and green foxtail grass (21). Settlement number and size increased significantly during the Erlitou period, and the first major urban center emerged at the Erlitou site (3). Settlement nucleation appears in the survey area for the first time. Shaochai is a large regional administration center, subsidiary to Erlitou (3). The rest of the settlements dating to this period consist of large, medium, and small sites. Small sites have no evidence of craft specialization (2), so they were probably agricultural villages.

**Erligang (Early Shang) Period.** Erligang samples are not as numerous as those from the preceding Erlitou period because of a significant reduction in population in the Yiluo valley. Most Erligang period sites are small because the primary urban center moved from Erlitou to Yanshi and subsequently ≈60 km east to Zhengzhou (2). Nevertheless, four sites have substantial plant remains. Foxtail millet still outnumbers other crops, but wheat has the second-highest representation next to foxtail millet at this time (Table 1). The Erligang association of wheat is confirmed by an AMS date (Fig. 2). Beefsteak plant, a potential domesticate for seasoning, oil, and possibly leafy greens, first appears in the flotation record at this time (SI Fig. 15). Rice constitutes a negligible proportion of the grain at the Shangzhuang and Tianposhuiku sites.

## Discussion

Conducting flotation during the survey stage of this project has proven to be an effective heuristic device as well as a method for developing basic knowledge of subsistence through time in a narrowly defined region, the Yiluo valley. Interpretations and limitations of the data must be contextualized in terms of sample size and type. In particular, plants that people rarely used are likely not represented in the flotation samples, so, for example, the initial appearance of introduced crops such as wheat and rice may not be resolvable yet. Two crops, hemp (*C. sativa*) and canola or rapeseed (*B. rapa*) reported from a few Neolithic sites in North China have not been found in the Yiluo sequence. Foxtail millet was an important crop, whereas broomcorn millet was a minor, secondary crop throughout the sequence. Broomcorn millet was probably an important insurance food in case of drought. We need to assess

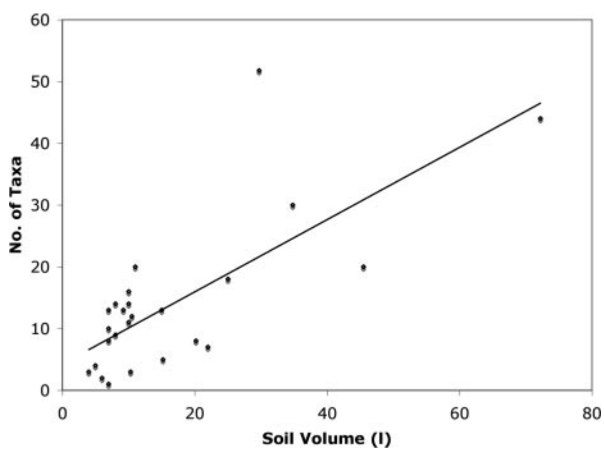


**Fig. 6.** Chart of number of plant taxa in each site plotted against soil-sample volume.

whether the Early Neolithic predominance of broomcorn over foxtail millet at Xinglonggou and Yuezhuang *ca.* 6000 cal B.C. is a regional phenomenon or whether broomcorn millet was domesticated earlier than foxtail millet. No occupations contemporary with these sites are known in the Yiluo valley. However, we suspect that the predominance of foxtail millet relative to broomcorn millet was established by the Late Peiligang/Early Yangshao. Rice was not domesticated in the Huanghe valley but was apparently used in the Yiluo region by Late Yangshao times as evidenced at Zhaocheng. Rice has occasionally been reported from other Yangshao contexts in North China, but none of these specimens has been AMS-dated. Its Yangshao association is feasible because it was as far north as Yuezhuang in Shandong by 6000–5800 cal B.C. AMS dates on rice clearly associate the crop with Longshan occupations at both Huizui in this study and the Liangchengzhen site in Shandong (9). If rice was a valuable commodity, it may have been consumed primarily by the elite lineages living at the largest towns that so far are the only sites with rice in the Yiluo region. However, large sites with rice are situated in the lowlands close to wetlands where rice could have been grown productively, so rice may have been a resource available mainly in these locales. More extensive sampling will help answer such questions related to the distribution and importance of rice in the region.

Wheat, the only crop in the Yiluo samples not native to East Asia, appears during the Erligang (Early Shang) period and was probably a significant crop by then. It is a rare component of Longshan period crop assemblages in Shandong (9) and elsewhere, so we surmise that it was grown in the Yiluo region during the Longshan period as well. More sampling should resolve this issue. Soybean is also a minor component of the Yiluo plant remains from Longshan times onward. Soybean domestication is an unresolved problem, with historic and archaeological data hinting that it was present from the Xia period (equivalent to the Erlitou period) and domesticated by the Zhou period. Where it was domesticated, or whether there were multiple domestications, are unanswered questions. Beefsteak plant, a potential cultigen, is rare but was also present by Erligang times. There is a limited record of this plant for the Late Neolithic period elsewhere (9). A wide range of annual weeds consistent with agricultural land disturbance and possibly fodder for domesticated animals is a component of all assemblages in the region.

Differences in site function and/or taphonomy are suggested by the contrast in seed densities between small and large sites. The highest seed densities are found at small sites, particularly from the Late Yangshao and later periods from which we have substantial samples. Crops are found in higher densities in small sites, but small Late Longshan and Erlitou sites have higher proportions and densities of crops than do larger sites. In contrast, all other artifact classes are common in the larger sites, indicating that craft production and administration occurred only in large settlements. Future research will examine this issue closely by broader sampling of a variety of contexts, particularly to test the possibility that some form of redistributive system that moved products from specialized production centers has a long history in the region. The archaeological record indicates, in fact, that social complexity was well developed by Late Yangshao times in the Yiluo valley (3). Site functions were apparently becoming specialized by the Late Yangshao; smaller settlements may have functioned mainly for agricultural production. Future research will assess whether crops were a component of the redistributive system. However, crops were probably produced as well as consumed at the large sites. Late Longshan agriculture at the large and complex Liangchengzhen and Shantaisi sites to the east have a wide variety of plant remains that vary in composition depending on their context. The same situation likely holds true in the Yiluo valley. The Yiluo plant remains are generally similar to those from both Shantaisi and Liangchengzhen with respect to both weeds and crops, suggesting that food production throughout North China shared many features. Another similarity lies in the limited evidence for the use of nuts and fleshy fruits. These and other questions pertaining to the relationship between plants and people in the Yiluo valley will be more adequately tested in the excavation phase of the project.

## Materials and Methods

The Yiluo team systematically surveyed 219 $km^2$ of alluvial plains and loess terraces (Fig. 1) (3). Sediment samples were collected from each site. Assemblages of plant remains tend to vary by context, so every reasonable effort was made to minimize the impact of contextual variation on this stage of the study by sampling the same type of context at each site. Sites are often buried 0.5–2 m below the surface, but pit features visible in vertical cuts of the loess terraces enabled the collection of samples from pits representing domestic contexts (SI Fig. 16). Pit fill normally represents secondary deposition (i.e., infill of general sediment and refuse resulting from a variety of activities by the site occupants). Thus, such samples are ideal for intersite comparisons of a general nature. Samples were collected from one to seven pits at each site depending on the number that was visible. To some extent, the soil volume collected is proportional to the number and complexity of sites in each period (Fig. 4). Individual sample volumes are proportional to the size of each pit and range from 3 to 14 liters of sediment. The relatively small sample from each site limits interpretations to discussions of fundamental similarities and differences among the assemblages. One variable that is affected by the sample size is the number of plant taxa recovered. The number of taxa in the samples exhibits a positive correlation with sample volume (Fig. 6), so small samples tend to contain fewer plant taxa and few or no examples of plants that are rare in the collection as a whole. Details of the flotation process are available elsewhere (22), and sample processing procedures are described in *SI Text*.

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