

‘Cropping the margins’: New evidence for urban agriculture at mid-3rd millennium BCE Tell Brak, Syria

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Abstract

The excavation of a large administrative building at the city of Tell Brak in northern Syria saw the recovery of a considerable quantity of charred cereals dated to the mid-3rd millennium BCE. This remarkable discovery provides a rare snapshot into the nature of agriculture in Upper Mesopotamia during the Early Bronze Age. The material has been studied using a combination of primary archaeobotanical analysis, crop stable isotope determinations and functional weed ecology to deliver new insights into cultivation strategies at Tell Brak, as well as contributing to the wider debate regarding trade and crop importation in this region. Specific crop regime choices also reveal how the farmers of Tell Brak were able to reduce the overall risk of crop failure by careful water management, a vitally important factor in this semi-arid region with potential implications for the analysis of other large-scale urban agro-economies in the Middle East and beyond.

Introduction

At the site of Tell Brak, the excavation of the TC Oval, a large burnt building dated to the mid-3rd millennium BCE, saw the recovery of large quantities of well-preserved charred macrobotanical remains (Emberling & McDonald, 2003). The analysis of this material has allowed an in-depth examination of agricultural production and crop management at the site during the Early Bronze Age. Previous discussions of Upper Mesopotamian agriculture during this period have highlighted the importance of water management due to the semi-arid nature of the environment in this region today (e.g. McCorrison & Weisberg, 2002; Riehl *et al.* 2014). To this end, farmers would have been heavily reliant on winter rains with even minor climatic fluctuations potentially devastating for the harvest (Riehl, 2009). This paper combines crop stable isotope analysis and functional weed ecology to assess crop growing conditions as represented by plant remains recovered from the TC Oval building. It also assesses how specific regime choices made by farmers ultimately reduced the overall risk of crop failure at Tell Brak, as well as the role of the city as a centre for mobilisation of staples during the mid-3rd millennium BCE.

Tell Brak

Location and Topography

The site of Tell Brak is situated within northern Mesopotamia, an area that includes modern south-east Turkey, north-east Syria and northern Iraq (**Figure 1**) The region is separated geographically from southern Mesopotamia by the abuttal of the southern alluvial plains to the Jezira limestone plateau (Lloyd, 1984), and is bounded on the east and west by the Tigris and Euphrates rivers (Oates *et al.* 2001). The site itself is located *c.* 40 km north-east of the modern city of Al-Hasakah on the Upper Khabur plain (**Figure 2**) at an altitude of 357 m asl on a large expanse of flat, rolling landscape ideally suited for rain-fed agriculture (Weiss, 1986; Wilkinson *et al.* 2014). The area is bordered to the south and east by the wadis Radd and Jaghjagh. Today these water courses are quite small and farmers must rely on diesel-powered irrigation systems to provide enough water for crop growth (Charles *et al.* 2010). During the Bronze Age, however, these wadis must have been extremely important as can be seen from the number of tell sites (e.g. Tell Barri and ancient Nisibis) constructed on their banks, and control of these water sources would have been vital (Oates, 1990; Wilkinson, 2001; Ur, 2010).

Climate

The current climate of this region is typically continental with hot, dry summers and cool winters (BSh semi-arid steppe, Koppen-Geiger classification). Average daily temperatures range from about 25–35°C in July and August but can increase to highs of around 44°C.¹ Winter temperatures can drop to below freezing but tend to average around 5–6°C. In terms of rainfall, Tell Brak is located in a marginal area for rainfed agriculture, lying between the 250–300 mm annual rainfall isohyets (Charles *et al.* 2010). This level of annual rainfall can easily support the cultivation of barley but it is less suitable for the cultivation of wheat, especially if there are sporadic drought periods (Hole & Zaitchik, 2007). Modern rainfall levels in general have tended to be slightly higher with an average of 363 mm/year (Hijmans *et al.* 2005) but inter-annual rainfall variability has meant that some years the precipitation levels do not reach the amount needed to support rainfed farming. During the last 15 years in particular, this region has become much drier, with recorded rainfall levels in Al-Hasakah barely topping 100 mm/year.

Past climate reconstructions for Tell Brak and northern Mesopotamia have been hampered by the lack of local climate proxy records in the form of pollen cores. Late Chalcolithic and Early Bronze Age local proxy data from archaeobotanical macro-remains (e.g. Miller, 1997; McCorrison & Weisberg, 2002; Deckers & Pessin, 2011) and stable isotope analysis of crops (e.g. Riehl, 2009; Styring *et al.* 2017) have shown that precipitation levels in the region, after dipping during the 5.2kyr BP event, did recover slightly but that general conditions remained fairly dry. Using speleothem $\delta^{18}\text{O}$ values from Soreq Cave in Israel (Bar-Matthews & Ayalon, 2011), and the present-day calibration relationship between these values and rainfall, has led to the estimation that rainfall was, on average, 300–320 mm/year during the period 2900–2300 BC (Styring *et al.* 2017). This would place mid-3rd millennium BCE Tell Brak right on the edge of the ‘zone of uncertainty’ (Wilkinson *et al.* 2014), an area of land located between the 200–300 rainfall isohyets where cereal cultivation was thought to be much more risky. This estimate suggests that Tell Brak farmers were heavily reliant on the winter rains for cereal cultivation and that any short periods of drought would have been devastating (Riehl, 2009; Lawrence *et al.* 2021). The location of Tell Brak between the wadis Jaghjagh and Radd, however, may have mitigated this source of water stress to a certain extent, as they would have allowed Bronze Age farmers to access better-watered soils in certain areas of the urban hinterland (c.f. Riehl, 2011; Wilkinson *et al.* 2014).

¹ Modern climate data from <https://www.worldweatheronline.com/>.

Vegetation and Soils

The present day vegetation of northern Mesopotamia is primarily steppic, bordered by forests to the north in Turkey and desert to the south in Iraq. Tell Brak itself is located in the ‘Moist Steppe’ vegetation zone (although Dry Steppe could also be applicable in the south of the region due to the low average rainfall) and is dominated by grass steppe and land predominantly under cultivation. Trees and woodland are mainly absent, although there are small pockets of *Pistacia – Amygdalus* forest located near the rivers and wadis (Guest, 1966). Zohary (1950) has said that steppic environments consist of open plant communities that are limited primarily by climatic conditions and lack of rainfall. Certainly the local environs of Tell Brak are fairly bare in the dry summer months, but covered with diverse grassland species such as *Artemisia herba-alba* Asso. and *Poa bolbosa* L. after the arrival of the winter rains (Zohary, 1973). Past vegetation reconstructions of this region have indicated the presence of extensive *Quercus* woodland (e.g. Bottema & Cappers, 2000), but that during the Late Chalcolithic and Early Bronze Age increasing aridity and human activity in the area led to reduction in woodland and an expansion of grass/shrub steppe (Deckers, 2011). In terms of soils suitable for arable agriculture, Tell Brak is located in an area of flat land with reasonably fertile calcic xerosols (Wilkinson, 2003). Furthermore, alluvial soils located on the banks of the nearby wadis would have been enriched with nutrients potentially providing prime arable land (French, 2003). Today, the soils around the site have been affected by erosion and leaching caused by continuous farming activity, leading to a reduction in fertility from that of the Bronze Age (Charles *et al.* 2010).

Historical Background

The earliest excavated occupation at Tell Brak is dated to the Ubaid period (c. 5th millennium BCE), although the recovery of Halafian ceramics and Pre-pottery Neolithic B chipped stone from these levels may indicate settlement in the area as early the 8th millennium BCE (Oates *et al.* 2001). The site continued to grow into a complex settlement throughout the Late Chalcolithic (4000–3200 BCE), covering an area of ca. 100–130 hectares at its peak with an estimated population of around 20,000 inhabitants (Oates & Oates, 1993; Emberling, 2002; Hald, 2008; Ur *et al.* 2011). At the end of the 4th millennium BCE (c. 3200 BCE), a period of aridity (e.g. Bar-Matthews *et al.* 2003; Riehl *et al.* 2014) saw the abandonment of many Uruk colony sites in northern Mesopotamia (Lawrence *et al.* 2021). Several urban sites, including Tell Brak, are thought to have declined in size (Wilkinson, 2000; Ur *et al.* 2011), as city dwellers moved away to more sustainable rural communities (Ur, 2010). Archaeobotanical evidence from this period at Tell Brak, however, shows

a greater reliance on cereals such as einkorn which have greater water requirements, indicating that the remaining urban community was able to adapt to fluctuating climatic conditions (Charles *et al.* 2010; Lawrence *et al.* 2021). Certainly, by the first half of the 3rd millennium BCE improving conditions saw a surge in re-urbanization in northern Mesopotamia (Matthews, 2004) and by c. 2600 BCE the greater urban area at Tell Brak (**Figure 3**) had reached 65–70 hectares (Emberling *et al.* 1999). Moreover, during this period documentary evidence recovered from the nearby site of Ebla identified Tell Brak as ‘Nagar’, the most important settlement in the area (Oates & Oates, 2001).

Area TC

Excavation began at Tell Brak in the 1930s under the direction of Max Mallowan, focusing primarily on deposits from the later 3rd millennium BCE. Work was then resumed in 1976 by David and Joan Oates and was continued by a series of field directors from 2003–2011 including Roger Matthews, Geoff Emberling and Helen McDonald, and Augusta McMahon. These studies focused on a range of periods, including the earlier 5th and 4th millennium BCE levels (e.g. Matthews, 2004), the 3rd millennium BCE (e.g. Oates *et al.* 2001) and intensive surveys of the wider landscape (Ur, 2003). In the 1998 field season, a large Oval building was first identified in Area TC (**Figure 4**). This structure², dated to the mid-3rd millennium BCE, was found to cover an area c. 45 x 50 m organized around two central courtyards (Emberling & McDonald, 2001). Internally, the building was divided into a number of different rooms (**Figure 5**), many of which contained objects associated with food storage and processing. Around the outer courtyard were rooms thought to have been used for the production of bread. This included Rooms 4, 6, 7 and 8, which were used for grain storage and the larger Room 2 (c. 2 x 6m in area) which contained seven small bread ovens along the east and south walls (Emberling *et al.* 1999). The inner courtyard by contrast seems to have been more domestic in character containing a small kitchen (Room 14) and a corridor (Room 12) with a drainage feature and a large number of broken pottery sherds and stones. This part of the building also had further storage areas thought to be used for agricultural produce, this included Room 16, a reception/storage room with benches built in to the outer walls and a mudbrick bin, and Room 15 another small store room. Also found in the building were 250 door and package sealings indicating bureaucratic control over the produce being stored and manufactured in the TC Oval. This has led to the interpretation that the TC Oval was a public building associated with the administration of grain and bread rations to a segment of the wider population of Tell Brak (Emberling & McDonald, 2003). The TC Oval building was almost entirely destroyed by fire close

² From here on, referred to as the TC Oval.

to the beginning of Akkadian imperial control in this region (Emberling & McDonald, 2003). Upon excavation, it was discovered that the building had still been in use at the time of destruction and contained very significant concentrations of intact, well-preserved charred cereal grain. In particular, Room 16 contained piles of pure grain alongside mixed piles of grain and chaff, suggesting that inhabitants were engaged in the final stages of crop processing at the time of the fire. This material was recovered and has been studied and analysed at the School of Archaeology, University of Oxford.

Previous archaeobotanical work at mid-3rd millennium BCE Tell Brak

There have been a number of previous archaeobotanical studies carried out on material recovered from Tell Brak (e.g. Hald, 2005: 2008; Colledge, 2003) and one of these studies (Charles & Bogaard, 2001) also focused on the mid-3rd millennium BCE. This previous study was completed on archaeobotanical material recovered from earlier excavations (1978-84 seasons) on both public and domestic areas of the site. The results of this study showed that several cereals, 2-row hulled barley, emmer and einkorn wheat, were commonly found during this period, whilst pulses were also present but much less frequently (Charles & Bogaard, 2001). Spatial variation in sample composition indicated that there may have been a contrast between domestic and public production of agricultural goods during this period. For example, in Level 3 of Area FS, sampling of an Akkadian public building (**Figure 4**) shows that hulled barley was ubiquitous but pulses were entirely absent. By comparison, samples taken from domestic contexts in areas CH and ER included pulses alongside various cereal species. These results led Charles & Bogaard (2001) to suggest that there were two separate, yet complementary, systems of production in existence during the 3rd millennium BCE at Tell Brak. Firstly a ‘specialized institutional agriculture’ administered by the temple which focused on hulled barley and wheat production as a means of providing bread rations for workers and fodder for palace livestock. Secondly, a ‘household-scale agriculture’ which included the private cultivation of a much wider range of crops including pulses, cereals and other species such as flax. Crop stable isotope analysis has also been carried out on this material as part of a larger investigation by Styring *et al.* (2017) into farming practices in northern Mesopotamia. These studies will be discussed below along with the new results presented in this paper to form a more comprehensive picture of agricultural production at Tell Brak during the mid-3rd millennium BCE.

Methods

Soil samples of 30-40 litres were taken systematically from every undisturbed archaeological unit in the TC Oval resulting in 85 archaeobotanical samples. Areas of particular interest within the building were sampled using a grid system (Emberling & McDonald, 2001) and on occasion, visible concentrations of charred plant remains were sampled at close intervals by hand to assist in the identification of spatial variation within the plant assemblage. All samples were processed using a flotation machine based on the French design (French, 1971). Initial sample scanning was carried out to assess sample richness with a target of 300 identified cereal grains set. From this evaluation 25 samples were chosen for part of a preliminary study undertaken by Mette Marie Hald & Mike Charles at the University of Sheffield (Emberling & McDonald, 2001). Full quantification, identification and analysis of these 25 samples and a further selected 33 samples from the TC Oval was carried out at the School of Archaeology, University of Oxford from 2014–2018 (**Table 1**). Samples for full analysis were chosen due to their apparent archaeobotanical richness, the range of species represented and their contextual provenance within the TC Oval.

All samples were sorted and identified using a Nikon stereomicroscope (x7-80); this included the re-analysis of plant remains identified during earlier studies so that a formal identification criterion could be standardised across the site. Charred plant items were identified using a comparative modern reference collection and relevant published resources such as the *Flora of Iraq* (Guest, 1966; Townsend & Guest, 1966-88) and the *Nouvelle Flore du Liban et de la Syrie* (Mouterde, 1966). Latin nomenclature for all plant remains follows Zohary *et al.* (2012) and Townsend & Guest (1966–88). The minimum number of individuals (MNI) was used to quantify all plant remains by counting easily identifiable diagnostic plant item areas (Jones, 1991). With regard to cereal grains, both embryo and apical ends were recorded separately but only the most abundant category was used to determine the final grain total. Similarly, for glume wheat chaff, each glume base was scored individually, and spikelet forks were recorded as two glume bases. Seeds from wild or weed taxa were largely scored individually even when fragmented, except for when it was clear that broken fragments belonged to the same seed (cf. van der Veen, 1992).

Correspondence analysis (CA) was used to explore relative compositional variation through the arrangement of samples along a set of axes based on species composition. Associations between species and/or samples are shown by the direction and distance in which they diverge from the

central (origin) point of the plot. Samples that cluster have a relatively similar composition whereas divergent samples are more compositionally distinct. CA was carried out using CANOCO 5 for Windows 8 (Ter Braak & Smilauer 2012). In all diagrams axis 1 (which accounts for the most variation) was plotted horizontally and axis 2 vertically.

Analysis of crop carbon and nitrogen stable isotope values was undertaken to infer water availability and soil nitrogen composition in order to characterise crop growing conditions and arable land management practices. Within archaeological stable isotopic research crop water availability is linked to the fractionation of carbon during photosynthesis and crop manuring status can be inferred from the volatilisation of the lighter nitrogen isotope after soil enrichment. The relative stable isotope ratios of carbon and nitrogen can then be used to infer the extent of human crop management systems and the use of varying husbandry techniques. Samples representing the four main cereal grain varieties, emmer wheat, hulled barley, 'small' barley and 'small' wheat, were selected from a range of contexts within the TC Oval as a means of assessing variation in crop growing conditions. In total, 41 subsamples, each containing 10 homogenized cereal grains, were selected for analysis (**Supplementary Table 1**). Cereal grains from representative samples were first screened using Fourier Transform Infrared Spectroscopy (FTIR) to identify possible post-depositional contamination. In each spectrum peaks characteristic of carbonate contamination (870 and 720 cm^{-1}) were observed. A hydrochloric acid pre-treatment (following Vaiglova *et al.* 2014) was, therefore, used on all cereal grains to remove carbonate traces. Stable isotope analysis was conducted using a Sercon EA-GSL mass spectrometer at the Research Laboratory for Art History and Archaeology at the University of Oxford. All values were measured with reference to international standards and were calibrated using an internal alanine standard. For $\delta^{13}\text{C}$ determinations, isotope ratios were normalized to the Vienna Pee Dee Belemnite scale (VPDB) using IAEA-C6 and IAEA-C7 standards (**Supplementary Table 2**). Values for $\delta^{15}\text{N}$ were calculated against the atmospheric composition of N_2 , using caffeine and IAEA-N2 standards (**Supplementary Table 3**). All calculations regarding crop stable isotope values were performed using the statistical programming language R (3.2.3). Calculation of $\Delta^{13}\text{C}$ values (following Farquhar *et al.* 1989) was accomplished using the $\delta^{13}\text{C}$ value of atmospheric CO_2 estimated from the AIRCO2_LOESS system (Ferrio *et al.* 2005). All results reported are also corrected for the minor effects of charring on $\delta^{13}\text{C}$ (by subtracting 0.11‰) and $\delta^{15}\text{N}$ (by subtracting 0.31‰) following Nitsch *et al.* (2015). Measurement uncertainties for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were calculated using the within-run variability of the raw measurements and the known uncertainty of the two reference standards using the approximation method (Kragten, 1994). The average measurement uncertainty for $\delta^{13}\text{C}$ was 0.094‰

and for $\delta^{15}\text{N}$ was 0.38‰. On the basis of the difference between the observed and known δ values of an in-house alanine and the long-term standard deviations of the alanine, accuracy or systematic error (u(bias)) was determined to be ± 0.125 for $\delta^{13}\text{C}$ and ± 0.2 $\delta^{15}\text{N}$ (following the Szpak *et al.* 2017 protocol).

Functional weed ecology was used to examine the intensity of crop cultivation and the level of labour input related to soil fertility. Discriminant analysis was used to make comparisons between modern weed floras grown under high- or low-input conditions and the archaeobotanical weed data presented in this paper. Modern studies were undertaken in a range of climatically varied regions including semi-arid regions of Morocco and southern Europe (Jones *et al.* 1999, 2000; Bogaard *et al.* 2018). Functional data on specific attributes (i.e. canopy height, canopy diameter, specific leaf area and leaf area per node: thickness) of arable weeds from known agricultural traits was gathered. Discriminant analysis was then performed using a combination of these functional weed traits that successfully separated the modern high- and low-input regimes, to produce a linear equation; this equation was then used to classify the TC Oval archaeobotanical samples based on the functional trait values of the weed species in each sample. Forty-six archaeobotanical samples, each containing 10 or more weed seeds identified to species, were included in this analysis. IBM SPSS Statistics 22 was used to perform the discriminant analysis.

Results

Assemblage Overview

The 58 samples analysed from the TC Oval primarily contained a very large quantity of well-preserved cereal grains, cereal chaff, pulses and weed seeds, as summarized in **Figure 6** (also see **Supplementary Table 4**). Cereal grains were, by far, the dominant component of the assemblage [averaging 84%]. By contrast cereal chaff [2%] and pulses [0.4%] were much less frequent. Weed/wild seeds (average composition of 13.8% per sample) were slightly higher, with nine samples found to contain over 40% of these taxa. Sample compositions were compatible with the results of crop processing analysis³, which will be presented fully as part of a planned future paper discussing storage context and plant consumption activities within the TC Oval assemblage. Overall, crop processing analysis indicated that cereals recovered from Rooms 4, 6, 8, 9 and 16 had been through

³ Based on a methodology developed by Jones (e.g. 1984, 1987).

threshing, winnowing, coarse- and fine-sieving stages and were likely being stored before final consumption, an interpretation consistent with the proposed function of these rooms (see above). Samples from Rooms 12, 13, 17, 18 and the North Courtyard appear more mixed potentially indicating their use for multiple activities including crop processing and grain storage.

Major Cereal Crops

Four different cereal species were identified from the TC Oval: 2-row hulled barley (*Hordeum vulgare* L.), the glume wheats emmer (*Triticum dicoccum* Schübl.) and einkorn (*Triticum monococcum* L.) and free-threshing wheat (*Triticum aestivum* L./*durum* Desf.). Of these, hulled barley was by far the most abundant component of the entire assemblage, totaling 563,629 grains and with 100% ubiquity across the assemblage (**Figure 7**). By comparison, the wheat species appear in much smaller proportions: emmer wheat was the most commonly identified, in 55% (32/58) of samples, with free-threshing wheat and einkorn wheat present in 38% (22/58) and 22% (13/58) of samples, respectively. A similar ratio between the glume wheats was also observed in terms of identified glume bases. Emmer wheat chaff was present in 26% (15/58) of samples whilst einkorn wheat chaff was present in 10% (6/58) of samples (**Table 2**).

Other Cultivated Crops and Collected Plants

Several pulse crops were also identified within the TC Oval assemblage (**Table 2**), lentil (*Lens culinaris* Medik.) and grass pea (*Lathyrus sativus* L./*cicera* L.) being the most common, occurring in 21% (12/58) and 12% (7/58) of samples, respectively. The ubiquities and total number of these species were significantly lower than the cereals, however, suggesting that they were not purposely being stored within the building. There was also a small amount of collected fruit/nut material present within the assemblage. These included grape seeds (*Vitis* sp.), pistachio (*Pistacia* sp.) and almond (*Amygdalus* sp.). The number of remains identified (all species had ubiquity of under 10%) again suggests that these plant items were not being stored in the TC Oval, but were likely to have been gathered and consumed in other areas of the city (Hald, 2005; 2008).

Weed/Wild Taxa

In total, 50 wild/weed taxa were identified from type- to species level, within the TC oval building, but only 17 were found in more than 10% of samples (see **Supplementary Table 4** for full species list). The most frequently identified remains were those of the wild grasses, particularly three species of goat grass (*Aegilops crassa* Boiss., *speltoides* Tausch. and *tauschii* Coss.) and *Lolium* cf. *rigidum* Guad (see **Table 3**), as well as *Sinapis* cf. *arvensis*, a species of wild mustard. These taxa

are all common arable weeds from cultivated fields and disturbed habitats (Guest, 1966) and are likely to have been found within the environs of Tell Brak. Additionally, the *Aegilops* species are known as crop mimics (Barrett, 1983; Anderson, 2006) and are very difficult to remove from the crop either in the field or during crop processing due to their appearance and size imitating that of domesticated cereals. There is no evidence that any of the wild/weed taxa were being cultivated as a crop and certainly the total sum of remains identified is significantly lower when compared with the total sum of cereal grains.

Small Cereal Grain Varieties

Throughout the TC assemblage a number of conspicuously small grains of barley (present in 86% - 50/58 samples) and wheat (present in 34% - 20/58 samples) were identified (**Figure 8**). These grains ranged from 0.5-1.5 mm in length, when compared with other 'normal' cereal grains which ranged from 3-4.5 mm. Morphologically, these grains appear to be small forms of domesticated *Hordeum vulgare* sp. and *Triticum* sp. rather than smaller wild species.

One hypothesis is that these smaller grains are 'tail' grains, i.e. the small grain commonly found in the distal florets of the cereal ear (Hillman, 1981). 'Tail' grains develop due to the process of floret growth within the ear. Glume primordia are initiated first, followed by the florets, after which spikelet growth decreases (Kirby & Appleyard, 1987). This leads to a gradient of floret development within the ear, with the most mature florets occurring at the base and in the middle of the cereal ear, whilst the top florets tend to be underdeveloped. Glume wheat grains developing in these top or very bottom florets tend to be smaller than grains from the lower and middle florets and in some cases a grain does not develop at all (Percival, 1921). The terminal spikelet of emmer wheat contains a single grain, in contrast to the other two-grained spikelets. Tail grains of wheat and barley are approximately 2/3rds of the larger grain but closely resemble them in shape. Under arid growing conditions or periods of drought grain, especially at the extremities of the ear may be under-developed or show signs of shrivelling due to the lack of water availability (Kirby, 2002), which, given the semi-arid nature of Tell Brak, the presence of 'tail' grains would not be implausible.

Within the TC Oval assemblage, however, the ratio of normal to small grains was lower than would normally be expected if small grains merely represented 'tail' grains⁴. Furthermore, 'tail' grains are

⁴ The ratios of normal to small grains in the TC Oval assemblage were: hulled barley = 563629:47914, emmer wheat = 29014:4860. The expected ratio of normal to 'tail' grains in unprocessed cereal ears are: hulled barley = 12:1, emmer

normally removed, along with small weed seeds and chaff, by sieving during crop processing activities. Clean, stored cereal grain would, therefore, be likely to contain a much higher ratio of ‘normal’ grains to ‘tail’ grains than would be present in the unprocessed ear (Hillman, 1981; Willcox, 2004). As discussed above, the proportion of cereal grains, chaff and weed/wild seeds within the TC Oval assemblage suggest that these stored crops had been through the fine-sieving process. This evidence combined with the ratios of normal to small grains identified in the assemblage indicate that the small grains do not *primarily* represent ‘tail’ grains of the normal hulled barley and wheat crops.

A second hypothesis is that these small grains instead represent the cultivation of a distinct *variety* or landrace of small-grained domesticated wheat and hulled barley at Tell Brak. These varieties may have been developed specifically to tolerate arid conditions and could potentially have been grown in less well-watered locations to maximise the use of marginal farming areas. The interpretation of these small grains will be explored in greater detail below with reference to the results of crop stable isotope analysis presented in this paper. Importantly, these small grained versions of barley and wheat do not resemble poorly developed grains but rather well developed grains of distinctly smaller absolute size (**Figure 8**).

Compositional Analysis

Correspondence analysis was carried out on all samples to explore the relationships between cereal crops and associated weed/wild taxa. **Figure 9a-b** show three discrete groups of samples: those dominated by hulled barley grains around the origin of the plot, those with relatively high proportions of glume wheat grains towards the right (positive) end of axis 1 and samples with a more variable composition of weed/wild taxa and free-threshing wheat toward the top (positive) end of axis 2 (see **Supplementary Table 5** for correspondence analysis codes). Each group of samples also has a distinctive set of accompanying weed/wild taxa. Hulled barley-dominated samples contained primarily large-seeded grasses (e.g. *Aegilops* sp. and *Lolium rigidum* Gaud.). Glume wheat dominated samples primarily contained *Galium* sp. and *Silene* sp. whilst the third grouping of samples had the widest range of species with significant quantities of *Gypsophila pilosa* Huds. and small-seeded legumes. These distinct groupings of cereals and weeds may indicate that each crop

wheat = 19:1 (these numbers are based on observations made of reference material at the University of Oxford). The estimated ratios then of normal to small grains in the TC Oval, if small grains represent ‘tail’ grains, should be hulled barley = 564501:47041, emmer wheat = 32180:1694.

was grown under distinct husbandry conditions and that the inhabitants of Tell Brak used a variety of farming strategies.

Crop Stable Isotope Analysis

Crop stable isotope analysis was carried out on the grains of two-row hulled barley, emmer wheat, small barley and small wheat (for full results of stable carbon and nitrogen isotope measurements see **Supplementary Table 6**). **Figure 10** shows the $\Delta^{13}\text{C}$ values from the four cereal taxa. Overall, variability within each taxon is limited (standard deviations are all within $\pm 0.5\text{‰}$ – cf. Nitsch *et al.* 2015), suggesting that each cereal was cultivated under consistently similar growing conditions. Due to the physiological differences between wheat and barley, such as the earlier ripening of the latter (Araus *et al.* 1997; Wallace *et al.* 2013), an offset of positive 1.0‰ was applied to the large and small barley grains. An ANOVA test was used to investigate inter-taxon variability and the results showed significant differences in $\Delta^{13}\text{C}$ values between the four cereals ($F(3, 37)=19.38$, $p<0.0001$). Further tests showed that the differences visible from **Figure 10** are statistically significant, in particular the $\Delta^{13}\text{C}$ values of small barley are considerably different from all other taxa (see **Table 4** for the results of all statistical tests). These results denote that whilst emmer wheat, small wheat and some hulled barley were grown under similar medium-low watering conditions, all of the small barley and a few of the hulled barley grains were grown under distinctly *drier* conditions. Overall, the $\Delta^{13}\text{C}$ values from all taxa are indicative of rain-fed farming rather than the use of artificial watering, but the values of small barley suggest that farmers were exploiting a range of growing conditions including the use of marginal arable land.

Stable nitrogen isotope values ($\delta^{15}\text{N}$) were also measured from all four taxa (**Figure 11**). These results showed a wide range of values and were more variable than would be expected from crops grown under consistent growing conditions (cf. Nitsch *et al.* 2015). Moreover, there were also significant differences *between* the values of hulled barley and the other three cereal taxa (see **Table 5** for the results of statistical tests). The manuring bands constructed by Bogaard *et al.* (2013) for temperate Europe have been adjusted using past rainfall estimates (cf. Bar-Matthews & Ayalon, 2011) from Tell Brak to take into account ecosystemic enrichment in ^{15}N caused by aridity (Styring *et al.* 2016, 2017). With this in mind, a number of samples still exhibit high $\delta^{15}\text{N}$ values that would exceed the enrichment caused by aridity alone. The use of manure has been extensively documented from Neolithic communities in south-east and central Europe (e.g. Bogaard *et al.* 2013, Vaiglova *et al.* 2021) and Bronze Age societies in the Middle East (Styring *et al.* 2017), where its use improved soil fertility and overall crop yields. The use of manure, however, was usually limited to the

immediate settlement environs as it is not easily transportable over long distances (e.g. Halstead, 2014). At Tell Brak emmer wheat, small wheat and some of the small barley indicate medium to high levels of artificial enrichment and may reflect preferential manuring. By comparison, hulled barley and the remaining small barley appear to have been grown without the use of manure and/or in areas of the landscape with low levels of enrichment.

The combined results of carbon and nitrogen stable isotope analysis indicate that there was preferential treatment of certain crops in terms of both manuring and better watered soils. Overall, the low $\Delta^{13}\text{C}$ values of small barley suggest that this crop was grown in much drier conditions than the wheats and hulled barleys. Similarly, the low $\delta^{15}\text{N}$ values of hulled barley (normal and small-sized) indicate that these crops were cultivated on land without artificial enrichment, whilst wheat crops did receive the application of some manure/midden material.

Functional Ecological Analysis of Weeds and the Intensity of Cultivation

The intensity of cultivation was assessed relative to known modern farming regimes using the functional ecological analysis of weed data presented in this paper from the Tell Brak TC Oval. A discriminant function extracted to distinguish high- and low-intensity agricultural systems in southern Europe and Morocco (**Figure 12a**) was used to classify the archaeological samples based on the functional ecological attributes of identified weed taxa (Bogaard *et al.* 2016, 2018). Of the functional attributes measured (see **Methods**), specific leaf area was found to be the most important attribute in terms of discriminating between both the ethnographic datasets and the archaeological data. **Figure 12b** shows the results of this discriminant analysis and clearly demonstrates that the majority of samples from Tell Brak are located towards the low-intensity end of the spectrum, with only one sample classified as high-intensity. This sample was taken from Room 12 and had a mixed composition of hulled barley and glume wheat, but also the lowest probability classification in the assemblage (76%) suggesting that the categorization of this sample as high-intensity is not reliable. All other samples were classified with very high probabilities (i.e. over 90%) and 40 samples were classified with 100% probability. When compared with modern weed datasets, the Tell Brak samples are significantly lower than all other results, but some points do correlate with samples from modern low-intensity agricultural regimes which were characterized by limited use of manuring, no large-scale irrigation and low rates of disturbance (i.e. weeding and tillage), e.g. fields in Haute Provence, France and Moroccan rain-fed terraces. The results from Tell Brak suggest therefore that crops stored in the TC Oval were managed in a similar fashion. They also reinforce

previous functional ecological analysis carried out on other mid-3rd millennium samples from Tell Brak (Bogaard *et al.* 2018) and are indicative of an extensive, low-input agricultural production system in use during this time period.

Discussion

The Role of Cereals at Tell Brak

At Tell Brak the cultivation and use of cereals is well attested from multiple periods (e.g. Colledge, 2003; Hald, 2008) and this evidence has been further strengthened by the results from the TC Oval building. Cereals appear to have been the primary source of food for human consumption with by-products used for animal fodder, and may also have been an important trading commodity between other settlements to the north and the major cities of southern Mesopotamia via the Euphrates River (Forrest *et al.* 2004). Of the cereals recovered from the TC Oval, 2-row hulled barley was by far the most commonly identified and was the dominant component of the entire assemblage. It is likely that the 2-row variety was favoured over the more productive 6-row due to its lower water requirements (Townsend *et al.* 1966: 85), whereas 6-row hulled barley has been recorded in southern Mesopotamia, presumably under irrigation (e.g. Renfrew, 1984). All recovered hulled barley from the TC Oval was in a well processed state with very little barley rachis or weed/wild remains identified. This level of cereal processing would have been very labour intensive and time consuming suggesting that this grain was intended for human consumption rather than for use as animal fodder.

The glume wheats, emmer and einkorn were also commonly recovered, albeit in much lower quantities than those of hulled barley grain. Of these species, emmer was the most frequently identified whereas einkorn was only occasionally recognised, indicating that it may have been a crop contaminant of emmer rather than a cultivated crop in its own right. In a similar manner, free-threshing wheat was also found in only a small number of samples and often separate from the clean hulled barley grain. This would suggest that both glume wheat and free-threshing wheat were still important crops for the inhabitants of Tell Brak but that they were not the primary focus of production within the TC Oval building. Furthermore, if as suggested by Emberling & McDonald (2003) the TC Oval was a public building for the production and administration of grain rations to workmen, it is possible that the emmer and free-threshing wheat were intended for another form of domestic human consumption within the structure. Further discussions around crop consumption at

Tell Brak are planned as part of a future paper on the TC Oval assemblage. This will combine crop processing data, storage context and material culture with ongoing bioarchaeological research at the site to expand current interpretations of agricultural production and consumption at Tell Brak during the Bronze Age.

The Question of Trade and Crop Importation

A source of debate with regards to the agricultural economy of Tell Brak is to what extent the archaeobotanical cereal grains recovered from the TC Oval are representative of crops grown in the immediate environs of the city, or whether staple foods could have been imported from other urban settlements in northern Mesopotamia (e.g. McCorriston, 1995; Wilkinson, 2000). Varying lines of evidence including the identification of early stage crop processing activities from the mid-3rd millennium BCE at Tell Brak (Charles & Bogaard, 2001) and presence of sherd scatters and the 'hollow ways' (Wilkinson, 1994; Ur, 2003 – **Figure 3**) indicates that some form of arable agriculture was taking place at the site. However during this period, semi-arid conditions meant that Tell Brak was located in a marginal area for rain-fed agriculture and even small changes to annual rainfall levels could have had a catastrophic effect on crop production (Wilkinson, 2003; Riehl, 2009). This has led to suggestions that Tell Brak would not have been able to survive periods of even minor drought without the assistance of regional trade networks (c.f. Wilkinson, 2000) In particular, it has been proposed that crops could have been imported from other sites further to the north, such as Tell Leilan, that were situated in wetter areas more favourable for rainfed agriculture (Weiss *et al.* 2002; Smith, 2012).

The lack of textual sources from Tell Brak during the Early Bronze Age period has, however, precluded the identification of these trade networks and made it difficult to ascertain exactly where traded crops were coming from. Instead, the assessment of crop stable carbon isotope values provides direct evidence of the growing conditions relevant to crops from a site. With this in mind, it is possible to compare the $\Delta^{13}\text{C}$ values from crops stored in the TC Oval with values from mid-3rd millennium BCE crops recovered from Tell Leilan (Styring *et al.* 2017) where higher rainfall levels would certainly have allowed for cultivation around the site, as well as other southerly sites in the middle Khabur valley (Riehl *et al.* 2014). Crops from the more northerly sites are expected to have been grown under wetter conditions due to the higher annual rainfall in this area. If the crops from the TC Oval originally came from these sites, the stable carbon isotope values would be expected to be similar to these northerly values. Comparison of the TC results with values from Tell Leilan

(Styring *et al.* 2017), however, indicates that the Tell Brak material was grown under significantly *drier* conditions overall (see **Table 6**). Furthermore, even the values from the TC emmer wheat, thought to have been grown in relatively well-watered soils, still appear drier than glume wheats from Tell Leilan.

These results indicate that the TC Oval crops are unlikely to have been grown in the higher rainfall zone of Tell Leilan, and by extension at other northern sites located within higher rainfall conditions. Instead the carbon stable isotope results from Tell Brak correlate roughly with carbon isotope results from other mid-3rd millennium BCE sites in the middle Khabur valley (Riehl *et al.* 2014) located within the same rainfall isohyet (see **Table 7**). Generally, the results from the TC Oval are a fraction higher than the middle Khabur sites and this may be reflective of Tell Brak's slightly higher annual rainfall due to latitude, but overall comparison of these values indicates that the TC crops were most likely to have been grown within the environs of Tell Brak. This does not lessen the role of Tell Brak with regards to the trade of goods and staple products with other sites in both northern and southern Mesopotamia, however, and it is likely that the site was mobilising as well as growing crops during this period (e.g. Powell, 1990).

Evidence for agricultural practice from the TC Oval

The results of crop stable isotope analysis and functional ecology, from the crops stored in the TC Oval, combined with other archaeological and topographical evidence provide insights into how the landscape of Tell Brak was farmed. Overall, agricultural production appears to have been large-scale and 'extensive' with relatively low inputs of labour, water and manure. Within this system, however, certain aspects of the farming regime would have been tailored to overcome the environmental challenges faced by the inhabitants of Tell Brak, specifically the preferential treatment of some cereal species.

The results of stable carbon isotope analysis of cereal grains suggest how the natural hydrology of the landscape around Tell Brak was exploited. In general, none of the cereal species appear to have been grown in markedly wet conditions, but a portion of the hulled barley and the small-grained barley variety do appear substantially drier than the emmer or small-grained wheat. This could indicate that both varieties of hulled barley were grown under drier conditions in marginal soils for agriculture, possibly because it is more tolerant of drought than wheat (Hillman, 1985; Riehl, 2009) with wheat grown in better watered soils near the wadis. Certainly, the isotopic values from the small-grained barley represent the driest conditions found in the TC Oval assemblage, and it is

likely that the production of this variety would have required less water than their larger grained counterparts (Alghabari & Zahid Ihsan, 2018). To date, these smaller grain varieties have not been reported from other sites in Mesopotamia, suggesting that they may have been developed and cultivated specifically at Tell Brak to take advantage of the range of farming conditions present around the main mound.

The use of manure or any other form of fertilization for agriculture is barely mentioned in Bronze Age texts; as Postgate (1992: 172) suggests, it was perhaps of no concern to the official scribes. Use of manuring/middening in the fields at Tell Brak has, however, been documented archaeologically from scatters of 3rd millennium BCE abraded pottery sherds, supporting the identification of specific cultivation areas around the mound (Wilkinson, 1994; Ur & Colantoni, 2010). Similarly, manure use has been attested at Tell Brak through the use of nitrogen stable crop isotope analysis (Styring *et al.* 2017; Bogaard *et al.* 2018) and has indicated that individual households had access to cereals grown under a range of conditions. The results of nitrogen ($\delta^{15}\text{N}$) stable isotope analysis from TC Oval seemingly mirror the carbon results discussed above with a clear separation between the values for wheat and barley. Results from hulled barley and the majority of the small-grained barley fell within the lowest manuring band, indicating that manure/middening material had not been applied to the field in which these crops grew within the last 3+ years (Bogaard *et al.* 2007; Fraser *et al.* 2011). By contrast, the higher isotope values for emmer and small-grained wheat showed that these crops were being grown in soils artificially enriched through the application of medium-high inputs of manure. Furthermore, if wheat crops were being grown in the better watered soils near the wadis, these alluvium soils would also be naturally enriched with nutrients (French, 2003).

As was discussed above, the use of manure has two limiting factors: availability and transportation. These limitations suggest that wheat crops were being grown in immediate 'infield' areas of Tell Brak where access to manure or household midden material would have been less constrained. By contrast, barley crops may have been being cultivated within the 'outfield' region further away from the urban centre. This model of landscape use seemingly fits with the 'halos' of sherd scatters located near the city (Wilkinson, 1994; Ur, 2003) and supports the existence of a manuring/middening spectrum which fades in intensity with distance from the main mound (Styring *et al.* 2017).

The cereal economy and crop production in north Mesopotamian

Evidence from the TC Oval then fits with wider evidence for the cereal economy in Mesopotamia. Archaeobotanical evidence from sites in both northern and southern Mesopotamia alongside documentary evidence from Tell Beydar (Van Lerberghe, 1996) and other palace archives in the south (Postgate, 1992: 170) indicate that cereal cultivation was the backbone of the agricultural economy in this region during the Bronze Age (see **Table 8** for summary of northern Mesopotamian sites in Syria with identified cereal grain remains). The staple cereal economy is thought to have supported the expansion of Late Chalcolithic populations during the early 4th millennium BCE as well as sustaining these communities through a period of urban ‘devolution’ during the Early Bronze Age (Wilkinson, 2000) and the subsequent phase of re-urbanization that followed in the 3rd millennium BCE (Ur, 2010).

The predominance of hulled barley seen at Tell Brak is consistent with a number of other sites in northern Mesopotamia including Tell Leilan (Miller, 1991) and Tell Bderi (van Zeist, 1999). Archaeobotanical evidence from the Khabur Basin Project (McCorriston & Weisberg, 2002), however, suggests that hulled barley has not always been the primary cereal crop cultivated in this region. Instead they suggest that during the 5th and 4th millenniums BCE that glume wheat was the dominant crop and that the cultivation and consumption of hulled barley did not expand until the early 3rd millennium BCE. Evidence for these changes to cereal production systems have been identified from a number of sites, such as Tell es-Sweyhat in eastern Syria ⁵ (Miller, 1997), Tell Atij in western Syria (McCorriston, 1995), a number of sites within the middle Khabur Basin (e.g. Hole, 1991; Zeder, 1994) and from cuneiform evidence in southern Mesopotamia (Jacobsen & Adams, 1981). Reasons for this change from wheat to barley are often associated with the period of aridity at the end of the 4th millennium BCE and the greater tolerance of hulled barley to drought and saline conditions (Hillman, 1985; Nesbitt, 1996; Riehl, 2009).

Other explanations suggest that increased hulled barley production was connected with an expansion in animal herding and equivalent need for large quantities of fodder (Miller, 1997). This is supported by texts from Tell Beydar that list hulled barley as a fodder crop (Van Lerberghe, 1996) as well as a regional expansion in cattle herding during this period (Zeder, 2003). At Tell Brak, glume wheat does appear to have been more prevalent than hulled barley during the Late Chalcolithic (Hald, 2005). Hulled barley when identified, however, was found in a number of storage contexts and, contrary to the theory outlined above, was thought to have been destined for

⁵ The lack of glume wheat grains identified at Tell es-Sweyhat could be due to the small number of samples recovered from this site.

human consumption, in the form of bread or possibly beer (Postgate, 1992: 170; McCorrison & Weisberg, 2002), due to its highly processed condition (Hald, 2005: 122). As discussed above, hulled barley from the TC Oval was recovered in a similarly well processed state suggesting that it was intended for human consumption.

In direct contrast to the increase in cultivation of hulled barley, the cultivation of glume wheats seems to have decreased within northern Mesopotamia during the Bronze Age. At Tell Brak, the occurrence of glume wheats decreased from the Early Uruk period (Colledge, 2003) and in the north Syrian Euphrates region the cultivation of emmer wheat is radically reduced during the Early Bronze Age (van Zeist & Bakker-Heeres, 1988). Similarly, when all the archaeobotanical results from Tell Brak are examined chronologically a decrease in the cultivation and use of glume wheats is apparent (c.f. Hald, 2008). This trend can also be seen in the TC Oval data. Glume wheat grain still forms an important portion of the assemblage, but was recovered in significantly lower quantities when compared with hulled barley. There have been a number of theories regarding this decrease in glume wheat production, including social choice and the worsening climatic conditions present in the Late Uruk period favouring the production of hulled barley. McCorrison & Weisberg (2002) also suggest that the reduced visibility of glume wheat within the archaeobotanical record during the 3rd millennium BCE is because these cereals require different methods of processing and so were stored separately from free-threshing hulled barley crops. Certainly, extra crop processing stages are needed in order to de-husk glume wheat spikelets (Hillman, 1985; Jones, 1990) leading to the suggestion that they were grown primarily within the domestic sphere and stored at the level of the individual household (McCorrison & Weisberg, 2002) rather than in large public buildings such as the TC Oval.

The results of crop stable isotope analysis from the TC Oval and the theory of 'extensive' crop production at mid-third millennium BCE Tell Brak as suggested by functional ecological analysis, also correlate with the findings of other stable isotope studies from sites such as Tell Leilan, Hamoukar, Tell Sabi Abyad and Tell Zeidan in northern Mesopotamia. Previous work by Riehl *et al.* (2014) and Styring *et al.* (2017) has found that there appears to be no significant changes to crop $\Delta^{13}\text{C}$ values from the Ubaid period to the Bronze Age (5300-2500 cal. BCE) at all sites in this region, a factor that would be expected if crops were reliant solely on variable annual rainfall. Instead, this lack of isotopic variation indicates that there was some type of water resource management, even if this was only the strategic sowing of certain crops in better-watered soils around the site. Work by Styring *et al.* (2017) has also shown that wheats and pulses, throughout sites in northern Mesopotamia, tend to be better watered than hulled barley crops. This again

corresponds directly with the stable isotope results from the TC Oval and indicates that the preferential treatment of some crops was a strategy to maximise yields in poor arable conditions at Late Chalcolithic and Bronze Age settlements in this region, rather than a practice unique to one site.

In terms of nitrogen crop stable isotope analysis, results from Araus *et al.* (2014) and Styring *et al.* (2017) indicate that there was a general decrease in cereal grain $\delta^{15}\text{N}$ values through time at various sites in the Near East and northern Mesopotamia. This has been linked with an overall decrease in soil fertility due to the increased exploitation of arable areas (Araus *et al.* 2014) and the cultivation of more marginal agricultural zones. Additionally, Styring *et al.* (2017) have linked the decrease in $\delta^{15}\text{N}$ values with an equivalent increase in site size at Tell Leilan, Hamoukar, Tell Sabi Abyad, Tell Zeidan and Tell Brak as populations expanded during the Bronze Age. Increased population sizes would have required the production of greater quantities of grain and the expansion of agricultural areas beyond the immediate environs of the main settlement. These ‘outfield’ plots would necessarily receive lower inputs of manure due to the difficulty associated with the transportation of this resource over long distances. The combined stable isotope and functional ecology results from the TC Oval seem to fit within this model (Styring *et al.* 2017) and as was discussed above, may indicate that wheat crops were grown within the ‘infield’ areas close to the Tell Brak main mound whilst barley was primarily cultivated within the ‘outfield’. The combination of these crops within the same storage area then would suggest that agricultural land ownership was spread over both of these disparate areas and that this spatially variable method of production may have been a risk-buffering mechanism.

Conclusion

The multi-stranded analysis of archaeobotanical material recovered from the TC Oval has provided a wealth of new information about agricultural production at Tell Brak in the mid-3rd millennium BCE. The use of traditional archaeobotanical techniques combined with crop stable isotope analysis and functional weed ecology has shown not only what was being grown, but also potentially how it was being grown and where. The Oval itself seems to have played an important administrative role at the site as a storage depot for fully processed cereal grains as well as potentially a centre for the distribution of worker’s rations. Within the building the predominance of clean hulled barley

suggests that, contrary to previous theories, hulled barley was prepared for human consumption, although this would not preclude its use as a fodder crop as well. Additionally, the identification of small-grained varieties of hulled barley and glume wheat indicates that the farmers of Tell Brak were growing a wider range of cereal varieties, including small-grained versions suited to poor growing conditions, than has been identified from other sites in the region. The use of crop stable isotope analysis has revealed that these different cereal crops were likely grown in different areas of the Tell Brak landscape to take advantage of the uneven environmental conditions. These results suggest that glume wheat crops were grown in wetter soils surrounding the nearby wadis whilst hulled barley, and the small barley variety in particular, were grown in drier areas with little artificial enrichment.

This use of both 'infield' and 'outfield' areas around the main city would have allowed the cultivation of large areas of land with limited labour resources whilst also maximising the potential arable yield by exploiting the stress-tolerant nature of barley for use in marginal environmental conditions. Finally, comparisons with carbon stable isotope studies from other nearby sites within the Upper Khabur plain would suggest that the crops stored in the TC Oval were not being imported from areas with higher precipitation levels to the north. Instead, the stored crops appear to have been grown locally, in the arable catchment surrounding the city. Overall, these results indicate that, even though mid-3rd millennium Tell Brak was located in a semi-arid region on the edge of the 'zone of uncertainty' (Wilkinson *et al.* 2014), careful agricultural management and regime choice allowed farmers to overcome environmental challenges and maximise arable production.

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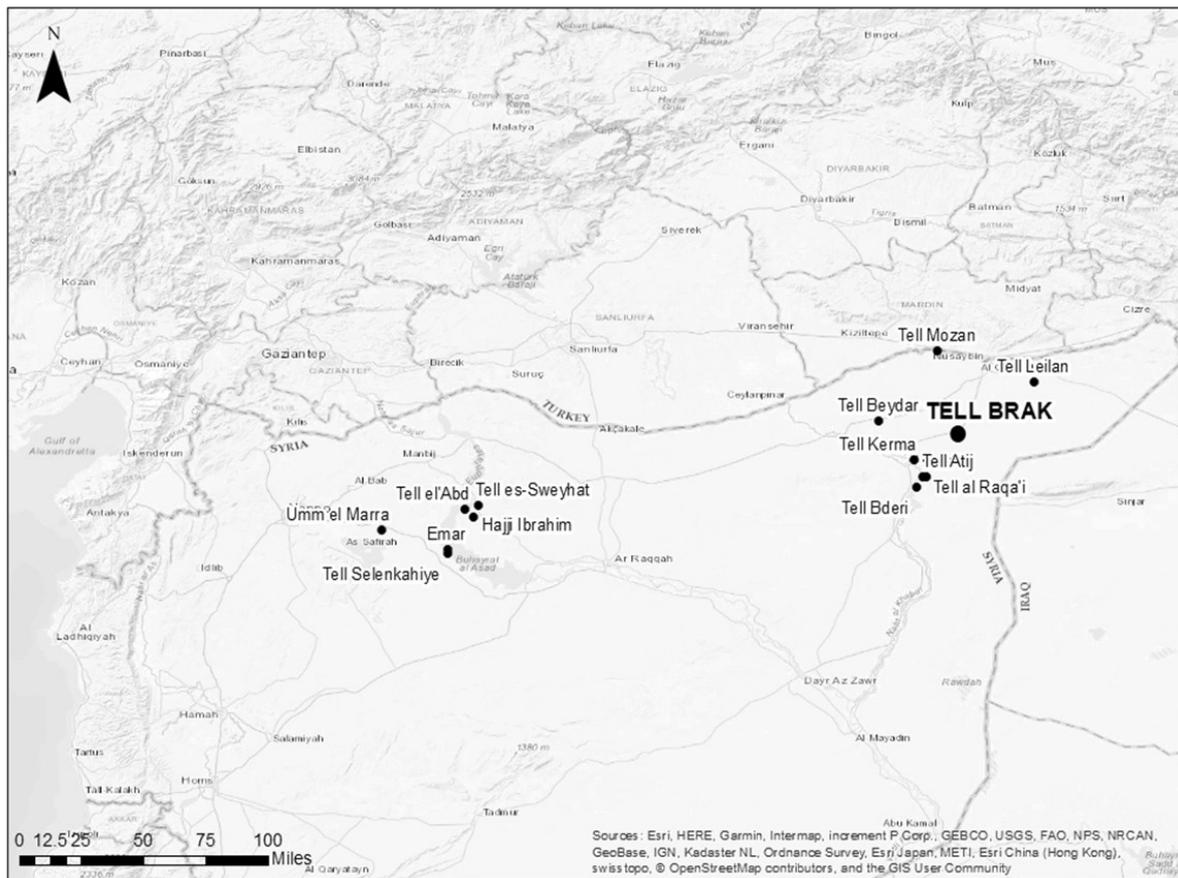


Figure 1 – Map showing the location of Tell Brak and other northern Mesopotamian sites with archaeobotanical remains mentioned in this paper

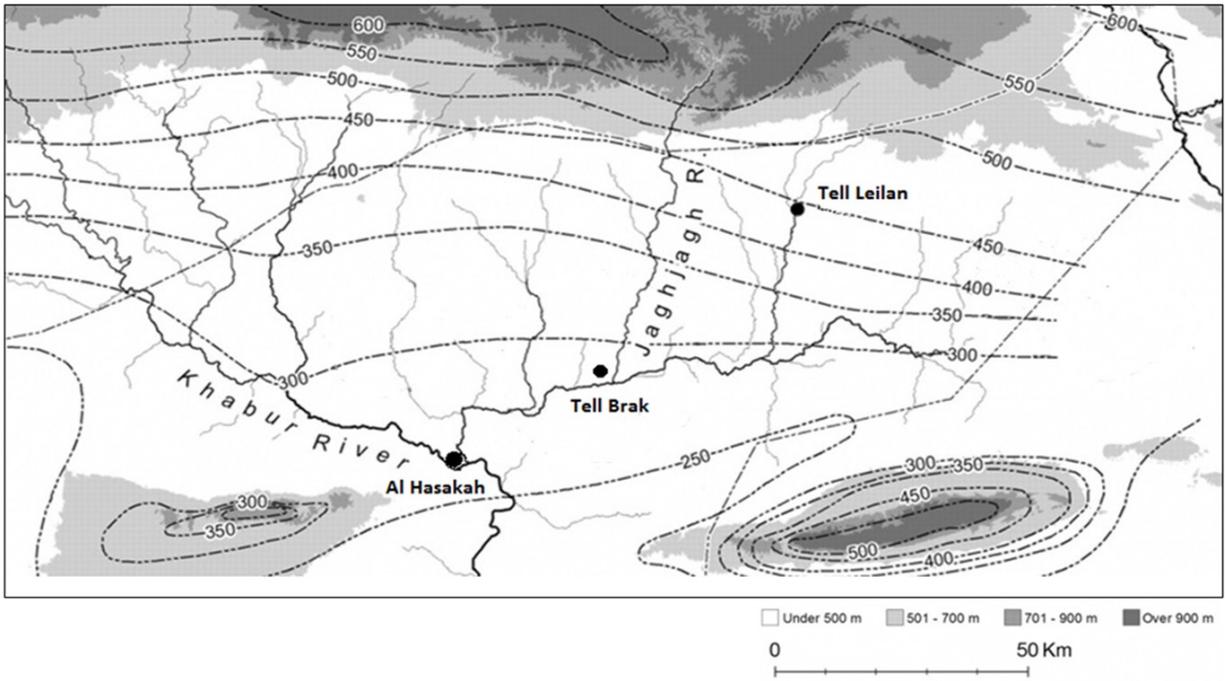


Figure 2 – Map showing the Upper Khabur Basin (based on Menze & Ur, 2012)



Figure 3 – CORONA satellite photo showing the ‘hollow ways’ radiating out from the central mound of Tell Brak (Ur, 2003).

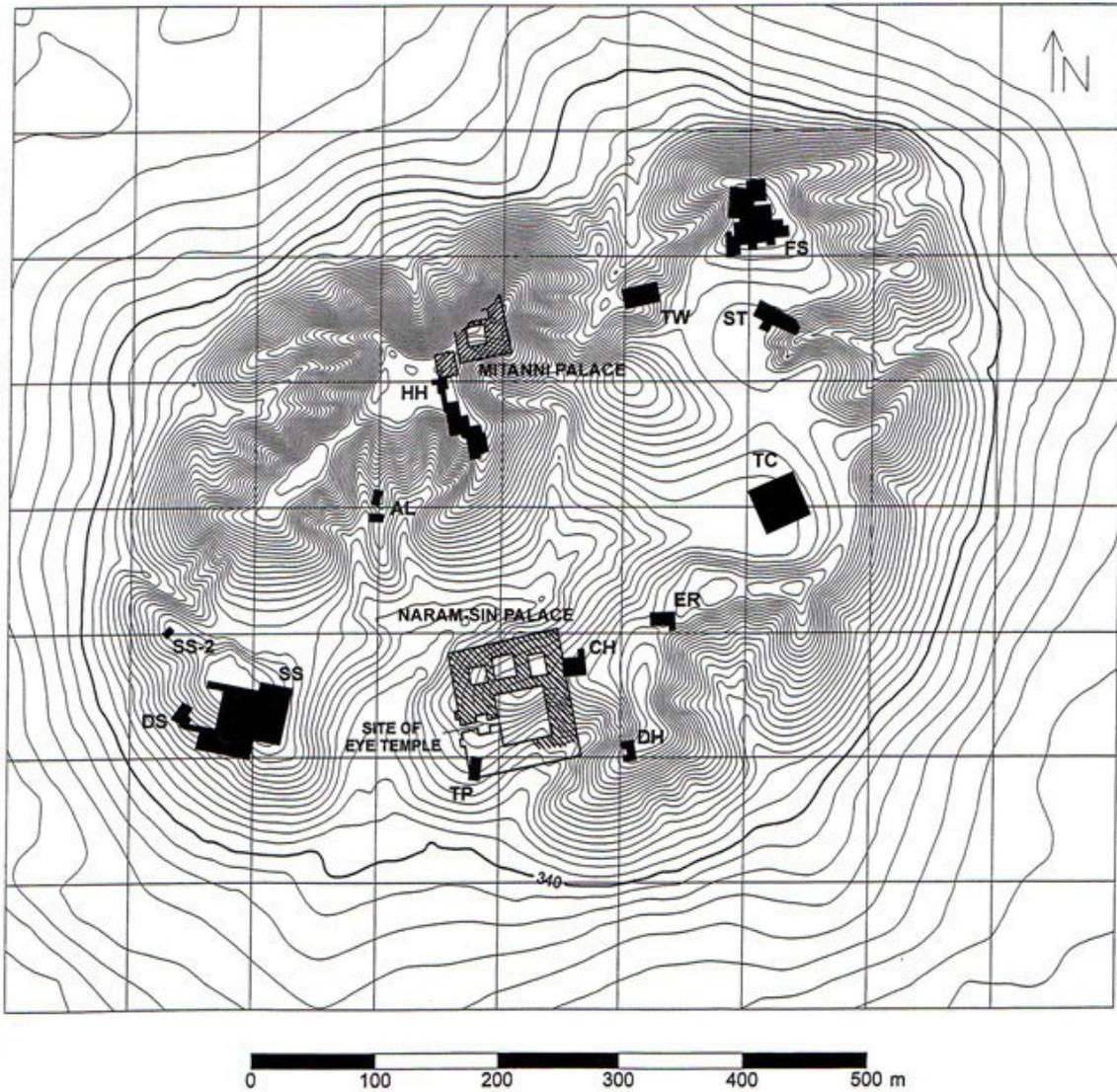


Figure 4 - Plan of the main mound at Tell Brak showing Area TC and other excavation areas (Emberling *et al.* 1999)

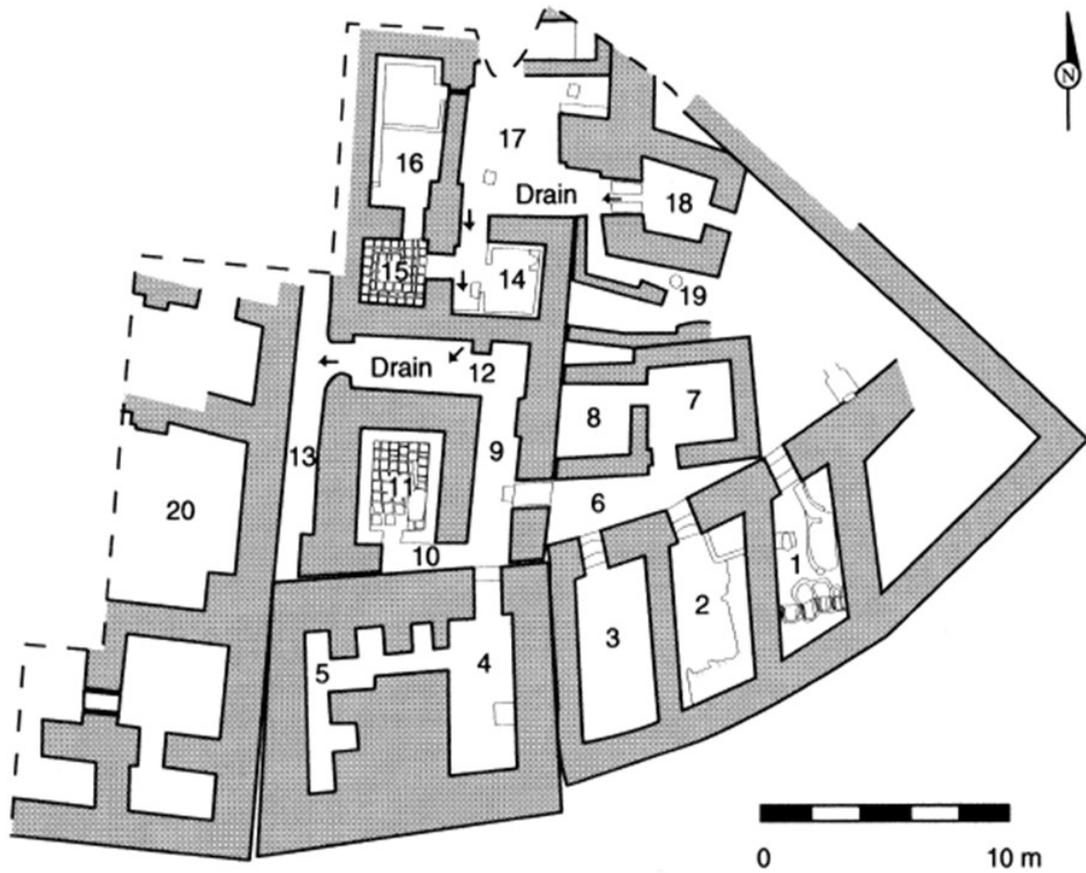


Figure 5 – Plan of Area TC and the Temple Oval building (Emberling & McDonald, 2001)

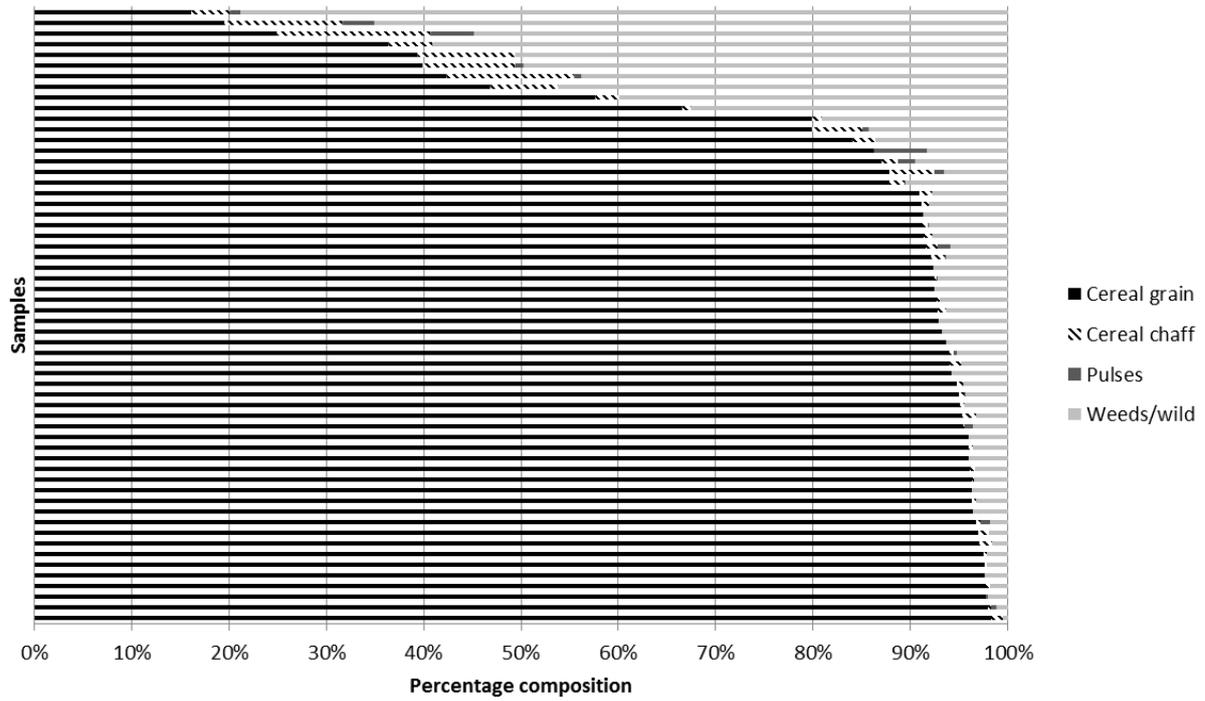


Figure 6 – Percentage stacked bar chart of all samples from Tell Brak showing the proportions of the four major categories of plant remains. Samples have been sorted to emphasize the contrast between those dominated by cereal grains and those dominated by weed/wild taxa

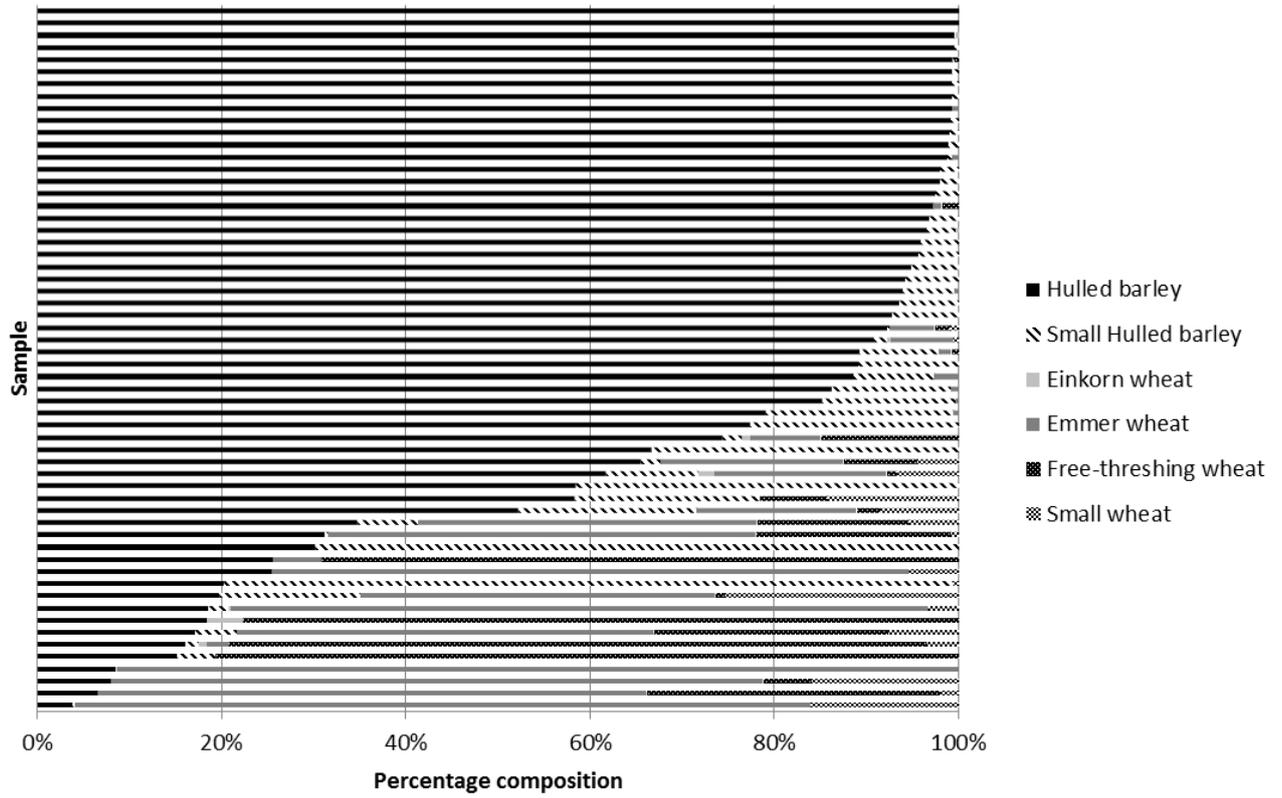


Figure 7 – Percentage stacked bar chart of all samples showing only major cereal proportions. Samples have been sorted to emphasize the contrast between those dominated by hulled barley grains and those dominated by emmer wheat grains



Figure 8 – Photos of the ‘normal’ and small hulled barley grain varieties (left) and ‘normal’ and small wheat grain varieties (right)

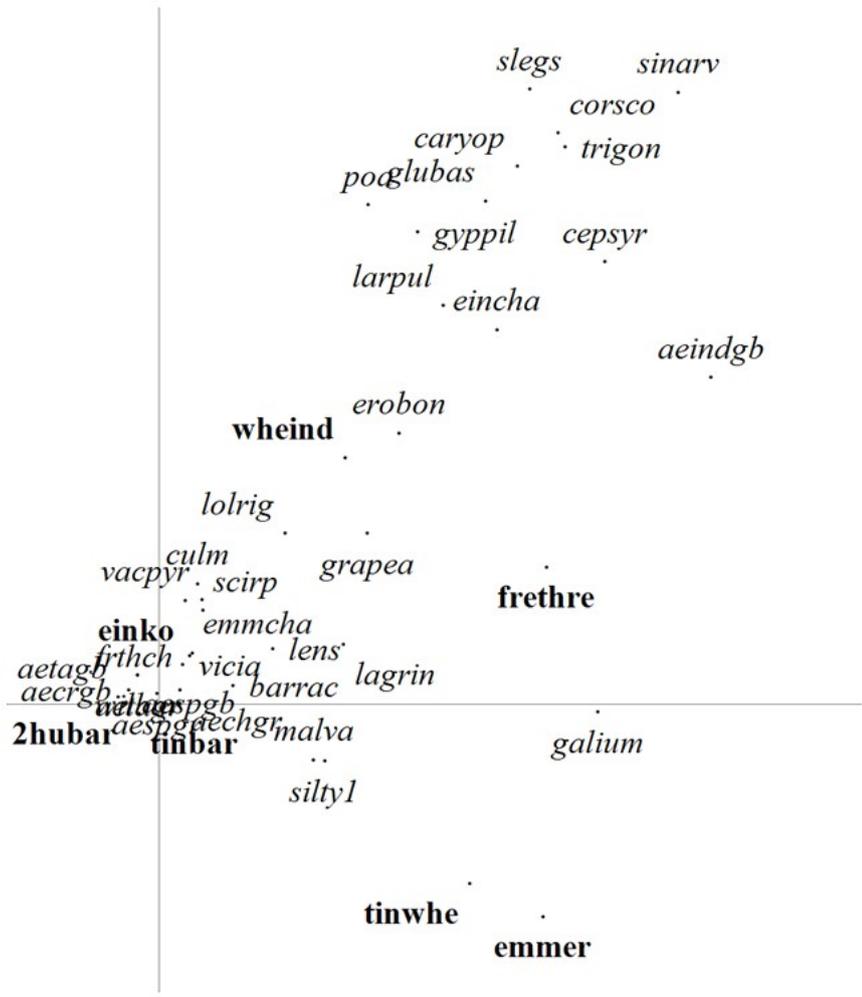
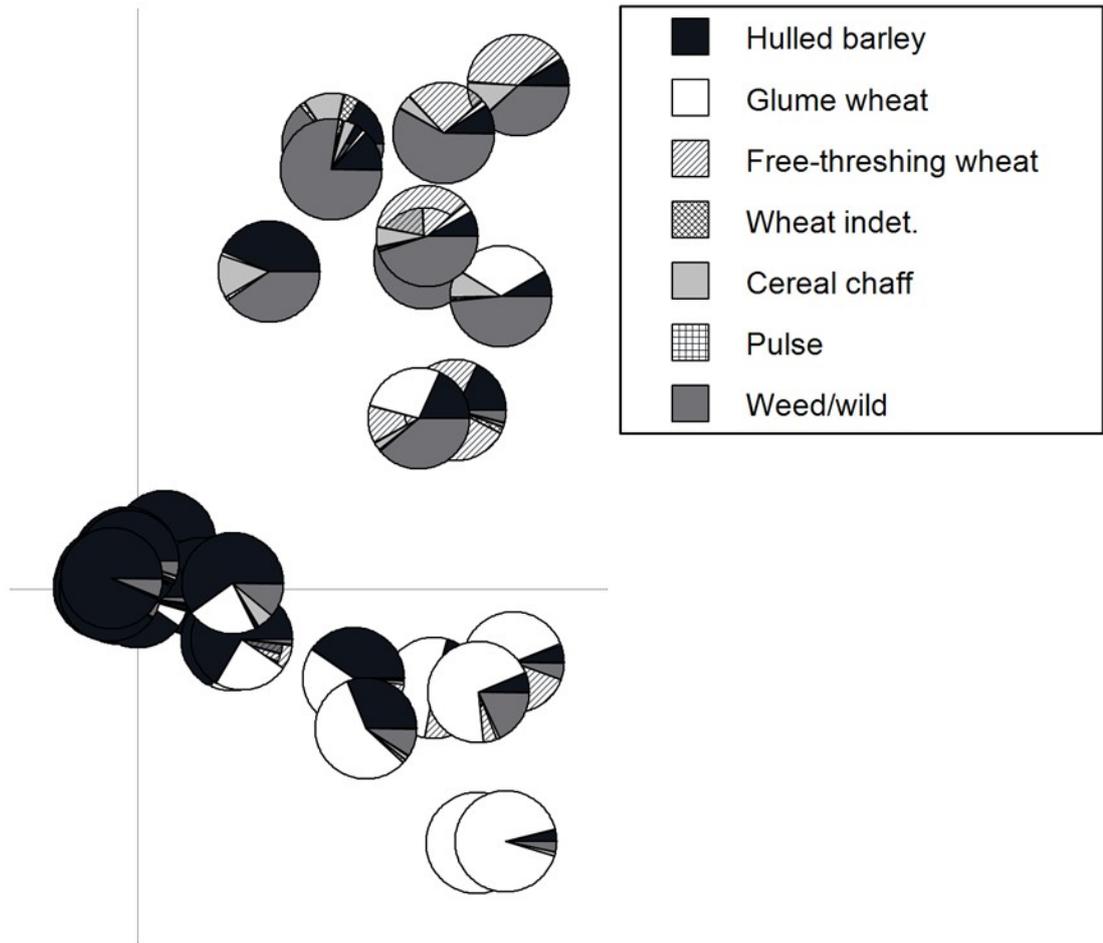


Figure 9a – Correspondence analysis scatterplot of 41 taxa



9b – Correspondence analysis plot of 58 samples with samples represented as pie charts showing the proportions of major plant item categories

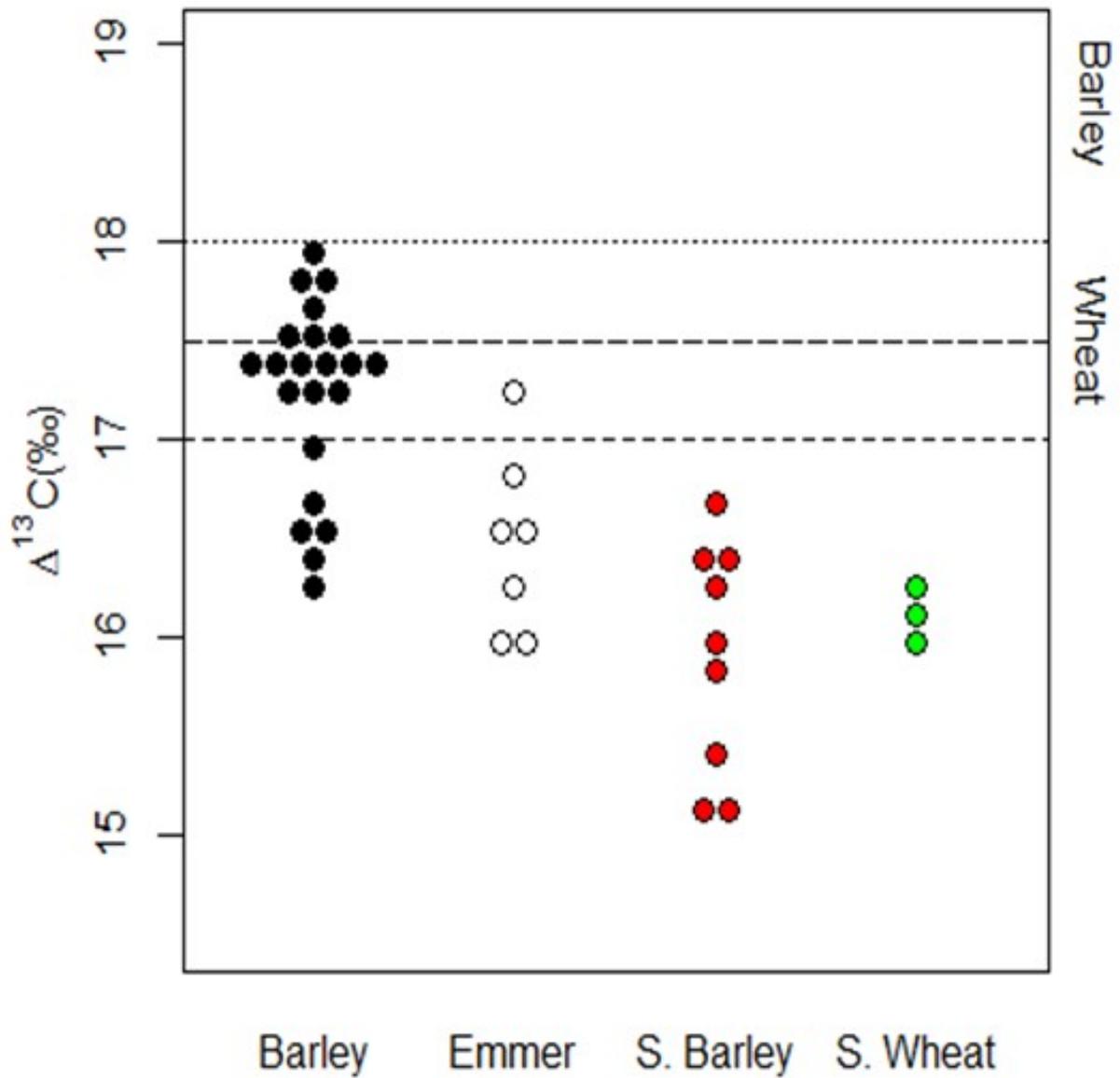


Figure 10 – $\Delta^{13}\text{C}$ values of the four major cereal taxa. The lower dashed line indicates the beginning of the ‘well-watered’ zone for wheat. The middle and upper dotted lines indicate the beginning of the two potential ‘well-watered’ zones for barley. S. Barley and S. Wheat refer to the small barley and wheat grain varieties

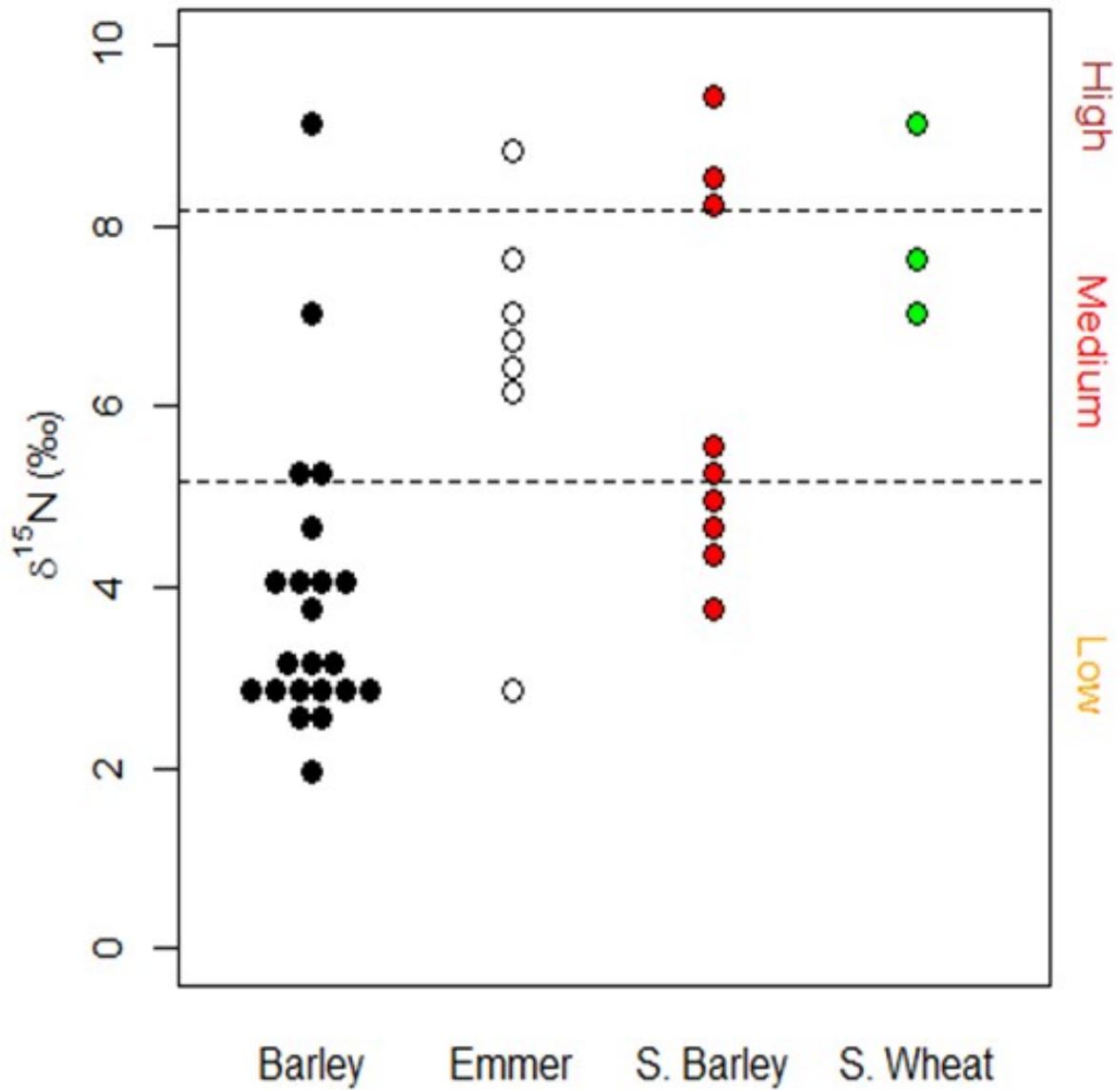


Figure 11 – $\delta^{15}\text{N}$ values of the four major cereal taxa, with manuring bands adjusted for aridity (after Styring *et al.* 2016, 2017)

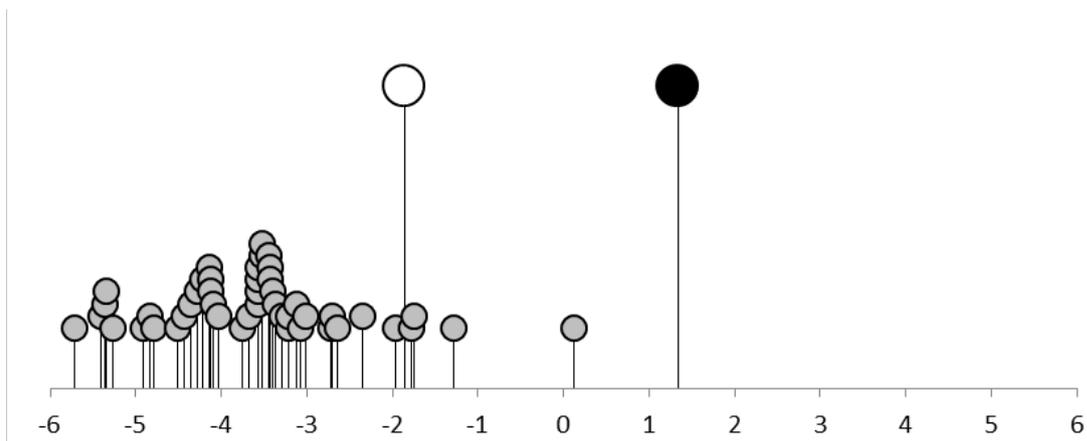
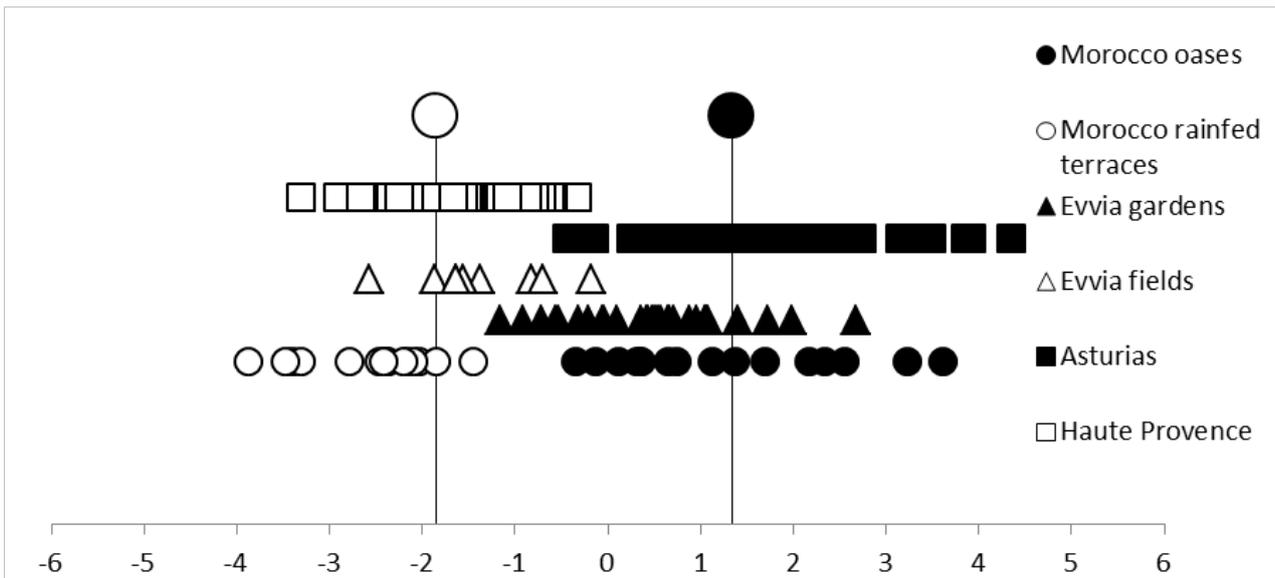


Figure 12a – Combined plot of modern field survey samples in relation to the discriminant function extracted to distinguish between high (black) and low (white) intensity crop husbandry regimes, **b** – Plot of Tell Brak samples in relation to the discriminant function extracted to distinguish between high and low intensity crop husbandry regimes

Table 1 – The number of samples studied from the Tell Brak TC Oval building, by room number

Room No.	No. of Samples
4	1
6	1
8	5
9	2
12	12
13	1
16	27
17	4
18	1
Ncy	3
Unknown	1
Total	58

Table 2 – Summary of the frequency and abundance of major plant taxa

Plant item	Presence	Ubiquity (%)	Max/Sample	Sum
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Cereal grains				
<i>Hordeum vulgare</i>	58	100	193280	563629
<i>Hordeum vulgare</i> (small)	50	86	33024	47914
<i>Triticum monococcum</i>	13	22	256	732
<i>Triticum dicoccum</i>	32	55	7579	28266
<i>Triticum aestivum/durum</i>	22	38	3432	11136
<i>Triticum</i> (small)	20	34	1112	4860
Chaff				
<i>Triticum dicoccum</i> glume base	15	26	768	2128
<i>Triticum monococcum</i> glume base	6	10	132	256
Glume base indet.	22	38	384	1117
<i>Triticum aestivum/durum</i> rachis	5	9	256	310
<i>Hordeum vulgare</i> rachis	16	28	768	1242
Culm node	21	36	128	376
Pulses				
<i>Lens culinaris</i>	12	21	128	278
<i>Pisum sativum</i>	2	3	8	9
<i>Lathyrus sativus</i>	7	12	12	31
<i>Vicia ervilia</i>	1	2	1	1
<i>Vicia/Lathyrus</i> type	6	10	256	294
Large pulse indet.	12	21	20	90
Weeds				
Weed/wild chaff	54	93	18588	35317
Weed/wild	58	100	2048	17786

Table 3 – Summary of the frequency and abundance of major weed/wild taxa

Weed/wild taxa	Presence	Ubiquity (%)	Max/sample	Sum
<i>Aegilops crassa</i>	38	66	538	1945

<i>Aegilops speltoides</i>	24	41	768	1216
<i>Aegilops tauschii</i>	28	48	397	1359
<i>Gypsophila cf. pilosa</i>	17	29	160	784
<i>Lolium cf. rigidum</i>	33	57	256	1222
<i>Sinapis cf. arvensis</i>	14	24	1200	2780
<i>Vaccaria pyramidata</i>	20	34	512	1232

Table 4 - Results of an ANOVA test and post-hoc analysis conducted on the $\Delta^{13}\text{C}$ values from all cereals with a 1‰ offset applied to the barley

Statistical Test	Species	Results (1.0‰ offset)
ANOVA	All	F(3,37)=19.38, p=<0.0001
Post-hoc Tukey's Test	Emmer-Barley	0.6465
Post-hoc Tukey's Test	S. Barley-Barley	<0.001
Post-hoc Tukey's Test	S. Wheat-Barley	0.9679
Post-hoc Tukey's Test	S. Barley-Emmer	<0.001
Post-hoc Tukey's Test	S. Wheat-Emmer	0.6643
Post-hoc Tukey's Test	S. Wheat-S. Barley	0.0035

Table 5 - Results of an ANOVA test and post-hoc analysis on the $\delta^{15}\text{N}$ values of the four cereal taxa

Statistical Test	Species	Results
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ANOVA	All	F(3,37)=0.807, p=4981
Post-hoc Tukey's Test	Emmer-Barley	0.0076
Post-hoc Tukey's Test	S. Barley-Barley	0.0160
Post-hoc Tukey's Test	S. Wheat-Barley	0.0034
Post-hoc Tukey's Test	S. Barley-Emmer	0.9596
Post-hoc Tukey's Test	S. Wheat-Emmer	0.6404
Post-hoc Tukey's Test	S. Wheat-S. Barley	0.3926

Table 6 - Results of Welch's two sample *t*-test between $\Delta^{13}\text{C}$ values from Tell Brak and Tell Leilan (based on Styring *et al.* 2017).

Statistical Test	Isotopic Analysis	Species	Sites	Results
Welch's two sample <i>t</i> -test	Carbon	Hulled barley	Tell Brak - Tell Leilan	T(16.83)= -5.94, p=<0.005
Welch's two sample <i>t</i> -test	Carbon	Emmer wheat	Tell Brak - Tell Leilan	T(5.77)= -8.03, p=0.0002

Table 7 - Mean stable carbon isotope values measured from Tell Brak, Tell Leilan (based on Styring *et al.* 2017) and other mid-3rd millennium BCE sites within the middle Khabur valley (based on Riehl *et al.* 2014).

Site	Taxon	Mean ($\Delta^{13}\text{C}$ ‰)
Tell Brak	Hulled barley	17.23
Tell Brak	Small barley	15.91
Tell Leilan	Hulled barley	18.10
Tell Kerma	Hulled barley	15.88
Tell Atij	Hulled barley	16.39
Tell Raqa'i	Hulled barley	16.75

Table 8 - Summary of Bronze Age northern Mesopotamian sites in Syria with identified cereal remains

Site	Region of Syria	C14 dates (if known)	Crops identified								Reference
			Hulled barley (2-row)	Hulled barley (6-row)	Barley indet.	Emmer wheat	Einkorn wheat	Glume wheat indet.	Free-threshing wheat	Cereal indet.	
Emar	West-central									X	Riehl, 1999
Hajji Ibrahim	West-central				X	X	X				Miller, 1997
Tell al Raqa'i	East	2900-2600 BCE	X					X	X		van Zeist, 1999/2000
Tell Atj	West		X	X	X	X	X				McCorriston, 1995
Tell Bderi	East	3000-2300 BCE	X			X	X				van Zeist, 1999/2000
Tell el'Abd	West		X	X				X			Riehl, 2012
Tell es-Sweyhat	East	2400 BCE			X	X	X		X		van Zeist & Bakker-Heeres, 1988; Miller, 1997
Tell Kerma	West		X			X	X		X		McCorriston, 1995
Tell Mozan	East		X			X	X		X		Riehl, 2000
Tell Selenkahiye	West/central	2400 BCE	X			X	X				van Zeist & Bakker-Heeres, 1985
Umm el-Marra	West	2500 BCE			X			X	X		Miller, 1997; Schwartz <i>et al.</i> 2000

Supplementary Data for Tell Brak paper

Supplementary Table 1 – The number of samples from the TC oval assemblage selected for crop stable isotope analysis, by crop species and room number

Room	Species	No. of Samples
6	Hulled barley	1
8	Hulled barley	2
8	Small barley	1
9	Hulled barley	2
9	Small barley	1
9	Emmer wheat	1
9	Small wheat	1
12	Hulled barley	5
12	Small barley	2
12	Emmer wheat	5
12	Small wheat	2
13	Hulled barley	1
16	Hulled barley	10
16	Small barley	5
17	Hulled barley	1
17	Emmer wheat	1
Total		41

Supplementary Table 2 – The average $\delta^{13}\text{C}$ values and standard deviations of standards in the carbon run

Standard	Average	Standard deviation
Alanine	-27.21	0.07
CH6	-10.45	0.06
CH7	-32.15	0.05

Supplementary Table 3 – The average $\delta^{15}\text{N}$ values and standard deviations of standards in the nitrogen run

Standard	Average	Standard deviation
Alanine	-1.68	0.35
Caffeine	-2.9	0.07
N2	20.3	0.18

Supplementary Table 4 - Summary of archaeobotanical results by room, weed/wild taxa are ordered alphabetically by plant family

Room No.		4	6	8	9	12	13	16	17	18	Ncy	TCH
Taxa	Plant part											
Crops												
<i>Hordeum vulgare</i> var. <i>vulgare</i> L.	Grain	1064	302	54865	3835	18754	276	473910	9996	21	406	200
<i>Hordeum vulgare</i> var. <i>vulgare</i> L.	Rachis	32		16		304		830		4	40	16
<i>Hordeum vulgare</i> sp.	Grain	16		2366	1249	2427		41393	424	1	18	20
<i>Triticum monococcum</i> L.	Grain	7		16		4	59	588	47		11	
<i>Triticum monococcum</i> L.	Glume base			48		172		36				
<i>Triticum dicoccum</i> Schübl.	Grain	78		354	2496	23539		1052	676		65	6
<i>Triticum dicoccum</i> Schübl.	Glume base			16		249		1703	160			
<i>Triticum monococcum</i> L./ <i>dicoccum</i> Schübl.	Grain							16				
<i>Triticum monococcum</i> L./ <i>dicoccum</i> Schübl.	Glume base			212		136	384	90	52	13	182	48
<i>Triticum aestivum</i> L./ <i>durum</i> Desf.	Grain				1768	6681	1173	70	153		1291	
<i>Triticum aestivum</i> L./ <i>durum</i> Desf.	Rachis			2		40		268				
<i>Triticum</i> sp.	Grain		6	17		24		4	8	7		
<i>Triticum</i> sp.	Grain	8			1135	3441		28	208		40	
Culm	Node			16	16	13		261	20	1	43	6
Culm top	Node					8					2	
Culm with straw (bottom of ear)	Node					16						
<i>Lens culinaris</i> Medik.	Seed	4		32		85		136		2	16	3

<i>Pisum sativum</i> L.	Seed				9					
<i>Lathyrus sativus</i> L.	Seed	1	12		12	4	2			
<i>Vicia ervilia</i> L. Willd.	Seed				1					
<i>Vicia</i> sp.	Seed				34		256		4	
Pulse indet.	Seed		8	4	37	8	4	8	18	3
Fruit/Nut										
<i>Vitis vinifera</i> L.	Seed	2							1	8
<i>Sambucus</i> sp.	Seed	2								
<i>Pistacia lentiscus</i> L.	Nut shell			32						
<i>Amygdalus</i> sp.	Nut shell frag.	8			1					
Fruit/nut shell (smooth)	Nut shell frag.			64			4			8
Fruit/nut indet.	Nut shell frag.						16			
Fruit indet. (ml)	Frag.						1			
Fruit flesh/bread (ml)	Frag.			19.2						
Fruit skin	Frag.							4		
Weed/wild										
<i>Artemisia</i> sp.	Seed								2	
Asteraceae	Seed							16		
<i>Centaurea</i> sp.	Seed		8		48					
cf. <i>Chrysanthemum</i>	Seed				64					
Boraginaceae	Seed				8		22			2
<i>Alyssum</i> sp.	Seed							16		
Brassicaceae	Seed					768				

Brassicaceae	Pod stalk					8			
<i>Sinapis cf. arvensis</i> L.	Seed		64		1936	768	2	2	8
<i>Cephalaria cf. syriaca</i> L. Schrad.	Seed				189		32		
Caryophyllaceae	Seed				24		16	16	96
<i>Gypsophila cf. pilosa</i> Huds.	Seed	48			32		82	184	2
<i>Silene</i> sp. Type 1.	Seed				128		144		24
<i>Silene</i> sp. Type 2.	Seed					4			
<i>Vaccaria pyramidata</i> Medik.	Seed				84		976	40	4
<i>Chenopodium album</i> L.	Seed								8
Chenopodiaceae	Seed				8		2	8	20
<i>Convolvulus</i> sp.	Seed								4
Cyperaceae	Seed	128			20			2	10
<i>Aegilops cf. crassa</i> Boiss.	Grain	264			210		1374	8	9
<i>Aegilops crassa</i> Boiss.	Glume base	382			324		10589	40	8
<i>Aegilops cf. speltoides</i> Tausch.	Grain	11	74	8	74		1005	30	14
<i>Aegilops speltoides</i> Tausch.	Glume base	48	228	32	338		13500	8	20
<i>Aegilops cf. tauschii</i> Coss.	Grain	5	35	16	27		1186	46	40
<i>Aegilops tauschii</i> Coss.	Glume base	24	120	24	67		9289	72	45
<i>Aegilops</i> sp.	Glume base				22	16			
<i>Aegilops</i> sp.	Grain					8		40	
<i>Bromus</i> sp.	Grain				16				
<i>Eremopyrum cf. bonaepartis</i> Spreng.	Grain				48		46	32	1
<i>Hordeum cf. murinum</i> L.	Grain						40		8

<i>Hordeum cf. spontaneum</i> K. Koch.	Grain		48		10		176	4		1	
Large grass indet.	Grain		36	152	142		82	40	2	48	2
<i>Lolium cf. rigidum</i> Gaud.	Grain		64	64	163		663	52	8	192	16
<i>Lolium temulentum</i> L.	Grain									8	
<i>Poa cf. annua</i> L.	Grain							16	1		
<i>Poa bulbosa</i> L.	Grain						32			8	
<i>Poa</i> sp.	Grain			16	16		20		8	16	36
<i>Taeniatherum</i> sp.	Grain										4
cf. <i>Teucrium</i> sp.	Seed				16						2
<i>Coronilla scorpiodes</i> L.	Seed	32		32	57				3	140	2
Small-seeded legumes	Seed	72	128	48	408	384	16	112	36	692	66
<i>Scorpirus</i> sp.	Seed							16			
cf. <i>Trigonella</i> sp.	Seed		16		204		11	16	1	340	4
cf. <i>Muscari</i> sp.	Seed		32		14						
<i>Ornithogalum/ Bellevalia/ Muscari</i> sp.	Seed			16	32					8	2
<i>Malva cf. parviflora</i> L.	Seed						32			8	
<i>Malva cf. sylvestris</i> L.	Seed							16	2	4	
<i>Malva</i> sp.	Seed			64	5		97	24			4
<i>Papaver cf. rhoeas</i> L.	Seed				24				1		4
<i>Papaver cf. argemone</i> L.	Seed				16						
<i>Papaver</i> sp.	Seed				104						8
Polygonaceae	Seed								2	16	2
<i>Adonis</i> sp.	Seed				8		258		1		

<i>Galium</i> sp.	Seed				149		6	4	47	2
cf. <i>Verbascum</i> sp.	Seed								1	
cf. <i>Valerianella</i> sp.	Seed								1	
Weed/wild indeterminate	Pod				16					
Weed/wild indeterminate	Seed			64	16		166	60	16	8
Charcoal >4mm/presence (ml)	Frag.	0.1	3.5	3	79.1	2	13.7	12	4.4	0.2

Supplementary Table 5 - List of taxa and their respective correspondence analysis codes used in Figure 9a

Taxa	CA code
<i>Hordeum vulgare</i> grain	2hubar
<i>Hordeum vulgare</i> (small) grain	tinbar
<i>Triticum monococcum</i> grain	einko
<i>Triticum dicoccum</i> grain	emmer
<i>Triticum aestivum/durum</i> grain	frethre
<i>Triticum</i> sp. grain	wheind
<i>Triticum</i> (small) grain	tinwhe
<i>Triticum monococcum</i> glume base	eincha
<i>Triticum dicoccum</i> glume base	emmcha
Glume wheat indet. glume base	glubas
<i>Hordeum vulgare</i> rachis	barrac
<i>Triticum aestivum/durum</i> rachis	frthch
Culm node	culm
<i>Lens culinaris</i>	lens
<i>Lathyrus sativus</i>	grapea
<i>Vicia</i> sp.	vicia
Pulse indet.	larpul
Caryophyllaceae	caryop
<i>Gypsophila</i> cf. <i>pilosa</i>	gyppil
<i>Silene</i> sp. Type 1.	silty1
<i>Vaccaria pyramidata</i>	Vacpyr
<i>Sinapis</i> cf. <i>arvensis</i>	sinarv
Cyperaceae	scirp
<i>Cephalaria</i> cf. <i>syriaca</i>	cepsyr
<i>Aegilops crassa</i> glume base	aecrgb
<i>Aegilops speltoides</i> glume base	aespgb
<i>Aegilops tauschii</i> glume base	aetagb
<i>Aegilops</i> sp. glume base	aeindgb
<i>Aegilops crassa</i> grain	aechgr
<i>Aegilops speltoides</i> grain	aespgr
<i>Aegilops tauschii</i> grain	aetagr
<i>Eremopyrum</i> cf. <i>bonaepartis</i>	erobon
<i>Hordeum</i> cf. <i>spontaneum</i>	wilbar
Large grass indet.	lagrin
<i>Lolium</i> cf. <i>rigidum</i>	lolrig
<i>Poa</i> sp.	poa
<i>Coronilla scorpiodes</i>	corsco
Small-seeded legumes	slegs
<i>Trigonella</i> sp.	trigon
<i>Malva</i> sp.	malva
<i>Galium</i> sp.	galium

Supplementary Table 6 – Results of stable isotope analysis at Tell Brak

Lab ID	Room No.	Crop Species	%C	$\delta^{13}\text{C}$ raw	$\delta^{13}\text{C}$ (-0.11‰ charring offset)	$\Delta^{13}\text{C}$	$\delta^{13}\text{C}$ sd	%N	$\delta^{15}\text{N}$ raw	$\delta^{15}\text{N}$ (-0.31‰ charring offset)	$\delta^{15}\text{N}$ sd	CN
TB01	16	Small barley	76.3	-21.9	-22	16	0.09	13.7	4.6	4.3	0.38	5.6
TB02	16	Small barley	65.2	-22.3	-22.4	16.4	0.09	14.3	5.4	5.1	0.38	6.4
TB03	12	Emmer wheat	53.6	-22.4	-22.6	16.6	0.09	14.5	7.0	6.7	0.38	5.5
TB04	8	Small Barley	63.6	-21.1	-21.2	15.1	0.09	16.9	9.6	9.3	0.39	5.1
TB05	12	Emmer wheat	65.1	-21.9	-22	16	0.09	12.1	7.4	7.1	0.38	6.0
TB06	16	Hulled barley	59.9	-23.2	-23.3	17.3	0.09	4.1	3.2	2.9	0.38	22.4
TB07	12	Hulled barley	56.4	-23.2	-23.3	17.4	0.09	6.3	3.2	2.9	0.38	11.8
TB08	9	Emmer wheat	65.6	-22.5	-22.6	16.6	0.09	9.3	7.9	7.6	0.38	7.1
TB09	12	Emmer wheat	69.7	-22.6	-22.8	16.8	0.09	10.1	6.9	6.6	0.38	8.5
TB10	12	Small barley	52.5	-22.2	-22.3	16.3	0.09	13.4	5.8	5.5	0.38	5.3
TB11	12	Small barley	55.6	-22.6	-22.7	16.7	0.09	16.9	4.9	4.6	0.38	5.9
TB12	9	Hulled barley	73.0	-23.7	-23.8	17.9	0.09	8.4	5.7	5.4	0.38	12.9
TB13	16	Hulled barley	62.1	-22.9	-23	17	0.09	4.7	3.2	2.9	0.38	23.9
TB14	6	Hulled barley	77.0	-23.3	-23.4	17.5	0.09	4.0	5.4	5.1	0.38	23.5
TB15	16	Hulled barley	63.8	-23.7	-23.8	17.9	0.09	3.6	2.8	2.5	0.38	25.6
TB16	9	Small wheat	52.7	-22.2	-22.3	16.3	0.09	12.0	9.4	9.1	0.39	5.4
TB17	8	Hulled barley	69.8	-23.3	-23.4	17.4	0.09	3.2	4.2	3.9	0.38	26.0
TB18	13	Hulled barley	71.7	-23.7	-23.8	17.9	0.09	3.6	4.8	4.5	0.38	20.7
TB19	8	Hulled barley	64.7	-23.1	-23.2	17.2	0.09	4.3	4.5	4.2	0.38	24.8
TB20	16	Hulled barley	70.8	-22.2	-22.3	16.3	0.09	3.7	3.1	2.8	0.38	21.0
TB21	12	Hulled barley	77.8	-23.2	-23.3	17.4	0.09	6.7	3.0	2.7	0.38	12.1
TB22	16	Small barley	57.1	-21.7	-21.8	15.8	0.09	17.2	8.8	8.5	0.39	5.1
TB23	16	Small barley	60.5	-21.0	-21.1	15.1	0.09	10.8	5.6	5.3	0.38	6.4
TB24	12	Small wheat	55.4	-22.0	-22.1	16.1	0.09	13.8	7.3	7	0.38	5.1

TB25	9	Hulled barley	61.7	-23.1	-23.2	17.3	0.09	9.8	7.5	7.2	0.38	8.1
TB26	12	Hulled barley	77.3	-23.4	-23.5	17.5	0.09	5.3	2.2	1.9	0.38	14.4
TB27	16	Small barley	56.2	-21.4	-21.5	15.5	0.09	8.9	4.0	3.7	0.38	9.2
TB28	9	Small barley	69.6	-22.2	-22.3	16.3	0.09	11.9	8.6	8.3	0.38	6.0
TB29	12	Emmer wheat	56.6	-21.9	-22	16	0.09	12.0	6.4	6.1	0.38	5.6
TB30	16	Hulled barley	75.9	-22.4	-22.6	16.6	0.09	4.6	3.4	3.1	0.38	19.0
TB31	12	Small wheat	48.1	-21.8	-21.9	15.9	0.09	23.4	7.9	7.6	0.38	3.9
TB32	16	Hulled barley	68.5	-23.1	-23.2	17.2	0.09	4.3	3.5	3.2	0.38	20.2
TB33	16	Hulled barley	68.1	-22.5	-22.6	16.6	0.09	4.8	3.1	2.8	0.38	24.9
TB34	16	Hulled barley	62.0	-22.5	-22.6	16.6	0.09	4.8	3.4	3	0.38	22.8
TB35	12	Hulled barley	70.8	-23.4	-23.6	17.6	0.09	11.9	9.5	9.2	0.39	7.4
TB36	16	Hulled barley	68.0	-23.4	-23.5	17.5	0.09	3.8	4.3	4	0.38	23.2
TB37	16	Hulled barley	59.6	-23.2	-23.3	17.3	0.09	3.1	3.1	2.8	0.38	23.5
TB38	17	Emmer wheat	64.0	-22.1	-22.2	16.2	0.09	10.6	3.0	2.7	0.38	9.2
TB39	17	Hulled barley	57.8	-22.3	-22.4	16.4	0.09	6.5	4.2	3.9	0.38	10.9
TB40	12	Emmer wheat	51.7	-23.0	-23.1	17.2	0.09	10.5	9.0	8.7	0.39	6.9
TB41	12	Hulled barley	57.9	-23.2	-23.3	17.3	0.09	10.0	4.3	4	0.38	7.5