Title: Isotopic Evidence for Changes in Cereal Production Strategies in Iron Age and Roman Britain

Published in: *Environmental Archaeology*

Authors:

Lisa Lodwick[1*], Gill Campbell[2], Vicky Crosby[2], Gundula Müldner[3]

*Corresponding author

[1] University of Oxford

Address: All Souls College, Oxford, OX1 4AL/ School of Archaeology, 1 South Parks Road, Oxford, OX1 3TG

Email: Lisa.Lodwick@all-souls.ox.ac.uk

Orcid Id: http://orcid.org/0000-0002-0473-2589

[2] Historic England

Address: Fort Cumberland, Fort Cumberland Road, Portsmouth, Hampshire, P04 9LD

[3] University of Reading

Address: Department of Archaeology, Whiteknights Box 227, Reading, RG6 6AB

Abstract

Following the Roman conquest, agricultural production in Britain faced increasing demand from large urban and military populations. While it has long been thought that this necessitated an increase in agricultural production, direct archaeological evidence for changes in cultivation practices has been scarce. Using a model that conceptualises cereal farming strategies in terms of intensive or extensive practices, this paper is the first study to address this question using carbon and nitrogen stable isotope data of crop remains. We report $\delta^{15}N$ and $\delta^{13}C$ values from 41 samples of spelt, emmer and barley from Bronze Age, Iron Age and Roman Stanwick (Northants., UK), in order to assess the intensiveness of arable farming and investigate shifts in cultivation practices in prehistoric and Roman Britain. The results demonstrate a decline in $\delta^{15}N$ in the Roman period, suggesting that farming practices moved to lower levels of manuring and, by implication, became more extensive. $\delta^{13}C$ values are comparable in all periods, supporting the suggestion that changes observed in human stable isotope data between the Iron Age and Roman period are best explained by dietary change rather than a shift towards higher $\delta^{13}C$ values in plants at the base of the food chain.

Keywords

Iron Age – Roman – Villa - Crop stable isotopes – manuring - diet

Introduction

It is well known that the agricultural economy of the Roman Empire was based on the large-scale production and trade of wine, olives, and cereals. Of this famous triad, the last has received by far the least research emphasis (Bowman and Wilson 2013), even though cereal production was a substantial part of the Roman economy and is hence crucial for understanding the Roman world. A range of agricultural strategies can be adopted to increase cereal production, including crop rotation, specialisation, investment in processing, as well as a shift towards either intensive or extensive cultivation practices, which have implications for labour and land use. Whilst (labour-) intensive production practices are often assumed, especially for the Mediterranean provinces, these assumptions have not been directly tested through environmental archaeology. Roman Britain provides an ideal case study through which to investigate Roman cereal production due to the availability of high quality archaeobotanical datasets, allowing us to directly assess agricultural production in a frontier province.

Debates on changes to food production systems in Roman Britain have mostly focused on the need to increase production for the burgeoning military and urban populations (e.g. Fulford 2004), in support of which clear evidence for the proliferation of rural farmsteads (Smith et al. 2016), increases in the scale of crop-processing and -storage facilities, specialisation in animal products and the large-scale exchange of plant and animal resources are most often cited (for a recent summary see Allen et al. 2017). Crop cultivation strategies have received far less attention, possibly as a result of the more ephemeral nature of the evidence. The development in recent years of crop stable isotope analysis as a new tool in archaeobotanical research, now provides a direct way to assess an important aspect of farming practice – changes in manuring as a proxy for cultivation intensity (Bogaard et al. 2013). So far, only few analyses exist from prehistoric Britain (Bogaard et al. 2013; Lightfoot and Stevens 2012), and none from the Roman period.

Whilst changes in the intensity of cereal husbandry across the Iron Age – Roman transition in Britain are therefore unexplored by stable isotope analysis, the method has identified a small (~ 0.5‰) but significant increase in average human (bone collagen) $\delta^{13}C$ values between Iron Age and Roman populations across Britain (Müldner 2013). As this shift was not mirrored in isotope data of herbivores from the same periods, it has been attributed to greater variability in the human diet and especially the increased importance of marine foods in Roman Britain. Stable isotope measurements on agricultural crops directly are needed in order to thoroughly test the alternative explanation, a change in the isotopic composition of plants caused by variation in environmental conditions or agricultural practices.

Whilst the primary aim of this paper is therefore to use carbon and nitrogen isotope analysis of cereal grains to explore changes in arable farming practices in Iron Age and Roman Britain, specifically with regards to models of intensification vs. extensification, the data from this study will also give the first opportunity to examine whether a shift in the plant isotope baseline could explain changes in the human isotope data between the Iron Age and Romano-British period.

Iron Age and Roman arable farming in Britain: Intensive or Extensive?

Intensive or Extensive Arable Farming

There is the potential of confusion over the meaning of the terms 'intensive' and 'extensive' by archaeobotanists as opposed to economic historians (see Van der Veen and O'Connor 1998, 127–129). Among economists, 'intensification' is often used to refer to an increase in production, which can be achieved by a range of agricultural strategies. In this article, however, the terms intensive and extensive are used in a strict crop-husbandry sense. Here, cereal agriculture is characterised on a scale from extensive (= low labour input per unit of land, leading to low yield per unit of land) to intensive (= high labour-input per unit of land, high yield per unit of land). Somewhat counterintuitively, extensive methods are generally regarded as the more productive, as there is a limit to the yield that can be gained from a single plot of land, regardless of labour input (Erdkamp 2015, 20; Jongman 2017). Extensification rather than intensification, i.e. expansion of the land under cultivation rather than increased investment in existing plots, is therefore the safest strategy for increasing per capita production. In traditional farming systems, intensive practices are often associated with household-based farming groups and long-term land tenure and take the form of small garden plots or infields, cultivated by manuring, hand tillage and weeding (Bogaard 2005, Van der Veen 2005). Extensive practices on the other hand usually involve the cultivation of large areas by animal tillage with lower levels of manuring and weeding. They generally also necessitate labour-sharing beyond individual households at harvest time in order to gather crops from the larger areas of land (Halstead 1995).

Archaeobotanists have long conceptualised past agricultural regimes in terms of their intensive-/extensiveness and the current consensus in respect of prehistoric and Roman agriculture in Britain is summarised below.

Late Bronze Age and Iron Age

Evidence suggests that the Mid- and Late Bronze Age in Britain was a period of intensive agriculture, with newly introduced crops (spelt wheat (*Triticum spelta* L.), pea (*Pisum sativum* L.) and bean (*Vicia faba* L.) cultivated in short-fallow, fixed plots and animals providing manure (Stevens and Fuller 2012; Serjeantson 2007). During the Iron Age farming was based on the cultivation of spelt wheat, emmer wheat (*Triticum dicoccum* L.) and barley (*Hordeum vulgare* L.), as well as the husbandry of sheep, cattle and pig (Cunliffe 2005). Establishing the scale and extent of specialisation of cereal production has long been a key focus of British Iron Age archaeobotanical studies (Stevens 2003, Van der Veen and Jones 2006), and to a lesser extent, farming practice. The frequent occurrence of grain storage pits, four-post storage structures, querns, farming tools, and charred cereal deposits following the Bronze Age/Iron Age transition (c. 800-600 BC), is interpreted as cereal production gaining even greater socio-economic importance in the Iron Age (Van der Veen and Jones 2006; Needham 2007; Valdez-Tullett 2017). On the basis of evidence of farming settlements spreading onto clay soils (made possible by increased use of iron tools), and a peak in colluviation, indicating increased erosion (Robinson 1984), this appears to have been achieved by expansion of the farmed area (i.e. extensification) rather than intensification (Van der Veen and O'Connor 1998).

Archaeobotanical investigations have identified an increase in the presence of leguminous weeds in the later first millennium BC, possibly linked to a decline in soil fertility caused by extensification (Jones 1981, 113; Moffett 2004; Van der Veen and Jones 2006). However, the association of specific cereal and weed assemblages with different settlements has been used to suggest differences in regional farming regimes, specifically intensification vs arable expansion (Van der Veen 1992). It has also been argued that the increased numbers of sheep in Late Iron Age faunal assemblages could be linked to intensification as it meant that manure was in much greater supply (Albarella 2007; Kerridge 1968: 58–59). Evidence from the continent has meanwhile shown the cultivation of heavy plateau soils indicating the expansion of cultivated areas (Haselgrove 2007, 503) and archaeobotanical analysis has evidenced extensification of cultivation practices in northern France (Zech-Matterne and Brun 2016).

Roman Period

The emergence of new forms of settlements, including road-side settlements, villas and complex farmsteads, and investment in processing methods and structures for both plants and animals illustrate the highly developed system of Roman agricultural production (Allen et al. 2017). Largely on the basis of ceramic 'manuring' scatters, it has been argued that the nature of agriculture in Roman Britain was intensive (Fulford and Holbrook 2011, 341; Lambrick 1992); however, a recent large-scale analysis faunal and charred plant assemblages from Roman Britain has confirmed that shifts towards the dominance of cattle and spelt wheat, which can be interpreted in terms of more extensive practices, occurred across large areas of Roman Britain (Allen and Lodwick 2017). A limited crop spectrum heavily based on spelt wheat has long been interpreted as an indicator of extensification, based on the perception that spelt wheat is a resilient crop, suited well to autumn sowing on heavy soils and therefore more extensive cultivation practices (Jones 1996, Van der

Veen and O’Connor 1998, 131-3; Van der Veen 1992, 145-6). A recent meta-analysis of arable weed seeds has also shown an increase in the frequency of indicator species for lower soil fertility in the Roman period, which again suggested extensification (Lodwick 2017a, 41). With a range of different arguments for both agricultural extensification and intensification and an uneven spatial and chronological distribution of the underlying evidence, it is clear that the detailed investigation of changes in cultivation practices requires more focused studies on specific aspects of farming practice.

Dietary change in Roman Britain

In contrast to the very limited research carried out on archaeological plant remains, carbon and nitrogen stable isotope analysis of human bone has been widely used to study diet in Britain. For the Iron Age and Roman period there are now sufficient data to observe wider changes in food consumption beyond site-level trends and a recent meta-analysis of human isotope data from 17 Iron Age and Roman-British sites demonstrated a small (+~0.5‰ on average) but significant increase in $\delta^{13}C$ values in the Roman period (Müldner 2013). Importantly, this shift was not mirrored in the isotope values of herbivores from the same sites, which are commonly used in palaeodietary studies to monitor isotopic variation in plants introduced by different growing conditions. The relatively small differences introduced by these environmental effects would be transferred up the food chain into the body tissues of human consumers, where they could mimic changes in human diet (Müldner 2013; see Hedges and Reynard 2007; Fraser et al. 2013a, Van Klinken et al. 2002).

There are indeed reasons why one might expect a shift towards more positive $\delta^{13}C$ values in Roman-period plants: the carbon stable isotope values of plants are affected by water status and light conditions amongst others (Heaton 1999). The Roman Warm Period (or Roman Climate Optimum), which was characterised by milder climatic conditions and drier summers than previously (McCormick et al. 2012; Swindles et al. 2010), as well as certain agricultural practices, such as large scale episodes of land clearance that are evidenced in the Late Iron Age and Roman Period (Dark 2000; Rippon et al. 2013), could consequently have influenced the plant isotope composition in this way. Indeed, for Northeast France, Aguilera et al. (2017) observed significantly increased $\delta^{13}C$ in bread wheat samples from the 1st and 3rd century AD from several sites which coincided with drought periods evidenced in Central European tree ring data. While the numerous available faunal isotope data-sets from Roman Britain which are expected to provide broad averages of the isotope values of vegetation do not indicate significant environmental variation (Müldner 2013), this present study is nevertheless a welcome opportunity to validate these conclusions by the direct analysis of plant remains.

Materials and Methods

Isotopic analysis of cereal remains

Nitrogen stable isotope analysis of charred cereals is a relatively new method to infer manuring directly from archaeobotanical remains. It has been applied for less than a decade, following research that showed charred plant isotope values are less affected by diagenetic processes than previously thought (DeNiro and Hastorf 1985; Bogaard et al. 2013). The nitrogen stable isotope composition of charred cereals grains provides a direct means of assessing the intensity and duration of manuring. Enrichment in ^{15}N in manured crops takes place due to the preferential loss of the lighter ^{14}N isotope from manure in form of gaseous ammonia (Bogaard et al. 2007). Whilst ^{15}N enrichment can have a number of causes, most notably wetland denitrification, salinity, aridity and recent land clearance (Styring et al. 2017a), none of these are factors of relevance in our study region. The landscape around Stanwick had long been cleared, and no areas of wetland were present other than hay meadows and occasional winter flooding (Brown 2006).

Carbon stable isotope ratios are frequently measured alongside nitrogen isotopes for quality control, along with C:N ratios, %C and %N (Bogaard et al 2013: 12593); however, they also give insights into plants' growing conditions in their own right and provide important baseline data for human dietary reconstructions based on stable isotope analysis (Fraser et al. 2013a). Water status is an important parameter that impacts on the carbon stable isotope composition of C_3 plants. During photosynthesis, the heavier ^{13}C is discriminated against, so that plant tissues are heavily ^{13}C depleted in relation to atmospheric CO_2, but when water availability is limited, discrimination is reduced, leading to higher $\delta^{13}C$ values in water-stressed plants (Wallace et al. 2013). Unlike in arid and semi-arid environments where water availability usually is the greatest limiting factor for plant growth and therefore has the greatest influence on their carbon isotope composition (Wallace et al. 2013; Flohr et al. 2019), other environmental variables that affect carbon isotope discrimination, such as light and nutrient availability as well as temperature, may play a greater role in temperate regions (Farquhar et al. 1989; Heaton 1999; see Aguilera et al. 2017).

Iron Age and Roman Stanwick

Due to the quality of evidence available, investigations of Iron Age and Roman farming have focused on the Upper Thames Valley and the chalk downlands of central-southern Britain, although recent development-led excavations have produced a large quantity of data from across the country (Lodwick 2017a). One such region is the Nene Valley in the East Midlands, which was a focus of settlement from the Mid-Iron Age onwards. From c. 300/200 BC, a dense pattern of unenclosed and enclosed settlements developed on the valley floor and adjacent clay soils. These were mixed farming communities, at the edge of the sphere of Late Iron Age social changes which occurred in south-eastern Britain, evident in elite burials, imported ceramics, coinage, and the development of *oppida* (Cunliffe 2005, 259-265; Hill 2007, 19-21; Knight 1984). The area remained densely settled in the Roman period, within the broader region of fertile river valleys and rolling clay uplands termed the Central Belt (Smith 2016). The closest urban centres were located at *Ratae* (Leicester) and *Verulamium* (St Albans). The Nene Valley was the focus of iron-working and pottery industries, and of relevance here, arable and pastoral farming, vineyards, and other horticulture, indicating the it was a key farming region of Roman Britain (Allen and Lodwick 2017).

Figure 1: Map indicating the location of the Raunds Area Project, and the Stanwick excavations. Prepared by Andrew Lowerre.

The best-investigated site in the Nene Valley is Stanwick (SP 97200 71600), where substantial open-area excavations have shown development from an Iron Age open settlement, through to a Roman roadside settlement and villa (Crosby and Muldowney 2011; Neal 1989). In advance of gravel quarrying, large-scale excavations were undertaken as part of the Raunds Area Project from 1979-1992 (Fig 1). The earliest evidence for cereal cultivation dates to the mid/late Bronze Age with established fields and drove ways. A scatter of early/mid Iron Age houses and four-post structures developed into an unenclosed settlement lying north of a ditched land boundary in the mid/late Iron Age. The layout of trackways, houses and enclosures which developed in the later Iron Age and early/mid first century AD formed the framework of the Roman period agricultural settlement (Fig 2). From the late first century AD, an extensive agricultural settlement developed, consisting of masonry rectangular and circular buildings, with an aisled building added in the mid third century AD, and a corridor villa in the late fourth century AD. Of note is evidence of large-scale agricultural activity in both periods – in the Iron Age, evidenced by numerous four-posters with charred cereal grain, and in the Roman period, through numerous corn-drying ovens, and an animal-powered mill (Crosby and Muldowney 2011, 126). Thus this study of crop isotopes through time at the site of Stanwick enables the continuous study of farming practice in an important agricultural region across the Iron Age and Roman periods.

Figure 2: Site plan of the Stanwick excavations showing the location of A: Bronze and Iron Age samples and B: Roman samples. Prepared by Andrew Lowerre.

Methodology

Large-scale sampling for charred plant remains was undertaken during the Stanwick excavations. The selection of samples for isotope analysis was undertaken on the basis of an initial assessment (Campbell 1995), targeting samples with an abundance of well-preserved grain. 41 samples of charred cereal grains for carbon and nitrogen isotope analysis were selected from 25 bulk flotation samples, taking into account site phasing by Crosby and Muldowney (2011). Most isotope samples consisted of 10 or more cereal grains, spanning from the Mid- to Late Bronze Age to the Late Roman period (Table 1). All barley grains were of the six-row hulled variety. The uneven distribution of samples was due to the poorer preservation of cereal grains in Roman phases, restricting the availability of grains suitable for isotope analysis. In addition, many of the larger cereal grain assemblages from the Roman phases were dominated by sprouted grains. This limited the number of assemblages suitable for isotope analysis, especially as the effects of germination on carbon and nitrogen isotope ratios within cereal grain have yet to be established.

Cereal grains were selected on the basis of the visual characteristics described by Charles et al. (2015) which indicate charring conditions between 220-240°C for 4-24hrs, where grains are optimally charred and identifiable to taxa, while sufficiently well-preserved for further analysis (see Nitsch et al. 2015). Cereal grains were examined under a low-power binocular microscope, and visible surface roots and soil were removed. In order to account for the isotopic variability within individual cereal ears and fields, usually ten grains were homogenised per sample (Nitsch et al. 2015). Grains were weighed and placed in glass tubes. Acid only pre-treatment (Vaiglova et al. 2014) was undertaken in order to remove diagenetic carbonates which were expected due to the calcareous soils (Brown 2006). Samples were heated in 10mL of 0.5 M HCl at 70°C for 40 min, until effervescence ceased. Samples were rinsed in distilled water 3 times, and then frozen and freeze-dried for 12-24 hours, after which they were ground into a homogenous powder and weighed into tin capsules for stable isotope analysis (Fraser et al. 2013b).

Table 1: Summary phasing information for crop isotope samples from Stanwick.

Samples were analysed on a Europa 20-20 isotope ratio mass spectrometer coupled to a Sercon elemental analyser at the Department of Archaeology, University of Reading. Carbon and nitrogen isotope compositions were analysed separately to account for the large differences in elemental concentrations (wt%C and wt%N) in the sample matter. Plant $\delta^{13}C$ and $\delta^{15}N$ were calibrated using internal reference materials calibrated against international standards (IAEA-CH-6, -CH-7, -N1, -N2, USGS40). An internal flour standard (FLR) with expected values of $\delta^{13}C$ -26.8 ‰ and $\delta^{15}N$ of 2.4 ‰ was used for additional quality control. Analytical precision, based on repeat analysis of internal standards over the period of analysis, was determined as ±0.1 ‰ for carbon and ±0.2 ‰ for nitrogen (1 standard deviation).

As recommended by Nitsch et al. (2015) and Styring et al. (2017b) on the basis of experimental data, a charring correction of -0.11‰ for $\delta^{13}C$ and -0.31‰ for $\delta^{15}N$ was applied. In order to account for fluctuations in atmospheric $\delta^{13}C$ over time, carbon isotope discrimination ($\Delta^{13}C$ (‰)) was calculated following Farquhar et al. (1982; as quoted in Wallace 2013), utilising the $\delta^{13}C$ values and interpolations of the AIRCO2_LOESS system (http://web.udl.es/usuaris/x3845331/AIRCO2_LOESS.xls) by Ferrio et al. (2005). Statistical analyses were carried out using SPSS 21.0.

Due to a very low frequency of wild herbivores in the Stanwick faunal assemblage it was not possible to calculate a wild herbivore $\delta^{15}N$ baseline in order to extrapolate unmanured wild forage (Bogaard et al. 2013). Manuring intensities were therefore inferred in relation to the manuring bands suggested by Bogaard et al. (2013) based on experimental data (Fraser et al. 2011). These are as follows: $\delta^{15}N$ <3‰ = low (no manure), 3‰ < $\delta^{15}N$ > 6‰ = medium (10-15 tons/ha), and $\delta^{15}N$ >6‰ = high (> 35+ tons/ha). Whilst these bands were defined based on experimental studies in Denmark, Germany and the UK, locations with temperate climates and loem and loess soils. Factors known to elevate $\delta^{15}N$, such as aridity or waterlogging, are not relevant for this study region, so the bands can be used with caution.

Results

Overall results

The C:N ratios of the crop samples mostly fall within the range of 17.9 – 40.3 (mean: 21.8) observed in modern charred cereal grains (Fraser et al. 2013b) (see Supplementary table 1). Five samples were outside of this band, with C:N ratios between 14.1 and 16.3; however, the δ-values of these samples fall within the general range of the rest of the Stanwick data-set and are also comparable to those previously reported from north-western Europe (Aguilera et al. 2017; Bogaard et al. 2013; Styring et al. 2017a). Given the absence of rigorous quality control indicators for isotope data of archaeological plants (see Szpak 2014, 6), it was decided not to exclude these samples, although they were monitored throughout the data analysis below.

$\Delta^{13}C$ values of the 41 samples range from 15.8–18.2‰ (mean 16.8± 0.6‰, 1 s.d.) and $\delta^{15}N$ values from 1.6–9.0‰ (mean 5.2 ± 1.5‰, 1 s.d.). Key descriptive statistics for individual groups are summarised in Table 2.

Differences between Crops

Comparison of isotope data for the different crop species across the whole data-set (Figures 3-4) reveals significant differences between barley and the two wheat species for $\Delta^{13}C$ (Independent-Samples Kruskal-Wallis Test, $\chi^2_{(2)}$=18.5, p<0.001; Dunn-Bonferroni post-hoc test p<0.001 for pairwise comparisons of barley-spelt and p=0.004 for barley-emmer, p=1.0 for spelt-emmer), but not for $\delta^{15}N$ ($\chi^2_{(2)}$ =0.25; p=0.88).

The differences in $\Delta^{13}C$ are apparent across all time-periods, so systematic differences between barley and wheat, as previously observed (see below), are most likely. As a result, barley was treated separately in all further analyses, whilst spelt and emmer samples were pooled into one 'wheat' data-set.

Figure 3: Boxplot comparison of $\Delta^{13}C$ values of different crop types for the whole data-set.

Figure 4: Boxplot comparison of $\delta^{15}N$ values of different crop types for the whole data-set.

Variation by period

For means of assessing chronological variations within the data-set, the samples were first combined into broad phases (Figures 5-6, see captions Figure 5 for details). Although the smaller sample size for barley especially makes it difficult to discern a robust trend, the data for both crop groups (barley and wheats) appear to follow the same pattern: $\Delta^{13}C$ isotope values become much more variable after the BC/AD divide, while $\delta^{15}N$ seem to decrease over time. The latter is especially apparent, if spelt wheat is considered on its own (Figure 6B). Indeed, if data of the two wheat species are compared only for the two phases in which they occur together (Mid/LBA and undefined IA) it is apparent that emmer wheat has significantly lower $\delta^{15}N$ values than spelt, suggesting they may have been treated differently (Independent sample t-test, unequal variances: $t_{(13.9)}=-2.5$, $p=0.024$), but the small sample size limits this interpretation.

Figure 5. $\Delta^{13}C$ values of barley (A) and wheat (B) samples through time. Phases are as follows: Mid-/Late Bronze Age to Mid-Iron Age (c. 1400/900-400 BC), unphased 'Iron Age' (c. 800-1 BC), Late Iron Age (c.100BC-0 BC/AD), 1st-early/mid 2nd cent. AD, Mid-2nd – mid-3rd cent. AD; late 3rd – mid-4th cent. AD, 4th –early 5th cent. AD, unphased 'Roman' (1st – early 5th cent. AD).

Figure 6: $\delta^{15}N$ values of barley (A) and wheat (B) samples through time. For phases see captions Figure 5.

Because of small group sizes in the finer chronological phases, the samples were combined into two broader periods, 'Prehistoric' (Mid-/Late BA to Late IA) and 'Roman' (1st – early 5th cent. AD) (Figure 7) for statistical analysis. The results confirm the impression from the visual assessment: While there are no significant differences in average $\Delta^{13}C$ between the Prehistoric and Roman samples (independent samples t-tests for equal variances (barley): $t_{(9)}$=-6.2, p=0.55, for unequal variances (wheat), $t_{(13.2)}$=-1.2, p=0.26), $\delta^{15}N$ values of both barley and wheat in the Roman group were significantly lower than in the Prehistoric one (independent samples t-test for equal variances (barley): $t_{(9)}$=2.3, p=0.046; independent samples Mann-Whitney U test (wheat): U=26, p=0.001. The Mann-Whitney test was chosen after a Kolmogorov-Smirnov test for normality indicated that $\delta^{15}N$ values in the Prehistoric group are not normally distributed (p=0.02).

Figure 7: Boxplots comparing $\Delta^{13}C$ (A) and $\delta^{15}N$ (B) values of barley and wheat (emmer and spelt) from broad time-periods ('Prehistoric' = Mid-/Late BA to late IA, n=7 for barley, n=19 for wheat; 'Roman' = 1st to early 5th cent. AD, n=4 for barley, n=11 for wheat).

Table 2: Summary of crop isotope results from Stanwick.

Discussion

Crop Growing Regimes

Systematic differences in $\Delta^{13}C$ between wheat and barley grown at the same sites are regularly observed in archaeological and modern crop samples. They are usually attributed to differences in phenology between the two cereals which dictate that they will enter key stages in the growth cycle at different times in the year and therefore under different environmental (and especially rainfall) conditions (Araus et al. 1999; Ferrio et al. 2005; Flohr et al. 2011; Wallace et al. 2013). Although Aguilera et al. (2017) point out that this explanation need not apply in temperate regions, where seasonal variation in precipitation is less pronounced than in the (semi-)arid environments where most reference data originate from, the fact that the same systematic differences between wheat and barley were present not only in Aguilera et al.'s own data-set from Northeast France but also now in Stanwick (Table 2), nevertheless suggest that their primary cause is plant ecology rather than any intentional agricultural strategy by humans - although the latter might be necessitated by the different requirements of the two crops and therefore contribute to the results.

The Stanwick nitrogen isotope data, on the other hand, allows at least the suggestion of differential treatment of different crops in terms of manuring. The significant differences in mean $\delta^{15}N$ between emmer and spelt in the Bronze and Iron Age samples, which are particularly evident in the earliest site phases, are especially important here, since they would suggest that emmer wheat may have received less manure. This is *contra* to the widespread view that emmer was grown under more intensive conditions than spelt (Lodwick 2017a). The number of samples is small, however, and the absolute difference in mean $\delta^{15}N$ between the two crops is only 1‰ (Table 2). Further investigation is therefore needed before coming to firm conclusions. The differences between the mean $\delta^{15}N$ values for spelt wheat and barley in these early periods are much smaller (0.4‰ in the Bronze/Iron Age, 0.1‰ in the Roman), and are within the range expected for variation in the same field (0.1-0.9‰; Kanstrup et al. 2012; Nitsch et al. 2015). Overall, there is no indication in this study that spelt wheat was cultivated under different conditions than barley.

Changes in Farming Practice over time

The clearest trend in the Stanwick data-set is the significant decline in nitrogen isotope values between the Prehistoric and Roman phases of the site. Using Bogaard et al.'s (2013) experimentally derived 'manuring bands' as a guide, the key implication of this is that cereal cultivation practice shifted from medium-high input of manure in the Bronze Age and Iron Age (mean $\delta^{15}N$ of 6.2‰ for spelt and 5.8‰ for barley), to lower levels in the Roman Period (4.1‰ for spelt, 4.0‰ for barley). Intriguingly, the most elevated $\delta^{15}N$ values for spelt (9.0‰ and 8.7‰) are from the earliest period, Phase 3 (900-400 BC), suggesting perhaps levels of manuring were already declining during the later Iron Age. Our results also suggest that barley and the glume wheats were receiving comparable treatments in the Prehistoric and Roman period.

Whilst the extent to which manuring was practiced has been debated for the Neolithic and Bronze Age periods in continental Europe (Bogaard 2005; Rösch et al. 2014), focused discussions of the practice in prehistoric and Roman Britain are scarce. Geoarchaeological analysis of Bronze Age soils has only shown evidence for middening – the application of mixed domestic waste – to arable fields (e.g. Macphail et al. 1990) and it has been suggested that widespread manuring did not occur until the Iron Age, even if evidence for this is so far limited (Guttmann 2005). Early Iron Age midden sites, such as at Potterne (Wilts.) certainly demonstrate the curation of animal dung in the Late Bronze Age – Early Iron Age (Waddington 2012), but whether this was being applied to crops is unclear. The increasing proportions of sheep in later Iron Age faunal assemblages from central-southern Britain may well be linked to the supply of manure for agricultural intensification (Albarella 2007, 395; Cunliffe 1995, 96), but we lack direct evidence for manuring practices during the Iron Age.

The writings of Roman agronomists indicate that a range of animal manure (cow, donkey, poultry, sheep), and other materials (green-manure, night soil, marling and sea weed) were used to improve soil fertility (White 1970, 125-131; Kron 2012, 158-9; Spurr 1986, 126-132). Occasional artistic evidence, such as a mosaic from St-Romain-en-Gal (Rhône, Eastern France), depicts labourers carrying manure to the fields (King 1990, 98), demonstrating the practice of manuring occurred at least in some settlements in the north-western provinces. Within Britain, the main source of evidence is the widespread occurrence of ceramic scatters (Fulford and Holbrook 2011, 341), for instance, at Drayton and Yarnton, Oxfordshire, (Barclay et al. 2003, 104-106; Hey 2011) and in the Berkshire Downs (Gaffney and Tingle 1989). The reliance on ceramic scatters is problematic; however, due to the differential survival of prehistoric and Roman ceramics, and a reliance on evidence from fieldwalking (Alcock et al. 1994; Bintliff and Snodgrass 1988). Other methods used to argue for manuring in Roman Britain include the measurement of increased levels of organic phosphates in the soil, applied, for example, at the roadside settlement at Scole, Norfolk (Macphail et al. 2000), and the absence of leguminous weed taxa, as observed at Roman settlements at Stansted and Heathrow, suggesting that soil fertility was maintained by other means (Carruthers 2009, 2010). Nevertheless, whilst providing broad indications of the practice of manuring and middening, these techniques give no information on the extent of its application.

The isotopic analysis of cereal grains from Stanwick has shown that manuring declined from the Iron Age to the Roman period. Hence, if manuring is used as a proxy for the intensiveness of cereal cultivation, we can infer that cereal cultivation practices at Roman Stanwick were more extensive than during the Iron Age, and, cereals were produced through lower labour inputs per unit area (Van der Veen and O'Connor 1998). This finding confirms previous suggestions that the Roman spelt- and cattle-based farming system was extensive (Allen and Lodwick 2017). This evidence for extensive farming is consistent with observations across Roman Britain of the use of larger cattle for traction (Albarella et al. 2008), common traction pathologies (Allen 2017), developments in fodder management (Lodwick 2017b), and specialised cattle ranches (Booth 2016), all indicating an emphasis on animal traction rather than hand tillage. Bioarchaeological investigations of periods of urbanisation in early Bronze Age northern Mesopotamia (Styring et al. 2017b), and the Late Bronze Age palaces in southern Greece (Halstead 1995) have also been linked to extensification of agriculture, which is now emerging as a wider strategy in achieving increasing food production in the past.

Agriculture in Roman Britain in the context of the Roman Empire

This study has suggested that agricultural production on a nucleated villa settlement in the core agricultural zone of Roman Britain was achieved through relatively extensive cereal agriculture. This fits well with Erdkamp's assertion that increases in agricultural productivity in the Roman world could be achieved through larger agricultural units (Erdkamp 2015). The Nene Valley provides an example of this. Although there would have been a regular supply of manure, as zooarchaeological evidence for cattle, sheep and pigs attests (Allen and Lodwick 2017), it may have been used for high-value horticultural crops such as grapevine which are evidenced here in the Roman period (Brown et al. 2001; see Spurr 1986: 127, who suggests such a system for Roman Italy, based on the writings of Roman agronomists). Whilst large work-parties would be required at harvest time to sustain the extensive cereal farming system (Halstead 1995), throughout the rest of the year labour could be invested in the other economic activities, which are archaeologically attested in the region, including iron working, pottery production, hay making and wine production (Allen and Lodwick 2017).

Although the isotopic evidence reported here suggests a shift towards a lower input of manure, which implies less labour-intensive farming practices, the widespread evidence for ceramic scatters in the Stanwick/Raunds Area, beginning from the first century AD but declining from the late 2nd century AD onwards (Parry 2006, 81-83), indicates that middening was still taking place. Middens contain a range of household waste, potentially including manure, which could elevate $\delta^{15}N$ values, but to a lesser extent than the direct application of high volumes of manure. The application of household waste to fields may have been a response to the fact that insufficient animal manure was available to fertilise the expanded areas of cultivation. Furthermore, the distribution of ceramic scatters, covering the majority of land between Roman settlements, could be interpreted as showing that much of the landscape was used for arable, with limited provision for pasture, leading to a lack of manure availability.

This study has found no evidence for increased manuring in the Roman period. However, intensification or extensification are only two of the many options for increasing agricultural production. Other strategies for maintaining soil fertility have been proposed for Roman Britain, including the use of pulses in crop rotation (Treasure and Church 2016), ley farming (Kron 2000) and the use of lime (Smith 2017: 208-9), which require further investigation.

Comparison with Iron Age and Roman crop isotope studies

A growing number of crop isotope studies from Iron Age and Roman north-western Europe enables comparison with the results from Stanwick. Most studies have indicated a medium level of manuring for some crops. Individual grain measurements of barley and spelt wheat from the mid-Iron Age hillfort of Danebury, Hampshire showed a range of $\delta^{15}N$ from 0.6–5.8 ‰ (Lightfoot and Stevens 2012). Mean $\delta^{15}N$ values per context were 3.6‰ and 4.3‰ for barley, and 2.4‰ and 2.9‰ for wheat, which places barley in the medium manuring band and wheat as receiving low quantities of manure. Analysis of crops from five sites in Early Iron Age south-west Germany found sustained high levels of manuring, with the majority of cereals receiving some manure, but wide ranging $\delta^{15}N$ values of 1.9–9.6‰ (Styring et al. 2017a). An extensive analysis of carbon and nitrogen isotopes from 12 farmsteads in north-east Gaul spanning 600/400 BC – 300/400 AD again found wide variation in $\delta^{15}N$ from 0.8-8.7 ‰, but consistent evidence for crops receiving medium levels of manure, with crops from most sites having $\delta^{15}N$ values between 3 and 6 ‰ (Aguilera et al. 2017). The north-eastern France study therefore supports the impression from Stanwick of medium-levels of manuring in the north-western Roman empire. However, unlike at Stanwick no chronological change was detected. At one of the few sites with multiple periods represented, analysis of *Triticum aestivum* from Palaiseau (Île de France) indicates largely stable $\delta^{15}N$ values through time, and hence similar levels of manuring from the 2nd century BC through to the 2nd century AD. In contrast, at Epais-le-Louvre, $\delta^{15}N$ values fluctuate between 2.6 and 5.4‰ from the late 1st century BC to the 4th century AD, without any detectable diachronic trend (Aguilera et al. 2017).

Other studies have reported differences in how some crops were grown. In southwest Germany, barley had more elevated $\delta^{15}N$ values than wheat, likely due to the preferential manuring of this crop for brewing (Styring et al. 2017a). At Danebury, $\delta^{15}N$ values for barley were elevated as compared to wheat (Lightfoot and Stevens 2012). In north-east France, free-threshing wheat had higher $\delta^{15}N$ values, and received more manure than hulled wheats (Aguilera et al. 2017, 10). The similarities in isotope values of wheat and barley at Stanwick suggests no difference in the way barley and wheat were grown. This is in contrast to the common suggestion that barley had a lower status as a fodder crop in prehistoric and Roman Britain (Britton and Huntley 2011).

Implications for palaeodiet and palaeoclimate studies

The use of herbivore stable isotope data for providing baselines for human dietary reconstructions is now a common approach, the idea being that herbivore bone will reflect average values for the plant foods available in any one area (Hedges and Reynard 2007; see Müldner 2013). Weaknesses of the approach, most notably that animals and humans may have been consuming plants grown under different conditions and isotopic changes in human plant foods would not necessarily be reflected in the herbivores, have long been known; however, it is only now that isotope analysis of plant remains has developed into a robust method, that gathering baseline data from the plants themselves has become a possibility (Fraser et al. 2013a). The results from Stanwick offer the first opportunity to consider plant isotope data for the Iron Age – Romano-British transition in the interpretation of human data-sets.

A recent survey of available stable isotope data from Iron Age and Romano-British humans showed a clear shift towards ^{13}C-enriched values in the Roman period. While this trend towards higher $\delta^{13}C$

values could be explained by the documented transition towards a warmer, drier climate at the end of the Iron Age (the "Roman Warm Period") or changes in land management and agricultural practices under the Romans, it was not mirrored in the corresponding herbivore data. It was therefore explained by a change in the human diet, rather than a shift in the isotopic baseline due to changed growing conditions for plants (Müldner 2013). The results from Stanwick appear to support this interpretation: Variation in the carbon isotope values values of the same crops between the Iron Age and Roman period at Stanwick are extremely small at <0.2‰ (Table 2), and suggest that any changes in the environmental conditions were not substantial enough to be reflected in the plant isotope composition. For now at least, a change in the human diet therefore remains the most likely cause for the shift towards higher human $\delta^{13}C$ in the Roman period (Müldner 2013, 140).

With regards to nitrogen, Müldner's (2013) survey found that although human $\delta^{15}N$ values at numerous Roman-period sites were elevated over Iron Age populations, these increases were usually cancelled out by corresponding ^{15}N-enrichments in the Roman herbivores. The 'normalised' (i.e. by comparison with site-specific herbivore baselines) human data-set therefore revealed no clear diachronic trend with regards to $\delta^{15}N$. Wide-spread, increased use of manure in the Roman period could explain the higher nitrogen isotope values of Romano-British herbivores compared to many Iron Age sites. However, the results from Stanwick, which on the contrary indicate a decrease in crop manuring in one of Roman Britain's agricultural heartlands, give at least due caution that further local studies of plant isotopes are necessary, before such a generalised inference can be made. Agricultural practices other than manuring, such as stocking rates, can affect animal nitrogen isotope values (see Szpak 2014). Whilst the results of our study therefore do not allow refining interpretations of human isotope data from Britain, they lend weight to arguments against the overreliance on faunal baselines in human palaeodietary studies.

Conclusions

The first application of long-term diachronic crop stable isotope analysis to archaeological cereal remains from an Prehistoric and Roman site in Britain has demonstrated that crops received lower levels of manure and hence farming practices became more extensive in the Roman period as compared to the earlier phases of occupation. This observation implies that increases in cereal production for the military and urban communities of Roman Britain was obtained through expanding the area of land under cultivation and investment in processing, storage facilities and mobilisation of crops, rather than increasing labour inputs per unit of cultivated land. These findings confirm previous suggestions that farming practice in Roman Britain was extensive in character, and indicate that further attention should be paid to the investment in cereal processing facilities, such as corn-drying ovens, and the organisation of rural settlements. The unexpected decrease in

$\delta^{15}N$ ratios but consistency in $\delta^{13}C$ values in the Roman period have implications for palaeodietary studies and further strengthen the argument for a significant change in human diet after Britain's incorporation in the Roman Empire; however, the data also highlight the need to expand crop isotope analysis into other regions and for other periods where conclusions have been drawn about human diet without consideration of potential fluctuations in the plant isotopic baseline.

This paper has examined agricultural strategies in only one small area of Roman Britain. In order to more fully understand the impact of the Roman Empire on frontier economies, the technique of crop stable isotope analysis must be applied across a range of geological areas, and importantly to sites with good chronological frameworks and abundant samples from a range of different crops to ensure that variations in practice can be teased out. In particular, combining isotopic analysis of crop plants with functional weed ecology (Bogaard et al. 2016) would enable a more rigorous appraisal of crop husbandry regimes during this period.

Acknowledgements

Stanwick excavations were undertaken by English Heritage (now Historic England) and directed by David S. Neal. The authors are grateful to Alice Ughi for assistance with isotope analysis, and to Amy Styring and Elizabeth Stroud for sampling advice. We are grateful to the reviewers for constructive comments.

Funding

This work was supported by the Association for Environmental Archaeology and the Roman Research Trust.

References

Aguilera, M., V. Zech-Matterne, S. Lepetz, and M. Balasse. 2017. "Crop Fertility Conditions in North-Eastern Gaul During the La Tène and Roman Periods: A Combined Stable Isotope Analysis of Archaeobotanical and Archaeozoological Remains." *Environmental Archaeology* doi:10.1080/14614103.2017.1291563.

Albarella, U. 2007. "The End of the Sheep Age: People and Animals in the Late Iron Age." In *The Later Iron Age in Britain and Beyond*, edited by C. Haselgrove, and T. Moore, 393–406. Oxford: Oxbow Books.

Albarella, U., C. Johnstone and K. Vickers. 2008. "The Development of Animal Husbandry from the Late Iron Age to the End of the Roman Period: A Case Study from South-East Britain." *Journal of Archaeological Science* 35 (7): 1828–1848. doi:10.1016/j.jas.2007.11.016.

Alcock, S. E., J. F. Cherry, and J. L. Davis. 1994. "Intensive Survey, Agricultural Practice and the Classical Landscape of Greece." In *Classical Greece: Ancient Histories and Modern Archaeologies*, edited by I. Morris, 137–170. Cambridge: Cambridge University Press.

Allen, M. 2017. "Pastoral Farming." In *The Rural Economy of Roman Britain*, by Allen, M., L. Lodwick, T. Brindle, M. Fulford, and A. Smith, 85–141. Britannia Monograph Series No. 30. London: Society for the Promotion of Roman Studies.

Allen, M., L. Lodwick, T. Brindle, M. Fulford, and A. Smith. 2017. *The Rural Economy of Roman Britain*. Britannia Monograph Series No. 30. London: Society for the Promotion of Roman Studies.

Allen, M., and L. Lodwick, L. 2017. "Agricultural Strategies in Roman Britain." In *The Rural Economy of Roman Britain*, by M. Allen, L. Lodwick, T. Brindle, M. Fulford, and A. Smith, 142–177. Britannia Monograph Series No. 30. London: Society for the Promotion of Roman Studies.

Araus, J., A. Febrero, M. Catala, M. Molist, J. Voltas, and I. Romagosa. 1999. "Crop Water Availability in Early Agriculture: Evidence from Carbon Isotope Discrimination of Seeds from a Tenth Millennium BP site on the Euphrates." *Global Change Biology* 5 (5): 201–212. doi:10.1046/j.1365-2486.1999.00213.x.

Barclay, A., G. Lambrick, J. Moore, and Robinson, M. 2003. *Lines in the Landscape: Cursus Monuments in the Upper Thames Valley: Excavations at the Drayton and Lechlade Cursuses*. Thames Valley Landscapes 15. Oxford: Oxford Archaeology.

Bintliff, J., and A. Snodgrass. 1988. "Off-Site Pottery Distributions: A Regional and Inter-Regional Perspective." *Current Anthropology* 29 (5): 506–513. doi:10.1086/203668.

Bogaard, A. 2005. " "Garden Agriculture" and the Nature of Early Farming in Europe and the Near East." *World Archaeology* 37 (2): 177–196. doi:10.1080/00438240500094572.

Bogaard, A., T. H. E. Heaton, P. Poulton, and I. Merbach. 2007. "The Impact of Manuring on Nitrogen Isotope Ratios in Cereals: Archaeological Implications for Reconstruction of Diet and Crop Management Practices." *Journal of Archaeological Science* 34 (3): 335–343. doi:10.1016/j.jas.2006.04.009.

Bogaard, A., J. Hodgson, E. Nitsch, G. Jones, A. Styring, C. Diffey, J. Pouncett, C. Herbig, M. Charles, F. Ertug, O. Tugay, D. Filipovic, and R. Fraser. 2016. "Combining Functional Weed Ecology and Crop Stable Isotope Ratios to Identify Cultivation Intensity: A Comparison of Cereal Production Regimes in Haute Provence, France and Asturias, Spain." *Vegetation History and Archaeobotany* 25 (1): 57–73. doi:10.1007/s00334-015-0524-0.

Bogaard, A., R. Fraser, T. H. E. Heaton, M. Wallace, P. Vaiglova, M. Charles, G. Jones et al. 2013. "Crop Manuring and Intensive Land Management by Europe's First Farmers." *Proceedings of the National Academy of Sciences* 110 (21): 12589–12594. doi:10.1073/pnas.1305918110.

Booth, P. 2016. "A Probable Cattle-Handling Settlement in the Windrush Valley, Oxfordshire: A Brief Summary of 25 Years Work at Gill Mill Quarry, Ducklington and South Leigh." *Britannia* 47: 253–261. doi:10.1017/S0068113X16000076.

Bowman, A., and A. Wilson, A. 2013. "Introduction: Quantifying Roman Agriculture." In *The Roman Agricultural Economy: Organization, Investment, and Production*, edited by A. Bowman and A. Wilson, 1–32. Oxford: Oxford University Press.

Britton, K., and J. Huntley. 2011. "New Evidence for the Consumption of Barley at Romano-British Military and Civilian Sites, from the Analysis of Cereal Bran Fragments in Faecal Material." *Vegetation History and Archaeobotany* 20 (1): 41–52. doi:10.1007/s00334-010-0245-3.

Brown, A. G. 2006. "The Environment of the Raunds Area." In *Raunds Area Survey: An Archaeological Study of the Landscape of Raunds, Northamptonshire 1985–94*, by S. Parry, 19–31. Oxford: Oxbow Books.

Brown, A. G., I. Meadows, S. S. Turner, and D. J. Mattingly. 2001. "Roman Vineyards in Britain: Stratigraphic and Palynological Data from Wollaston in the Nene Valley, England." *Antiquity* 75: 745–757. doi:10.1017/S0003598X00089250.

Campbell, G. 1995. "Charred Plant Remains." In *Raunds Iron Age and Romano-British Project: Assessment Report*, by R. Perrin. English Heritage Central Archaeology Service.

Carruthers, W. 2009. "Charred, Mineralized and Waterlogged Plant Remains." In *The Stanstead Framework Project* [data-set]. York: Archaeology Data Service [distributor] doi:10.5284/1000029.

Carruthers, W. 2010. "Charred and Waterlogged Plant Remains." In *Landscape Evolution in the Middle Thames Valley: Heathrow Terminal 5 Excavations Volume 2. CD Rom*, by Framework Archaeology. Oxford and Salisbury: Framework Archaeology.

Charles, M., E. Forster, M. Wallace, and G. Jones. 2015. " "Nor Ever Lightning Char thy Grain"[1]: Establishing Archaeologically Relevant Charring Conditions and their Effect on Glume Wheat Grain Morphology." *Science and Technology of Archaeological Research* 1 (1): 1–6. doi:10.1179/2054892315Y.0000000008.

Crosby, V, and L. Muldowney. 2011. *Raunds Area Project: Phasing the Iron Age and Romano-British Settlement at Stanwick, Northamptonshire (Excavations 1984-1992)*. English Heritage Research Department Report Series no. 54-2011. Available at https://research.historicengland.org.uk/Report.aspx?i=15006&ru=%2fResults.aspx%3fp%3d1%26n%3d10%26a%3d4429%26ns%3d1.

Cunliffe, B. 1995. *Danebury: An Iron Age Hillfort in Hampshire. Volume 6: A Hillfort Community in Perspective*. London: Council for British Archaeology Research Report 102.

Cunliffe, B. 2005. *Iron Age Communities in Britain*. Abingdon: Routledge.

Dark, P. 2000. *The Environment of Britain in the First Millennium A.D.* London: Gerald Duckworth & Co. Ltd.

DeNiro, M. J., and C. A. Hastorf, C. A. 1985. “Alteration of 15N/14N and 13C/12C Ratios of Plant Matter During the Initial Stages of Diagenesis: Studies Utilizing Archaeological Specimens from Peru.” *Geochemica et Cosmochimica* 49: 97–115. doi: 10.1016/0016-7037(85)90194-2.

Erdkamp, P. 2015. “Agriculture, Division of Labour, and the Paths to Economic Growth.” In *Ownership and Exploitation of Land and Natural Resources in the Roman World*, edited by P. Erdkamp, K. Verboven, and A. Zuiderhoek, 18-39. Oxford: Oxford University Press.

Farquhar, G. D., J. R. Ehleringer, and K. T. Hubick. 1989. “Carbon Isotope Discrimination and Photosynthesis.” *Annual Review of Plant Physiology and Plant Molecular Biology* 40: 503–537. doi:10.1146/annurev.pp.40.060189.002443.

Farquhar, G. D., M. H. O’Leary, and J. A. Berry. 1982. “On the Relationship Between Carbon Isotope Discrimination and the Intercellular Carbon Dioxide Concentration in Leaves.” *Australian Journal of Plant Physiology* 9: 121–137.

Ferrio, J. P., J. L. Araus, R. Buxo, J. Voltas, and J. Bort. 2005. “Water Management Practices and Climate in Ancient Agriculture: Inferences from the Stable Isotope Composition of Archaeobotanical Remains.” *Vegetation History and Archaeobotany* 14: 510–517. doi:10.1007/s00334-005-0062-2.

Flohr, P., G. Müldner, and E. Jenkins. 2011. “Carbon Stable Isotope Analysis of Cereal Remains as a Way to Reconstruct Water Availability: Preliminary Results.” *Water History* 3: 121–144. doi:10.1007/s12685-011-0036-5.

Flohr, P., E. Jenkins, H. R. S. Williams, K. Jamjoum, and G. Müldner 2019. What Can Crop Stable Isotopes Ever do for us? An Experimental Perspective on Using Cereal Stable Isotope Values for Reconstructing Water Availability in Semi-Arid and Arid Environments. *Vegetation History and Archaeobotany*. doi: 10.1007/s0033400180070805

Fraser, R., A. Bogaard, T. Heaton, M. Charles, G. Jones, B. T. Christensen, P. Halstead et al. 2011. “Manuring and Stable Nitrogen Isotope Ratios in Cereals and Pulses: Towards a New Archaeobotanical Approach to the Inference of Land Use and Dietary Practices.” *Journal of Archaeological Science* 38 (10): 2790–2804. doi:10.1016/j.jas.2011.06.024.

Fraser, R., A. Bogaard, M. Schäfer, R. Arbogast, and T. H. E. Heaton 2013a. “Integrating Botanical, Faunal and Human Stable Carbon and Nitrogen Isotope Values to Reconstruct Land Use and Palaeodiet at LBK Vaihingen an der Enz, Baden-Württemberg.” *World Archaeology* 45 (3): 492–517. doi:10.1080/00438243.2013.820649.

Fraser, R., A. Bogaard, M. Charles, A. K. Styring, M. Wallace, G. Jones, and P. Ditchfield. 2013b. “Assessing Natural Variation and the Effects of Charring, Burial and Pre-Treatment on the Stable Carbon and Nitrogen Isotope Values of Archaeobotanical Cereals and Pulses.” *Journal of Archaeological Science* 40 (12): 4754–4766. doi:10.1016/j.jas.2013.01.032.

Fulford, M. 2004. “Economic Structures.” In *A Companion to Roman Britain*, edited by M. Todd, 309–327. Oxford: Blackwell.

Fulford, M., and N. Holbrook. 2011. “Assessing the Contribution of Commercial Archaeology to the Study of the Roman Period in England, 1990-2004.” *The Antiquaries Journal* 91: 323–345. doi:10.1017/S0003581511000138.

Gaffney, V., and M. Tingle. 1989. *The Maddle Farm Project: An Integrated Survey of Prehistoric and Roman Landscapes on the Berkshire Downs*. British Archaeological Reports British Series 2000. Oxford: British Archaeological Reports.

Guttmann, E. 2005. “Midden Cultivation in Prehistoric Britain: Arable Crops in Gardens.” *World Archaeology* 37 (2): 224–239. doi:10.1080/00438240500094937.

Halstead, P. 1995. “Plough and Power: The Economic and Social Significance of Cultivation with the Ox-drawn Ard in the Mediterranean.” *Bulletin on Sumerian Agriculture* 8: 11–22.

Haselgrove, C. 2007. “The Age of Enclosure: Later Iron Age Settlement and Society in Northern France.” In *The Later Iron Age in Britain and Beyond*, edited by C. Haselgrove and T. Moore, 492–522. Oxford: Oxbow Books.

Heaton, T. H. E. 1999. “Spatial, Species and Temporal Variations in the $^{13}C/^{12}C$ Ratios of C_3 Plants: Implications for Palaeodiet Studies.” *Journal of Archaeological Science* 26: 637-649. doi: 10.1006/jasc.1998.0381.
Hedges, R. E. M., and Reynard, L. M. 2007. “Nitrogen Isotopes and Trophic Level of Humans in Archaeology.” *Journal of Archaeological Science* 34: 1240–1251. doi:10.1016/j.jas.2006.10.015.

Hey, G. 2011. “Fieldwalking.” In *Yarnton: Iron Age and Romano-British Settlement and Landscape: Results of Excavations 1990-98*, by G. Hey, P. Booth, and J. Timby, 267–272. Oxford: Oxford University School of Archaeology.

Hill, J. D. 2007. “The Dynamics of Social Change in Later Iron Age Eastern and South-Eastern England c. 300 BC-AD 43.” In *The Later Iron Age in Britain and Beyond*, edited by C. Haselgrove and T. Moore, 16-40. Oxford: Oxbow Books.

Jones, M. 1981. “The Development of Crop Husbandry.” In *The Environment of Man: The Iron Age to the Anglo-Saxon Period*, edited by M. Jones and G. Dimbleby, 95–127. British Archaeological Reports British Series 87. Oxford: British Archaeological Reports.

Jones, M. 1996. “Plant Exploitation.” In *The Iron Age in Britain and Ireland: Recent Trends*, edited by T. Champion and J. Collis, 29-40. Sheffield: Sheffield Academic.

Jongman, W. 2017. “The Benefits of Market Integration: Five Centuries of Prosperity in Roman Italy.” In *The Economic Integration of Roman Italy: Rural Communities in a Globalizing World*, edited by T. C. A. De Haas and G. W. Tol, 15–27. Leiden: Brill.

Kanstrup, M., I. K. Thomsen, P. H. Mikkelsen, and B. T. Christensen, B. T. 2012. “Impact of Charring on Cereal Grain Characteristics: Linking Prehistoric Manuring Practice to $\delta^{15}N$ Signatures in Archaeobotanical Material.” *Journal of Archaeological Science* 39 (7): 2533–2540. doi:10.1016/j.jas.2012.03.007.

Kerridge, E. 1968. *The Agricultural Revolution*. New York: Augustus M. Kelley.

King, A. 1990. *Roman Gaul and Germany*. Berkeley: University of California Press.

Knight, D. 1984. *Late Bronze Age and Iron Age Settlement in the Nene and Great Ouse Basins*. BAR British Series 130. Oxford: British Archaeological Reports.

Kron, G. 2000. “Roman Ley-Farming.” *Journal of Roman Archaeology* 13: 277–87. doi:10.1017/S1047759400018924.

Kron, G. 2012. “Food Production.” In *The Cambridge Companion to the Roman Economy*, edited by W. Scheidel, 156–174. Cambridge: Cambridge University Press.

Lambrick, G. 1992. “The Development of Late Prehistoric and Roman Farming on the Thames Gravels.” In *Developing Landscapes of Lowland Britain. The Archaeology of the British Gravels: A Review*, edited by M. Fulford and E. Nichols, 78–105. London: Society of Antiquaries.

Lightfoot, E., and R. E. Stevens 2012. “Stable Isotope Investigations of Charred Barley (*Hordeum vulgare*) and Wheat (*Triticum spelta*) Grains from Danebury Hillfort: Implications for Palaeodietary Reconstructions.” *Journal of Archaeological Science* 39 (3): 656–662. doi:10.1016/j.jas.2011.10.026.

Lodwick, L. 2017a. “Arable Farming, Plant Foods and Resources.” in *The Rural Economy of Roman Britain*, by M. Allen, L. Lodwick, T. Brindle, M. Fulford, and A. Smith, 11-84. Britannia Monograph Series No. 30. London: Society for the Promotion of Roman Studies.

Lodwick, L. A. 2017b. “Agricultural Innovations at a Late Iron Age oppidum: Archaeobotanical Evidence for Flax, Food and Fodder from Calleva Atrebatum, UK.” *Quaternary International* 460: 198–219. doi:10.1016/j.quaint.2016.02.058.

Macphail, R. I., M. A. Courty, and A. Gebhardt 1990. “Soil Micromorphological Evidence of Early Agriculture in North-West Europe.” *World Archaeology* 22 (1): 53–69. doi:10.1080/00438243.1990.9980129.

Macphail, R. I., G. M. Cruise, R. Engelmark, and J. Linderholm. 2000. “Integrating Soil Micromorphology and Rapid Chemical Survey Methods: New Developments in Reconstructing Past Rural Settlement and Landscape Organisation.” In *Interpreting Stratigraphy: Site Evaluation, Recording Procedures and Stratigraphic Analysis*, edited by S. Roskams, 71–80. Oxford: Archaeopress.

McCormick, M., U. Büntgen, M. A. Cane, E. R. Cook, K. Harper, P. Huybers, and K. Nicolussi 2012. “Climate Change During and After the Roman Empire: Reconstructing the Past from Scientific and Historical Evidence.” *Journal of Interdisciplinary History* 43 (2): 169–220. doi:10.1162/JINH_a_00379.

Moffett, L. 2004. “The Evidence for Crop-Processing Products from the Iron Age and Romano-British Periods and Some Earlier Prehistoric Plant Remains.” In *Gravelly Guy: Stanton Harcourt Oxfordshire: The Development of a Prehistoric and Romano-British Community*, by G. Lambrick and T. Allen, 421–445. Thames Valley Landscapes Monograph No. 21. Oxford: Oxford Archaeology.

Müldner, G. 2013. “Stable Isotopes and Diet: Their Contribution to Romano-British Research.” *Antiquity* 87: 137–149. doi:10.1017/S0003598X00048675.

Neal, D.S. 1989. “The Stanwick Villa, Northants: an Interim Report on the Excavations of 1964-1988. *Britannia* 10: 149-168. doi:10.2307/526160.

Needham, S. 2007. “800 BC: The Great Divide.” In *The Earlier Iron Age in Britain and the Near Continent*, edited by C. C. Haselgrove and R. Pope, 39–63. Oxford: Oxbow Books.

Nitsch, E. K., M. Charles, and A. Bogaard. 2015. “Calculating a Statistically Robust $\delta^{13}C$ and $\delta^{15}N$ Offset for Charred Cereal and Pulse Seeds.” *Science and Technology of Archaeological Research* 1 (1): 1–8. doi:10.1179/2054892315Y.0000000001.

Parry, S. 2006. *Raunds Area Survey: An Archaeological Study of the Landscape of Raunds, Northamptonshire 1985-94*. Oxford: Oxbow Books.

Rippon, S., C. Smart, B. Pears, and F. Fleming. 2013. “The Fields of Britannia: Continuity and Discontinuity in the Pays and Regions of Roman Britain.” *Landscapes* 14 (1), 33–53. doi:10.1179/1466203513Z.0000000005.

Robinson, M. 1984. “Landscape and Environment of Central Southern Britain in the Iron Age.” In *Aspects of the Iron Age in Central Southern Britain*, edited by B. Cunliffe and D. Miles, 1–22. Oxford: Oxford University Committee for Archaeology.

Rösch, M., A. Kleinmann, A, and J. Lechterbeck. 2014. “Botanical Off-Site and On-Site Data as Indicators of Different Land Use Systems: A Discussion with Examples from Southwest Germany.” *Vegetation History and Archaeobotany* 23 (1): 121–133. doi:10.1007/s00334-014-0437-3.

Serjeantson, D. 2007. “Intensification of Animal Husbandry in the Late Bronze Age? The Contribution of Sheep and Pigs.” In *The Earlier Iron Age in Britain and the Near Continent*, edited by C. Haselgrove and R. Pope, 80–93. Oxford: Oxbow Books.

Smith, A. 2016. “The Central Belt.” In *The Rural Settlement of Roman Britain*, by A. Smith, M. Allen, T. Brindle, and M. Fulford, 141–207. Britannia Monograph Series No. 29. London: Society for the Promotion of Roman Studies.

Smith, A., M. Allen, T. Brindle, and M. Fulford. 2016. *The Rural Settlement of Roman Britain*. Britannia Monograph Series No. 29. London: Society for the Promotion of Roman Studies.

Smith, A. 2017. “Rural Crafts and Industry.” In *The Rural Economy of Roman Britain*, by M. Allen, L. Lodwick, T. Brindle, M. Fulford, and A. Smith, 178–236. Britannia Monograph Series No. 30. London: Society for the Promotion of Roman Studies.

Spurr, S. 1986. *Arable Cultivation in Roman Italy*. London: Society for the Promotion of Roman Studies.

Stevens, C. 2003. “An Investigation of Agricultural Consumption and Production Models for Prehistoric and Roman Britain.” *Environmental Archaeology* 8 (1): 61–76. doi:10.1179/env.2003.8.1.61.

Stevens, C. J., and D. Q. Fuller 2012. “Did Neolithic Farming Fail? The Case for a Bronze Age Agricultural Revolution in the British Isles.” *Antiquity* 86: 707–722. doi:1017/S0003598X00047864.

Styring, A., M. Rösch, E. Stephan, H.-P. Stika, E. Fischer, M. Sillmann, and A. Bogaard 2017a. “Centralisation and Long-Term Change in Farming Regimes: Comparing Agricultural Practices in Neolithic and Iron Age South-West Germany.” *Proceedings of the Prehistoric Society* 83: 357–381. doi:10.1017/ppr.2017.3.

Styring, A. K., M. Charles, F. Fantone, M. Marie Hald, A. McMahon, R. H. Meadow, G. K. Nicholls et al. 2017b. “Isotope Evidence for Agricultural Extensification Reveals how the World’s First Cities were Fed.” *Nature Plants* 3: 17076. doi:10.1038/nplants.2017.76.

Swindles, G.T., A. Blundell, H. M. Roe, and V.A. Hall. 2010. “A 4500-year Proxy Climate Record from Peatlands in the North of Ireland: The Identification of Widespread Summer 'Drought Phases'?” *Quaternary Science Reviews* 29: 1577-1589. doi:10.1016/j.quascirev.2009.01.003.

Szpak, P. 2014. “Complexities of Nitrogen Isotope Biogeochemistry in Plant-Soil Systems: Implications for the Study of Ancient Agricultural and Animal Management Practices.” *Frontiers in Plant Science* 5 (288). doi:10.3389/fpls.2014.00288.

Treasure, E. R., and M. J. Church 2016. “Can’t Find a Pulse? Celtic bean (*Vicia faba* L.) in British Prehistory.” *Environmental Archaeology* 22 (2): 113–127. doi:10.1080/14614103.2016.1153769.

Vaiglova, P., C. Snoeck, E. Nitsch, A. Bogaard, and J. Lee-Thorp 2014. “Impact of Contamination and Pre-Treatment on Stable Carbon and Nitrogen Isotopic Composition of Charred Plant Remains.” *Rapid Communications in Mass Spectrometry* 28 (23): 2497-2510. doi:10.1002/rcm.7044.

Valdez-Tullett, A. 2017. “Sheep in Wealth’s Clothing: Social Reproduction across the Bronze Age to Iron Age Transition in Wiltshire, Southern England.” *European Journal of Archaeology* 20 (4): 663–681. doi:10.1017/eaa.2016.28.

Van der Veen, M. 1992. *Crop Husbandry Regimes: An Archaeobotanical Study of Farming in Northern England 1000 BC - AD 500*. Sheffield: J.R. Collis Publications.

Van der Veen, M. 2005. “Gardens and Fields: The Intensity and Scale of Food Production.” *World Archaeology* 37 (2): 157–163. doi:10.1080/004382405000130731.

Van der Veen, M., and G. Jones 2006. “A Re-analysis of Agricultural Production and Consumption: Implications for Understanding the British Iron Age.” *Vegetation History and Archaeobotany* 15 (3): 217–228. doi:10.1007/s00334-006-0040-3.

Van der Veen, M., and T. P. O’Connor 1998. “The Expansion of Agricultural Production in Late Iron Age and Roman Britain.” In *Science in Archaeology: an Agenda for the Future*, edited by J. Bayley, 127–143. London: English Heritage Occasional Paper 1.

Van Klinken, G. J., M. P. Richards, and Hedges, B. E. M. 2002. “An Overview of Causes for Stable Isotopic Variations in Past European Human Populations: Environmental, Ecophysiological, and Cultural Effects.” In *Biogeochemical Approaches to Paleodietary Analysis*, edited by S. H. Ambrose and M. A. Katzenberg, 39–63. Boston, MA: Springer.

Waddington, K. 2012. “(Re)cycles of Life in Late Bronze Age Southern Britain.”, in *Manure Matters: Historical, Archaeological and Ethnographic Perspectives*, edited by R. Jones, 41–59. Farnham: Ashgate Publishing Limited.

Wallace, M., G. Jones, M. Charles, R. Fraser, P. Halstead, T. H. E. Heaton, and A. Bogaard 2013. “Stable Carbon Isotope Analysis as a Direct Means of Inferring Crop Water Status and Water Management Practices.” *World Archaeology* 45 (3): 388–409. doi:10.1080/00438243.2013.821671.

White, K. D. 1970. *Roman Farming*. London: Thames & Hudson.

Zech-Matterne, V. and C. Brun, C. 2016. “Vers une agriculture extensive? Étude diachronique des productions végétales et des flores adventices associées, au cours de la période laténienne, en France septentrionale.“ In *Évolution des sociétés gauloises du Second âge du Fer, entre mutations internes et influences externes*, edited by G. Blancquaert and F. Malrain, 623–638. Amiens: Revue Archéologique de Picardie.

Table 1: Summary phasing information for crop isotope samples from Stanwick.

Site Phase	Period	Chronological Range	Spelt	Emmer	Barley
2	Mid to Late Bronze Age	1400 – 700 BC	1	1	
3	Late Bronze Age - Early to Mid Iron Age	900 – 400 BC	4	2	1
5	Late Iron Age	100 – 1 BC	2		
6	Late Iron Age/ Early Roman	1 – 70 AD			1
	Unphased Iron Age	800 – 1 BC	6	3	6
7	Early Roman	c. 70 – 125 AD	1		
9	Mid Roman	c. 170 – 230 AD	3		1
10	Mid Roman	c. 220 – 270 AD	2		
11	Late Roman	c. 270 – 340 AD	4		1
	Unphased Roman	c. 43 – 400 AD	1		1

Table 2: Summary of crop isotope results from Stanwick.

Period	**Crop**	**n**	**Δ ^{13}C range**	**Δ ^{13}C mean**	**δ^{13}C range**	**δ^{13}C mean**	**δ^{15}N range**	**δ^{15}N mean**
Bronze Age/Iron Age	Barley	7	17.0 – 18.1	17.5	-24.1 – -23.1	-23.6	4.4 – 7.3	5.8
Bronze Age/Iron Age	Emmer	6	16.0 – 17.1	16.5	-23.1 – -22.2	-22.6	4.6 – 6.0	5.2
Bronze Age/Iron Age	Spelt	13	16.0 – 17.0	16.5	-23.1 - -22.1	-22.6	3.7 – 9.0	6.2
Roman	Barley	4	17.0 – 18.2	17.7	-6.4	-23.6	1.6 – 5.9	4.0
Roman	Spelt	11	15.8 – 17.5	16.7	-23.5 - -21.8-	-22.7	2.7 – 6.2	4.1

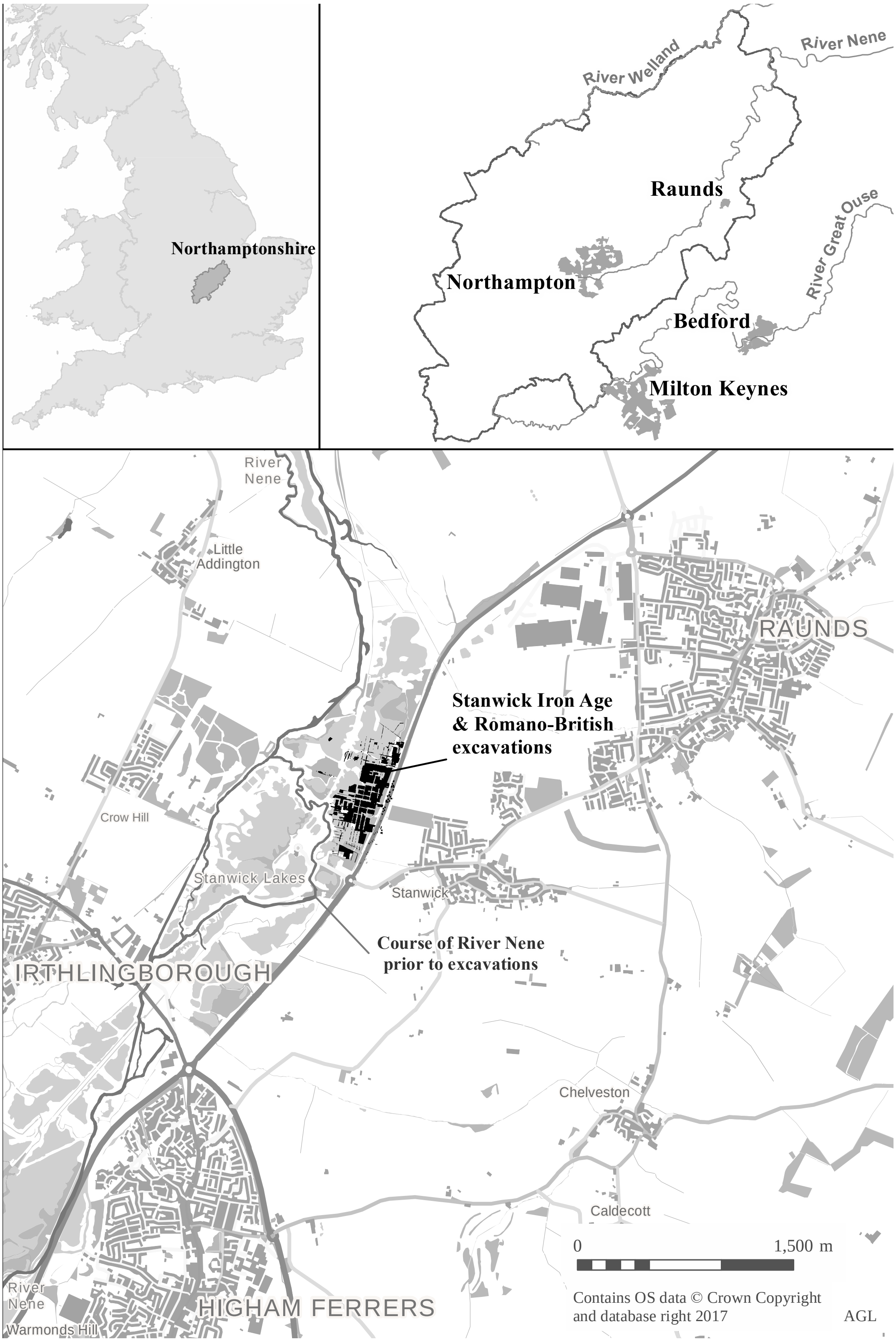


Figure 1: Map indicating the location of the Raunds Area Project, and the Stanwick excavations. Prepared by Andrew Lowerre.

Figure 2: Site plan of the Stanwick excavations showing the location of A: Bronze and Iron Age samples and B: Roman samples. Prepared by Andrew Lowerre.

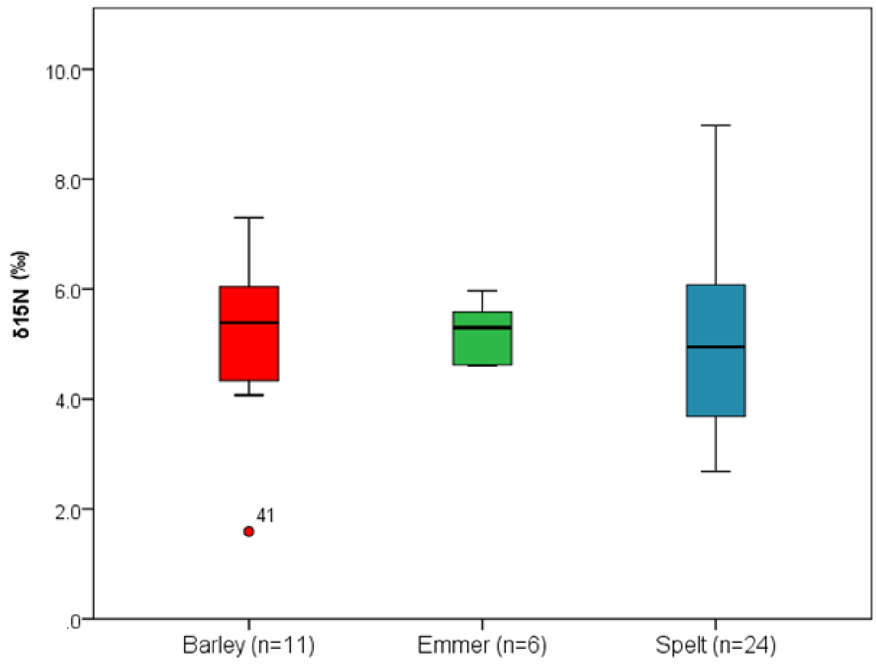


Figure 3: Boxplot comparison of $\Delta^{13}C$ values of different crop types for the whole data-set.

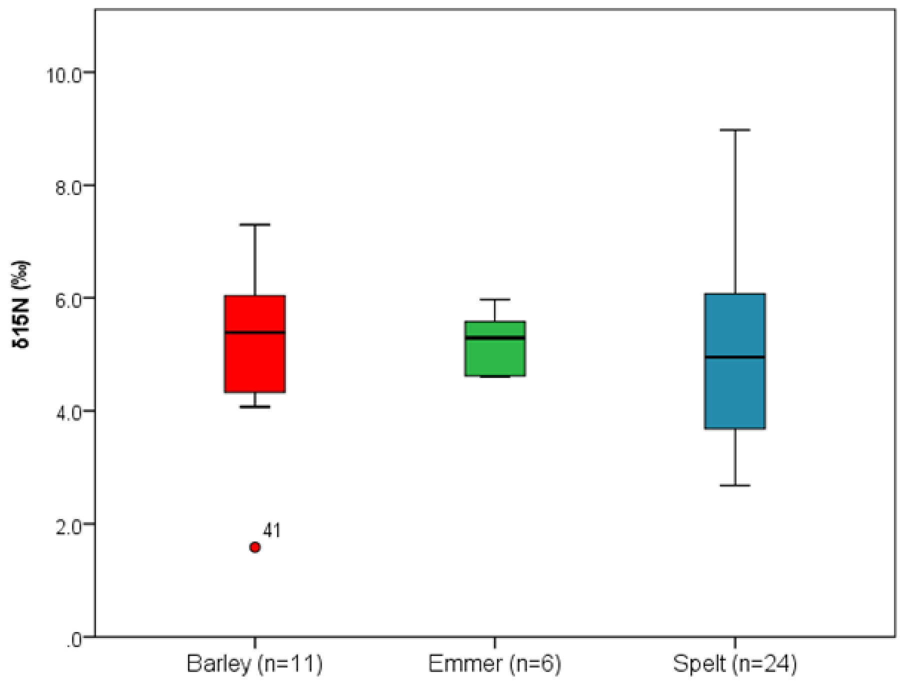


Figure 4: Boxplot comparison of $\delta^{15}N$ values of different crop types for the whole data-set.

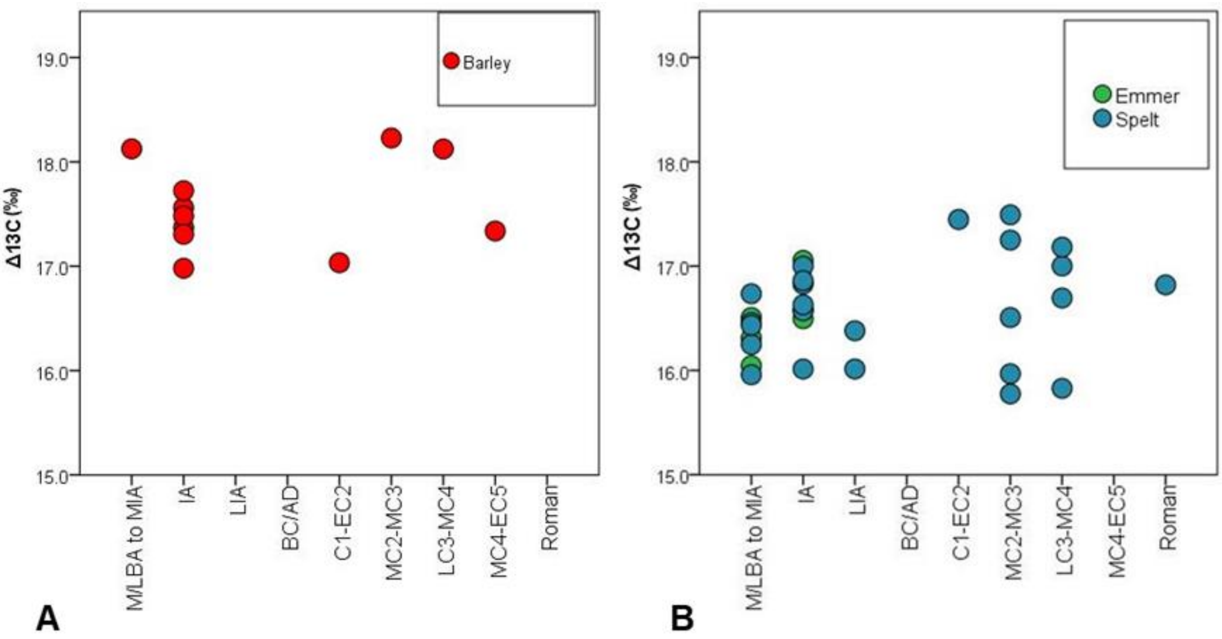


Figure 5: $\Delta^{13}C$ values of barley (A) and wheat (B) samples through time. Phases are as follows: Mid-/Late Bronze Age to Mid-Iron Age (c. 1400/900-400 BC), unphased 'Iron Age' (c. 800-1 BC), Late Iron Age (c.100BC-0 BC/AD), 1st-early/mid 2nd cent. AD, Mid-2nd – mid-3rd cent. AD; late 3rd – mid-4th cent. AD, 4th –early 5th cent. AD, unphased 'Roman' (1st – early 5th cent. AD).

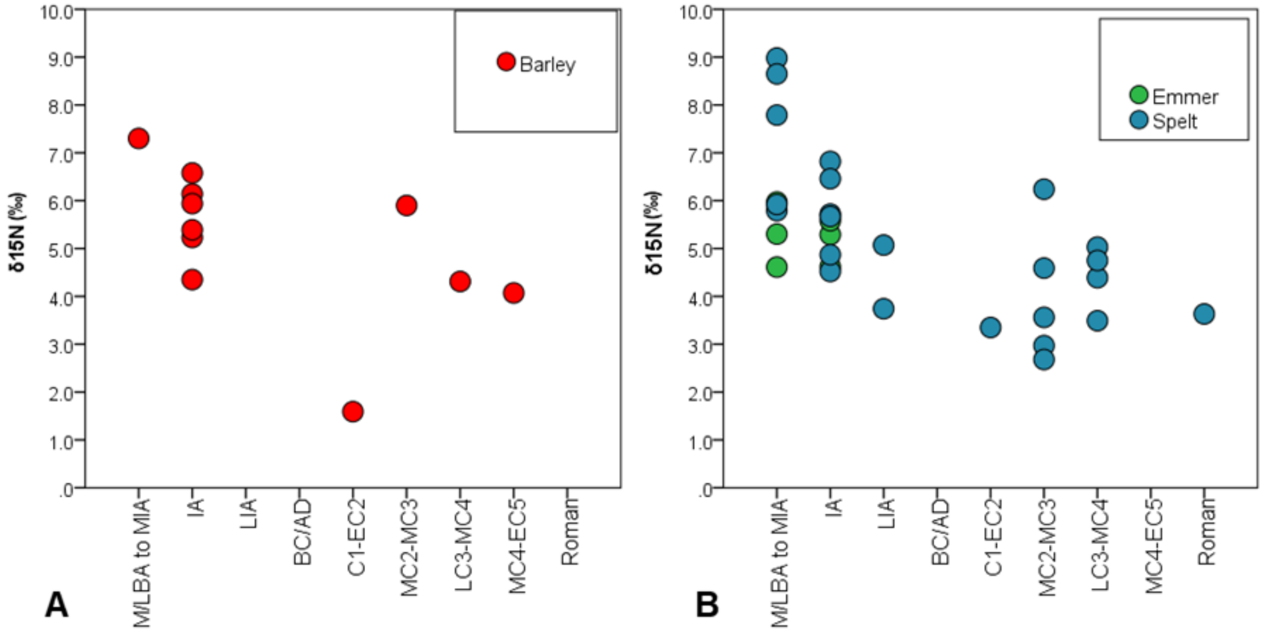
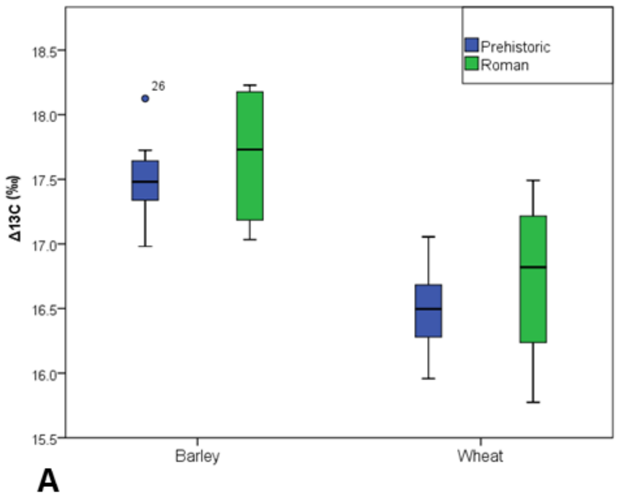


Figure 6: δ^{15}N values of barley (A) and wheat (B) samples through time. For phases see captions Figure 5.



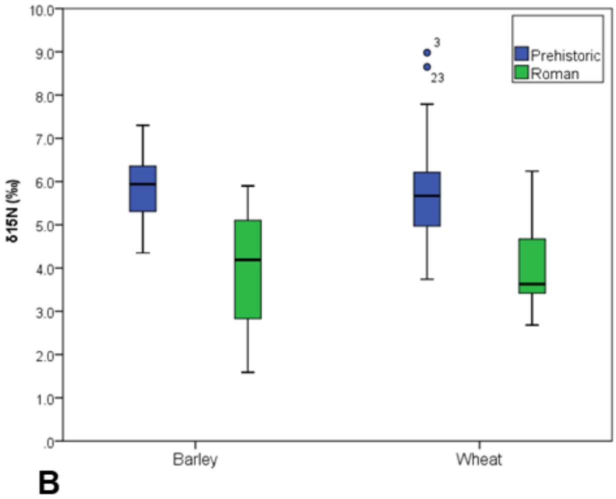


Figure 7: Boxplots comparing $\Delta^{13}C$ (A) and $\delta^{15}N$ (B) values of barley and wheat (emmer and spelt) from broad time-periods ('Prehistoric' = Mid-/Late BA to late IA; 'Roman' = 1st to early 5th cent. AD).