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The Neglected Plant Resources in Chinese Archaeobotany: Revealing Animals' Feed during the Pre-Qin Period Using the Flotation Results in Northern China

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Abstract: The functions of non-agricultural crops unearthed from archaeological sites mainly pertain to their usage as livestock feed. However, the studies of livestock feed have predominantly relied on qualitative analysis, which often lacks descriptive objectivity and relies heavily on subjective feelings and experiences. In this paper, we aim to address this gap by focusing on quantitative analysis, utilizing macro-plant remains from the data of seventy-five archaeological settlements and one archaeological investigation in northern China spanning the Neolithic Age to the Bronze Age, as well as stable isotope analyses of carbon and nitrogen. This research delves into various aspects, including the exploration of the plant resources and livestock farming and the categorization of feed types for cattle and pigs in captivity. By employing quantitative analysis, we can gain a more comprehensive and objective understanding of these subjects. This approach aligns with studies on ancient livestock management and feed diversity. In essence, the discussion of civilization development and social changes during the Pre-Qin period holds significant value when considering forage analysis, just as crop analysis has proven insightful. By focusing on the quantitative analysis of non-agricultural crops and their role as livestock feed, we can shed light on important aspects of ancient societies and their agricultural practices.

Keywords: livestock management; feed; charred plant remains; stable isotope analyses of carbon and nitrogen ($\delta^{13}C$ and $\delta^{15}N$)

Citation: Tang, L.; Yang, A.; Han, K. The Neglected Plant Resources in Chinese Archaeobotany: Revealing Animals' Feed during the Pre-Qin Period Using the Flotation Results in Northern China. *Agronomy* **2023**, *13*, 2191. https://doi.org/10.3390/agronomy13092191

Academic Editors: Xinyi Liu and Giedrė Motuzaitė Matuzevičiūtė

Received: 2 July 2023
Revised: 14 August 2023
Accepted: 16 August 2023
Published: 22 August 2023

1. Introduction

China has played a significant role in the early domestication of animals. During China's prehistoric period, specifically at the onset of the Holocene around 10,000–9000 B.P., both pigs and dogs were domesticated [1]. This places China as one of the original regions where these animals were first domesticated. While herbivores like sheep were domesticated in southwestern Asia [2], it was not until approximately 5000 B.P. that they were introduced to the Gansu and Qinghai areas of China [3–6]. Consequently, a package of domesticated animals from southwestern Asia gradually became widespread in central China. This package included sheep, cattle, and goats, which became equally significant as the indigenous poultry in the region [1].

Triticeae, a group of crops domesticated in southwestern Asia, was considered to have been introduced to central China along with other domesticated crops [7]. However, compared to herbivores, the widespread nature of wheat in central China, as well as in the Gansu and Qinghai regions, appears to be relatively delayed, dating back to approximately 4000 years ago [8]. While the dating of wheat remains from the Zhaojiazhuang site and the Dinggong site in the Shandong province has been definitively established as 4500–4200 ca.

B.P. [9,10], the majority of wheat remains excavated from the Longshan relics in the Central Plain do not correspond to prehistoric grains [11]. Instead, their ages obtained through carbon-14 dating technology often fall into the historic periods.

This situation challenges the previous belief that wheat should have been spread relatively widely in China since the Longshan period [12]. In other words, it is unlikely that feed plants like Triticeae crops and their companion weeds were used as feed for sheep and cattle during this time.

The field of China's archaeobotany has traditionally focused on crop analysis, with an emphasis on understanding the origins of agriculture, human dietary patterns, and agricultural production [11,13–16]. However, non-crop remains have received limited attention due to their scarcity and uneven distribution. Moreover, qualitative analyses of non-crop remains often lack objectivity as they rely on subjective opinions. Recent studies on weed utilization during the late Neolithic period in the Yulin area of Shaanxi have been limited in scope and have not provided a comprehensive understanding of the underlying human behaviors associated with weed utilization [17].

To address these gaps, this paper utilizes quantitative analyses based on the flotation results from the data of seventy-five archaeological settlements and one archaeological investigation during the Pre-Qin period in northern China (SI-1 in Supplementary file). By studying feed utilization and human behaviors over an extended period and a wider geographical area, this research aims to explore the role of feed as a fundamental resource in livestock farming. Feed is closely linked to feeding levels, meat supply, and even soil quality, making it a crucial aspect of agricultural productivity [18].

Chenopodiaceae and Leguminosae are not useless weeds, and this paper argues that they are relevant plant resources in livestock farming [17]. Therefore, it is important to conduct research on agriculture from the perspective of feed plants, just as it is conducted for crop plants.

Indeed, scholars have conducted a spatial analysis using isotope methods to examine the animal diet structure in various regions [19]. In contrast, this paper focuses on the exploration of plant resources and the categorization of feed types in livestock farming from a temporal perspective. By complementing existing spatial analyses with a temporal focus, this research contributes to a more nuanced understanding of livestock farming and its reliance on plant resources throughout history.

2. Materials and Methods

The study area encompasses the northern regions of China, as the plant remains were rarely found in the southern part due to unfavorable environmental conditions, particularly, acidic soil [20]. The northern area in this context includes the northern Qinling Mountains–Huaihe River region, certain sections of the southern portion of the Inner Mongolia plateau, the western Greater Khingan Mountains, the eastern part of the Qinghai–Tibet plateau, and a section of the eastern residual branch region of the Qinling Mountains [21] (see Figure 1a). The area exhibits diverse landforms, including plains, plateaus, and mountains.

A comprehensive analysis was conducted based on a partial dataset comprising the reports of 75 archaeological settlements and 1 archaeological investigation (SI-1 in Supplementary file). The archaeological sites examined in this study pertain to the Pre-Qin period, which encompasses both the Neolithic era and the Bronze Age. The paper focuses on six phases that align with chronological milestones: 11,000–7000 years Before Present (y. B.P.) (the first and second phases of Neolithic era, or the early–middle Neolithic Age), 7000–5000 y. B.P. (the third phase of Neolithic Age, or the late Neolithic Age), 5000–4000 y. B.P. (the last phase of Neolithic Age), 4000–3500 y. B.P. (Xia Dynasty), 3500–3000 y. B.P. (Shang Dynasty), and 3000–2300 y. B.P. (Zhou Dynasty) (as depicted in Figure 1a). These divisions were based on the classification of prehistoric and Bronze Age archaeology cultures in China. The study encompassed eight districts, namely Shaanxi, Inner Mongolia, Hebei, Henan, Gansu, Shandong, Shanxi, Qinghai, and Beijing, and unveiled the presence of over 60 families and 170 genera (SI-2,3 in Supplementary file).

Forage plays a critical role in linking crops, non-crops, cultivation, and livestock farming. In the research on forage, it is necessary to reference isotope analyses of animal skeletons as an effective method to investigate dietary structure, subsistence, and animal domestication [22–25]. It is important to note that the average $\delta^{13}C$ values of C3 plants during the Neolithic Age in China are around −25‰, while for C4 plants it is around −11‰. The contribution of CAM plants to the diet of prehistoric humans and animals in China is relatively limited; it is widely accepted that $\delta^{13}C$ values ranging from −18‰ to −7‰ in ancient bone collagen indicate a combination of C3 and C4 plants [22]. However, these findings demonstrate slight deviations from the applicable values and usage of modern terrestrial C3 and C4 plants [26].

There should exist a certain level of similarity between the types of forage plants used in prehistoric and modern eras. It is worth noting the significant impact of plants from the Americas on the Eurasian continent following the Columbian Exchange [27]. Consequently, when deducing the types of prehistoric forage plants based on modern counterparts, it is imperative to eliminate the influence of the Columbian Exchange.

The concept of ubiquity, or discovery probability, is incorporated in this study. Within the vast spatial expanse of northern China, ubiquity represents the frequency at which specific plant types are found across all the available settlements considered in this paper, presented as a percentage. A higher ubiquity value indicates a greater likelihood of plant utilization, highlighting their significant association with human activities.

Regarding the taxonomic categorization of plants, considering the non-uniform standards of identification in different reports, the data analysis is based on genera, which provides a more objective approach than species and offers a more in-depth analysis than family-level classification.

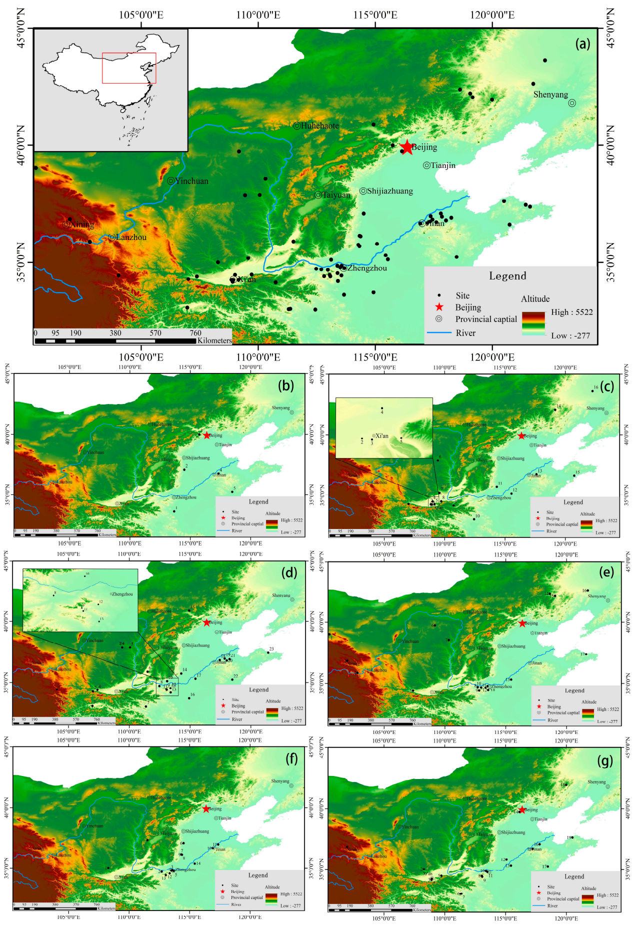

Figure 1. Distribution of Pre-Qin archaeological sites involved in this paper (This figure was made by Kai Han, Anqi Yang and Liya Tang, and the site information came from the references [8,28–98]). (**a**) Distribution

of all sites across the history in the northern area (SI-1 in Supplementary file). (**b**) Sites belonging to ca. 11,000–7000 B.P.; 1. Jiahu, 2. Zhangmatun, 3. Donghulin, 4. Xihe, and 5. Dongpan (SI-4 in Supplementary file). (**c**) Sites belonging to ca. 7000–5000 B.P.; 1. Anban, 2. Yuhuazhai, 3. Gongbeiya, 4. Yanguanzha, 5. New Street, 6. Miaoliang, 7. Nanshantou, 8. Dongyang, 9. Xipo, 10. Gouwan, 11. Liuzhuang, 12. Helou, 13. Jiaojia, 14. Weijiawopu, 15. Beiqian, and 16. Haminmangha (SI-4 in Supplementary file). (**d**) Sites belonging to ca. 5000–4000 B.P.; 1. Shuzha, 2. Anban, 3. Longgangsi, 4. Zhouyuan (Wangjiazui Locus), 5. Zhaimaoliang, 6. Taosi, 7. Xiawanggang, 8. Wanggedang, 9. Wangchenggang, 10. Xijincheng, 11. Chengyao, 12. Guchengzhai, 13. Wadian, 14. Dalaidian, 15. Dashuigou, 16. Pingliangtai, 17. Shilipubei, 18. Ningjiabu, 19. Dinggong, 20. Fangjia, 21. Tonglin, 22. Dongpan, 23. Wutai, and 24. Miaoliang (SI-4 in Supplementary file). (**e**) Sites belonging to ca. 4000–3500 B.P.; 1. Xichengyi, 2. Jinchankou, 3. Guanting basin (investigation), 4. Lajia, 5. Zhouyuan (Wangjiazui Locus), 6. Donghuishan, 7. Shimao, 8. Erlitou, 9. Nanwa, 10. Huadizui, 11. Dongzhao, 12. Xinzhai, 13. Shilipubei, 14. Sanzuodian, 15. Erdaojingzi, 16. Xiaonailingao, 17. Zhaogezhuang, and 18. Guchengzhai (SI-4 in Supplementary file). (**f**) Sites belonging to ca. 3500–3000 B.P.; 1. Zaolinhetan, 2. Erlitou, 3. Dongzhao, 4. Xiaoshuangqiao, 5. Zhengzhou Shang City, 6. Zhaocun, 7. Dasikong, 8. Xin'anzhuang, 9. Liujiazhuangbeidi, 10. Liujiazhuang, 11. Daxinzhuang, 12. Wangchenggang, 13. Guchengzhai, and 14. Shilipubei (SI-4 in Supplementary file). (**g**) Sites belonging to ca. 3000–2300 B.P.; 1. Fengtai, 2. Zaolinhetan, 3. Fengxi, 4. Gongbeiya, 5. Dongyang, 6. Shenmingpu, 7. Xiawanggang, 8. Wangchenggang, 9. Chengyao, 10. Guanzhuang, 11. Dongzhao, 12. Jinqiao, 13. Shilipubei, 14. Dingjiawa, 15. Tangye, 16. Chenzhuang, 17. Dongpan, 18. Reshuitang, and 19. Longkouguicheng (SI-4 in Supplementary file).

3. Results: The Basic Quantitative Analysis for the Plant Remains

3.1. Relationship between the Quantity of Plant Categorization in Genus Names and Their Ubiquity

This study capitalizes on the extensive site sample size available for quantitative analysis. Since the data on the discovery probability of plant remains had undergone several transformations during the analysis, it is necessary to provide explanations for these transformations. In this section, the various archaeological sites were first arranged in chronological sequence from early to late.

In the following part, a table (SI-5 in Supplementary file) was used to display the plant remains (in genera) unearthed at each site in detail. Then, regardless of the absolute quantity of the plants, the ubiquity of a certain kind of plant was calculated for each archaeological site within a specific time period (SI-5 in Supplementary file). These discovery probabilities, categorized in chronological sequence set by different colors in Figure 2, start from greater than 0% to then increase in intervals of 10% until they are greater than or equal to 90%. The number of plant taxa falling within each ubiquity category was calculated for each period. For instance, during the period ca. 5000–4000 B.P., there were 134 plant taxa that appeared with a frequency greater than 0% (at the genus level), and among them, 52 plant taxa had a frequency greater than or equal to 20%, etc. (SI-5 in Supplementary file, Figure 2).

The purpose of this analysis was to show the relationship between the quantity of plant categorization at the genera level and their ubiquity.

To differentiate whether a plant was utilized as a resource or not, a ubiquity threshold of $\geq$20% is employed, although it entails some subjectivity. Using the last phase of the Neolithic period as a representative example, in Figure 2, it is observed that when the discovery probability is <20%, the exponential trend line exhibits a relatively steep slope. However, when the discovery probability is $\geq$20%, the exponential trend line becomes less steep. In other words, a negative relationship exists between the quantity of the types of plant remains in genus names and their ubiquity. This phenomenon can be attributed to the increasing prevalence of crop taxa within the plant remains, while the impact of plants that were sporadically introduced to the site becomes minimal.

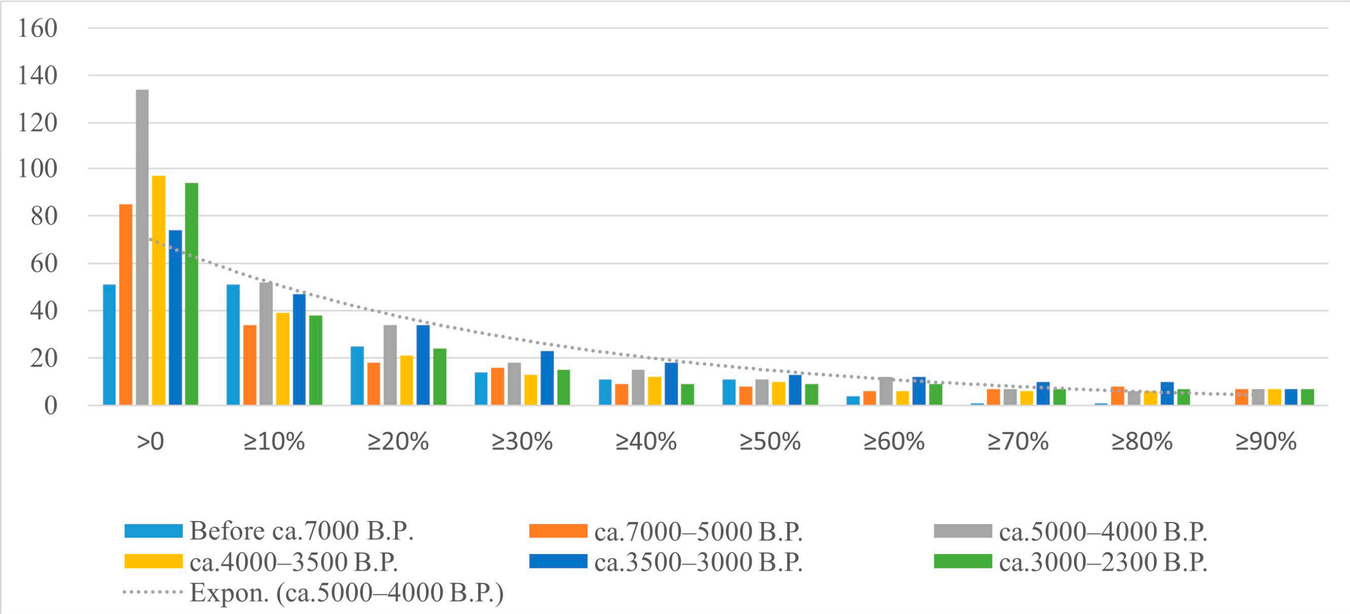

Figure 2. The quantity of plant categorization in genus names and their ubiquity measured at intervals of 10%. (The *x*-axis means the ubiquity of plant taxa; *y*-axis means the quantity of the taxa of plant remains in genus name).

3.2. Ubiquity of Plant Taxa Reflected from Radar Chart

Furthermore, Figure 3 presents a radar chart that utilizes different colors to visually represent the prevalence of plant taxa remains found in different time periods. As previously mentioned, using 20% as a threshold, Figure 3 retained the plant taxa that reached a discovery probability of 20% or higher in any time period. It excluded data for plant taxa whose discovery probability was consistently below 20% in all periods. The study considers the latter to have played a limited role in ancient human activities (SI-6 in Supplementary file). Plants belonging to the same families are closely clustered, while plants associated with crops are grouped together. The absence of the line signifies the absence of certain plant species, while the length of the line corresponds to their level of ubiquity. It can be clearly drawn from Figure 3 that there is great distinction between the time before ca. 7000 B.P. and the subsequent periods, highlighting the presence of various plant species with high ubiquity beyond cultivated crops.

3.3. Concentration, Dispersion, and Fluctuation of Plant Taxa after ca. 7000 B.P. Revealed from Bar Chart

In this section, both the data belonging to Figure 2 for plant taxa with a discovery probability consistently below 20% in all periods were excluded and the data of ca. 11,000–7000 B.P. (the first and second phases of the Neolithic period) were not considered. This allows for a more focused investigation into the concentration, dispersion, and fluctuation patterns of plant resources from ca. 7000–5000 B.P. (Yangshao period) to ca. 3000–2300 B.P. (Zhou Dynasty).

In Figure 4, the number of plant taxa unearthed at various sites during different periods was counted (SI-7 in Supplementary file). Based on these data, a boxplot was created to compare the variations in the number of plant taxa over different time periods. Each data point in the boxplot corresponds to one archaeological site.

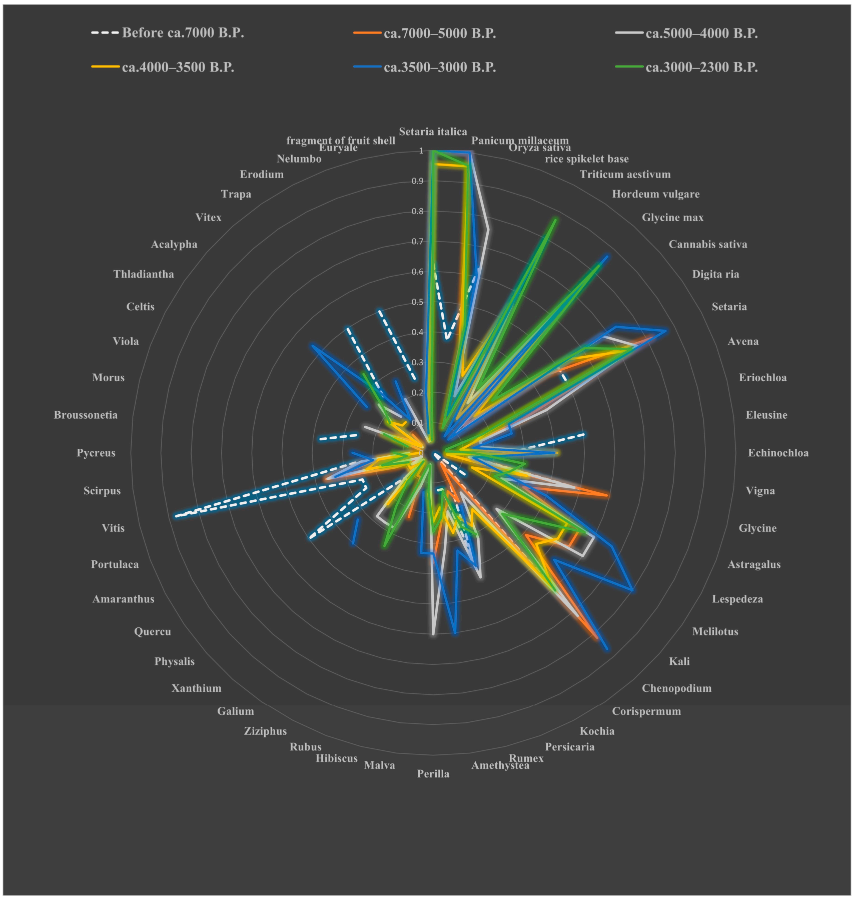

Figure 3. Ubiquity ≥20% of plant taxa reflected from radar chart.

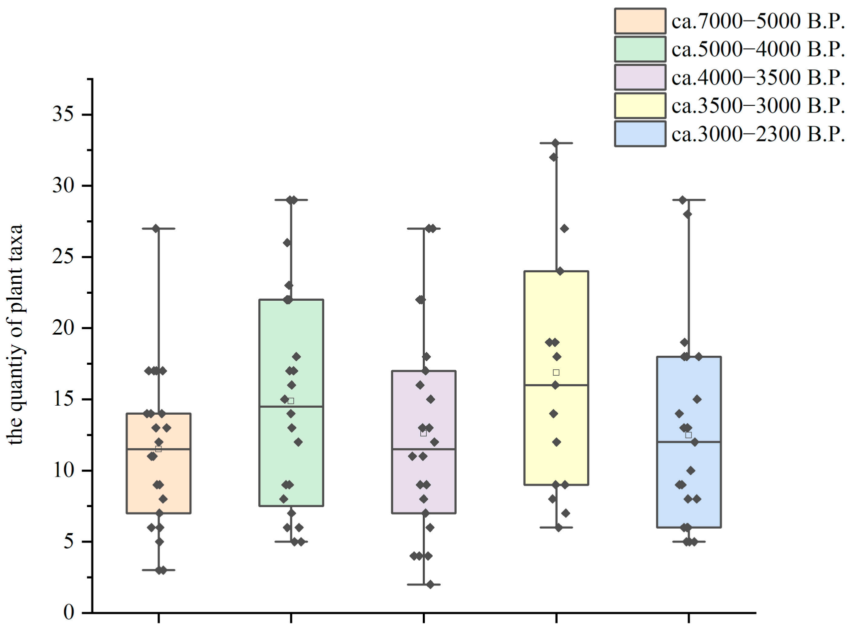

Figure 4. Concentration, dispersion, and fluctuation of plant taxa from the Yangshao period to the Zhou Dynasty.

A noticeable pattern is observed in the jagged wave of the data. It shows an increase in plant taxa during ca. 5000–4000 B.P. and ca. 3500–3000 B.P., while a decrease is observed during ca. 7000–5000 B.P., ca. 4000–3500 B.P., and ca. 3000–2300 B.P.

3.4. Diet Analysis Summarized by Stable Isotope Analysis

Although regional environmental differences such as climate, soil, and vegetation can lead to variations in crop combinations, crop cultivation strategies, and human cultural adaptations, there are still overall trends and patterns in the dietary preferences of cattle and sheep. Stable isotope analyses of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) were conducted on 52 cattle, 62 sheep, and 112 pig samples from the Longshan period (ca. 5000–4000 B.P.) to the Erligang period (early Shang Dynasty, ca. 3500–3300 B.P.) in China (Figure 5, SI-8 in Supplementary file). The results reveal that the $\delta^{13}C$ values of both cattle and sheep fall within a range indicating a mixed diet of C3 and C4 plants. However, there is a noticeable difference in plant preference between sheep and cattle. Sheep demonstrate a clear inclination towards consuming C3 plants; whereas, cattle displayed a preference for C4 plants, similar to pigs.

Figure 5. Stable isotope values of $\delta^{13}C$ and $\delta^{15}N$ of cattle, sheep, and pigs from Longshan period to Erligang period (early Shang Dynasty) in China. (This figure was made by Anqi Yang & Liya Tang, and we gathered the data came from the references [19,99–105].)

4. Discussion

4.1. The Possible Preference for Feed

Figure 3 provides an illustration of the development of ancient agriculture. During ca. 11,000–7000 B.P., there is evidence suggesting the frequent utilization of certain non-crop plant types. However, a deliberate reduction in their usage is observed during the subsequent periods. This reduction is likely a result of the active development of crop cultivation and the increasing dominance of agriculture as the primary livelihood during prehistoric times [13]. Furthermore, there is an intensification in the utilization of foxtail millet and broomcorn millet since ca. 7000–5000 B.P., i.e., the Yangshao period or the late Neolithic time. Actually, such a phenomenon may have occurred since ca. 9000 B.P. [106]. The utilization of rice shows fluctuations across different periods, while soybean utilization demonstrates a noticeable growth trend starting from ca. 5000–4000 B.P. The presence of wheat during the Yangshao period remains uncertain, but it is likely that large-scale development and utilization began during ca. 3500–3000 B.P., i.e., the Shang Dynasty. On the other hand, barley and cannabis plant remains are relatively scarce, potentially due to specific utilization methods such as brewing barley grains or utilizing cannabis fibers.

In addition to these observations, Figure 3 also suggests a possible preference for feed. Plants belonging to the genera *Setaria*, *Digitaria*, *Chenopodium*, as well as the grasses *Melilotus* and *Lespedeza*, consistently exhibit high and relatively equal probabilities of discovery across each period. These plants represent a category of extensively utilized plants with high utilization rates. The non-crop plant remains predominantly consist of common weeds found in modern northern China [107]. The utilization of companion weeds belonging to the genera *Setaria* and *Digitaria* may involve complex factors, including unintentional introduction during harvest and intentional use as animal feed. Conversely, plants belonging to the genera *Kali*, *Perilla*, *Amethystea*, and *Persicaria* show the secondary probabilities of discovery across different periods with intermittent fluctuations in some data. Although these plants were commonly utilized, their utilization rates were lower compared to grasses of the genera *Setaria*, *Digitaria*, and *Chenopodium*.

4.2. Interval Expansion of Feed Resources

According to scholarly research, the middle of the late Neolithic period (ca. 6000–5500 B.P.) in prehistoric Chinese society witnessed a significant transition from a hunter-gatherer economy to an agricultural society [13]. However, Figure 4 presents a contrasting pattern, showing a steady increase and peak in the abundance of plant species after the late Neolithic period (ca. 5000–4000 B.P.). This indicates that the last phase of Neolithic time had a greater variety of plants available compared to the period previously.

It should be noted that certain crops, such as wheat, had not spread to the central plains, although they appeared in the Shandong province of China during ca. 4500–4000 B.P. [9,10]. Therefore, the augmented number of plant species discovered in Longshan settlements in northern China, as determined through statistical probability analysis, shows a limited correlation with the stages of agricultural development and the crop structure. Instead, this pattern is closely associated with changes and advancements in animal husbandry which had a more significant impact on the progress of society. In other words, the introduction of foreign domesticated animals, such as cattle and sheep, during ca. 5000–4000 B.P., led to an expansion in the diversity and quantity of livestock. While agriculture had already become the primary occupation [34], it was still in its early stages, resulting in an unstable reliance on agricultural products as livestock feed. As a result, ancient humans actively sought to expand the utilization of non-crop plant resources.

Cultivation and livestock farming continued to progress during the Bronze Age in China. However, there were notable differences between the Xia dynasty (ca. 4000–3500 B.P.) and the Shang Dynasty (ca. 3500–3000 B.P.) concerning the use of large, domesticated animals for sacrificial rituals in high-status settlements. Evidence indicates that cattle were primarily used for sacrificial purposes during the Shang Dynasty, while pigs were favored in the Xia Dynasty [108,109]. This observation suggests an increasing emphasis on cattle breeding, which required more extensive grasses for cattle feed. This is further supported by Figure 4, which clearly demonstrates a higher diversity of plant categories during the Shang Dynasty.

4.3. Feed for Cattle: Crops, Grasses, and Indigenous Leguminous Plants

Cattle and sheep, classified as part of the Six Domestic Animals (Liu chu) [110], are highly valuable animal resources. They provide numerous benefits through their ability to consume coarse feed, their resistance to diseases, and their consistent yield of milk, meat, and other by-products [110]. During the Longshan period, when the Triticeae crop was not widely available, cattle and sheep, introduced from southwestern Asia, had to rely on local forage for their sustenance.

Different feeding strategies were employed for cattle and sheep based on their distinct eating habits. Sheep exhibited a high utilization of feed, often consuming a variety of preferred weed grasses and browsing on grasses that were shorter than 6 cm in height, therefore, allowing sheep breeding to take place in various environments, including ravines, mud flats, field edges, and harvested fields [100]. In contrast, meeting the dietary needs of cattle was more challenging. Cattle have a significantly higher food intake, consuming approximately five times as much as sheep [100]. Moreover, their unique anatomical structure, specifically the absence of upper incisors, required them to use their tongues to scoop up grasses that were taller than 12 cm. If cattle were limited to consuming grass shorter than 12 cm, it would be difficult for them to obtain sufficient nourishment [100].

Section 3.4 and Figure 5 indicate that cattle showed a preference for feed derived from C4 plants; whereas, sheep exhibited a preference for feed composed of C3 plants. These studies highlight a gradual shift towards confining cattle in enclosures, while sheep continued to predominantly roam freely based on their dietary analyses [111]. Consequently, this study provides valuable insights into the composition of cattle feed to a certain extent.

Millet stands out among other plants due to its suitability as feed for C4 plants [18]. It requires less investment in terms of fertilizer and water to achieve a higher growth rate and yield, and they can grow in virtually all types of soil [18,112]. Some species of *Setaria* and *Digitaria* offer tender leaves, stems, and mature grains that make them excellent sources for cattle feed [113]. Naturally, the by-products of wheat became a preferred choice of forage for cattle [114], particularly with the extensive cultivation of wheat since the Shang Dynasty (Figure 3).

This study examines the significant probabilities associated with the discovery of two C3 indigenous plant species, *Melilotus* and *Lespedeza*, with respective probabilities of 39% and 35%. These leguminous plants are widely recognized as preferred forage options for both cattle and sheep [115]. *Melilotus* is categorized as an herbaceous plant, whereas *Lespedeza* exhibits a shrub-like growth pattern [116]. Considering the prevailing influence of the East Asian monsoon in northern China [21], which poses challenges to the drying, preservation, and utilization of animal manure, it is plausible to hypothesize that the presence of these leguminous plants at archaeological sites signifies intentional collection for cattle in captivity, while also serving as immediate food sources for free-range sheep in their natural habitats.

4.4. The Possible C4 and C3 Plants as Ingredients in the Feed of Domestic Pigs

China holds a significant position in the origins of domestic pigs, and pig rearing has been a crucial aspect of livestock farming in the country's major agricultural regions—the Yellow River and Yangtze River basins—since ancient times [1]. This tradition dates back to the Neolithic period and continued during the Yangshao culture when agriculture-based subsistence was established in these regions [1]. However, it is important to note that during the Yangshao period, before the emergence of states and civilizations in the subsequent Longshan era, productivity and social cohesion remained relatively limited. Consequently, the cost of raising domestic pigs needed to be carefully considered [117].

Pigs served as a vital source of meat for ancient populations in East Asia, even before the introduction of cattle and sheep. The nutritional demands during the growth stage of domestic pigs were higher compared to other smaller livestock. In situations where productivity was not yet well developed, it is likely that humans did not have sufficient surplus food to adequately feed domestic pigs. This led to the inclusion of wild resources in pig feed or allowing pigs to free range. Isotope analyses conducted on pig bones from sites such as Beiqian in Jimo [19], Qugou in Huaibei [118], and Xiawanggang in Xichuan [119] during the Yangshao period indicate that pigs were predominantly raised in a free-ranging manner, primarily consuming wild grasses.

Moreover, specific settlements, such as the Qinglongquan site located south of the Qinling Mountains, may have experienced significant influences from artificial vegetation environments. The residents belonging to the Qujialing and Shijiahe cultures at this site practiced both rice and millet cultivation [120]. Studies have revealed that the dietary composition of pigs at this site closely mirrored that of the residents. The pigs had a mixed diet comprising C3 plants, including rice, and C4 plants, such as millet, with C3 plants being the primary component [99].

However, the primary focus of this study is to investigate the extent of human intervention in northern China regarding the ingredients of feed used for domestic pigs kept in captivity. The dietary pattern of pigs during the Longshan period to the Erligang period (Figure 5) demonstrates a clear preference for C4 plants [111]. Additionally, as time progressed, the overall $\delta^{15}N$ values of domestic pig bones increased, indicating a higher trophic level and the inclusion of a significant portion of human food remains in the pig's diet [111]. However, when referring to C4 plants, it is important to note that they not only include foxtail millet and broomcorn millet but also encompass wild herbaceous C4 plants with a higher likelihood of discovery in archaeological sites in northern China, such as the genera *Setaria*, *Digitaria*, *Kali*, and *Chenopodium* (Figure 3). The tender and soft stems of these plants during their growth stage make them more appealing to domestic pigs [121]. Hence, ancient residents likely collected a certain quantity of wild herbaceous C4 plants in addition to millets [17]. In fact, the diet of pigs is quite diverse as they are omnivorous, and besides grains, they can be fed with melons, fruits, vegetables, and grass [117,121]. Drawing upon modern pig farming practices, grasses like *Pennisetum purpureum* and *Pennisetum sinese* from the Poaceae family, both categorized as C4 plants, are preferred forage for domestic pigs [18].

During the middle and late Yangshao periods (ca. 6000–5000 B.P.) when cattle and sheep had not yet been introduced, some C3 legumes like *Melilotus* and *Lespedeza* could have been utilized as feed for pigs. Although they may have been less significant overall, they played a significant role at specific sites such as the New Street site in Lantian, Shaanxi Province [45], and the Yangguanzhai site in Gaoling, Shaanxi Province [122]. At the Xinjie site, a total of 721 leguminous seeds were discovered, accounting for 23.58% of all weed seeds, including 353 *Lespedeza* seeds and 313 *Melilotus* seeds [45]. Similarly, at the Yangguanzhai site, 101 *Melilotus* seeds were excavated with a discovery probability of 43.16%, and 94 *Lespedeza* seeds were excavated with a discovery probability of 40.17% [122]. However, since there have been no isotopic studies conducted on animal bones from these sites, further verification is needed to confirm whether domestic pigs were raised and fed with C3 leguminous plants.

Hence, in the investigation of the dietary habits of domestically raised pigs through isotopic analysis, it is essential to consistently explore the assortment of gathered grasses offered to these pigs due to pigs holding a significant role as domesticated animals for prehistoric inhabitants in northern China.

5. Conclusions

The key conclusions of this study can be summarized as follows:

During ca. 5000–4000 B.P. and ca. 3500–3000 B.P., there was a notable increase in the number of plant species with a discovery probability of $\geq$20%, indicating an expanded range of feed selection. This expansion is closely linked to the introduction of cattle and sheep during the Longshan period and the more widespread use of cattle for sacrificial purposes during the Shang Dynasty.

Besides crop straw or residues, humans may have regularly collected some plants, discovered in archaeological sites in the northern region, as intentional animal feed. These plants in genera include *Setaria*, *Digitaria*, *Chenopodium*, and *Kali,* belonging to C4 plants, and *Melilotus*, *Lespedeza*, *Perilla*, *Amethystea*, and *Persicaria,* belonging to C3 plants.

In general, it is recommended to raise pigs and cattle primarily in confinement, while sheep are better suited for free-range conditions. As a result, the diet of pigs and cattle more closely resembles that of ancient humans, with a significant portion of their feed consisting of millets and other C4 plants such as *Setaria*, *Digitaria*, *Chenopodium*, and *Kali*. In comparison, cattle's diet includes some C3 plants, suggesting thes intentional collection of *Melilotus* and *Lespedeza*.

Animal husbandry and cultivation were vital production activities for ancient Chinese societies, and feed played a crucial role in maintaining artificially reared animals. In Europe, at some archaeological sites in Romania, scholars have also speculated about the animal feed used during the early Neolithic period (Soimus–Tilighi site) and the Chalcolithic Age (Cucuteni A3a sub-phase, Hoisesti site) [123,124]. At the Soimus–Tilighi site, there was a larger number of cattle and sheep, but very few pigs, suggesting a mobility of the evaluated communities which may have relied on livestock (cattle and sheep/goat) for their subsistence. However, the presence of elongate dendritic and crenat, while indicating an anthropogenic accumulation, does not necessarily indicate the cultivation of cereals, but rather the consumption of wild grasses by the animals raised by a pastoral community [123]. The combined results of soil chemistry, pollen, and animal archaeology analyses at the Hoisesti site suggest that compared to the contemporary sites, the surrounding area was not suitable for agriculture, as there were fewer crop pollen remains. The number of domestic pigs and wild boars was higher than that of other domesticated animals and wild animals, indicating that the inhabitants of this site were small-scale agriculturalists, with equal importance given to animal husbandry and hunting [124]. Since agriculture was not fully developed at this site, the source of feed for domestic pigs becomes crucial. However, existing research has not provided very detailed explanations regarding this aspect. Therefore, it is evident that examining the characteristics and changes in the utilization of feed plant can provide insights into the development and transformations of the ancient society, both in China and abroad. Furthermore, conducting comparison studies between the East and the West of the Old World would be highly meaningful.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy13092191/s1.

Author Contributions: Writing—review and editing, supervision, and methodology, L.T.; writing—original draft and data curation, A.Y.; visualization and formal analysis, K.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Bureau of Foreign Experts Affairs, China Ministry of Education, grant number D18004 (Project 111).

Data Availability Statement: The data presented in this study are available in Supplementary Materials here.

Acknowledgments: During the writing of this paper, the analysis of isotopes greatly benefited from the assistance and inspiration provided by Xianglong Chen from the Institute of Archaeology, Chinese Academy of Social Sciences, Yi Guo from the School of Art and Archaeology, Zhejiang University, and Xue Ling from the School of Cultural Heritage, Northwest University. Their valuable contributions have enhanced the quality of this research!

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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