Crop husbandry strategies in the North-east of England, inferred from carbon, nitrogen, and sulphur stable isotopes on archaeobotanical assemblages from corn-drying kilns from commercial palaeoenvironmental archives

IOSIFIDI, IOANNA

Crop husbandry strategies in the North-east of England inferred from carbon, nitrogen, and sulphur stable isotopes on archaeobotanical assemblages from corn-drying kilns from commercial palaeoenvironmental archives

Ioanna Iosifidi
001131512

Submitted to the Department of Archaeology, Durham University
for the qualification of MSc by Research in Archaeology

2025

Table of Contents

Abstract

This MSc by Research dissertation presents the results of stable isotope analysis on archaeobotanical assemblages associated with corn-drying kilns from four sites in the North-east of England, selected from the palaeoenvironmental archive of Archaeological Services Durham University. Nitrogen, carbon, and sulphur stable isotope analysis on carbonised cereal grains are used to understand crop growing conditions and soil amendment strategies employed in cereal cultivation from the 11th to the 15th centuries. The findings here highlight the untapped potential of legacy material from developer-funded excavations when applied to archaeobotanical research. By focusing on corn-drying kilns, this work also establishes these structures as a valuable source of well-preserved archaeobotanical assemblages and illustrate their potential in enhancing our understanding of crop cultivation in the past. Finally, the data presented in this study contribute to a more comprehensive understanding of agricultural investment and socio-economic status of past communities in the North-east, as well as provide insight into the long-term trajectories of soil health and management and traditional agriculture in Britain.

Acknowledgements

Thank you to Prof Mike Church for his supervision and support throughout the undertaking of this work and to Prof Darren Gröcke for conducting the stable isotope analysis. Thanks are also owed to the palaeoenvironmental specialists at Archaeological Services – Durham University for allowing us access to their archives and helping with site and sample selection. Thanks also to David Jones of Coquetdale Community Archaeology for allowing us access to the cereal grains from Linbrig.

List of Contributions

J. Iosifidi undertook the seed sampling, identification, measuring, and the isotope sample preparation, in addition to the biomass and isotope data analysis, and writing and illustrating of this dissertation. M. Church designed the project, supervised the work and provided advice and direction. D. Grocke provided guidance on the isotope sample preparation, undertook the mass spectometry isotope analysis and formatted the stable isotope data for further analysis. C. O'Brien and L. Elliott carried out the initial post-excavation palaeoenvironmental analysis of the samples used for this work, as part of their work at Archaeological Services - Durham University.

Ethics statement

Generative AI tools were used to assist with grammar checking, proofreading, and improving the readability of the text, but not to contribute new insights, information, or to generate entirely new content.

List of figures

List of Tables

Chapter 1
Introduction

Understanding food production, particularly cereal cultivation, is key to understanding daily life and societal structures in late medieval England. Cereals were a primary food source for humans and livestock, and the cyclical nature of crop cultivation and harvest outcomes deeply impacted both rural and urban communities (Murphy, 1998, p. 120; Stone, 2006, p.11; Banham, 2022, p. 288). As a result, the study of cereal cultivation is vital for understanding the broader economic and social framework of this period.

Archaeological investigations have been instrumental in uncovering these processes and since the introduction of Planning Policy Guidance 16 (PPG 16) in 1990, which integrated archaeological evaluation into construction planning, the vast majority of archaeological investigation takes place within the commercial sector (Fulford, 2011). However, the extensive palaeoenvironmental archives generated by commercial archaeology units are often underutilised due to limited funding and opportunities for further analysis beyond recording (Hall and Kenward, 2006). Consequently, it is important to find strategies to maximise the value of these resources.

Here, it is proposed that a more collaborative approach between commercial archaeology units and the Higher Education sector to address this issue. The aim is to demonstrate the potential of these palaeoenvironmental archives as a rich source of material suitable for research taking place within the Higher Education sector, as well as contribute to a more comprehensive understanding of agricultural investment and practice in the North-east of England during the late medieval period, particularly in terms of soil amendment and field rotation.

To begin with, chapter 2 will provide an overview of the lifecycle of cereal grains in late medieval England, covering their cultivation, processing, distribution, and consumption. It will discuss open-fields and rotation systems which incorporated fallow periods and helped to maintain soil fertility, as well as soil amendment and the use of the mouldboard plough. Post-harvest processing of cereal grains in the form of drying, threshing, and milling will be discussed, as well as the distribution and consumption of the grains.

Chapter 3 will present research on stable isotope analysis on archaeobotanical assemblages associated with corn-drying kilns, selected from the archive of Archaeological Services – Durham University. Nitrogen, carbon, and sulphur stable isotope analysis is applied on assemblages from corn-drying kilns from four archaeological sites in Durham and Northumberland: Linbrig medieval village in Alwinton, Hallgarth Street in Durham, Belsay Hall drainage in Belsay, and Lightpipe Farm in Longframlington (Figure 1, table 1). Stable isotope analysis of archaeobotanical material is a valuable tool for reconstructing past environments and human/environment interactions. While traditionally applied to bone collagen in palaeodietary studies, when applied to plant tissues carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), and sulphur ($\delta^{34}S$) isotope ratios can also provide insights into agricultural practices and environmental conditions. Recent experimental studies, particularly on cereal grains, have established links between isotopic compositions and factors such as water stress, soil amendment, and environmental variability, enabling more precise interpretations of past agricultural systems (Fiorentino et al. 2014; Szpak. 2014; Styring et al. 2018; Gron et al. 2021; Styring et al. 2022; Blanz et al. 2024). Stable isotope analysis is most effective with well-preserved material, and archaeobotanical remains preserve best under moderate temperatures and low-oxygen conditions (Stroud et al. 2023; Bishop, 2019; Szpak and Chiou, 2019). Medieval corn-drying kilns were extensively used to dry grain before storage and transport, preventing germination and mould growth (McKevith, 2004; Monk and Kelleher, 2005; Banham and Faith, 2014). Here, it is hypothesised that the low-temperature, oxygen-reducing environments of corn-drying kilns make archaeobotanical assemblages associated with these structures ideal for stable isotope analysis. Furthermore, because grain was typically dried near its cultivation site, these assemblages offer valuable insights for research in regional agricultural practices.

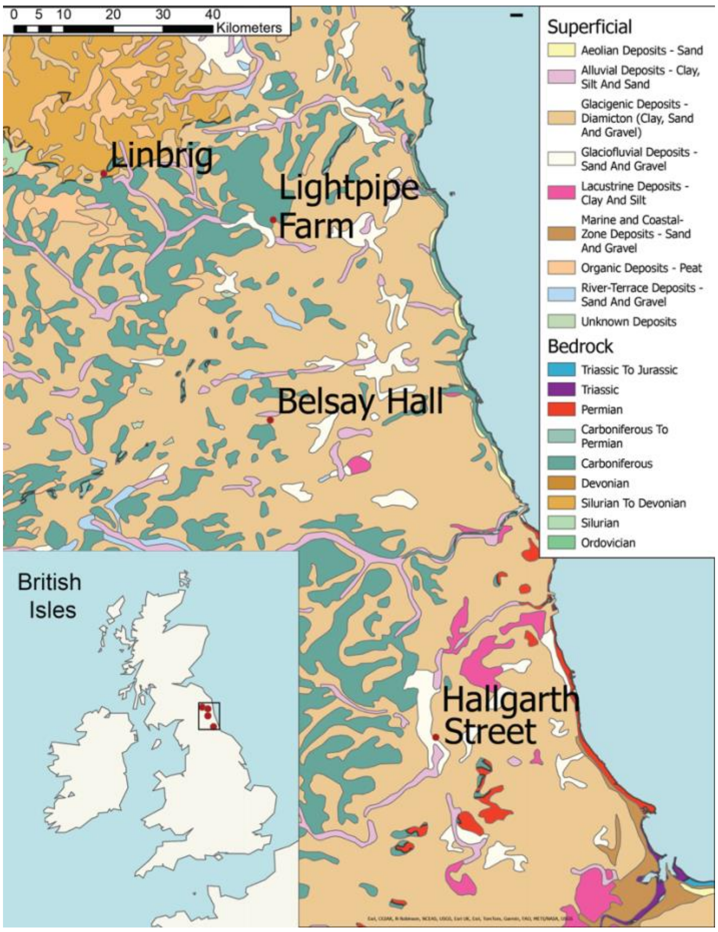

Figure 1. Geological map of study sites. (British Geological Survey, 2025)

Table 1. Summary table of study sites.

Site	Chronology	Cereal types present	Geology/soil type (BGS, LandIS)	National Grid Reference
Linbrig	1296 - 1424 CE	Barley, rye, bread wheat, bristle oat, common oat	Sandstone, siltstone and dolomitic limestone of the Ballagan formation, overlain by Devensian diamicton till. Slowly permeable seasonally wet acid loamy and clayey soils.	NT 9250 0649
Hallgarth St.	C12th-C13th	Barley, bristle oat, common oat	Carboniferous Westphalian Coal Measures overlain by glacial drift deposits of sand and gravel. Freely draining slightly acid sandy soils.	NZ 2770 4205
Lightpipe Farm	1395 - 1409 CE	Bristle oat, common oat	Carboniferous mudstone, siltstone and sandstone of the Stainmore Formation, overlain by Devensian till. Slowly permeable seasonally wet acid loamy and clayey soils.	NU 1293 0152
Belsay Hall drainage	1168 - 1265 CE	Bristle oat, common oat	Carboniferous sandstone of the Stainmore Formation, overlain by Devensian diamicton till. Slowly permeable seasonally wet acid loamy and clayey soils.	NZ 0846 7859

Chapter 4 will discuss the benefits of collaboration between commercial archaeology and Higher Education, emphasizing its potential to enhance research and heritage preservation. It is proposed that by utilising archived materials from developer-funded excavations, such partnerships can improve archive accessibility, refine research strategies, and expand understanding of the archaeological record. Recommendations are also made on how this collaboration is best practiced and make suggestions on other feature types and deposits that are commonly found in commercial archives that can be targeted in future research.

The last chapter will provide the conclusion and summary of the findings.

Chapter 2
Cereal grain in medieval England

Introduction

Cereal grain production was central to life in medieval England. Cereals served as a primary food source for both humans and livestock: the diet of the majority of medieval England's population was heavily reliant on cereals and it has been estimated that as much as 80% of one's calorific intake in medieval England would come from grain (Murphy, 1998, p. 120; Stone, 2006, p.11; Banham, 2022, p. 288). For those working the land, who constituted a substantial portion of the population, daily life was closely tied to the cyclical nature of cereal agriculture, while those who did not would still feel the impact of a good or bad harvest. Therefore, understanding the intricacies of cereal cultivation is essential for comprehending the broader social and economic structures during this period. This chapter outlines the production process for cereal grains, with a particular look at field systems and cultivation, as well as post-harvest processing and distribution and consumption of grain. By considering these practices, this chapter highlights the centrality of cereal production to medieval economies and diets.

Medieval field systems

The incorporation of open fields and a three-field rotation system is thought to have played a key role in the expansion and explosion of cereal cultivation that is seen during the Medieval period. The typical field in medieval England comprised of a group of *furlongs*, which were collections of strips (or *lands*) ploughed parallel to each other and separated by ridges (figure 1). In an open field system, which became widespread in England from the 12th-13th centuries onwards but may have been in use as early as the 8th century, nucleated communities would work several fields in which individually managed strips of land lay interspersed within each furlong. In areas where there was enough available arable land, this practice would be combined with a regular crop rotation system (Astill, 1997, p.200). Typically, one field would be sown in spring, with either a cereal crop, like barley (*Hordeum vulgare*) or oat (*Avena* spp.) or with legumes (*Fabaceae)* which would also serve as nitrogen-fixers that would help preserve and improve the fertility of the soil. A second field was sown in autumn to plant another cereal type, usually wheat (*Triticum* spp.) or rye (Secale cereale), and another would be left fallow. Farmers could utilise the fallow field to fold their sheep and cattle, and by doing so necessary nutrients, particularly nitrogen and phosphorus, could be replenished (Hamerow, 2022, p.12). Another benefit of the open field system was that lands were interspersed across the community's fields, ensuring that the arable was fairly divided amongst each peasant holding (or *yardlands*). The increasingly widespread adoption of open field and crop rotation systems is likely to have contributed to a general trend towards greater emphasis on extensification (i.e. low-input in terms of soil amendment and human labour per unit of land) over intensification (high-input per unit of land) in agriculture from the 8th century onwards, continuing onto the late medieval period (Hamerow, 2022, p.13).

Along with the community-led approach of open fields, much of the arable land in the country would have been demesne land, i.e. legacy land belonging to large estates, such as manors and priories, which, up until the early 14th century, would have been worked by peasants on behalf of the estate owners (Hall, 2014, p.95). In these cases, the production output was usually used to support the estates and for commercial purposes, and peasant workers would have been paid in wages and small portions of the yearly harvest. From the second half of the fourteenth century, and particularly following the impact of the Black Death, a combination of rising labour costs and market contractions rendered demesne farming less profitable, and it became increasingly common for parts of these demesnes to be let on short leases (Lomas, 1978).

Figure 2. Medieval open fields and ridge-and-furrow cultivation on Haystack Hill, Northumberland (Photo credit: Tim Gates)

Ploughing, sowing, and harvesting

The cyclical nature of crop cultivation was a defining element of working people's lives in late Medieval

England. The year could be generally divided into two seasons, winter and summer: winter being the more restful period of the two, while reserves of the supplies of the most recent harvest were still holding up, and summer, starting in early spring, would bring with it hard work and diminishing grain supplies up until the new harvest (Banham, 2022, p. 291). The focal tasks associated with cereal cultivation would be amending and ploughing the soils, sowing and harvesting the crops, and then processing and distributing the grain.

Cereal production would begin by ploughing the arable land and spreading manure, which would also require its own preparation by mixing animal dung with 'good earth' and composting, as suggested by Walter of Henley in *The Husbandry* (c.1276-1290) (Davis, 2024). Manure played a crucial role in ensuring soil fertility, and its availability, or lack thereof, could determine the quality and yield of harvests, and therefore the survival of the communities dependent on them (Jones, 2009). In peasant agriculture, the quantity of manure that could be applied to the fields was restricted by a number of different factors: the number of animals available to produce dung, the time it took to collect and prepare the manure heap, and the labour it required to spread the manure in the fields. By contrast, in demesne agriculture the same factors were not necessarily as restricting, as lords could demand that peasants fold their animals in demesne fields to provide dung, and where manure had to be spread by hand, labour was readily available either by payment or as part of the tenants' owed labour services (Jones, 2009). In addition, the quality of the manure itself also differed between demesne and peasant farming. Peasant manure, in shorter supply as it was, was often bulked up by the addition of household waste, which would include any composted kitchen and human waste, but also materials such as potsherds and other non-biodegradable household detritus. Lords, on the other hand, were reluctant to use anything from the domestic sphere, instead using manure derived only from animal, plant and soil matter, as suggested in agricultural treatises like *The Husbandry* and *The Seneschaucy* (c.1260-1276). These texts suggest that the distinction was largely determined by cultural factors, with manure containing domestic matter being considered tainted and taboo in some cases (Jones, 2009).

Ploughing would sometimes take place several times prior to sowing, in order to release nutrients (Campbell, 2008). The widespread adoption of the mouldboard plough is likely to have been at the heart of the technological innovation that is thought to have brought forth the so-called Medieval Agricultural Revolution (figure 2). Compared to the ard, evidence for which has been found in Europe since the Neolithic period (Rowley-Conwy, 1987) the mouldboard plough presented a more efficient way of tilling the soil by not just cutting but also turning over the ploughed soil (Astill, 1997, p.201; Banham and Faith, 2014). Direct archaeological evidence of the use of the mouldboard plough is relatively sparse and ambiguous, and therefore it is unclear when its use became widespread as opposed to being reserved for the wealthy estate owners who could afford it (Banham and Faith, 2014).

Figure 3. Experimental ploughing using a reconstructed mouldboard plough (Photo credit: Staatliche Schlösser and Gärten Hessen in Hamerow et al. 2023)

Zooarchaeological evidence shows that draught cattle, i.e. cattle whose primary purpose was to draw heavy loads started to become more common from the 9th century onwards in areas with heavy soils, prior to becoming widespread in the rest of England from the 11th century onwards, suggesting that the mouldboard plough was employed to take advantage of those harder to cultivate areas (Holmes, 2022, p.107). Indeed, the mouldboard plough was recognised as a key factor in cereal production: the beginning of the agricultural year in January would be marked by the Plough Monday festival, during which individuals involved at some stage of the cereal cultivation and post-cultivation process – ploughers, sowers, harvesters, threshers, millers, and others – would make a procession with the plough around the village and collect money (Banham, 2022, p.296). Even so, both documentary and archaeological evidence indicate that the mouldboard plough did not completely replace the ard, suggesting that the adoption of the mouldboard plough as the main tool for tilling the soil may have occurred at different stages in different regions (Astill, 1997, p.201).

Sowing for spring crops is likely to have taken place in March. The choice of which cereals to sow would have been made carefully, by taking into consideration a number of factors in order to maximise a return of investment: hardiness of the crop, yield potential, soil type, and market demands would all factor into the crop selection. As a result, different cereal crops tended to dominate in different parts of the country (Power and Campbell, 2008). Cluster analysis based on manorial and county records has indicated which crop combinations were particularly common in which parts of the country; the most common 'crop cluster' was the one where the most common crops were oat (*Avena* spp.) and wheat (*Triticum* spp.), which is also where the majority of the North-east (particularly County Durham and Northumberland) fell. Additionally, demesne lands belonging to wealthy owners would grow different types of crops compared to peasant holdings – for example, wheat was more common in demesne land, whereas peasant land was more likely to grow inferior bread grains such oats or maslin (Stone, 2006, p.19). Even so, regionally the staple cereal crops appear to have been consistent throughout the medieval period: broadly speaking, barley, oats, wheat, rye and legumes such as beans and peas in their various forms would have been commonly planted; autumn sowing would typically focus on wheat, barley and rye, while spring sowing would see oats, barley, and legumes (Stone, 2006, p.13). Both sowing seasons would also include mixed crops.

When the ploughing of the arable land and the sowing of the crops had been completed, the summer season would begin from around May onwards, and time would be taken up by preparatory tasks such as weeding, while waiting for the harvest. The harvesting process was a communal effort, often involving the labour of nearly every able-bodied member of the community, including small children and the elderly, in order to gather the crops as quickly as possible. Crops like barley, oats, and wheat were reaped with sickles, bundled into sheaves, with the head of the grain placed inwards within the sheaves to protect from birds, mice, and the weather (Gardiner, 2013). The sheaves were left to dry in stooks (upright bundles) in the fields, or they were placed in stacks, which sometimes included timber structures that consisted of a raised floor of either stone or timber to keep the grain off the ground, and a moveable roof that could be adjusted depending on the quantity of grain (Gardiner, 2013; Hinton, 2023). The drying period varied by crop: wheat dried relatively quickly, while oats and barley, retaining more moisture, needed a longer period to prevent spoilage. Once sufficiently dried, sheaves were moved to the farmyard, sometimes stacked outdoors and covered with thatch to protect against rain.

Post-harvest grain processing

Harvested grain would be vulnerable to a number of different factors, such as insects and vermin or mildew, thus necessitating the need for secure storage for any grain that would not be distributed or consumed immediately. For producers of grain, safe storage would also have served as an important insurance strategy against poor harvests: storing grain during seasons of plentiful yields would provide some cushioning for seasons of poor yields (McCloskey and Nash, 1984). Hay and other fodder were often stored outdoors in stacks until use, while cereals intended for human consumption were typically kept in barns. Barns were particularly important to large estates that needed to store extensive amounts of grain because, by the early Middle Ages, threshing had stopped taking place immediately after harvest; instead, it was carried out gradually in the autumn and winter (Gardiner, 2013). In addition to providing indoor space in which threshing could take place during the colder and wetter months, barns also provided the benefit that grain could be kept unthreshed for a time and processed in batches as needed and when labour was available (Gardiner, 2013; Hinton, 2023). In the archaeological record, barns are commonly found on demesne land from the 12th century onwards, as they were solidly-built structures intended to be permanent. By comparison, barns are not found on peasant land until the 15th century, indicating either that peasant-built barns were temporary structures, or that they were not used extensively in small farms that produced limited amounts of grain (Gardiner, 2000).

Whether it was taking place indoors in barns, or outdoors, threshing was manually demanding work. It had to be carried out on a smooth surface and involved beating the sheaves of grain with flails to separate the grain from the chaff. Flails consisted of a long wooden hand staff and a slightly shorter swingle, which were linked at the ends by a small leather looped hinge; swinging the hand staff allowed the swingle to make contact with the sheaves, and the force loosened the grain from the chaff (figure 3) (Hinton, 2023). Threshing was followed by winnowing to remove impurities (Banham and Faith, 2014). The stalks would be scythed and typically used for thatching, animal bedding, as well as fuel (Hinton, 2023).

Figure 4. Illustration from the 14th century Luttrell Psalter manuscript depicting peasants threshing wheat using flails (Credit: British Library)

Corn-drying kilns would have been vital, particularly in the wet climate of Northern England. Drying the grain prior to storage is vital to prevent mould, grain germination, and pest infestation, as well as general deterioration of the grain quality and breakdown of starch (McKevith, 2004; Banham and Faith, 2014). Additionally, drying the grains prior to transport would reduce the weight of the grains, thus increasing cost-efficiency and ease of transport and trade. In documents such as the 11th century *Gerefa* manuscript, there is a reference to the building of a stove on the threshing floor 'for an oven and a kiln' as a winter task, indicating that the drying of the grain would often occur as close to the processing site as possible (Hinton, 2023). In addition, corn-drying kilns could be used to dry partially processed grain to help de-husk and harden the grain prior to milling. Some corn-drying kilns would have been used for malting (Banham and Faith, 2014).

They were often stone-built and ranging in size from temporary small pits cut into the ground to large above-ground structures, which were sometimes attached to buildings (Monk and Kelleher, 2005). They typically consisted of three key elements: a drying chamber on one end and a stoking area on the other, with the two connected by a flue in the middle where a hearth or firepit would be placed (figure 4). A layer of grain would be placed in the chamber, either on a bed of straw or elevated on a wooden platform, and would be slowly dried by the heat and smoke of the hearth which would travel through the flue and into the drying chamber. The stoking area was important to control the temperature of the fire (Rickett, 2021, p.13). They were often sited into slopes to take advantage of wind direction, with the drying chamber placed upslope with the stoking area down the slope (Monk and Kelleher, 2005).

Ownership of corn-drying kilns and malting kilns would vary; large estate owners and otherwise wealthy individuals would have their own kilns, as evident by their widespread presence in castles and estate grounds throughout the country, as well as documentary references to individuals such as local ministers and vicars owning kilns (Rickett, 2021, pp. 35-36). These privately-owned kilns may have also been rented out for a charge to the general population (Rickett, 2021, p.36). In some cases, communities in nucleated settlements would own and manage their own kilns (Rickett, 2021, p.36).

Figure 5. The corn-drying kiln at Linbrig, Alwinton, Northumberland (Photo credit: Jones and Carlton, 2023)

In large estates that could afford specialist buildings, grain that had been threshed and dried would be stored in granaries rather than barns, while smaller farms would keep the processed grain in storage containers, such as wooden chests or storage jars, within the home (Gardiner, 2013). Granaries were typically roofed structures, often built on posts with a raised floor to protect from vermin, and locks on doors for security (Hinton, 2023).

A large amount of the harvested grain would be ground into flour in mills. Mills, particularly those powered by water, were extensively used in medieval England and it has been suggested that between the 11th and 16th centuries there were as many as 10000 mills in England (Langdon, 2004, pp.14-15). Mills operated in four different sectors, namely demesne, tenant, borough, and domestic, but the basic model of operation remained the same: in all four, individual customers would go to with their grain and would have it ground for a fee (either in the form of cash or grain) (Langdon, 2004, p.15-19). In the demesne milling sector, which is estimated to have processed approximately 40% of all milled grains, manors owned and operated their own mills, and tenants were required to use those mills for their own grain (Langdon, 2004, p.15-19). From the 12th century onwards, many of these demesne mills were leased to tenants, many of which ended up in hereditary tenure that operated independently of the original demesne (Langdon, 2004, p.17). Borough corporations also owned and managed mills for communities and settlements, while in domestic settings, smaller horse-mills or hand-mills may have been used by individual households to process grain as needed, and services of these mills may have been illegally offered to other individuals as a cheaper alternative to demesne, tenant, or borough mills (Langdon, 2004, p.18-19).

Distribution

By the 13th century, the grain market in England was robust and efficient enough to facilitate the distribution of grain across counties (Clark, 2014). This ensured that local grain prices were independent to local yields, and remained relatively consistent throughout the country (Clark, 2014). In years when certain regions experienced poor harvests, grain could be imported from areas that had a surplus, therefore stabilising prices by lowering costs in regions with shortages and raising them in regions with surpluses. This equilibrium was often facilitated by the authorities through market regulations, such as forcing low grain prices at times of scarcity (Clark, 2014). As a result, the grain market functioned as a balancing mechanism, maintaining relatively even price levels across England despite regional fluctuations in productivity (Clark, 2014).

Nevertheless, prices did fluctuate throughout the agricultural year. During the harvest period of July to September, grain was abundant and many fieldworkers would receive grain as part of their wages. Consequently, overall grain prices were relatively low (Dyer, 2006). The period from October to December would typically see the lowest grain prices, as producers sought to pay off debts accumulated earlier in the year. Peasant producers, who often lacked the appropriate storage facilities such as barns and granaries were also looking to sell during this period, particularly in preparation of rents being due to be paid by the end of September and around Christmas (Dyer, 2006, p.213).

By spring and early summer, grain stocks from the previous harvest were running low, leading to heightened demand and higher prices. This was also the period when the labour-intensive tasks of preparing for the new harvest began, creating additional pressure on grain availability (Banham, 2022, pp. 292–293). Wealthier employers or landowners with access to storage facilities could influence market prices during this time by strategically managing their grain reserves (Clark, 2014). If indications suggested a good harvest, they would sell the bulk of their stored grain before the new harvest, driving prices down; on the other hand, if they anticipated a poor harvest, they retained more grain as insurance, causing prices to rise (Clark, 2014). However, civic authorities discouraged the extensive accumulation of grain with the intent to store and sell later at exorbitant prices; at times of extreme grain shortages, they could force traders to sell at lower prices and even confiscate grain (Lee, 2011).

Consumption

Cereal grains were a cornerstone of the medieval English diet, contributing as much as 80% of the caloric intake across all social classes (Murphy, 1998, p. 120). Grain could be prepared for consumption in numerous different types of preparation, and most commonly in the form of bread, pottage, and ale. Even so, the types of grains and their forms of preparation varied significantly depending on consumer affluence and social status.

The most common form of consumption of cereal grains was bread, and not all bread was made alike. Wheat, and especially bread wheat, would have made the nicest loaves and therefore was the preferred cereal for bread-baking (Stone, 2006, p.13). However, the increased costs associated with the cultivation of wheat, i.e. higher nutrient requirements and lower yields than other cereal crops, restricted its regular consumption to more affluent households (Dyer, 2023). Other crops, mostly rye and maslin (a mixture of various cereal types, such as wheat and barley, sown together in one plot) were more common for those who could not afford wheat; those poorer still would typically make use of a coarse mixture of barley and oats for bread of much lower value (Stone, 2006, p.13). Most people, even those from relatively wealthy households, would either purchase their bread or prepare the dough at home and then pay for access to community ovens, which was more fuel-efficient than maintaining a bread-baking oven at home (Woolgar, 2016, p. 62).

Beyond its use as an affordable but lower-quality alternative to wheat for bread-baking, barley was more commonly used in brewing ale, which was an essential staple in medieval diets (Dyer, 2023). In the brewing process, the grain would initially be steeped in water and then laid out and left to germinate prior to being placed to dry in a malting kiln (Dineley, 2015). The malted grain would be crushed and mixed with hot water in a mash tun to extract what is known as the wort or wash, which would then be boiled with herbs or hops and left to ferment with added yeast (Dineley, 2015, p.79). While barley was the preferred grain for brewing, oats were also used, albeit producing ale of lesser quality compared to barley or wheat-based brews (Stone, 2006, p. 13).

Overall, consumption of cereal grains was varied, and social hierarchy and wealth was a significant factor in determining access to certain types of food. However, this distinction became less pronounced during periods of agricultural scarcity. For example, following the poor harvests of the early 14th century and the ensuing Great Famine (1315-1317), even elite households had to resort to consuming coarser bread and lower quality ale, as well as pottage, a thick soup typically made with unmilled barley or oats (Stone, 2006, p. 25). This suggests that, while social status generally influenced dietary patterns, these distinctions were not always rigid and could be disrupted by external pressures such as food shortages.

Conclusion

The majority of the population of medieval England was entirely reliant on grain, and so every step in cereal grain production was vital to the prosperity and survival of the population. This chapter has provided a broad outline of the lifecycle of grain, from the workings of field systems in which it grew to its cultivation, processing, distribution and consumption. Open fields were common in nucleated settlements, and where enough arable land was available, a three-field rotation system was employed in order to incorporate regular fallow periods and avoid diminishing soil fertility. Soil amendment through manure was also important in maintaining soil fertility, and the mouldboard plough, while not completely replacing the ard, made ploughing more efficient, allowing for the extensification of arable land and bringing into cultivation land with previously untillable soils. While wealthy estates could afford to grow luxury crops, such as wheat, peasant farmers tended to prioritise more reliable crops, like oats and barley. Once harvested, the grain underwent several stages of processing, including drying in the fields and in specialist corn-drying kilns, threshing, and winnowing. Where economically feasible, it would be stored in barns and granaries. The efficient grain market of medieval England allowed the grain to be transported throughout the country and keep prices consistent regardless of local harvest yields, prior to being prepared for consumption either as bread, ale, or pottage. Overall, the central role of cereal grains in medieval England's economy and daily life cannot be overstated.

Chapter 3

Stable isotopes in archaeobotany

The past five decades of research on stable isotopes in archaeobotanical remains have demonstrated the value of this work in understanding crop growing conditions in the past. The following chapter will provide a review of the history and use of this method in archaeobotany.

Isotopes are different forms of the same element, with the same number of protons but different numbers of neutrons. Unlike unstable isotopes, which are radioactive and can disintegrate, stable isotopes are non-radioactive and they do not decay or form other isotopes or elements over time (Fiorentino et al. 2015). However, the ratio of stable isotopes of the same element is impacted by many different physiological and chemical processes, and so studying these ratios can provide information as to what processes occurred. In archaeobotany, the study of archaeological plant remains, the stable isotope ratios of carbon (C13:C12), nitrogen (N15:N14), and sulphur (S34:S32) can provide valuable insight in the conditions and environments in which these plants grew.

Early applications of stable isotope research in archaeology during the 1970s and 1980s focused primarily on animal and human remains, particularly using carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratios to reconstruct diet and trophic relationships (e.g. Vogel & van der Merwe, 1977; Schoeninger and DeNiro, 1984; Minagawa and Wada, 1984). These palaeodietary models often inferred diet directly from bone collagen stable isotope ratios, assuming relatively uniform plant inputs and thus attributing any variation in bone collagen $\delta^{13}C$ and $\delta^{15}N$ values to trophic-level effects or to differences between terrestrial and marine protein consumption (Schoeninger and DeNiro, 1984; Hedges and Reynard, 2007). At the same time, agronomic studies started to show evidence that plant $\delta^{13}C$ and $\delta^{15}N$ values, and therefore isotopic baselines, could be impacted by plant growing conditions (Farquhar and Richards, 1984; Amundson et al. 2003), highlighting the necessity for direct analysis of archaeological plant remains. This work was aided by research that showed that $\delta^{13}C$ and $\delta^{15}N$ values in archaeological carbonised plant remains are similar to their modern counterparts, and therefore not significantly affected by diagenesis (DeNiro and Hastorf, 1985).

Experimental, agronomic, and archaeobotanical studies have since demonstrated that plant stable isotope ratios vary systematically in response to environmental conditions and agricultural management practices, including water availability,soil type, and fertilisation regimes (Bogaard et al., 2013; Wallace et al., 2013; Nitsch et al., 2015; Styring et al. 2017; Gröcke et al. 2021; Larsson et al. 2024). This variability directly influences herbivore and human isotopic compositions and must be taken into account in order to provide accurate baselines for dietary reconstructions. Consequently, the direct analysis of archaeological plant remains is now recognised as essential for establishing local isotopic baselines, as well as understanding crop cultivation and soil management strategies in the past (e.g. Fraser et al. 2011; Styring et al. 2017; Gron et al. 2017 and 2021).

Nitrogen

Nitrogen has two stable isotopes: ^{14}N (the lighter, more abundant form) and ^{15}N (the heavier, less common form) (Sharp, 2017). Plants can take up nitrogen in the form of ammonium (NH_4^+) or nitrate (NO_3^-), depending on soil conditions (Marschner, 2012). During ammonium uptake, nitrogen isotope fractionation is minimal, meaning plants take up both ^{14}N and ^{15}N with little discrimination (Evans, 2001). During nitrate uptake, the lighter ^{14}N is preferentially reduced, leaving the soil nitrate pool relatively enriched in ^{15}N (Robinson, 2001). Microbial processes like nitrification (ammonium to nitrate) and denitrification (nitrate to nitrogen gas) also contribute to ^{15}N enrichment by selectively releasing ^{14}N in gaseous forms (Robinson 2001). As a result, plants can exhibit different $\delta^{15}N$ values depending on the form of nitrogen absorbed and the extent of soil nitrogen cycling (Evans 2001; Szpak 2014).

Long-term intensive soil amendment regimes with organic fertilisers such as animal manure have been shown to elevate plant $\delta^{15}N$ values in cereal crops, and understanding this process is key to accurate palaeodietary reconstructions, as well as investigating agricultural practices in the past (Bogaard et al. 2007; Bogaard et al. 2013; Fraser et al. 2011; Szpak 2014). The addition of animal manure to agricultural soils typically leads to enrichment in ^{15}N (Bogaard et al. 2007; Fraser et al. 2011; Szpak 2014). Manure contains organic nitrogen that, during decomposition, leads to ^{14}N being preferentially lost as gases (such as ammonia or nitrogen gas), leaving behind ^{15}N-enriched nitrogen (Robinson 2001). The nitrogen in manure is mostly in organic form, which soil microbes break down into ammonium, making it available for plant uptake (Marschner, 2012). Therefore, plants that have been grown on manured soils have a ^{15}N-enriched isotopic composition (higher $\delta^{15}N$ values) that can be detected through stable isotope analysis (reviewed in Szpak 2014). While moderate soil amendment can enrich cereal to at least the trophic level (c. 3‰), more intensive soil amendment can result in $\delta^{15}N$ values from c. 6‰ to as high as 10‰ greater than in non-manured cereals (Bogaard et al. 2007; Bogaard et al. 2013; Fraser et al. 2011; Blanz et al. 2019). Typically, a human consuming primarily a diet consisting of herbivore protein would be expected to show $\delta^{15}N$ values +3–5‰ above those of local herbivores (Hedges and Reynard 2007). This means that consumption of manured cereal crops by both humans and herbivore animals could impact palaeodietary reconstructions based on $\delta^{15}N$ data (Bogaard et al. 2013; Szpak 2014). Therefore, $\delta^{15}N$ ratios on plant materials can help create more robust palaeodietary reconstructions but can also provide information on past agricultural practices and soil fertility (Bogaard et al. 2007; Fraser et al. 2011; Szpak 2014).

However, other factors can also impact $\delta^{15}N$ values in plants. In cereal grains, which have often been the focus of experimental work due to their ubiquity in the archaeological record, there are indications that taxon, species, and potentially landrace-specific physiological differences may influence their $\delta^{15}N$ values. Most foundational experimental work on stable isotopes in carbonised cereals has focused on barley and wheat (e.g. Bogaard et al. 2007 and 2013; Fraser et al. 2011; Wallace et al. 2013; Van Bommel et al. 2021), and these studies generally show similar $\delta^{15}N$ values for both cereal types when grown under comparable conditions. More intensive experimental work on additional cereal species that are also commonly recovered from archaeological contexts, such as oat and rye, remains limited, and modern agronomic studies examining $\delta^{15}N$ values in cereals beyond wheat and barley often rely on synthetic nitrogen fertilisers. Unlike organic fertilisers, which are more analogous to those used in the past, synthetic fertilisers typically lower soil $\delta^{15}N$ values (Choi et al. 2017), and therefore results from agronomic experiments using synthetic N fertilisers, such as those reported by Kolmanič et al. (2022), are not directly transferable to archaeological contexts. Although limited, there is some experimental work on oats and rye that suggests that $\delta^{15}N$ values in these species may not respond to manuring intensity in the same way as wheat and barley. In their experiments, which included oat and rye, Larsson et al. (2024) identified some statistically significant species-level differences in $\delta^{15}N$ values; for example, oats exhibited $\delta^{15}N$ values up to ~1.5‰ higher than bread wheat when cultivated under the same manuring regime. However, this pattern was not consistent across the two study locations, with the species effect being less pronounced at the second site of the experiment. Similarly, the results of manuring experiments on rye by Schlütz et al. (2025) did not completely align with the manuring intensity thresholds proposed by Bogaard et al. (2007 and 2013). However, in both studies, it appears that it was soil type, rather than species, that had a biggest impact on $\delta^{15}N$ values, with sandy soils resulting in lower $\delta^{15}N$ values compared to the clay soils in Larsson et al. (2024) and the loess soils in Schlütz et al. (2025). These findings suggest that, although physiological differences among cereal species may indeed influence $\delta^{15}N$ values, that effect may be secondary to other influencing factors, particularly soil type. Until a consistent, species-specific framework for interpreting $\delta^{15}N$ values in archaeological cereal grains becomes established in the literature, the current manuring thresholds in the research outlined above (e.g. Bogaard et al. 2007 and 2013; Fraser et al. 2011, etc.) based on barley and wheat are still a useful starting point for estimating soil nitrogen enrichment until a more nuanced, species-specific framework becomes available.

As mentioned, soil type can significantly impact crop $\delta^{15}N$ values. Highly organic soils, even without anthropogenic amendment, often accummulate and recycle nitrogen over long periods of time, which can elevate $\delta^{15}N$ values in plants grown in such soils (Amundson et al., 2003; Hobbie et al., 2017). Soil texture can also have a significant impact; for example, clay-rich soils typically retain nutrients, including ammonium and organic nitrogen, more effectively than sandy soils, which leads to slower nitrogen cycling and less isotope fractionation. This longer nitrogen residence time promotes cumulative isotopic fractionation and often results in enriched $\delta^{15}N$ values in crops (Amundson et al., 2003; Craine et al., 2015). By contrast, quick-drying sandy soils typically contain less organic matter and lose nutrients faster, which can shorten nitrogen residence times and limit ^{15}N enrichment in the soil, often leading to lower crop $\delta^{15}N$ values (Amundson et al., 2003). However, in some cases, preferential loss of ^{14}N can enrich the remaining soil nitrogen pool in ^{15}N, potentially resulting in elevated crop $\delta^{15}N$ values even in sandy soils (Robinson, 2001; Craine et al., 2015).

Climate can also plays a significant role on plant $\delta^{15}N$ values by regulating nitrogen availability in soils prior to plant uptake (Robinson, 2001; Amundson et al., 2003; Craine et al., 2015). Water availability in particular can have a significant impact on $\delta^{15}N$ values in plants. Arid or semi-arid conditions tend to enhance processes that lead to nitrogen isotope fractionation, preferentially removing more ^{14}N and thus leaving the soil nitrogen pool enriched in ^{15}N, leading to plants growing in these conditions to exhibit higher $\delta^{15}N$ values than those grown in more humid environments (Handley et al., 1999; Craine et al., 2009; Craine et al., 2015). In high-rainfall environments, nitrate leaching can remove nitrogen before extensive fractionation occurs, often resulting in lower plant $\delta^{15}N$ values (Robinson, 2001). Temperature is another influencing factor, as it can speed up microbial activity, leading to faster nitrogen cycling and thus increasing the potential for isotopic fractionation and elevated $\delta^{15}N$ values in soils and plants (Amundson et al., 2003; Hobbie et al., 2017).

Carbon

There is a close relationship between $\delta^{13}C$ values and water availability during the growing season, which, through stable isotope analysis, can be used to understand the conditions under which the analysed plant tissues were grown. During photosynthesis, plants discriminate between carbon isotopes, preferentially taking up the lighter ^{12}C over the heavier ^{13}C, leading to lower ratios of ^{13}C to ^{12}C (expressed as $\delta^{13}C$) in plant tissues compared to atmospheric CO_2. The degree of discrimination (expressed as $\Delta^{13}C$ and calculated by taking into account atmospheric CO_2 and plant tissue $\delta^{13}C$) is highest in optimal conditions, when stomata are fully open, and lowest in the presence of environmental stressors such as low water availability, when stomata are closed and photosynthesis limited (Fiorentino et al, 2014). The degree of discrimination is stronger in plants that follow the C_3 photosynthetic pathway, such as trees, legumes, and most cereals. Cereal $\delta^{13}C$ values are widely interpreted as a proxy for water availability during the growing season and have been used to infer crop irrigation practices in the past (Ferrio et al. 2005; Wallace et al., 2013; Fiorentino et al., 2015; Styring et al. 2017).

Soil type can also impact water availability, and therefore influence crop $\delta^{13}C$ values. Some soil types will hold moisture better than others, with clay-rich and loamy soils generally retaining water more effectively than sandy or free-draining soils (Fiorentino et al., 2015; Wallace et al., 2015). Crops grown on soils that retain more moisture are less likely to experience water stress and typically show lower $\delta^{13}C$ values (higher $\Delta^{13}C$ values), while crops grown on shallow, coarse, or quick-draining soils are more likely to experience water stress and often have higher $\delta^{13}C$ values (lower $\Delta^{13}C$ values) (Wallace et al., 2013; Fiorentino et al., 2015). Soil depth and root development also influence how well plants can access stored soil moisture, particularly during dry periods, which can lead to variation in $\delta^{13}C$ values even within the same site (Wallace et al., 2013).

As with $\delta^{15}N$ values, there is some indication that different cereal species respond differently to water input, which must be taken into account when interpreting $\Delta^{13}C$ data: the framework proposed by Wallace et al. (2013) suggests that barley (*Hordeum* spp.) exhibits $\Delta^{13}C$ values below 17‰ when water-stressed and above 19‰ when well-watered. By comparison, wheat (*Triticum* spp.) thresholds are 1-2‰ lower than barley, with anything above 17‰ indicating high water availability and anything below 16‰ suggesting water stress (Wallace et al. 2013). The results in Larsson et al. (2024) were consistent with this framework where wheat and barley are concerned, and expanded it to include oat (*Avena* spp.) and rye (*Secale cereale*), which responded at c. 1‰ and c. 2-3‰ lower than barley respectively. The Supplementary Material of Hamerow et al. (2020) included the results of a preliminary analysis on a modern rye crop with free-threshing wheat and oat contaminants, which found that rye and wheat showed no statistically significant difference in their $\delta^{13}C$ values, while in oats the values were 2.5‰ lower than rye. This oat offset is also used in Stroud et al. (2022) and Hamerow et al. (2025) as part of the FeedSax project. However, very little detail is provided in Hamerow et al. (2020) for this preliminary analysis, notably lacking information on the number of grains analysed for each species, whether the samples were single-grain or aggragate, or the conditions under which the crops were cultivated. Therefore, more robust research is required before $\delta^{13}C$ offsets for oats can be established.

Sulphur

The application of sulphur stable isotope analysis to archaeological material is relatively recent and less widespread compared to carbon and nitrogen. Sulphur stable isotope analysis on bone collagen can help differentiate between consumption of marine vs terrestrial food sources, identify freshwater fish intake, and assess geographic or ecological variation in diets, which provides important information in palaeodietary studies (Nehlich, 2015). Although the potential of studying sulphur stable isotopes in human tissues had become apparent since the late 1980s, the large sample size required for the analysis prevented it from being applied widely (Krause et al. 1987; Richards et al. 2003). It was only when developments in mass spectrometry allowed for the use of much smaller sample sizes that the use of sulphur stable isotopes started to become more common in archaeology (e.g. Richards et al. 2001, Craig et al. 2006).

Sulphur has multiple stable isotopes, with ^{32}S and ^{34}S being the most abundant. The ratio of ^{32}S and ^{34}S is expressed as $\delta^{34}S$.Most terrestrial plants take up sulphur in the form of dissolved sulfate (SO_4^{2-}) with relatively little discrimination, and so $\delta^{34}S$ values in plant tissues tend to be similar to environmental SO_4^2 (Trust and Fry. 1992). Marine sulfate is isotopically enriched (approximately +21 ‰), whereas terrestrial and freshwater sulphur sources tend to be lower and more variable. These differences allow $\delta^{34}S$ measurements to be used in archaeology to distinguish input from marine versus terrestrial sources in dietary and environmental reconstructions (Nehlich, 2015). In recent years, it has become clear that crop cultivation practices, particularly fertilisation with seaweed, can elevate $\delta^{34}S$ values in crops, with the result that marine resource consumption may be overestimated in palaeodietary reconstructions where humans and animals consumed seaweed-fertilised cereals (Gröcke et al. 2021; Blanz et al. 2024).

In field experiments, seaweed (such as *Fucus* spp., *Laminaria* spp., and other species) fertilisation has been shown to raise $\delta^{34}S$ values in cereals by approximately 2-3‰, although this effect may be more significant in soils that don't already have elevated $\delta^{34}S$ values due to exposure to other factors such as sea spray and oceanic-influenced rain (Blanz et al. 2024). In celtic beans, seaweed fertilisation has been shown to raise $\delta^{34}S$ values by as much as 10‰, while cod fish fertilisation raised $\delta^{34}S$ values by 5‰ (Gröcke et al. 2021). Carbonised plant remains have been shown to preserve their $\delta^{34}S$ values, meaning that direct analysis on archaeological material preserved through carbonisation is possible, and it can make a significant contribution to palaeodietary studies, as well as improve our understanding of crop cultivation and soil amendment strategies in the past (Nitsch et al. 2019).

In addition to fertilisation with marine resources, other environmental factors can influence $\delta^{34}S$ values in plants. Proximity to the coast can also elevate plant $\delta^{34}S$ values, as sea spray can deposit high $\delta^{34}S$ sulphate onto soils, leading to elevated $\delta^{34}S$ values (Trust & Fry, 1992; Nehlich, 2015). The underlying geology of where crops are cultivated can also be particularly influential, as different rock types contain sulphur with distinct isotopic signatures. This means that crops grown on sulphide-rich bedrock, marine sediments, or evaporitic deposits may show elevated $\delta^{34}S$ values even in inland locations (Nehlich, 2015). Finally, soil moisture can impact sulphur isotope values, as microbial processes in waterlogged soils can alter sulphur cycling and the isotopic composition of soil sulphate (Nitsch et al., 2019).

Together, these factors mean that $\delta^{34}S$ values in crops can reflect both crop cultivation practices, as well as local environmental and geological conditions, and the interaction between these different areas remains poorly understood. It has beenestablished that in certain location types, such as coastal fields, it is difficult to differentiate elevated sulphur values that are due to marine fertilisation as opposed to oceanic influence (Szpak et al. 2019). For instance, Blanz et al. (2024) observed only a moderate elevation in $\delta^{34}S$ values in cereal grains fertilised with seaweed during field experiments in Orkney, which the authors speculated was due to already high baseline soil $\delta^{34}S$ values in the region that may have mitigated the effect of the seaweed amendment. Conducting additional field experiments across a wider range of locations would help create a more nuanced understanding of how marine-based soil amendment can influence $\delta^{34}S$ values in plant tissues and contribute to more robust interpretations of crop $\delta^{34}S$ values.

Additional considerations and future directions

Charring offsets

Plant remains are most commonly preserved through charring, a process that has been shown to have a small but measurable impact on $\delta^{13}C$ and $\delta^{15}N$ values, depending on charring temperature and duration.

Experimental studies have shown that, assuming charring temperatures between approximately 230 and 300 °C, average isotopic offsets of ~0.2‰ for $\delta^{13}C$ and ~0.3‰ for $\delta^{15}N$ can be expected, and it is recommended that these offsets be applied when comparing carbonised cereal grains with fresh ones (Nitsch et al., 2015; Styring et al., 2024). Comparable experimental research has not yet been undertaken for sulphur isotopes. Although Nitsch et al. (2019) observed that archaeological cereal grains often containlower S concentrations than modern grains, no systematic assessment of charring-related effects on $\delta^{34}S$ values has been carried out, and no correction offsets have been established. Controlled experimental studies using both laboratory furnaces and outdoor hearth settings would therefore be valuable in assessing how carbonisation affects $\delta^{34}S$ values in plant tissues and improve the interpretation of sulphur isotope data from carbonised archaeobotanical remains.

Intra-plot variability

Individual grains can exhibit variable $\delta^{15}N$ and $\delta^{13}C$ values even when growing in the same plot, and even within a single cereal ear, reflecting small-scale differences in growing conditions. Though research in intra-plot isotopic variability has been limited, Styring et al.'s (2024) synthesis of experimental datasets indicates that the standard deviation for intra-plot values can be as high as 0.76‰ for $\delta^{15}N$ and 0.30‰ for $\delta^{13}C$. The greater standard deviation for $\delta^{15}N$ values is likely due to uneven distribution of organic soil amendments, such as manure, differences in soil nitrogen cycling, and localised nitrogen losses (Fraser et al. 2011; Styring et al., 2024; James et al. 2025). In contrast, water availability within small areas of a field is often more uniform, resulting in lower intra-plot variability in $\delta^{13}C$ values (Wallace et al., 2013). Experimental work on modern barley has demonstrated that variation within individual plants is limited and close to analytical uncertainty, indicating that single grains generally provide a reliable reflection of local growing conditions (James et al., 2025).

In the case of archaeological grains recovered from depositional contexts such as barns, granaries, or corn-drying kilns, variability in $\delta^{15}N$ above 2‰ might indicate that the crops were cultivated in different fields (Lightfoot and Stevens, 2012; James et al. 2025). This in itself can be informative as to crop cultivation strategies in the past. For example, under a field rotation system, a common cultivation method in medieval England, each field receives the same treatment in terms of soil amendment and fallow periods, which, over a long period of time, might result in an averaging of $\delta^{15}N$ values across all fields under this system (Stroud, 2022; Hamerow et al. 2025). High variability in $\delta^{15}N$ isotopes in cropswould rule out the possibility of crops grown under a two-field or three-field system.

Conclusion

The application of stable isotope analysis to archaeobotanical material is a valuable method of reconstructing past environments and human-environment interactions. Through a combination of field experiments and archaeological studies, it has been shown that carbon, nitrogen, and sulphur stable isotope ratios in carbonised plant remains are able to provide valuable information on agricultural practices and environmental conditions. However, a range of different factors, including soil type, anthropogenic soil amendment and species-specific responses to it, and intra-plot variability can impact stable isotope values in archaeobotanical material and these should be taken into account when interpreting this type of data.

Chapter 4

Crop husbandry strategies in the North-east of England inferred from carbon, nitrogen and sulphur stable isotopes on archaeobotanical assemblages from corn-drying kilns

J. Iosifidi, D. R. Gröcke, C. O’Brien, L. Elliott, M. Church

Introduction

Soil fertility was a key concern for agricultural communities in late medieval England, directly influencing the quality and quantity of harvests, and therefore a community’s degree of vulnerability to famine (Jones, 2009). Agricultural practice would be informed by the goal to maximise productivity with the available resources at hand (Clark, 1992). This paper explores the agricultural practices in County Durham and Northumberland during the late medieval period, with particular attention to soil amendment, extensification vs intensification, and field rotation strategies, using stable isotope analysis on archaeobotanical assemblages from corn-drying kilns from developer-funded excavations. As such, we evaluate the potential of corn-drying kilns as a source of archaeobotanical material suitable for stable isotope research.

Stable isotopes in archaeobotany

The application of stable isotope analysis to archaeobotanical material has become a valuable method of reconstructing past environments and human-environment interactions. While carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios from bone collagen are traditionally used in palaeodietary studies, when applied to archaeobotanical material, along with sulphur ($\delta^{34}S$), they can also provide valuable data on agricultural practices and environmental conditions (Fiorentino et al., 2014; Szpak, 2014; Styring et al, 2017; Gron et al, 2021; Styring et al, 2022; Blanz et al. 2024). Experimental studies over the last two decades have generated modern datasets that facilitate the interpretation of archaeobotanical stable isotope results, with a particular focus on cereal grains (Bogaard et al., 2007, 2013; Fraser et al., 2011; Wallace et al., 2013). These studies highlight the relationship between the isotopic composition of plant tissues and factors like water stress, soil amendment, and environmental variability (Bogaard et al, 2007; Bogaard et al, 2013; Fraser et al, 2011; Wallace et al, 2013; Gröcke et al, 2020; Stroud et al, 2023; Larsson et al, 2024).

Corn-drying kilns and stable isotope analysis

Corn-drying kilns would have been used extensively in the medieval period to dry grain prior to transport and storage, as well as to inhibit germination and mould growth (McKevith, 2004; Monk and Kelleher, 2005; Banham and Faith, 2014). Stable isotope analysis provides the most reliable results when performed on well-preserved material, and archaeobotanical material has been experimentally shown to preserve best under moderate temperatures in reducing oxygen conditions (Stroud et al, 2023; Bishop, 2019; Szpak and Chiou, 2019). Corn-drying kilns were designed to protect the grain from high temperatures whilst drying, by laying it on a bed of straw. Even in cases of accidents, such as with the kiln at Hallgarth Street, where the fire would get out of control, the straw would create reducing conditions that would allow preservation. Here we hypothesise that the low-temperature, oxygen-reducing conditions under which carbonisation would have occurred in these kilns are ideal for facilitating excellent preservation of organic material, making such assemblages well-suited for stable isotope analysis (Church, 2002; Styring et al, 2024). Additionally, grain is unlikely to have been transported long distances prior to drying, as any moisture would make it heavier and leave it vulnerable to spoiling during travel. This suggests that archaeobotanical assemblages recovered from these kilns predominantly represent crops cultivated in close proximity to the kiln, therefore making these assemblages ideal for regional research.

This research focuses on archaeobotanical assemblages recovered from corn-drying kilns from four sites excavated and analysed by Archaeological Services – Durham University (ASDU) (figure 5). In Britain, as much as 90% of archaeological investigation is carried out through the commercial sector (Fulford, 2011). Consequently, commercial archaeology units such as ASDU maintain extensive palaeoenvironmental archives, often with a regional focus. By choosing assemblages from ASDU's archive, we highlight the untapped potential of commercial archaeology archives for advancing archaeological research beyond initial recording and assessment.

Grain biomass in archaeobotany

Basic measurements of cereal grains (length/width/depth) are commonly collected in archaeobotanical studies to help with identification and provide descriptions of archaeobotanical material. In cereals, grain size can be influenced by a range of factors, and so collecting biometric data of cereal grains can also provide information on agricultural practices and crop development, along with soil productivity and crop growing conditions in the past. Manuring has been correlated with increased grain size in experimental studies (Larsson and Bergman, 2023) as has fertilising with seaweed (Blanz et al. 2024). However, correlations between grain size and stable isotope values are inconsistent, with some studies failing to detect a significant relationship (e.g. Bishop et al., 2019). As such, combining biometric data with isotopic analysis strengthens interpretations by allowing multiple lines of evidence to assess crop growing conditions and cultivation strategies in the past.

Background to the region: Durham and Northumberland

The two centuries following the Norman Conquest witnessed significant agricultural and economic development in the North-east of England, including expansions into both pasture and arable land. In Northumberland and Durham much emphasis was placed on cereal cultivation, which dominated the lowlands and often extended into more marginal areas, including uplands and hillsides (Miller, 1976). The broad region running from the North-east through the Midlands and along the South Downs was characterised by nucleated villages that employed open field systems, within which individually managed strips of land lay interspersed within furlongs that made up each field. In some of the lowland areas of Northumberland and Durham, this was implemented as a regular three-field rotation system, i.e. one field used for winter-sown grain, one field for spring-sown grain, and one field left fallow, to maintain soil fertility. However, the predominance of acidic soils and a climate-induced short growing season often precluded widespread use of the three-field system. Instead, communities in more marginal areas made use of any available arable land in the form of strip-divided furlongs, and making the most of the growing season by placing emphasis on spring-sown grain, particularly oats (Miller, 1976).

In addition to community-managed open fields, some arable land was owned and managed by large estates, both ecclesiastical and secular. In Durham, the Bishopric estate, controlled by the Bishop of Durham, and the Priory estate, managed by Benedictine monks of Durham Cathedral, were central to the region's agricultural economy (Larson, 2006). In Northumberland, much of the land was under the control of religious institutions, such as Tynemouth Priory, as well as noble estates such as Alnwick Castle and Bamburgh Castle.

Linbrig

The medieval settlement of Linbrig is located in the southern Cheviot Hills and divided into two parts approx. 350m apart (figure 1). The settlement was occupied at least during the 14th and 15th centuries and fell into the boundaries of the medieval manor of Aldensheles, with some evidence that the main chapel of the manor may have been located there (Jones, 2022). A Level 3 topographic survey of the site, commissioned by the Ministry of Defense and undertaken Northern Archaeological Associates (NAA) in 2005, revealed several structures including a circular structure that appeared to be a corn-drying kiln (figure 6) (Jones, 2022; Jones and Carlton, 2023). Later excavations by Coquetdale Community Archaeology (CCA) in 2019 investigated this structure and in 2021 samples were collected from above and below the kiln floor (Jones and Carlton, 2023).

Figure 6. The corn-drying kiln at Linbrig, Alwinton, Northumberland (Photo credit: Jones and Carlton, 2023)

The palaeoenvironmental analysis of the samples identified charred cereals, mainly oats, rye, barley, and wheat, suggesting that the kiln was primarily used to dry processed grains, with no indication of malting. The kiln fills above and below the kiln floor were both radiocarbon dated to the 14th century. The fill below the kiln floor was dominated by oat, but also included large quantities of barley (*Hordeum vulgare*), rye (*Secale cereale*), and bread wheat (*Triticum aestivum*). By comparison, the fill above the kiln floor was primarily oat (*Avena* spp.), with only a very small number of other cereals present.

Hallgarth Street, Durham

Durham's Hallgarth Street fell within the Barony of Elvet during the medieval period (figure 1). By the 14th century, the street, along with Church Street which runs parallel to it, would have consisted of tenements which would have paid rent to the nearby Elvethall Manor, as well as industrial spaces such as brewers, tailors, and several kilns (Archaeological Services, 2006). Elvethall Manor was part of the estate of the Priory of Durham and administered by the Hollister. The Manor operated primarily as a specialised corn farm, growing crops for commercial purposes as well as to provide for the Manor and contribute to the grain used by the Priory. Of the crops grown for sale, barley was the most important one, whereas oat was grown extensively and typically used to support the priory, most likely as fodder (Lomas, 1978).

Archaeological evaluation was undertaken in 2005/6 by Archaeological Services Durham University on 99-100 Hallgarth Street, Durham City, ahead of construction on the site. A key finding as a result of the excavation was a medieval corn-drying kiln, consisting of a rectangular pit with a hearth on one end and a dome-shaped superstructure of withies and clay set on top of it, where grain would be laid to dry prior to storage (figure 7). The kiln contained a thick layer of charred grain, primarily barley (*Hordeum vulgare*), unevenly distributed and thickest at the west end and around the kiln's perimeter. The grains analysed for the purposes of this research were collected from this layer. It also contained medieval pottery, charred wooden laths, iron nails, and clay lumps. These elements suggest that this context represents the remains of the kiln's collapsed roof structure after it caught fire during its last use. No radiocarbon date is available for this layer, but pottery included in the same context indicates a date no earlier than c. 12th-13th centuries (Archaeological Services, 2006).

Figure 7. Post-excavation view of the corn-drying kiln at Hallgarth Street, Durham (Photo credit: Archaeological Services, 2006).

Belsay Hall

The parish of Belsay, within which Belsay village was located, is first recorded as a settlement in the 1200s (figure 1). The village was part of the estate of Belsay, belonging to the Middleton family, and it remained occupied and was densely populated until the 19th century, when the settlement was cleared and its underlying stone quarried for the construction of Belsay Hall (Oakey, 2017). The area which the settlement occupied was extensively cultivated to support a large population, as evidenced by several surviving furlongs of ridge and furrow earthworks in close proximity to the village and the wider settlement area (Oakey, 2017).

A watching brief was undertaken by Archaeological Services – Durham University between November 2021 and February 2023 across the grounds of Belsay Hall and Castle. A corn-drying kiln was uncovered within the stables and coach house, measuring 3.5m x 2.98m x 1.05m. (figure 8). The bottom layer of this structure consisted of a dark brown-grey sandy clay silt containing frequent blocks of sandstone. On top of that layer was a soft and smooth black clayey sandy silt deposit containing an abundance of charred cereal grains, primarily oats (*Avena* spp.) with some barley (*Hordeum vulgare*) and flax (*Linum* sp.) (Archaeological Services, 2023). The layer was radiocarbon dated to 1168 – 1265 cal CE (SUERC Radiocarbon Laboratory, 2024).

Figure 8. Corn-dryer at Belsay Hall, looking west (Photo credit: Archaeological Services, 2023)

Lightpipe Farm

Lightpipe Farm is located on the outskirts of Longframlington, Northumberland (figure 1). The site showed evidence of medieval cultivation, indicated by ridge and furrow earthworks, suggesting that the area was predominantly used for agricultural activities.

Archaeological excavation was conducted in 2021 by Archaeological Services – Durham University in advance of a residential development on the site. The main findings included a corn-drying kiln, radiocarbon dated to the 14th century and consisting of a pear-shaped pit with associated wall and stone working surface (figure 9). This corn-dryer was interpreted as being used for drying cleaned cereal grains, primarily oats, with some barley (*Hordeum vulgare*) and possible bread wheat (*Triticum* sp.), before milling or storage.

Figure 9. The corn-dryer at Lightpipe Farm, looking North-east (Archaeological Services, 2021)

Methods

The stable isotope analysis was carried out at the Stable Isotope Biogeochemistry Laboratory (SIBL) at Durham University. A breakdown of materials used from each site can be found in Table 2. For each sample, grains were measured in three dimensions (length/width/depth) using the internal graticule of a Leica M80 stereomicroscope. Up to 10 of the best-preserved grains were selected for single-grain stable isotope analysis from each sample and for each species, best-preserved referring to P1-P3 external preservation after Hubbard and Al Azm (1990) and good to borderline internal preservation after Stroud et al. (2023). Internal morphology was not used to assess charring temperature, but levels of preservation were consistent with charring in temperatures between 230 and 300°C, as recommended in Styring et al. (2024). Apart from gentle scraping off of any visible sediment, no other pre-treatment was undertaken, due to the current lack of consensus as to whether pre-treatment of archaeobotanical remains is necessary to remove potential contaminant carbonates and nitrates, and the uncertainties around the effect of pre-treatment on the isotope ratios of uncontaminated grains, as well as the potential for loss of material on single-grain samples (Styring et al. 2024.) The mass of each grain was measured to the nearest 0.001mg using a Mettler PM480 Delta Range balance.

After all measurements were taken, each single grain was crushed into a powder using a small pestle to create a homogeneous isotope sample. For each C and N sample, a sample aliquot of 1.5-1.8mg was weighed into a 6x4 tin capsule on a Mettler Toledo XP6 microbalance, then combusted using a Costech Elemental Analyser (ECS 4010) connected to a Thermo Scientific Delta V Advantage isotope ratio mass spectrometer. C and N were analysed in tandem from the same sample aliquot. The $\delta^{13}C$ isotope ratios were corrected for ^{17}O and are reported in standard delta (δ) notation in per mil (‰) relative to Vienna Pee Dee Belemnite (VPDB) and $\delta^{15}N$ isotope ratios are reported against atmospheric nitrogen (AIR). Isotopic accuracy was monitored through routine analyses of in-house standards, calibrated daily using international standards (IAEA-600, IAEA-CH-3, IAEA-CH-6, IAEA-N-1, IAEA-N-2, NBS 19, USGS24, USGS40, USGS61) that provided a linear range between -4.52 ‰ and +20.35 ‰ for $\delta^{15}N$ and -35.05 ‰ and +1.95 ‰ for $\delta^{13}C$. Total organic carbon and nitrogen data were obtained as part of the isotopic analysis using the internal standard, glutamic acid (40.82 wt % C, 9.52 wt % N). Alpha cellulose and IVA urea were analysed throughout the sequence and reported $\delta^{13}C$ standard errors of ±0.2 ‰ (2 s.d.) and for IVA urea $\delta^{15}N$ of ±0.2 ‰ (2 s.d.). Analytical uncertainty in carbon and nitrogen isotope analysis was <0.2 ‰ for replicate analyses of the international standards analysed as unknowns during the analytical sequence of samples. The long-term (>5 years) average and standard deviation of two in-house standards, Glutamic Acid and Urea, consistently analysed in the Stable Isotope Biogeochemistry Laboratory (SIBL) at Durham University produce the following $\delta^{15}N$ and $\delta^{13}C$ analytical uncertainty of ± 0.21 ‰ and ±0.16 ‰ respectively. In order to account for atmospheric changes in $\delta^{13}C$ and allow for comparison between sites, long-term $\delta^{13}C$ data were normalised relative to variation in atmospheric CO2 (Eggleston et al., 2016) and converted into $\Delta^{13}C$ using the method outlined in Ferrio et al. (2005).

For the sulphur stable isotope ratios, remaining C and N samples were combined to create 2-4 sulphur samples for each cereal group from each site. The stable isotope measurements were performed using a Thermo Fisher Scientific EA IsoLink coupled to a Thermo Scientific Delta V Plus Advantage isotope ratio mass spectrometer. Samples were weighed into 5x8mm tin capsules with a weight range between 8-10mg. Sulphur isotope ratios are reported in standard delta (δ) notation in per mil (‰) relative to the VCDT scale. Correction of $\delta^{34}S$ was performed using four international standards (IAEA-S-1, IAEA-S-2, IAEA-S-3, NBS 127): this provided a linear range in $\delta^{34}S$ between –32.49 ‰ and +22.62 ‰. Analytical uncertainty of $\delta^{34}S$ is typically ±0.2 ‰ (2 s.d.) for replicate analyses of the international standards. Total sulphur is determined as part of the isotopic analysis using an internal standard, sulphanilamide (18.6196 % sulphur). Internal standards (Acros silver sulphide and sulphanilamide) were analysed throughout the sequence and reported $\delta^{34}S$ standard errors of ±0.2 ‰ and ±0.4 ‰ respectively (2 s.d.).

Replicate analysis on individual grains was not possible due to insufficient sample amount.

For the analysis, dry mass estimates were created for barley and wheat based on Ferrio et al. (2004). As no such model exists for oats, the length (without the embryo) was used to compare oat sizes. Where oats lacked floret bases and could not be identified to species level, oat grains were sieved at 2mm and only those over 2mm were measured.

The $\delta^{13}C$ and $\delta^{15}N$ isotope data are reported without any charring offsets, as suggested by Nitsch et al. (2015.) Charring offsets are highly dependent on charring temperature, which is unknown for the grains used in the present study, and they are primarily intended for use when comparing fresh and charred grains (Nitsch et al. 2015.) As only charred grains are considered here, the data are reported as uncorrected values relative to VPDB and AIR, as recommended.

Microsoft Excel and R software were used for the statistical analysis and production of graphs. Differences in oat grain length and isotopic values ($\Delta^{13}C$ and $\delta^{15}N$) among sites were evaluated using one-way ANOVA, with Welch's ANOVA applied where variances were unequal, followed by post-hoc Tukey tests. Where only two sites were compared (barley grain mass, $\Delta^{13}C$, and $\delta^{15}N$), Welch's two-sample *t*-tests were used.

Table 2. Breakdown of materials used in the study.

Site	Chronology	Cereal type	Cereal species	Biomass grain total	Isotope grain total
Linbrig	1296 - 1400 CE	Barley	*Hordeum vulgare*	44	10
Linbrig	1296 - 1400 CE	Rye	*Secale cereale*	143	10
Linbrig	1296 - 1400 CE	Bread wheat	*Triticum aestivum*	17	10
Linbrig	1296 - 1424 CE	Oat	*Avena sp.*	232	20
Linbrig	1306 - 1424 CE	Bristle oat	*A. strigosa*	20	10
Linbrig	1306 - 1424 CE	Common oat	*A. sativa*	20	10
Hallgarth St.	C12th-C13th	Barley	*Hordeum vulgare*	209	20
Hallgarth St.	C12th-C13th	Oat	*Avena sp.*	20	10
Hallgarth St.	C12th-C13th	Bristle oat	*A. strigosa*	9	9
Hallgarth St.	C12th-C13th	Common oat	*A. sativa*	17	10
Lightpipe Farm	1395 - 1409 CE	Oat	*Avena sp.*	92	10
Lightpipe Farm	1395 - 1409 CE	Bristle oat	*A. strigosa*	8	8
Lightpipe Farm	1395 - 1409 CE	Common oat	*A. sativa*	6	6
Belsay Hall	1168 - 1265 CE	Oat	*Avena sp.*	93	10
Belsay Hall	1168 - 1265 CE	Bristle oat	*A. strigosa*	10	10
Belsay Hall	1168 - 1265 CE	Common oat	*A. sativa*	10	10

Results

Biomass

Barley

Barley was analysed at two sites, Linbrig and Hallgarth Street. The estimated dry mass of the Hallgarth Street grains showed mean values of 18.7±5.8mg, whereas in Linbrig the mean values 16.0±5.3mg (figure 10). Statistical analysis confirmed that differences in the grains from the two sites were statistically significant (Welch's t-test, $t = 2.94$, $df = 66.5$, $p = 0.0045$).

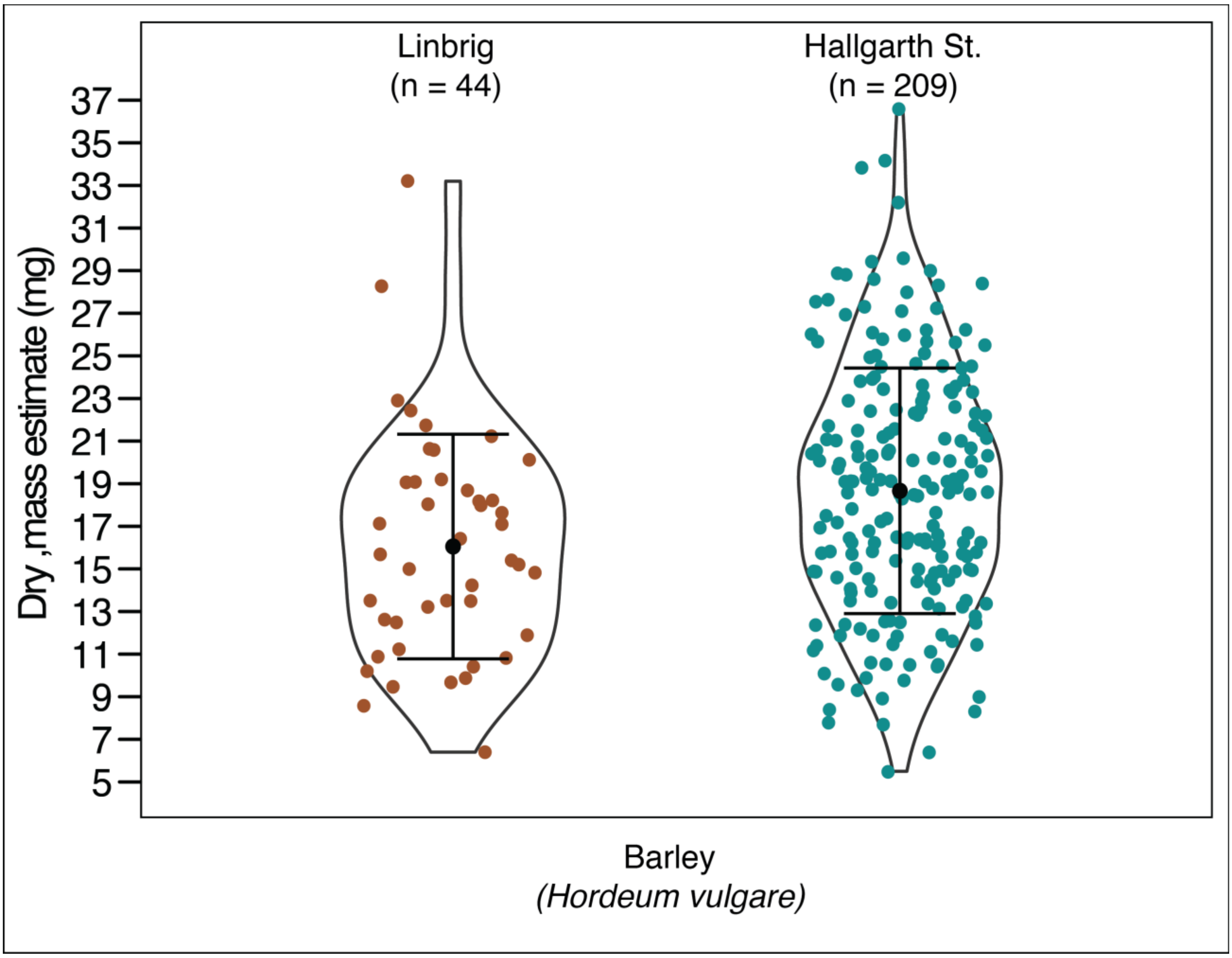

Figure 10. Dry mass estimate (mg) comparison for barley grains from Linbrig and Hallgarth Street.

Oats

Some oats were identifiable to species level and are therefore considered in three groups: oats not identifiable to species level, (*Avena* sp.), bristle oat (*A. strigosa*), and common oat (*A. sativa*). All three oat groups were present across all four sites (figure 11).

For oats not identifiable to species level (*Avena* sp.), the longest grains were recorded at Hallgarth Street (6.8 ± 0.3 mm), and Welch's one-way ANOVA followed by post-hoc Tukey showed that oats from Hallgarth Street were significantly longer than those from Belsay Hall (6.2 ± 0.6 mm), Linbrig (6.0 ± 0.7 mm), and Lightpipe Farm (6.0 ± 0.5 mm), while no significant differences were detected among the latter three sites ($F_{3,94.32} = 22.16$, $p < 0.001$).

The results for the bristle oat (*Avena strigosa*) showed that the longest grains were recorded at Lightpipe Farm (6.3 ± 0.7 mm), followed by Hallgarth Street (5.6 ± 1.2 mm), Belsay Hall (5.2 ± 0.3 mm), and Linbrig (5.0 ± 1.0 mm). Welch's one-way ANOVA and post-hoc Tukey indicated a significant difference only between Lightpipe Farm and Linbrig, with no significant differences detected among the remaining site pairs ($F_{3,17.86}$ = 5.57, p = 0.007).

By comparison, common oat (*Avena sativa*) grain length showed no significant variation among sites, according to either classical one-way ANOVA ($F_{3,49}$ = 1.38, p = 0.26) or Welch's ANOVA ($F_{3,19.55}$ = 1.54, p = 0.24), and post-hoc Tukey indicated that there was no significant differences between sites.

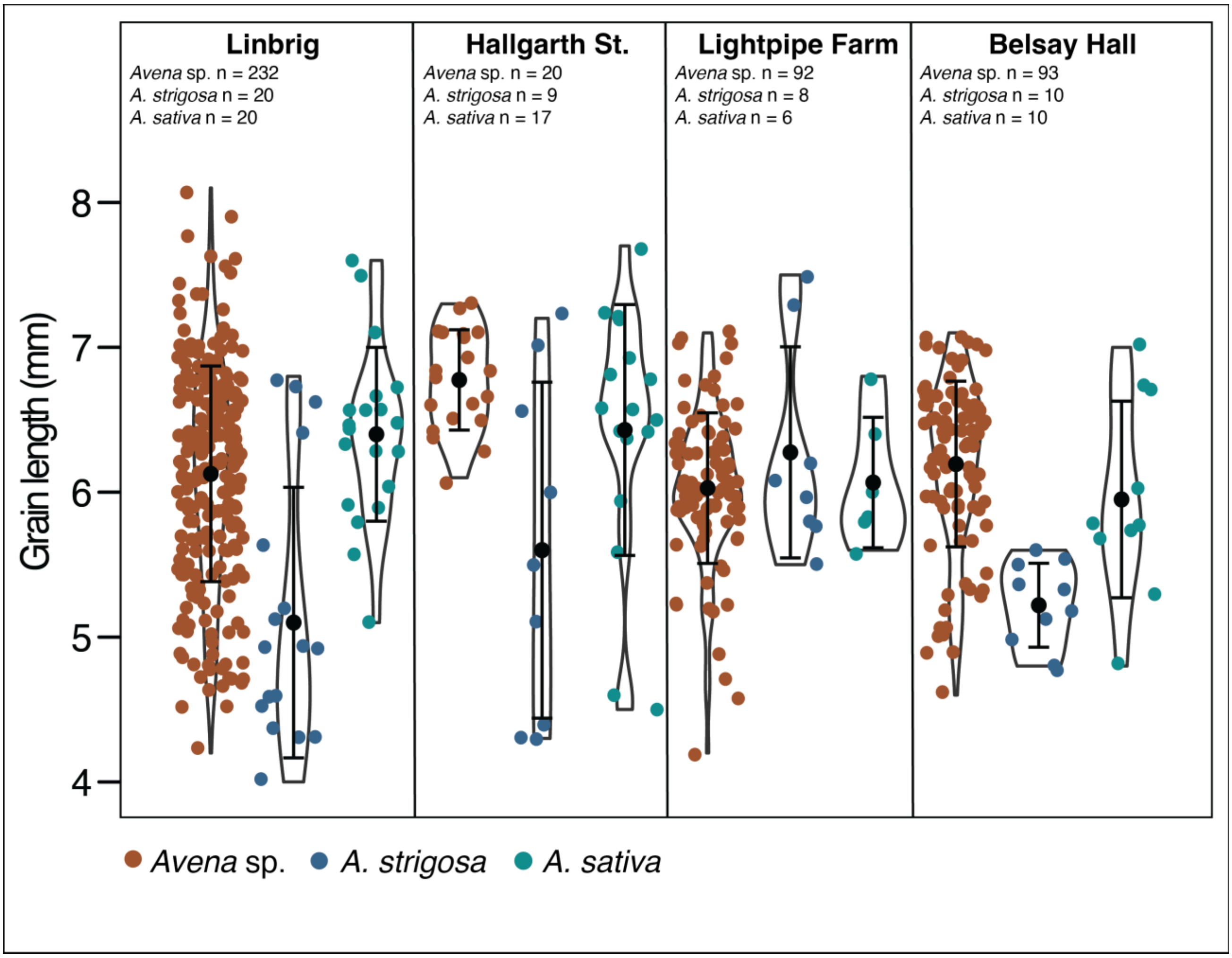

Figure 11. Oat grain length comparison for each site.

Pearson's correlation analysis was used to examine the relationship between grain length and stable isotope values. With all the species pooled, the analysis showed no significant correlation between grain length and $\Delta^{13}C$ (r = 0.12, p = 0.13), while a weak but statistically significant positive correlation was detected between grain length and $\delta^{15}N$ (r = 0.17, p = 0.027). In species-specific analysis, grain length was negatively correlated with $\Delta^{13}C$ values in the bristle oat ($r = -0.43$, $p = 0.007$) and rye ($r = -0.79$, $p = 0.007$), indicating that longer grains were associated with lower water availability in these taxa. In contrast, no significant relationships between grain length and $\Delta^{13}C$ were observed for barley, the general oat group, common oat or bread wheat. For $\delta^{15}N$ values, a positive correlation with grain length was observed only in the general oat group ($r = 0.32$, $p = 0.025$), with no significant correlations were detected for the remaining species.

Stable isotopes

A summary of the stable isotope results is shown in table 1.

*Barley (*Hordeum vulgare*)*

At Linbrig, barley exhibited moderate $\Delta^{13}C$ values, with a mean of 17.80±0.71‰, compared with the higher $\Delta^{13}C$ values at 18.54±1.01‰ at Hallgarth Street. The $\delta^{15}N$ values also differed significantly at the two sites, with the Linbrig values at 5.96±1.73‰ and the Hallgarth Street values significantly higher at 7.50±1.79‰ (figures 12 and 13). At Linbrig, barley exhibited lower $\Delta^{13}C$ values (17.80 ± 0.71‰) than those recorded at Hallgarth Street (18.54 ± 1.01‰), with the difference being statistically significant (Welch's *t*-test, $t = 2.33$, $p = 0.028$). Similarly, the barley $\delta^{15}N$ values were significantly lower at Linbrig (5.96 ± 1.73‰) than at Hallgarth Street (7.50 ± 1.79‰; Welch's *t*-test, $t = 2.27$, $p = 0.035$) (figures 12 and 13). These differences indicate that barley from Hallgarth Street was grown under conditions of greater water availability and with higher levels of soil nitrogen enrichment compared to barley from Linbrig.

*Rye (*Secale cereale*)*

Rye was only available for analysis at Linbrig. Although it exhibited lower $\Delta^{13}C$ values than other cereals at the same site, at 16.29±1.07‰, it falls within the moderate-to-well-watered range for rye (Larsson et al. 2024). Rye also exhibited the highest $\delta^{15}N$ values of the Linbrig cereals at 6.38±1.40‰, making it the only cereal type from Linbrig to fall within the highly intensive soil amendment range (figures 12 and 13).

*Bread wheat (*Triticum aestivum*)*

Bread wheat was also only analysed from Linbrig. It had the lowest mean $\Delta^{13}C$ value of the site at 15.57±0.82‰ and it displayed moderate $\delta^{15}N$ values at 4.69±0.82‰, suggesting significant water stress and only moderate amounts of biofertilisation (figures 12 and 13).

*Oat (*Avena *spp.)*

All three oat groups exhibited $\Delta^{13}C$ values suggestive of high water availability: of the oats that were not identifiable at species level, the highest in $\Delta^{13}C$ values were those from Hallgarth Street at 19.19±1.02‰, followed by those at Lightpipe Farm (18.48±0.99‰), Belsay Hall (18.15±0.73‰), and finally Linbrig (18.08±1.40‰); however, statistical analysis showed that the mean values did not differ significantly among sites (one-way ANOVA, $F_{3,46} = 2.30$, $p = 0.089$; Welch's ANOVA, $F_{3,23.13} = 2.62$, $p = 0.075$).

Of the bristle oat (*A.strigosa*) statistically significant higher $\Delta^{13}C$ values were seen at Belsay Hall (19.63±0.63‰), with no significant differences in the Linbrig (18.84±0.82‰), Hallgarth Street (18.45±1.27‰), and Lightpipe Farm (18.08±0.95‰) grains (one-way ANOVA, $F_{3,33} = 4.63$, $p = 0.008$; Welch's ANOVA, $F_{3,17.11} = 6.04$, $p = 0.005$).

For the common oat (*A.sativa*) the highest $\Delta^{13}C$ values were at Hallgarth Street at 19.34±0.79‰, followed by Lightpipe Farm (18.81±0.55‰), Belsay Hall (18.28±0.74‰), and Linbrig (17.56±0.96‰) (figures 12 and 13). Statistical analysis indicated signficant differences among sites (one-way ANOVA, $F_{3,32} = 8.91$, $p < 0.001$; Welch's ANOVA, $p = 0.003$): common oat grains from Hallgarth Street had significantly higher $\delta^{13}C$ values than those from Belsay Hall and Linbrig, while Linbrig also differed significantly from Lightpipe Farm, while no significant differences were detected between Belsay Hall and Lightpipe Farm or between Hallgarth Street and Lightpipe Farm.

In terms of $\delta^{15}N$ values, all oat groups across sites consistently suggest high levels of nitrogen enrichment, apart from the oats from Linbrig, which only exhibit low to moderate enrichment. For the oats not identifiable at species level (*Avena* sp.), the highest mean $\delta^{15}N$ values were recorded at Hallgarth Street (9.30 ± 1.32‰), followed by Belsay Hall (8.32 ± 1.41‰) and Lightpipe Farm (7.48 ± 1.52‰), while Linbrig displayed markedly lower values (3.59 ± 1.68‰). Statistical analysis (one-way ANOVA, $F_{3,46} = 41.07$, $p < 0.001$; Welch's ANOVA, $F_{3,22.34} = 38.31$, $p < 0.001$) and post-hoc *Tukey* comparisons indicated that Linbrig differed significantly from all other sites, while no significant differences were detected among Hallgarth Street, Belsay Hall, and Lightpipe Farm. A similar pattern was observed for bristle oat (*Avena strigosa*), where mean $\delta^{15}N$ values were highest at Lightpipe Farm (9.93 ± 3.07‰), followed by Hallgarth Street (9.55 ± 1.06‰) and Belsay Hall (8.02 ± 1.87‰), with Linbrig again exhibiting substantially lower values (2.80 ± 1.36‰). Statistical analysis (one-way ANOVA, $F_{3,33} = 28.54$, $p < 0.001$; Welch's ANOVA, $F_{3,17.02} = 44.37$, $p < 0.001$) with post-hoc Tukey comparisons again indicated that the Linbrig grains showed significantly depleted $\delta^{15}N$ values compared to the other sites, with no significant differences among the remaining sites.

For the common oat (*Avena sativa*), $\delta^{15}N$ values followed the same overall trend. The highest mean values were recorded at Hallgarth Street (8.44 ± 0.69‰), followed by Belsay Hall (8.20 ± 1.94‰) and Lightpipe Farm (7.34 ± 1.43‰), with Linbrig again displaying the lowest values (3.04 ± 1.31‰). Statistical analysis (one-way ANOVA, $F_{3,32} = 31.63$, $p < 0.001$; Welch's ANOVA, $F_{3,14.39} = 41.12$, $p < 0.001$) with post-hoc Tukey comparisons showed that Linbrig again differed significantly from all other sites, while no significant differences were observed among Hallgarth Street, Belsay Hall, and Lightpipe Farm (figures 12 and 13).

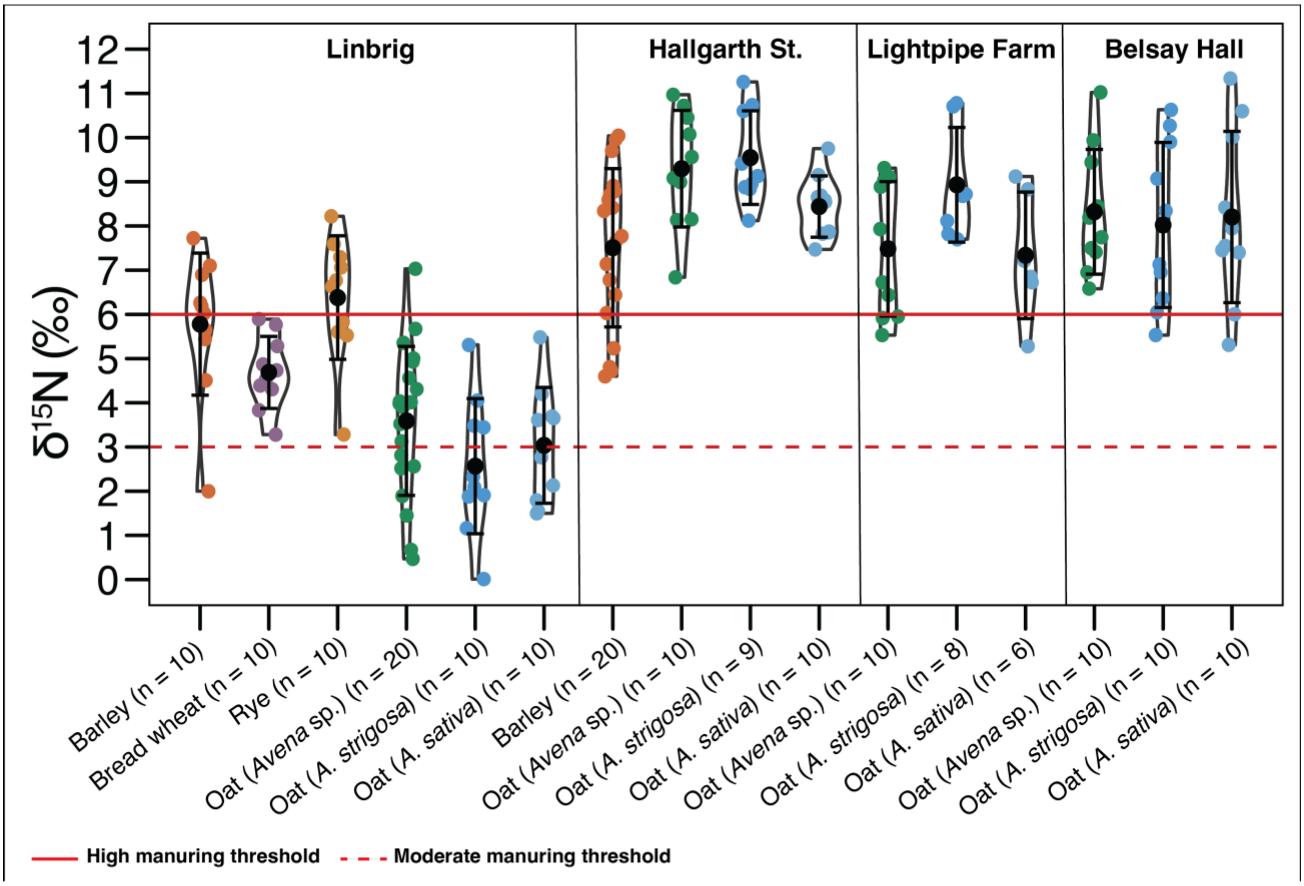

Figure 12. The $\delta^{15}N$ results.

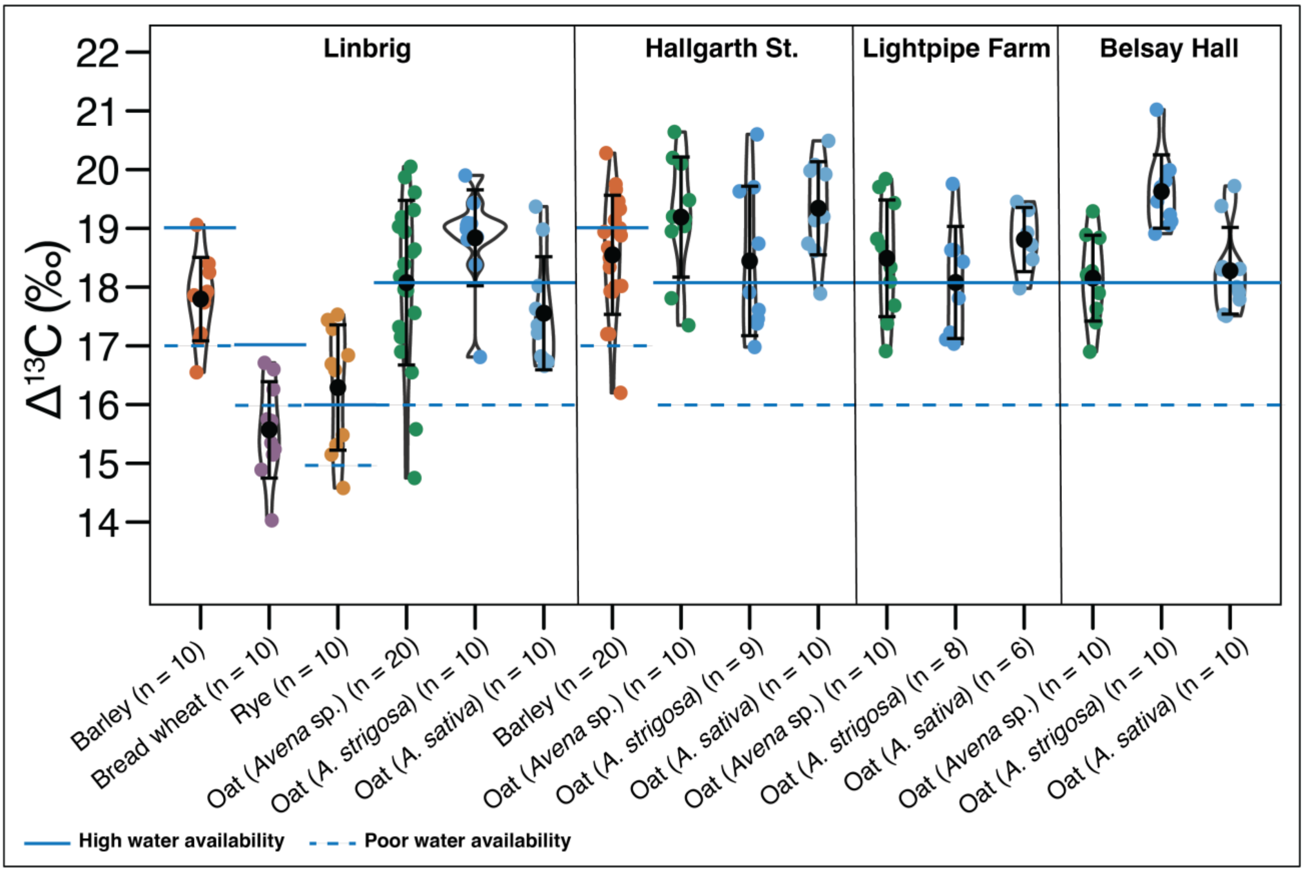

Figure 13. The $\Delta^{13}C$ results. Species-specific water availability thresholds calculated based on Larsson et al. (2024) and Wallace et al. (2013).

Sulphur stable isotopes ($\delta^{34}S$)

Sulphur values for individual cereal types are presented in table 1. Overall, Linbrig exhibited the highest $\delta^{34}S$ values at 14.20±2.7‰, followed by Hallgarth St. (10.24±0.8‰), Belsay Hall (12.35±0.8‰), and Lightpipe Farm (1.40±7.0‰). In terms of individual cereal types, the Lightpipe Farm grains showed the most variation, with the common oat having the highest $\delta^{34}S$ values at 5.21‰, followed by bristle oat at 1.04±11.1‰ and the general oat group at -1.71‰. Linbrig also show significant variation, with bristle oat and the general oat group having the highest values at 16.60±1.8‰ and 15.53±1.4‰ respectively, and the common oat slightly lower at 14.73±09‰. Rye and bread wheat exhibited similar $\delta^{34}S$ values at 13.77±0.1‰ and 13.44±2.4‰, while barley was the lowest at 10.79±2.2‰. The Hallgarth St. barley was similar to Linbrig at 10.23±0.5‰, but grains across cereal types were more uniform, with bristle oat at 11.72‰, the general oat group at 10.26±1.0‰ and common oat at 9.52±0.9‰. Belsay Hall also had little variation, with 12.61±0.8‰ for the general oat group and 12.09±1.1‰ for the common oat (figure 14).

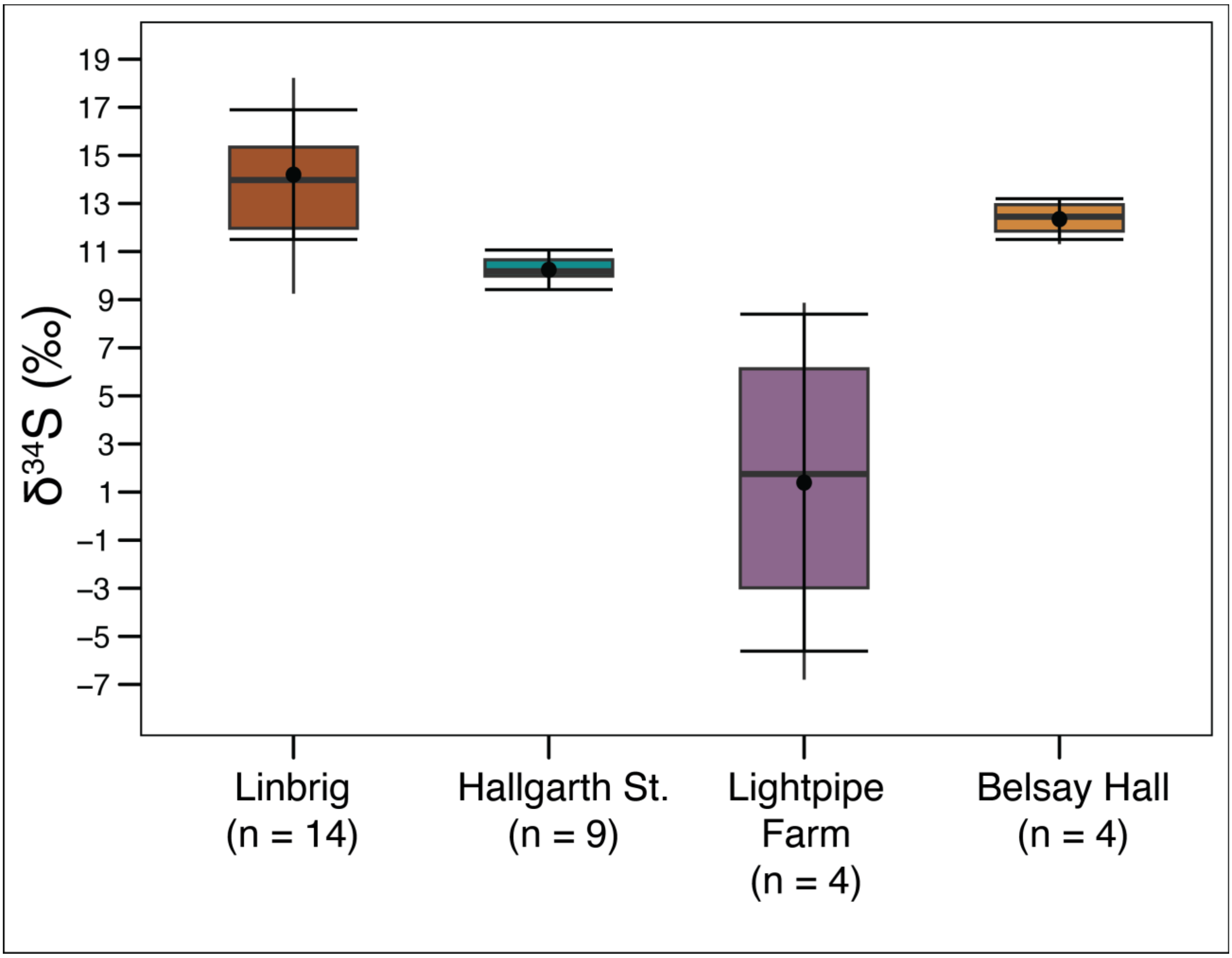

Figure 14. Comparison of δ34S result. All cereal types combined for each site..

Table 3. Summary of stable isotope ratios for each cereal type from each site. δ13C results are discussed in the text as converted Δ13C values, but they are available in Appendix 2

Site	Cereal type	Species	Isotope grain total	$\delta^{13}C$ ‰	$\Delta^{13}C$ ‰	$\delta^{15}N$ ‰	$\delta^{34}S$ ‰
Linbrig	Barley	*Hordeum vulgare*	10	-23.6±0.7‰	17.8±0.7‰	6.0±1.7‰	10.8±2.2‰
Linbrig	Rye	*Secale cereale*	10	-22.2±1.0‰	16.3±1.1‰	6.4±1.4‰	13.8±0.1‰
Linbrig	Bread wheat	*Triticum aestivum*	10	-21.5±0.8‰	15.6±0.8‰	4.7±0.8‰	13.4±2.4‰
Linbrig	Oat	*Avena* sp.	20	-23.9±1.3‰	18.1±1.4‰	3.6±1.7‰	15.5±1.4‰
Linbrig	Bristle oat	*A. strigosa*	10	-24.6±0.8‰	18.8±0.8‰	2.8±1.4‰	16.6±1.8‰
Linbrig	Common oat	*A. sativa*	10	-23.4±0.9‰	17.6±1.0‰	3.0±1.3‰	14.7±1.0‰

Hallgarth St.	Barley	*Hordeum vulgare*	20	-24.4±1.0‰	18.54±1.0‰	7.5±1.8‰	10.2±0.5‰
Hallgarth St.	Oat	*Avena* sp.	10	-25.0±0.9‰	19.2±1.0‰	9.3±1.3‰	10.3±1.0‰
Hallgarth St.	Bristle oat	*A. strigosa*	9	24.3±1.2‰	18.5±1.3‰	9.6±1.7‰	11.72‰
Hallgarth St.	Common oat	*A. sativa*	10	25.1±0.8‰	19.3±0.8‰	8.4±0.7‰	9.5±0.9‰
Lightpipe Farm	Oat	*Avena* sp.	10	-24.3±1.0‰	18.5±1.0‰	7.5±1.5‰	-1.71‰
Lightpipe Farm	Bristle oat	*A. strigosa*	8	-23.9±0.9‰	18.1±1.0‰	9.9±3.1‰	1.0±11.1‰
Lightpipe Farm	Common oat	*A. sativa*	6	24.6±0.5‰	18.8±0.6‰	7.3±1.4‰	5.21‰
Belsay Hall	Oat	*Avena* sp.	10	-24.0±0.7‰	18.2±0.7‰	8.3±1.4‰	12.6±0.8‰
Belsay Hall	Bristle oat	*A. strigosa*	10	-25.4±0.6‰	19.6±0.6‰	8.0±1.9‰	-
Belsay Hall	Common oat	*A. sativa*	10	-24.1±0.7‰	18.3±0.7‰	8.2±1.9‰	12.1±1.1‰

Discussion

The work presented here highlights the suitability of archaeobotanical assemblages from corn-drying kilns in stable isotope analysis, as each assemblage provided enough P1-P3 grains for meaningful results. Furthermore, corn-drying kilns are commonly excavated by commercial archaeology units, and the archaeobotanical material used in this work were selected from the palaeoenvironmental archive of Archaeological Services – Durham University, highlighting the potential of legacy material from developer-funded excavations in archaeobotanical and regional research.

Grain size and crop growing conditions

Previous experimental research on the relationship between grain size and soil amendment has provided inconsistent results. For example, Van Bommel et al. (2021) found that dung fertilisation resulted in smaller cereal grains compared to no fertilisation, while Larsson and Bergman (2023) found that manure application was the biggest environmental factor that increased grain size, followed by soil type and plant density. Blanz et al. (2024) also found that fertilisation, this time with seaweed, increased the overall grain size as well as the

$\delta^{34}S$ values in grains. However, the results in the present study show minimal relationship between grain size and stable isotope values, suggesting that grain size metrics from archaeological cereal grains are not a reliable indicator of crop growing conditions in the past, and more research is required in this area.

Cereal cultivation practices in the North-East

The results of the stable isotope analysis reveal notable variability in resource investment and cultivation practices for different cereal types across the four sites. At Linbrig, cereal cultivation appears to have varied across the different cereal types, with rye and barley benefiting from more intensive soil amendment through animal manure compared to bread wheat and oats. The variability in the $\delta^{15}N$, $\Delta^{13}C$ and $\delta^{34}S$ values across the different cereal types suggests that Linbrig's agricultural practices did not follow a conventional two- or three-field rotation system, which typically results in more uniform isotopic signatures as soil $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ values average out over time (Stroud, 2022; Hamerow et al. 2025). The relatively low $\delta^{15}N$ values at Linbrig further indicate an emphasis on extending arable land rather than intensifying production through consistent manuring. This strategy may reflect limited access to labour or materials, such as manure, required for widespread soil amendment.

Given these constraints, the Linbrig community likely prioritised certain crops for intensive treatment. Barley and rye, being more reliable and higher-yielding, received greater investment in soil amendment than bread wheat. Bread wheat, often considered a luxury crop, appears to have been grown under drier conditions with only moderate fertilisation, suggesting that it was not a central focus of agricultural efforts. Similarly, rye shows evidence of some water stress but was cultivated on more intensively amended soil, similarly to barley, in order to maximise returns. Ridge-and-furrow features identified near Aldensheles (Jones and Carlton, 2023) suggest that rye and bread wheat were likely grown on upland areas in well-drained soils such as ridges or slopes, resulting in some water stress. Additionally, similar $\delta^{34}S$ values in the two cereal types suggest that they may have been grown relatively close to each other in similar conditions, with rye receiving greater soil amendment than bread wheat.

Oats, including both the bristle and common varieties, seem to have been utilised to extensify the available arable land cultivated by the Linbrig community, which would be typical for the region in this time period (Miller, 1976). These cereals were likely cultivated on wetter, more marginal fields unsuitable for other crops but where oats could still thrive. The widespread presence of oat grains across all four sites is not surprising, as they tend to be a resilient crop, capable of growing on poorer, unamended soils. Although oat yields cannot compete with those of cereals like barley in high yielding environments, in low yield environments that may be too moist, acidic, or alkaline, oats outcompete other cereals (Strychar, 2011). In the upland Cheviot areas, where Linbrig is located, oats may have been strategically employed to make use of marginal fields unsuitable for other crops, or as a mitigation strategy against wet conditions.

In contrast to Linbrig, the isotopic evidence from Hallgarth St., Belsay Hall, and Lightpipe Farm points to more intensively managed agricultural systems. Cereal crops at these sites were cultivated on heavily amended soils with high water availability. Although oats are capable of growing on unamended soils, the high $\delta^{15}N$ values of the oats growing at these three sites suggests high N input in the soil, likely in the form of manuring. The relative uniformity (close to or less than 2‰) in $\Delta^{13}C$ and $\delta^{15}N$ values across each site, and $\delta^{34}S$ values in Hallgarth St. and Belsay Hall, suggests either the use of a field rotation system or that crops were grown in the same fields, benefiting from consistent soil management practices (Lightfoot and Stevens, 2012; Stroud, 2022; James et al. 2025). This is consistent with the trends identified by Hamerow et al. (2025) in the FeedSax Project, which demonstrated a reduction in variability of $\delta^{15}N$ values in crops from the 9th century onwards, suggesting that field rotation became a more widespread practice (Hamerow et al. 2025). Although the Lightpipe Farm $\delta^{34}S$ values varied greatly across and within cereal types, in the context of the $\Delta^{13}C$ and $\delta^{15}N$ values on the site, the $\delta^{34}S$ variation is difficult to interpret.

Sulphur isotope ratios were relatively high for all sites except for Lightpipe Farm. Considering the inland location of the sites, it is unlikely that background factors such as oceanic-influenced rain or sea spray are causing these elevated values, but underlying geology may be an influencing factor. The elevated values could also be a result of the addition of seaweed and other marine sources, such as fish waste, to manure. The medieval period in England, particularly around 1000 CE, saw a substantial increase in the exploitation of marine resources, especially fishing of herring and cod (Barrett et al. 2004). Peasant farmers routinely added kitchen waste to manure, so it is possible that the expansion of fishing would have resulted in more fish waste ending up in fields. However, medieval agricultural treatises such as like *The Husbandry* (c. 1276-1290) and *The Seneschaucy* (c.1260-1276) record that owners of demesne land, unlike peasants, were reluctant to bulk up their manure with kitchen waste. Hallgarth Street and Belsay Hall all fell within the boundaries of demesne land, therefore, if the elevated $d^{34}S$ values are due to the addition of fish waste in manure, this would indicate that some demesne managers were willing to add waste material to manure. The Linbrig grains are also likely to represent demesne land, but higher $\delta^{15}N$ values would be expected if the plants had been fertilised with fish waste. Given the consistently low $\delta^{15}N$ values on the site, it is more likely that the elevated $d^{34}S$ values are due to another factor, such as seaweed fertilisation or underlying geology. Further research is required to better interpret these results.

Chronology of sites

The grains from Hallgarth Street and Belsay Hall were both recovered from archaeological contexts dated to the 12th-13th centuries, while both Linbrig and Lightpipe Farm's grains were recovered from contexts dated from the 14th to the early 15th century. However, there doesn't appear to be any identifiable chronological trends. Grains from the early sites, Hallgarth Street and Belsay Hall, show high $\delta^{15}N$ values, but so do grains from Lightpipe Farm, while the Linbrig grains are consistently lower.

Soil conditions

The exact location in which the crops from each site were cultivated is unknown and therefore any discussion on soil conditions is mostly speculative. Data from the LandIs Soilscapes for England (2025) shows that Hallgarth Street is located on freely draining sandy soils, while Linbrig, Lightpipe Farm, and Belsay hall are located on slowly permeable loamy and clayey soils. Despite Hallgarth St. being located on quick-draining sandy soils, it appears that there was sufficient ^{15}N enrichment in the soils for the crops to exhibit high $\delta^{15}N$ values and high water availability. Similarly, the clayey soils of Lightpipe Farm and Belsay Hall seem to have had sufficient ^{15}N enrichment and water availability, which is what would be expected of such soils. However, under similar soil conditions in Linbrig there was only moderate ^{15}N enrichment and some of the crops exhibit some water stress.

Soil fertility and health in late medieval England

It has been hypothesised that this period saw a significant decline in soil health, leading to low grain yields and overall poor harvests (Postan, 1972; Newman and Harvey, 1997; Dodds, 2008). The results from the four sites considered here contribute to this discussion by providing some insights into soil health and fertility in Northumberland and Durham during the 12th-15th centuries.

A number of causes have been put forward in explanation for the declining soil fertility and low yields seen in medieval England. Postan (1972) suggested that the cause of the decline in soil fertility was that the expansion of arable land led to limited pasture, which subsequently resulted in lower numbers of farm animals being able to be sustained, leading to a shortage of manure. Combined with the expansion of the population at the time, and subsequently the greater demand on cereal agriculture, this led to soil exhaustion and decline. Adding to Postan's hypothesis, Clark (1992) suggested that fallow periods were not economically appealing to medieval farmers as benefits to soil health would take significant time to materialise. Newman and Harvey (1997) pointed to low phosphorus levels as the cause, as natural inputs such as weathering of rock, were too slow to replenish this nutrient in the face of unsustainable agricultural practices. Additionally, from the mid-14th century onwards, the demographic losses due to the Black Death would also mean that the labour needed for soil amendment was in short supply (Davis, 2024). Campbell (2008) has suggested that demesne farmers would have been more likely to respond to declining soil fertility levels by expanding the arable land, while peasant farms, lacking that option, would have emphasised soil amendment and intensification.

The stable isotope results of the case studies presented here indicate that, at least in Northumberland and Durham, declining soil fertility was unlikely to be caused by a lack of nitrogen. Nitrogen levels are consistently high across all sites except for Linbrig, where significantly lower levels suggest that some arable land may have indeed been less fertile. However, it is worth noting that among the two sites with multiple cereal types, Hallgarth St. shows less isotopic variability compared to Linbrig, suggesting the use of a field rotation system at Hallgarth St., which would naturally include a regular fallow period for each field. This practice may explain the better yields and higher nitrogen content observed there, as a regular fallow period is key in traditional agriculture to replenish nutrients and avoid soil exhaustion. In contrast, the significant variability at Linbrig implies the absence of such a system, potentially accounting for the lower nitrogen levels and smaller size of its grains compared to those from Hallgarth Street. Given that the intensively manured Hallgarth Street and Belsay Hall grains were almost certainly growing on demesne land, this also suggests that, contrary to Campbell's (2008) suggestion, some demesne farmers were investing in arable intensification as opposed to extensification.

Future research directions

This study provides insights into agricultural practices and soil fertility in late medieval Northumberland and Durham through the analysis of stable isotope ratios in archaeological cereal grains. Expanding this type of research to other regions of Britain would help develop a more comprehensive understanding of agricultural strategies and soil management during this period. Targeting specific archaeological features that are frequently excavated and likely to yield well-preserved archaeobotanical assemblages, such as the corn-drying kilns used in the present study, is an effective approach for sourcing material for this type of analysis. Palaeoenvironmental archives from commercial archaeology units are likely to produce numerous suitable archaeobotanical assemblages, and therefore should continue to be considered for this type of research in the future.

Further experimental research into the various factors influencing carbon, nitrogen, and sulphur stable isotope ratios in cereal grains would enhance the reliability of interpretations. In particular, understanding the effects of field location, such as upland versus lowland cultivation and the influence of underlying geology would be beneficial. Moreover, adapting the Ferrio et al. (2004) model for estimating cereal grain dry mass into a region-specific framework tailored to Britain and northwestern Europe would likely improve accuracy and strengthen interpretations of the data.

Conclusion

This study has provided insights into the cultivation strategies employed by medieval farming communities in Northumberland and Durham. The findings reveal variability in agricultural practices across communities, particularly in terms of field rotation and soil amendment, and in some cases different treatment for different cereal types. The results also indicate that during a period when soil fertility was in decline, in some areas field rotation and soil amendment may have mitigated some of the negative effects of soil exhaustion.

Additionally, archaeobotanical assemblages from corn-drying kilns have been demonstrated to be suitable for stable isotope analysis and to provide significant insights on cereal cultivation in the past. Further research into the factors influencing isotope ratios and the development of region-specific dry mass estimate models will enhance the accuracy of these analyses and provide a clearer picture of medieval agricultural practices across Britain.

Chapter 5
Discussion and future research directions

Introduction

Since the Planning Policy Guidance 16 (PPG 16) was published in 1990, establishing archaeological evaluation as an integral part of planning and development, the commercial archaeology sector has been the biggest contributor to archaeological research in the UK (Fulford, 2011, p.33). As a result, commercial units hold extensive archives of archaeological material. The work presented here highlights the potential of collaboration between commercial and university research archaeology in drawing from these archives, with emphasis on palaeoenvironmental material, to extract material that can be used in regional research and synthesis. This pilot study was undertaken between the Department of Archaeology at Durham University and Archaeological Services – Durham University and specifically focused on a single feature type commonly excavated by commercial units, i.e. corn-drying kilns. The following chapter will first discuss the strengths and limitations of this work, and provide some recommendations on how this type of collaboration between the commercial and academic sectors is best carried out. We will then discuss other features and deposit types often excavated by commercial units that can serve as sources of material that can be used in regional palaeoenvironmental research.

Benefits of a collaborative approach

Some of the largest commercial units in the UK are registered charities: Oxford Archaeology Ltd (charity number 285687), Wessex Archaeology Ltd. (charity number 287786), and Cotswold Archaeology Ltd (charity number 1001653), to name a few (Charity Commission for England and Wales, 2024). As such, part of their charitable status is tied to the expectation that they will help to preserve heritage and archaeology for the public interest. However, a number of logistical considerations, such as lack of funding for full post-excavation analysis and storage constraints, mean that the heritage value extracted from palaeoenvironmental material recovered from developer-funded evaluations and excavations falls short of its true potential. Post-excavation, the majority of this material remains unpublished and is kept in archives, where it is less likely to be consulted for research purposes compared to material in published reports, and then discarded when storage becomes limited (Hall and Kenward, 2006; Fulford, 2011). Archaeobotanical reports, in particular, are rarely published beyond grey literature (Van der Veen et al. 2013). In the present study, the findings of only one of the sites, Linbrig, have been published (Jones, 2022 and Jones and Carlton, 2023), whereas Hallgarth Street, Lightpipe Farm, and Belsay Hall are currently only accessible as grey literature (Archaeological Services, 2006; 2021; 2023). This is antithetical to the charitable responsibilities of the commercial archaeology sector, but the sheer scale of annual production output of commercial units across the country means that timely publication becomes an exceedingly difficult task. A collaborative approach with the Higher Education sector on archived material would help reduce the strain of publication on the commercial archaeology sector, therefore increasing the heritage value of work that has already been carried out.

Furthermore, this approach would increase value for other regional stakeholders, such as community archaeology groups which routinely employ commercial units for specialist post-excavation analysis. Participants of community archaeology projects are primarily drawn to excavation, and these projects often struggle to retain community interest through to post-excavation (Simpson and Williams, 2008). It is worth considering that the commercial and Higher Education sectors can contribute to retaining public interest in community projects beyond excavation by incorporating material from community-excavated sites into broader research projects. One of the sites used in the present study, Linbrig, was excavated by the Coquetdale Community Archaeology (CCA) group, which employed Archaeological Services – Durham University to conduct the palaeoenvironmental analysis of their excavation at the corn-drying kiln found there. By allowing us access to some of the material from the excavation through Archaeological Services – Durham University, we were able to contribute to the heritage value of the CCA's work at no extra cost to the group, which may help to regenerate interest in the project.

A collaboration between the two sectors would also offer clear benefits to research archaeology within Higher Education. Firstly, the archives of commercial units are a rich source of archaeological material that warrants further investigation and aligns well with much of the research conducted in academic archaeology. For example, and specifically relating to archaeobotanical research, many feature types that are commonly excavated by commercial units, such as the corn-drying kilns used in this study, provide the ideal conditions for excellent preservation of organic material, which is suitable for a host of different analyses in archaeobotanical research. Given the extensive scale of these archives, the most effective and efficient approach is to target specific themes, feature types, time periods, or regional contexts. The latter is particularly suitable for this type of research, since many of the smaller commercial units prioritise contracted work relatively local to them and so their archives tend to have a distinct regional focus.

This approach to a collaboration between the commercial and Higher Education sectors would also allow for better synthesis of archaeological findings, leading to more robust research agendas. Developer-funded evaluations investigate an extensive and diverse range of sites across the country (Hall and Kedward, 2006). However, because only a small number of these findings ever reach publication, many are not routinely incorporated into research agendas, and, as a result, a large amount of archaeological research is planned on the basis of an outdated understanding of the archaeological record (Fulford, 2011). By engaging with archived material from developer-funded excavations, archaeologists from both sectors can help to update research strategies (Huntley and Stallibrass, 1995, p.2 and Fulford, 2011). In turn, updated research agendas can contribute to better and more relevant research questions that can lead to more robust archaeological investigations in both the commercial and Higher Education sectors.

Approaching commercial archives with particular themes and research agendas in mind can also increase the likelihood of securing funding for these projects. In the past, the work of synthesising archaeological material from developer-funded evaluations has not been considered a priority and, as a result, funding has been limited (Fulford, 2011). Integrating this material into focused projects within a broader research agenda, as demonstrated here with corn-drying kiln assemblages and their relationship to agricultural intensity and soil health in the medieval period, increases the likelihood of securing funding for further investigation.

Logistics and practicalities will inevitably vary on a case-by-case basis, but certain considerations should be taken into account in order to ensure successful collaboration between the two sectors. First, ideally both parties should be involved from the early stages of research to identify relevant research questions and archived materials that merit further investigation. In this study, after selecting corn-drying kilns in the North-east as our feature type and region of focus, we consulted the palaeoenvironmental specialists at Archaeological Services – Durham University, who were able to identify suitable sites from their archive that aligned with our research objectives and warranted additional analysis. Accessing certain materials will require client permission, and not all sites will have direct dating, which can pose challenges for specific research objectives. For instance, one of the sites in this study, Hallgarth Street, lacked direct dating. In such cases, using relative dating methods or securing additional funding for direct dating may be necessary. Furthermore, when destructive analyses like stable isotope analysis are employed, this should be made clear to any stakeholders and researchers should adhere to established recording guidelines, such as those outlined by Styring et al. (2024).

Targeting specific excavated features as a source of well-preserved archaeobotanical material

The present study has highlighted the potential of focusing on specific, commonly excavated features associated with cereal grain production as a source of well-preserved archaeobotanical material suitable for use in stable isotope research, and particularly for research focused on past agricultural practices. Below are some recommendations of other features and deposit types that can be targeted in future research.

Grain stores

Sites of grain stores, either in homes or in barns and granaries that may have accidentally burnt down have great potential to produce large, well-preserved archaeobotanical assemblages that represent primary deposits, i.e. deposits that are found and recorded on the same spot where they became carbonised. These assemblages can provide information on both crop cultivation practices and consumption on a regional and local level. For example, the Neolithic site of Braes of Ha'Breck on Wyre, a small island near Orkney, contains a conflagration layer of what is likely to have been a grain store, which produced one of the largest Neolithic cereal assemblages in North-west Europe (Bishop et al. 2022). Although barns are relatively rare in the archaeological record for most of the medieval period in England, they appear more frequently from the 13^{th}-14^{th} centuries and they often produce large archaeobotanical assemblages. For instance, two out of the four barns found at the site of Higham Ferrers in Northamtonshire produced large quantities of charred grain (Hardy et al, 2007; Gardiner, 2013). An early example of a probable barn at Yarnton, dated to the 8^{th}-9^{th} centuries, also produced thousands of charred grains, likely due to an accidental fire that caused the barn to burn down (Hey, 2004; Gardiner, 2013). It is worth noting, however, that grain stores may contain non-locally grown grains, particularly in regions and time periods with an extensive grain market, such as England in the medieval period (Clark, 2014). Grain stores are also likely to contain grains from multiple harvests. Therefore, these assemblages may be more suitable in providing an overview of general trends in crop cultivation and consumption.

Thatch roofs

Thatch roofs were extensively used in the past and typically incorporated cultivated plants, mostly mixed cereal straw, as well as weeds and reeds. These would be collected from nearby fields, rather than grown specially for thatching. Because of that, well-preserved archaeobotanical assemblages from thatch roofs can be a source of information on both regional agricultural practice and wider field ecology in the past.

Thatch roofs are often preserved in the archaeological record through conflagration events that involve the inward collapse of structural elements, including the roofs themselves. These conflagration events often burn relatively slowly over several hours, with the collapsed structures creating reducing atmospheric conditions that lead to excellent preservation of organic material (Church, 2002). The site of Dun Bharabhat, a complex Atlantic roundhouse located on an islet on Loch Bharabhat in the Bhaltos Peninsula of the Isle of Lewis, is a good example. The end of the secondary phase of occupation is marked by a clear destruction horizon, left behind by a significant conflagration event that collapsed the roof (Harding and Dixon, 2000; Church, 2002). This conflagration layer produced huge amounts of archaeobotanical material, largely deriving from the collapse of the thatch roof. The majority of this archaeobotanical assemblage was extremely well-preserved and allowed for a full palaeoenvironmental analysis, as well as stable isotope analysis on some of the cereal grains (Church, 2002; Iosifidi et al., in prep.).

Thatch roofs are also preserved intact in heritage buildings, often as a result of soot produced by indoor open hearths, which covers the plant material and prevents any bacterial activity (Letts, 1999). Material from these smoke-blackened thatch roofs is often even better preserved than from conflagration contexts due to the lack of carbonisation, which results in minimal distortion of the plant material (figure 15). This high level of preservation can aid identification, sometimes even on a landrace level (Letts, 1999). Thatch roofs would have been built with material from nearby fields, likely from a single harvest, so samples collected from smoke-blackened thatch can provide an overview of the composition of these fields. A survey of thatch roofs in southern England was able to corroborate documentary evidence of the most common weed types with the weeds present in the thatch (de Moulins, 2007). Weed ecology can be used to understand crop cultivation intensity, and so combining this with stable isotope analysis on cereal grains from the thatch roofs and beyond can contribute to our understanding of crop cultivation practices in the past significantly (Bogaard et al. 2017). Since smoke-blackened thatch is typically found in heritage buildings, any research focusing on it would need to be in collaboration with heritage management organisations, such as English Heritage. These organisations are at the interface between academic and commercial archaeology, however they routinely employ commercial units to help with specialist survey and sampling, and so some of the material managed by these organisations may often be handled and stored in the archives of commercial archaeology units.

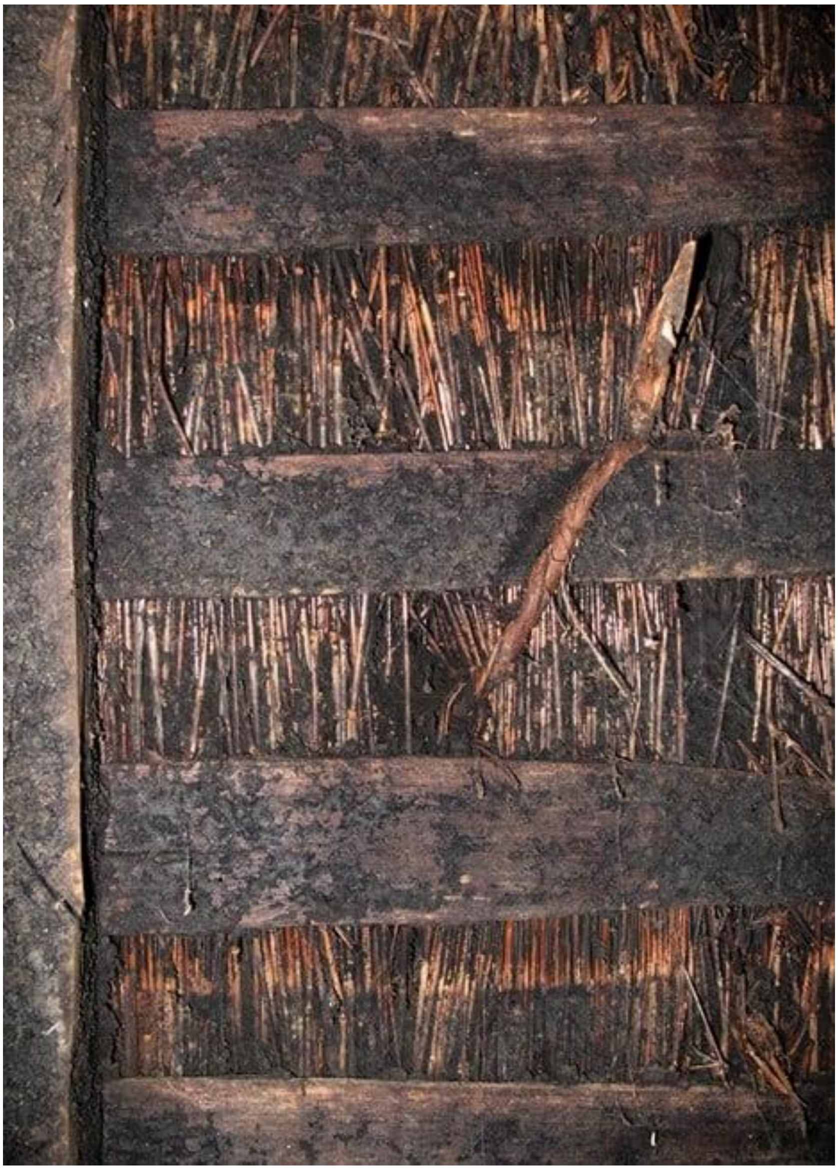

Figure 15. Medieval smoke-blackened thatch (Credit: Historic England)

Pit sites

Pits containing caches of domestic or wild food plants are relatively common in prehistoric Britain and they are often associated with temporary or seasonal settlements. It has been suggested that these features may have served as storage or specialist plant processing sites (Bishop et al., 2009). For instance, the Neolithic pit site at Dubton Farm in North-east Scotland yielded a substantial archaeobotanical assemblage, including domestic plants such as cereal grains, chaff, and weed seeds, alongside wild plants like crab apples (*Malus sylvestris*) and hazelnut (*Corylus avellana*) (Bishop et al., 2009). The presence of chaff in this assemblage suggests that initial crop processing occurred nearby, possibly to supply food for one of the contemporary timber halls in the area. The carbonisation of the plants may have been a result of accidental charring during the drying process (Church, 2002; Bishop et al., 2009).

It is important to note, however, that not all pit site archaeobotanical assemblages represent primary deposition, and some are poorly preserved. For example, a pit cluster at Newton Road, comparable to Dubton Farm, produced only a small quantity of clean cereal grains without processing by-products. This indicates that crop processing likely occurred elsewhere and that these grains were deposited as a result of small-scale food preparation (White et al., 2009). Unlike the pit assemblages associated with crop-processing, these assemblages may not be as suitable for stable isotope analysis due to their poor preservation.

Waterlogged deposits

Another deposit type that can be targeted in this type of research is waterlogged remains. Waterlogging is one of the most common methods of preservation of organic material in the British archaeological record. Unlike carbonised archaeobotanical assemblages, which are typically rich in cereals and pulses, waterlogged assemblages are more likely to contain remains of fruits, herbs and spices, as well as nuts and oil/fibre plants, with vegetables being preserved more rarely (Van der Veen, 2013; Moffett, 2018). As a result, waterlogged archaeobotanical assemblages can provide information on horticultural practices in the past. Examples of features that may preserve waterlogged remains include wells, cess pits and latrines, and old river channels, amongst others (Moffett, 2018). Waterlogged deposits are much more common on urban sites compared to rural. Town ditches and moats were often cut deep enough to fill with water, and often served as a dumping ground for household waste, resulting waterlogged remains often being found in these features (Moffett, 2018). Commercial units often excavate waterlogged remains, and occasionally these deposits are rich in well-preserved archaeobotanical assemblages. Wetland sites in Scotland, such as Iron Age crannogs have produced extensive archaeobotanical assemblages (see for example Cavers et al. 2011; Henderson and Cavers, 2011). It is worth noting, however, that the impact of waterlogging on stable isotopes in plant tissues has not yet been investigated, and this is a knowledge gap that should be covered prior to any significant work on stable isotopes and waterlogged archaeobotanical remains (Styring et al. 2024).

Conclusion

To sum up, fostering collaboration between the commercial and Higher Education sectors offers significant benefits for both archaeological research and heritage preservation. By targeting archived materials from developer-funded excavations, researchers from both sectors can help to enhance the accessibility and heritage value of commercial archives and contribute to updating and refining research strategies. Ultimately, such collaboration can lead to a more comprehensive understanding of the archaeological record, benefiting academia, commercial archaeology, and the wider public alike. Here, we provide some recommendations on specific archaeological features and deposits, namely grain stores, thatch roofs, pit sites, and waterlogged deposits, that can be used in future collaborative research between the two sectors, particularly with reference to stable isotope analysis. These contexts offer opportunities to examine crop cultivation, processing, and storage, contributing to a more detailed understanding of ancient agricultural systems.

Chapter 6
Conclusion

The present study has demonstrated the potential of applying stable isotope analysis on archaeobotanical material from corn-drying kilns to provide insights in agricultural practices and soil management in Northumberland and Durham during the medieval period. Our findings show significant variability in cereal cultivation strategies across the four sites, reflecting differences in resource investment and agricultural management. While the sites of Hallgarth Street, Belsay Hall, and Lightpipe Farm showed evidence of intensive soil amendment through manuring and the use of field rotation systems, the Linbrig site revealed a reliance on extensification of arable land as a way to maximise production, with less amendment and no evidence of crop rotation. Based on the high sulphur isotope ratios found on most of the sites, it is suggested that the use of marine resources such as fish waste in manure was more common than previously thought. Contrary to hypotheses about widespread soil exhaustion in medieval England, nitrogen levels in this study suggest that soil fertility, particularly in Northumberland and Durham, was not uniformly in decline, with all sites except for Linbrig exhibiting intensive levels of nitrogen in the soil. However, variability in practices, such as the absence of field rotation at Linbrig, may have contributed to localised declines in productivity. These results emphasise how agricultural practice varied within different communities in the past, and contribute to our understanding of agricultural intensity and soil fertility in medieval England.

The study also demonstrates that corn-drying kilns, frequently excavated by commercial archaeology units, offer well-preserved assemblages ideal for stable isotope analysis. Here, we also suggest a number of other feature and deposit types that can be used in this type of research in the future: grain stores, thatch roofs, preserved either through carbonisation in conflagration layers or as smoke-blackened thatch in heritage buildings, prehistoric pit sites used for crop-processing, and waterlogged deposits. These features and deposit types are commonly excavated by commercial archaeology units, making their palaeoenvironmental archives a likely source of material suitable for this type of research. Additionally, as commercial archives are often regionally focused and rich in palaeoenvironmental material, they provide ideal opportunities for targeted research into specific themes, such as agricultural practices and soil health, on a regional level.

Given the untapped potential of commercial palaeoenvironmental archives, this work highlights the significant benefits of collaboration between the commercial and Higher Education sectors in advancing archaeological research and heritage preservation. Despite their charitable status, many commercial archaeology units face challenges in maximising the heritage value of their extensive palaeoenvironmental archives, due to funding, storage limitations, and limited opportunities for further analysis and publication. Collaborating with the Higher Education sector can help address these challenges by enabling the publication and utilisation of archived materials and enhancing their public and heritage value. This collaborative approach benefits not only commercial units and academic researchers but also regional stakeholders such as community archaeology groups, as it allows their contributions to be integrated into broader research projects, sustaining public interest beyond excavation. Additionally, this collaboration would allow for better synthesis of archaeological findings, the updating of research agendas, and the development of more robust investigations. Effective collaboration will requires early engagement between sectors, clear research objectives, and adherence to ethical guidelines, particularly when employing destructive analyses. Aligning projects with broader research agendas will enhance the likelihood of securing funding.

Overall, this study demonstrates that agricultural practices in medieval England was varied, both in terms of field rotation, extensification and intensification, and soil amendment strategies. Collaboration between the commercial and Higher Education sector can significantly contribute to a more comprehensive understanding of the archaeological record while enhancing its accessibility and relevance. Expanding this methodology to additional regions and conducting further experimental studies on isotopic influences, including geology and land use, will further enhance our understanding of agricultural practices and soil health in the past. By integrating palaeoenvironmental archives generated from developer-funded archaeological investigations into future research, it is possible to create a more nuanced picture of agriculture practice in the past.

Bibliography

Amundson, R., Austin, A.T., Schuur, E.A.G., Yoo, K., Matzek, V., Kendall, C., Uebersax, A., Brenner, D. and Baisden, W.T. (2003). Global patterns of the isotopic composition of soil and plant nitrogen. *Global Biogeochemical Cycles*, 17(1). doi:https://doi.org/10.1029/2002gb001903.

Astill, G. (1997). An archaeological approach to the development of agricultural technologies in medieval England. In: Astill, G. and Langdon, J. (eds). Medieval farming and technology: The impact of agricultural change in Northwest Europe. Brill: Leiden, New York, and Köln.

Archaeological Services. (2006). Land at Hallgarth Street, Durham: Evaluation and excavation. Report 1370, Archaeological Services Durham University.

Archaeological Services. (2021). Lightpipe Farm, Longframlington, Northumberland: Post-excavation analysis. Report 5603, Archaeological Services Durham University.

Archaeological Services. (2022). Linbrig, Alwinton, Northumberland: Palaeoenvironmental analysis. Report 5676, Archaeological Services Durham University.

Archaeological Services. (2023). Belsay Hall drainage and coach house, Belsay, Northumberland: Archaeological watching brief. Report 5690, Archaeological Services, Durham University.

Banham, D., & Faith, R. (2014). Anglo-Saxon farms and farming. Oxford: Oxford University Press.

Bishop, R. R., Church, M. J., & Rowley-Conwy, P. A. (2010). Cereals, fruits and nuts in the Scottish Neolithic. *Proceedings of the Society of Antiquaries of Scotland*, *139*, 47–103. https://doi.org/10.9750/PSAS.139.47.103

Banham, D. (2022). From field to feast: The life (and afterlife) course of cereal crops in early medieval England. In: Porck, T. and Soper, H. Early medieval English life courses: Cultural-historical perspectives. Brill: Leiden and Boston.

Bishop, R.R. (2019). Experiments on the effects of charring on hazelnuts and their representation in the archaeological record. *Journal of Archaeological Science: Reports*, 26, p.101839. doi:https://doi.org/10.1016/j.jasrep.2019.05.004.

Bishop, R.R., Gröcke, D.R., Ralston, I., Clarke, D., Lee, D.H.J., Shepherd, A., Thomas, A.S., Rowley-Conwy, P.A. and Church, M.J. (2022). Scotland's first farmers: new insights into early farming practices in North-west Europe. *Antiquity*, [online] 96(389), pp.1087–1104. doi:https://doi.org/10.15184/aqy.2022.107.

Blanz, M., Ascough, P., Mainland, I., Martin, P., Taggart, M.A., Dieterich, B., Wishart, J., Sayle, K.L., Raab, A., & Feldmann, J. (2019). Seaweed fertilisation impacts the chemical and isotopic composition of barley: Implications for analyses of archaeological skeletal remains. *Journal of Archaeological Science, 104*, pp.34–44. doi:https://doi.org/10.1016/j.jas.2019.02.003.

Blanz, M., Gröcke, D.R., Martin, P., & Church, M.J. (2024). The effect of seaweed fertilisation on sulfur isotope ratios ($\delta^{34}S$) and grain size in barley: implications for agronomy and archaeological research. *Frontiers in Environmental Archaeology, 3*, 1465082. doi:https://doi.org/10.3389/fearc.2024.1465082.

Bogaard, A., Heaton, T.H.E., Poulton, P. and Merbach, I. (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), pp.335–343. doi:https://doi.org/10.1016/j.jas.2006.04.009.

Bogaard, A., Fraser, R., Heaton, T.H.E., Wallace, M., Vaiglova, P., Charles, M., Jones, G., Evershed, R.P., Styring, A.K., Andersen, N.H., Arbogast, R.-M.., Bartosiewicz, L., Gardeisen, A., Kanstrup, M., Maier, U., Marinova, E., Ninov, L., Schafer, M. and Stephan, E. (2013). Crop manuring and intensive land management by Europe's first farmers. *Proceedings of the National Academy of Sciences*, 110(31), pp.12589–12594. doi:https://doi.org/10.1073/pnas.1305918110.

Bogaard, A., Hodgson, J., Nitsch, E., Jones, G., Styring, A., Diffey, C., Pouncett, J., Herbig, C., Charles, M., Ertuğ, F., Tugay, O., Filipovic, D. and Fraser, R. (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*, [online] 25, pp.57–73. doi:https://doi.org/10.1007/s00334-015-0524-0.

Campbell, B.M.S. (2008). Economic rent and the intensification of English agriculture, 1086-1300. In: Campbell, B.M.S. (ed). Field systems and farming systems in late medieval England. Routledge: London.

Cavers, G., Crone, A., Engl, R., Fouracre, L., Hunter, F., Robertson, J. and Thoms, J. (2011). Refining Chronological Resolution in Iron Age Scotland: Excavations at Dorman's Island Crannog, Dumfries and Galloway. *Journal of Wetland Archaeology*, 10(1), pp.71–108. doi:https://doi.org/10.1179/jwa.2011.10.1.71.

Church, M. (2002). The archaeological and archaeobotanical implications of a destruction layer in Dun Bharabhat, Lewis. In B. Ballin-Smith, & I. Banks (Eds.), *In the shadow of the brochs: the Iron Age in Scotland* (pp.67–75). Tempus.

Choi, W.-J., Kwak, J.-H., Lim, S.-S., Do Hyun Park, Chang, S.X., Lee, S.-M., Arshad, M., Yun, S.-I. and Kim, H.-Y. (2017). Synthetic fertilizer and livestock manure differently affect δ15N in the agricultural landscape: A review. *Agriculture, Ecosystems and Environment*, 237, pp.1–15. doi:https://doi.org/10.1016/j.agee.2016.12.020.

Clark, G. (1992). The Economics of Exhaustion, the Postan Thesis, and the Agricultural Revolution. *The Journal of Economic History*, 52(1), pp.61–84. doi:https://doi.org/10.1017/s0022050700010263.

Clark, G. (2014). Markets before economic growth: the grain market of medieval England. *Cliometrica*, 9(3), pp.265–287. doi:https://doi.org/10.1007/s11698-014-0117-7.

Craig, O.E., Ross, R., Andersen, S.H., Milner, N. and Bailey, G.N. (2006). Focus: sulphur isotope variation in archaeological marine fauna from northern Europe. *Journal of Archaeological Science*, 33(11), pp.1642–1646. doi:https://doi.org/10.1016/j.jas.2006.05.006.

Craine, J.M., Brookshire, E.N.J., Cramer, M.D., Hasselquist, N.J., Koba, K., Marin-Spiotta, E. and Wang, L. (2015). Ecological interpretations of nitrogen isotope ratios of terrestrial plants and soils. *Plant and Soil*, 396(1-2), pp.1–26. doi:https://doi.org/10.1007/s11104-015-2542-1.

Davis, J. (2024). Maintaining the earth: Soil management and sustainability in medieval agricultural manuals. In: Cesario, M., Magennis, H. and Ramazzina, E. (eds). The elements in the medieval world: Earth (Volume 2). Brill: Leiden and Boston.

DeNiro, M.J. and Hastorf, C.A. (1985). Alteration of and ratios of plant matter during the initial stages of diagenesis: Studies utilizing archaeological specimens from Peru. *Geochimica et Cosmochimica Acta*, 49(1), pp.97–115. doi:https://doi.org/10.1016/0016-7037(85)90194-2.

Dineley, M. (2015). Brewing/malting. In: Bescherer Metheny, K. and Beaudry, M. C. (eds). Archaeology of food, Volume 2: L-Z. Rowman and Littlefield: London.

Dyer, C. C. (2006). Seasonal patterns in food consumption in the later Middle Ages. In: Woolgar, C. M., Serjeantson, D., Waldron, T. (eds). Food in medieval England. Oxford University Press: Oxford.

Dyer, C. (2023). A simple food with many meanings: bread in late medieval England. *Journal of Medieval History*, pp.1–20. doi:https://doi.org/10.1080/03044181.2023.2250947.

Eggleston, S., Schmitt, J., Bereiter, B., Schneider, R., & Fischer, H. (2016). Evolution of the stable carbon isotope composition of atmospheric CO2 over the last glacial cycle. *Paleoceanography, 31*(3), pp.434–452. doi:https://doi.org/10.1002/2015pa002874.

Evans, R. D. (2001). Physiological mechanisms influencing plant nitrogen isotope composition. *Trends in Plant Science*, 6(3), 121–126. https://doi.org/10.1016/S1360-1385(01)01889-1

Farquhar, G.D. and Richards, R.A. (1984). Isotopic Composition of Plant Carbon Correlates With Water-Use Efficiency of Wheat Genotypes. *Functional Plant Biology*, [online] 11(6), pp.539–552. doi:https://doi.org/10.1071/pp9840539.

Ferrio, J.P., Alonso, N., Voltas, J. and Araus, J.L. (2004). Estimating grain weight in archaeological cereal crops: a quantitative approach for comparison with current conditions. *Journal of Archaeological Science*, 31(11), pp.1635–1642. doi:https://doi.org/10.1016/j.jas.2004.04.006.

Ferrio, J.P., Araus, J.L., Buxó, R., Voltas, J., & Bort, J. (2005). Water management practices and climate in ancient agriculture: inferences from the stable isotope composition of archaeobotanical remains. *Vegetation History and Archaeobotany, 14*(4), pp.510–517. doi:https://doi.org/10.1007/s00334-005-0062-2.

Fiorentino, G., Ferrio, J.P., Bogaard, A., Araus, J.L. and Riehl, S. (2014). Stable isotopes in archaeobotanical research. *Vegetation History and Archaeobotany*, 24(1), pp.215–227. doi:https://doi.org/10.1007/s00334-014-0492-9.

Fraser, R.A., Bogaard, A., Schäfer, M., Arbogast, R., & Heaton, T.H.E. (2013). 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), pp.492–517. doi:https://doi.org/10.1080/00438243.2013.820649.

Fulford, M. (2011). The impact of commercial archaeology on the UK heritage. In: Cunliffe, B. (ed). History for the taking? Perspectives on material heritage. The British Academy: London.

Gardiner, M. (2000) Vernacular buildings and the development of the later medieval domestic plan in England. *Medieval Archaeology*, 44(1), pp. 159–179. https://doi.org/10.1179/med.2000.44.1.159

Gardiner, M. (2013). Stacks, barns, and granaries in early and high medieval England: Crop storage and its implications. In: Vigil-Escalera Guirado, A., Bianchi, G., and Quirós Castillo, J. A. (eds). Horrea, barns, and silos. Storage and incomes in early medieval Europe. Vitoria: University of the Basque Country.

Gröcke, D.R., Treasure, E.R., Lester, J., Gron, K.J., & Church, M.J. (2021). Effects of marine biofertilisation on Celtic bean carbon, nitrogen, and sulphur isotopes: Implications for reconstructing past diet and farming practices. *Rapid Communications in Mass Spectrometry, 35*(5). doi:https://doi.org/10.1002/rcm.8985.

Gron, K.J., Larsson, M., Gröcke, D.R., Andersen, N.H., Andersen, M.H., Bech, J., Henriksen, P.S., Hilton, R.G., Jessen, M.D., Møller, N.A., Nielsen, F.O., Nielsen, P.O., Pihl, A., Sørensen, L., Westphal, J., Rowly-Conwy, P., & Church, M.J. (2021). Archaeological cereals as an isotope record of long-term soil health and anthropogenic amendment in southern Scandinavia. *Quaternary Science Reviews, 253*, p.106762. doi:https://doi.org/10.1016/j.quascirev.2020.106762.

Hall, D. (2014). The open fields of England. Oxford University Press: Oxford.

Hall, A. and Kenward, H. (2006). Development-driven archaeology: Bane or boon for bio archaeology? *Oxford Journal of Archaeology*, 25(3), pp.213–224. doi:https://doi.org/10.1111/j.1468-0092.2006.00258.x.

Hamerow, H. (2022). Unpacking the 'Mouldboard Plough Package': The feeding of Anglo-Saxon England project. In: M. McKerracher & H. Hamerow (Eds.). New perspectives on the medieval 'agricultural revolution': Crop, Stock and Furrow. Liverpool University Press: Liverpool.

Hamerow, H., Zerl, T., Kropp, C. and Bogaard, A. (2023). Roman to early medieval cereal farming in the Rhineland: weeds, tillage, and the spread of the mouldboard plough. *Landscape History*, 44(2), pp.5–13. doi:https://doi.org/10.1080/01433768.2023.2284544.

Hamerow, H., McKerracher, M., Bogaard, A., Charles, M., Forster, E., Holmes, E., Bronk Ramsey, C., Stroud, E. and Thomas, R. (2025) *Feeding Medieval England: A long "agricultural revolution", 700–1300*. Oxford: Oxford University Press.

Harding, D.W. and Dixon, T.N. (2000). *Dun Bharabhat, Cnip, an Iron Age Settlement in West Lewis: Volume 1 - The structures and material culture*. Edinburgh: Edinburgh University Press.

Handley, L.L., Austin, A.T., Stewart, G.R., Robinson, D., Scrimgeour, C.M., Raven, J.A., Heaton, T.H.E. and Schmidt, S. (1999) 'The ^{15}N natural abundance ($\delta^{15}N$) of ecosystem samples reflects measures of water availability', *Australian Journal of Plant Physiology*, 26(2), pp. 185–199. https://doi.org/10.1071/PP98146

Hardy A., Mair B., and Williams, R. J., (2007). Death and taxes: the archaeology of a Middle Saxon estate centre at Higham Ferrers, Northamptonshire. Oxford Archaeology Monograph. Oxford: Oxford Archaeologicy.

Hedges, R.E.M. and Reynard, L.M. (2007). Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archaeological Science*, 34(8), pp.1240–1251. doi:https://doi.org/10.1016/j.jas.2006.10.015.

Henderson, J., & Cavers, G. (2012). An Iron Age crannog in south-west Scotland: underwater survey and excavation at Loch Arthur. *Proceedings of the Society of Antiquaries of Scotland*, *141*, 103–124. https://doi.org/10.9750/PSAS.141.103.124

Hey G. (2004). Yarnton: Saxon and medieval settle- ment and landscape. Results of excavations 1990-96. Oxford Archaeology Monograph. Oxford: Oxford Archaeology.

Hinton, D.A. (2023). Barns, granaries and security: crop storage, processing and investment in medieval England. *Journal of Medieval History*, pp.1–29. doi:https://doi.org/10.1080/03044181.2023.2253677.

Hobbie, E.A., Chen, J., Hanson, P.J., Iversen, C.M., McFarlane, K.J., Thorp, N.R. and Hofmockel, K. (2017). Long-term carbon and nitrogen dynamics at SPRUCE revealed through stable isotopes in peat profiles. *Biogeosciences*, 14(9), pp.2481–2494. doi:https://doi.org/10.5194/bg-14-2481-2017.

Holmes, M. (2022). Innovation, technology, and social change. The adoption of the mouldboard plough and its impact on human-animal relationships. In: M. McKerracher & H. Hamerow (Eds.). New perspectives on the medieval 'agricultural revolution': Crop, Stock and Furrow. Liverpool University Press: Liverpool.

Hubbard, R.N.L.B., & al Azm, A. (1990). Quantifying preservation and distortion in carbonized seeds; and investigating the history of friké production. *Journal of Archaeological Science, 17*(1), pp.103–106. doi:https://doi.org/10.1016/0305-4403(90)90017-Y.

Huntley, J.P. and Stallibrass, S. (1995). Plants and vertebrate remains from archaeological sites in northern England: Data reviews and future directions. Research Report No. 4. Architectural and Archaeological Society of Durham and Northumberland: Durham.

James, N., Winter-Schuh, C., Kenoyer, J.M., D'Alpoim Guedes, J. and Makarewicz, C.A. (2025). Differences in the isotopic composition of individual grains and aggregated seed samples affect interpretation of ancient plant cultivation practices. *Frontiers in Environmental Archaeology*, 4. doi:https://doi.org/10.3389/fearc.2025.1510394.

Jones, D. (2009). Manure and the medieval social order. In J.G. Evans, M.J. Allen, N. Sharples, & T.P. O'Connor (Eds.), *Land and people: Papers in memory of John G. Evans*. Oxford: Oxbow Books.

Jones, D. (2022). The medieval Cheviot manor of Aldensheles. *Archaeologia Aeliana, series 6, vol. 1*, pp.259–290.

Jones, D., & Carlton, R. (2023). A medieval grain-drying kiln in the Upper Coquet valley and its role in food supply. *Archaeologia Aeliana, series 6, vol. 2*, pp.209–234.

Kolmanič, A., Sinkovič, L., Nečemer, M., Ogrinc, N. and Meglič, V. (2022). The Effect of Cultivation Practices on Agronomic Performance, Elemental Composition and Isotopic Signature of Spring Oat (Avena sativa L.). *Plants*, [online] 11(2), p.169. doi:https://doi.org/10.3390/plants11020169.

Krouse, H.R., Levinson, A.A., Piggott, D. and Ueda, A. (1987). Further stable isotope investigations of human urinary stones: comparison with other body components. *Applied Geochemistry*, 2(2), pp.205–211. doi:https://doi.org/10.1016/0883-2927(87)90034-5.

Langdon, J 2004, Mills in the Medieval Economy : England 1300-1540, Oxford University Press, Oxford.

Larsson, M. (2017). Barley grain at Uppåkra, Sweden: evidence for selection in the Iron Age. *Vegetation History and Archaeobotany*. doi:https://doi.org/10.1007/s00334-017-0633-z.

Larsson, M., Bergman, J. and Pål Axel Olsson (2024). Soil, fertilizer and plant density: Exploring the influence of environmental factors to stable nitrogen and carbon isotope composition in cereal grain. *Journal of archaeological science*, 163, pp.105935–105935. doi:https://doi.org/10.1016/j.jas.2024.105935.

Lee, J.S. (2011). Grain shortages in late medieval towns. In: Dodds, B. and Liddy, C. 2011. *Commercial Activity, Markets and Entrepreneurs in the Middle Ages: Essays in Honour of Richard Britnell*. Boydell and Brewer: Boydell and Brewer. https://doi.org/10.1515/9781846159886

Letts, J, 1999: Smoke-blackened thatch: A unique source of medieval plant remains from southern England. Reading: English Heritage and University of Reading.

Lightfoot, E. and Stevens, R.E. (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), pp.656–662. doi:https://doi.org/10.1016/j.jas.2011.10.026.

Lomas, R.A. (1978). The priory of Durham and its demesnes in the fourteenth and fifteenth centuries. *The Economic History Review, series 2, vol. 31*(3).

Marschner, P. (2012). Part II – Plant-soil relationships. *Marschner's Mineral Nutrition of Higher Plants* (3rd ed.). Academic Press, London. https://doi.org/10.1016/C2009-0-63043-9

McCloskey, D. N., & Nash, J. (1984). Corn at interest: The extent and cost of grain storage in medieval England. *The American Economic Review*, *74*(1), 174–187. http://www.jstor.org/stable/1803317

McKevith, B. (2004). Nutritional aspects of cereals. *Nutrition Bulletin*, [online] 29(2), pp.111–142. doi:https://doi.org/10.1111/j.1467-3010.2004.00418.x.

Miller, E. (1976). Farming in Northern England During the Twelfth and Thirteenth Centuries. *Northern History, 11*(1), pp.1–16. doi:https://doi.org/10.1179/nhi.1976.11.1.1.

Minagawa, M. and Wada, E. (1984). Stepwise enrichment of 15N along food chains: Further evidence and the relation between δ15N and animal age. *Geochimica et Cosmochimica Acta*, 48(5), pp.1135–1140. doi:https://doi.org/10.1016/0016-7037(84)90204-7.

Moffett, L. (2018). The archaeology of late medieval plant remains: the resource and the research. In: Gerrard, C. and Gutiérrez, A. (eds). *The Oxford Handbook of Later Medieval Archaeology in Britain*, Oxford Handbooks. doi.org/10.1093/oxfordhb/9780198744719.001.0001

Monk, A., & Kelleher, E. (2005). An Assessment of the Archaeological Evidence for Irish Corn-Drying Kilns in the Light of the Results of Archaeological Experiments and Archaeobotanical Studies. *The Journal of Irish Archaeology, 14*, pp.77–114. doi:https://doi.org/10.2307/20650842.

Moulins, D. de (2006). The weeds from the thatch roofs of medieval cottages from the south of England. *Vegetation History and Archaeobotany*, 16(5), pp.385–398. doi:https://doi.org/10.1007/s00334-006-0035-0.

Murphy, M. (1998). Feeding medieval cities: Some historical approaches. In: M. Carlin and J. Rosenthal (eds.), Food and Eating in Medieval Europe. Hambledon Press: London.

Nitsch, E.K., Charles, M. and Bogaard, A. (2015). Calculating a statistically robust $\delta^{13}C$ and $\delta^{15}N$ offset for charred cereal and pulse seeds. *STAR: Science & Technology of Archaeological Research*, 1(1), pp.1–8. doi:https://doi.org/10.1179/2054892315y.0000000001.

Nitsch, E., Lamb, A.L., Heaton, T.H.E., Vaiglova, P., Fraser, R., Hartman, G., Moreno-Jiménez, E., López-Piñeiro, A., D. Peña-Abades, Fairbairn, A., Eriksen, J. and Bogaard, A. (2018). The Preservation and Interpretation of $\delta^{34}S$ Values in Charred Archaeobotanical Remains. *Archaeometry*, 61(1), pp.161–178. doi:https://doi.org/10.1111/arcm.12388.

Oakey, M. (2017). Belsay awakes: Historic England contribution landscape survey report. Historic England research report no.48-2017. Available at: https://historicengland.org.uk/research/results/reports/7199/BelsayAwakes_HistoricEnglandContributionLandscapeSurveyReport

Power, J.P. and Campbell, B.M.S. (2008). Cluster analysis and the classification of medieval demesne-farming systems. In: Campbell, B.M.S. (ed). Field systems and farming systems in late medieval England. Routledge: London.

Richards, M.P., Fuller, B.T., Sponheimer, M., Robinson, T. and Ayliffe, L. (2003). Sulphur isotopes in palaeodietary studies: a review and results from a controlled feeding experiment. *International Journal of Osteoarchaeology*, 13(1-2), pp.37–45. doi:https://doi.org/10.1002/oa.654.

Rickett, R. (2021). *Post-Roman and Medieval Drying Kilns*. Archaeopress Publishing Ltd.

Robinson, D. (2001). $\delta^{15}N$ as an integrator of the nitrogen cycle. *Trends in Ecology & Evolution*, 16(3), 153–162. https://doi.org/10.1016/S0169-5347(00)02098-X

Rowley-Conwy, P. (1987). The interpretation of ard marks. *Antiquity 61*, pp.263-266.

Schlütz, F., Bittmann, F., Jahns, S., König, S., Lyudmila Shumilovskikh, Baumecker, M. and Wiebke Kirleis (2025). Stable isotope analyses (δ^{15} N, δ^{34} S, δ^{13} C) locate early rye cultivation in northern Europe within diverse manuring practices. *Philosophical Transactions of the Royal Society B Biological Sciences*, 380(1926). doi:https://doi.org/10.1098/rstb.2024.0195.

Schoeninger, M.J. and DeNiro, M.J. (1984). Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta*, 48(4), pp.625–639. doi:https://doi.org/10.1016/0016-7037(84)90091-7.

Sharp, Z. D. (2017). Chapter 9 – Nitrogen. *Principles of Stable Isotope Geochemistry* (2nd ed.). Pearson Education, Boston.

Simpson, F. and Williams, H. (2008). Evaluating community archaeology in the UK. *Public Archaeology*, 7(2), pp. 69–90. doi: 10.1179/175355308X329955.

Stone, D. J. (2006). The consumption of field crops in late medieval England. In: Woolgar, C. M., Serjeantson, D., Waldron, T. (eds). Food in medieval England. Oxford University Press: Oxford.

Stroud, E. (2022) Understanding early medieval crop and animal husbandry through isotopic analysis. In: McKerracher, M. and Hamerow, H. (eds.) *New perspectives on the medieval "agricultural revolution": Crop, stock and furrow*. Liverpool: Liverpool University Press, pp. 93–112.

Strychar, R. (2011) World oat production, trade, and usage. In: Webster, F.H. and Wood, P.J. (eds.) Oats: Chemistry and technology. 2nd ed. AACC International Press, pp. 1–10. ISBN: 9781891127649. doi:10.1016/B978-1-891127-64-9.50006-3.

Styring, A.K., Manning, H., Fraser, R.A., Wallace, M., Jones, G., Charles, M., Heaton, T.H.E., Bogaard, A., & Evershed, R.P. (2013). The effect of charring and burial on the biochemical composition of cereal grains: investigating the integrity of archaeological plant material. *Journal of Archaeological Science, 40*(12), pp.4767–4779. doi:https://doi.org/10.1016/j.jas.2013.03.024.

Styring, A., Charles, M.B., Fantone, F., Hald, M.M., McMahon, A., Meadow, R., Nicholls, G.K., Patel, A.K., Pitre, M.C., Smith, A., Sołtysiak, A., Stein, G.J., Weber, J., Weiss, H.R., & Bogaard, A. (2017). Isotope evidence for agricultural extensification reveals how the world's first cities were fed. *Nature Plants, 3*(6). doi:https://doi.org/10.1038/nplants.2017.76.

Styring, A.K., Knipper, C., Müller-Scheeßel, N., Grupe, G., & Bogaard, A. (2018). The Proof is in the Pudding: Crop Isotope Analysis Provides Direct Insights into Agricultural Production and Consumption. *Environmental Archaeology, 27*(1), pp.61–72. doi:https://doi.org/10.1080/14614103.2018.1497832.

Styring, A.K., Vaiglova, P., Bogaard, A., Church, M.J., Gröcke, D.R., Larsson, M., Liu, X., Stroud, E., Szpak, P., & Wallace, M.P. (2024). Recommendations for stable isotope analysis of charred archaeological crop remains. *Frontiers in Environmental Archaeology, 3*. doi:https://doi.org/10.3389/fearc.2024.1470375.

Stroud, E., Charles, M., Bogaard, A., & Hamerow, H. (2023). Turning up the heat: Assessing the impact of charring regime on the morphology and stable isotopic values of cereal grains. *Journal of Archaeological Science, 153*, pp.105754–105754. doi:https://doi.org/10.1016/j.jas.2023.105754.

SUERC Radiocarbon Laboratory (2024). Radiocarbon dating certificate for SUERC-127691 (GU68183) (Belsay Hall Northumberland, context 2449). [Unpublished report]

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*. doi:https://doi.org/10.3389/fpls.2014.00288.

Szpak, P., Longstaffe, F.J., Macdonald, R., Millaire, J.F., White, C.D., & Richards, M.P. (2019). Plant sulfur isotopic compositions are altered by marine fertilizers. *Archaeological and Anthropological Sciences, 11*(6), pp.2989–2999. doi:https://doi.org/10.1007/s12520-018-0716-5.

Szpak, P., & Chiou, K.L. (2019). A comparison of nitrogen isotope compositions of charred and desiccated botanical remains from northern Peru. *Vegetation History and Archaeobotany, 29*(5), pp.527–538. doi:https://doi.org/10.1007/s00334-019-00761-2.

Trust, B.A., & Fry, B. (1992). Stable sulphur isotopes in plants: a review. *Plant, Cell and Environment, 15*(9), pp.1105–1110. doi:https://doi.org/10.1111/j.1365-3040.1992.tb01661.x.

Van Bommel, D., Bruins, H.J., Lazarovitch, N. and van der Plicht, J. (2021). Effect of dung, ash and runoff water on wheat and barley grain sizes and stable isotope ratios: Experimental studies in ancient desert agriculture (Negev, Israel). *Journal of Archaeological Science: Reports*, [online] 39, p.103172. doi:https://doi.org/10.1016/j.jasrep.2021.103172.

Van der Veen, M., Hill, A. and Livarda, A. (2013) The archaeobotany of medieval Britain (c. AD 450–1500): Identifying research priorities for the 21st Century', *Medieval Archaeology*, 57(1), pp. 151–182. doi: 10.1179/0076609713Z.00000000018n/a.

Vogel, J.C. and Van der Merwe, N.J. (1977) 'Isotopic evidence for early maize cultivation in New York State', *American Antiquity*, 42(2), pp. 238–242. https://doi.org/10.2307/278984

Wallace, M., Jones, G., Charles, M., Fraser, R., Halstead, P., Heaton, T.H.E., & Bogaard, A. (2013). Stable carbon isotope analysis as a direct means of inferring crop water status and water management practices. *World Archaeology, 45*(3), pp.388–409. doi:https://doi.org/10.1080/00438243.2013.821671.

Woolgar, C. M. (2016). The culture of food in England, 1200 – 1500. Yale University Press: New Haven and London.

White, R.H.M., Richardson, P. and O'Connell, C. (2009). Prehistoric pit clusters and a rectilinear enclosure at Newton Road, Carnoustie, Angus. *Tayside and Fife Archaeological Journal*, Vol. 15, pp. 1-21.

Appendix 1. Stable isotope and biomass summary statistics.

Site	Cereal type	Cereal species	Biomass grain total	x (mm)	y (mm)	z (mm)	Isotope grain total	Carbonised mass (g)	%N	δ15N (‰)	%C	δ13C (‰)	Δ13C (‰)2	δ34S (‰)
Linbrig	Barley	*Hordeum vulgare*	44	5.0±0.6	2.8±0.4	2.3±0.3	10	0.009±0.002	2.4±0.2	6.0±1.7‰	63.3±4.6	-23.6±0.7	17.8±0.7‰	10.8±2.2‰
Linbrig	Rye	*Secale cereale*	143	5.1±0.6	2.4±0.3	2.2±0.3	10	0.007±0.003	2.6±0.8	6.4±1.4‰	61.2±6.1	-22.2±1.0	16.3±1.1‰	13.8±0.1‰
Linbrig	Bread wheat	*Triticum aestivum*	17	4.5±0.4	3.2±0.4	2.5±0.3	10	0.010±0.003	2.3±0.5	4.7±0.8‰	60.1±6.2	-21.5±0.8	15.6±0.8‰	13.4±2.4‰
Linbrig	Oat	*Avena sp.*	232	6.1±0.1	2.3±0.2	1.9±0.3	20	0.009±0.003	3.5±0.8	3.6±1.7‰	63.7±4.9	-23.9±1.3	18.1±1.4‰	15.5±1.4‰
Linbrig	Bristle oat	*A. strigosa*	20	5.0±1.0	1.9±0.4	1.7±0.3	10	0.006±0.003	3.3±0.3	2.8±1.4‰	62.9±4.4	-24.6±0.8	18.8±0.8‰	16.6±1.8‰
Linbrig	Common oat	*A. sativa*	20	6.4±0.6	2.3±0.3	1.9±0.3	10	0.008±0.002	3.3±0.6	3.0±1.3‰	61.8±4.5	-23.4±0.9	17.6±1.0‰	14.7‰
Hallgarth St.	Barley	*Hordeum vulgare*	209	5.6±0.8	2.8±0.3	2.2±0.3	20	0.015±0.004	2.6±0.6	7.5±1.8‰	64.7±5.9	-24.4±1.0	18.6±1.0‰	10.2±0.5‰
Hallgarth St.	Oat	*Avena sp.*	20	6.8±0.3	2.0±0.1	1.4±0.1	10	0.010±0.001	3.6±0.8	9.3±1.3‰	69.3±6.7	-25.0±1.0	19.2±1.0‰	10.3±1.0‰
Hallgarth St.	Bristle oat	*A. strigosa*	9	5.6±1.2	1.5±0.2	1.1±0.3	9	0.005±0.002	3.6±0.6	9.5±1.1‰	74.1±5.7	-24.3±1.2	18.5±1.3‰	11.72‰
Hallgarth St.	Common oat	*A. sativa*	17	6.4±0.9	1.8±0.2	1.4±0.3	10	0.007±0.002	3.1±0.7	8.4±0.7‰	67.0±17.3	-25.1±0.8	19.3±0.8‰	9.5±0.9‰
Lightpipe Farm	Oat	*Avena sp.*	92	6.0±0.5	2.3±0.2	1.9±0.2	10	0.008±0.002	3.4±0.7	7.5±1.5‰	55.0±8.2	-24.3±1.0	18.5±1.0‰	-1.7‰
Lightpipe Farm	Bristle oat	*A. strigosa*	8	6.3±0.7	2.0±0.2	1.6±0.3	8	0.006±0.002	2.7±0.5	9.9±3.1‰	50.5±8.4	-23.9±0.9	18.1±1.0‰	1.0±11.1‰
Lightpipe Farm	Common oat	*A. sativa*	6	6.1±0.5	2.3±0.2	2.0±0.1	6	0.006±0.002	2.9±0.5	7.3±1.4‰	48.7±5.3	-24.6±0.5	18.8±0.6‰	5.21‰
Belsay Hall	Oat	*Avena sp.*	93	6.2±0.6	2.3±0.2	1.9±0.2	10	0.011±0.002	3.5±0.3	8.3±1.4‰	57.6±3.2	-24.0±0.7	18.2±0.7‰	12.6±0.8‰
Belsay Hall	Bristle oat	*A. strigosa*	10	5.2±0.3	1.7±0.2	1.6±0.2	10	0.005±0.001	3.3±0.4	8.0±1.9‰	57.9±4.4	-25.4±0.6	19.6±0.6‰	-
Belsay Hall	Common oat	*A. sativa*	10	6.0±0.7	2.1±0.1	1.8±0.2	10	0.006±0.002	3.3±0.5	8.2±1.9‰	60.0±3.6	-24.1±0.7	18.3±0.7‰	12.1±1.1‰

Appendix 2. Stable isotope data.

C:S and N:S ratios not provided as C and N data were represent single-grain analysis, whereas S data represent bulk-grain analysis.

The C:N ratio describes the amount of carbon relative to nitrogen based on sample mass, calculated by dividing %C by %N. The CNatomic ratio presents the proportion of carbon to nitrogen based on the number of atoms present, and it is calculated from %C and %N after accounting for the different atomic weights of carbon and nitrogen.

SIBL ID	Site	Sample	Context	Period	Cereal type	Cereal species	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	%N	d15N	%C	d13C	Δ13C	CNatomic	C:N
LB21 IS.1	Linbrig	10	-	1296 - 1400	Barley straight	*Hordeum*	P3	Borderline	4.9	2.5	2.3	0.008	2.41	7.79	56.35	-23.66	17.84	23.4	66.55
LB21 IS.2	Linbrig	10	-	1296 - 1400	Barley twisted	*Hordeum*	P2	Good	5.9	3	2.6	0.012	2.65	5.65	65.38	-23.68	17.86	28.7	73.68
LB21 IS.3	Linbrig	10	-	1296 - 1400	Barley twisted	*Hordeum*	P2	Borderline	5.1	3.2	2.3	0.01	2.37	2.00	65.87	-23.06	17.21	32.4	70.24
LB21 IS.4	Linbrig	10	-	1296 - 1400	Barley straight	*Hordeum*	P2	Good	4.8	2.4	2.3	0.006	2.45	6.18	60.47	-23.56	17.74	28.8	69.1
LB21 IS.5	Linbrig	10	-	1296 - 1400	Barley twisted	*Hordeum*	P2	Borderline	5.4	2.8	2.4	0.009	2.38	5.44	69.35	-24.05	18.25	34	77.17
LB21 IS.6	Linbrig	10	-	1296 - 1400	Barley twisted	*Hordeum*	P2	Borderline	4.8	3	2.3	0.008	2.58	6.26	60.61	-24.19	18.40	27.4	69.45
LB21 IS.7	Linbrig	10	-	1296 - 1400	Barley twisted	*Hordeum*	P2	Borderline	4.4	2.4	2.6	0.006	2.54	7.72	58.59	-22.43	16.55	26.9	68.85
LB21 IS.8	Linbrig	10	-	1296 - 1400	Barley straight	*Hordeum*	P2	Borderline	5.5	2.7	2.3	0.008	2.44	7.10	60.17	-22.98	17.13	28.7	69.71
LB21 IS.9	Linbrig	10	-	1296 - 1400	Barley straight	*Hordeum*	P2	Borderline	5.2	2.9	2.5	0.011	2.14	6.90	69.03	-24.82	19.06	37.6	78.07
LB21 IS.1	Linbrig	10	-	1296 - 1400	Barley straight	*Hordeum*	P2	Borderline	5.5	3.2	2.5	0.011	1.93	4.51	67.18	-23.73	17.92	40.5	73.62
LB21 IS.1	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Good	4.3	3.2	2.1	0.009	2.71	4.73	64.21	-20.01	14.03	27.6	71.65
LB21 IS.1	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Borderline	4.7	3	2.7	0.011	2.27	5.77	63.46	-21.28	15.35	32.6	71.5
LB21 IS.1	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Borderline	4.8	2.8	2.4	0.008	2	3.28	61.84	-21.17	15.24	36	67.12
LB21 IS.1	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Good	4.9	3.5	2.5	0.012	2.43	4.31	63.02	-21.63	15.72	30.2	69.76
LB21 IS.1	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Good	4.8	3.4	2.8	0.015	2.94	3.83	67.2	-21.66	15.75	26.7	73.97
LB21 IS.1	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Good	4.4	3.6	2.8	0.011	2.18	4.52	57.67	-22.58	16.71	30.9	64.37
LB21 IS.1	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Good	4.1	3.3	2.8	0.012	2.97	4.39	61.59	-20.84	14.89	24.2	68.95
LB21 IS.1	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Good	4.1	3.3	2.9	0.008	2.1	4.87	55.69	-21.09	15.15	31	62.66
LB21 IS.1	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Borderline	3.5	2.5	2.3	0.005	1.42	5.89	45.06	-22.47	16.60	37	52.37
LB21 IS.2	Linbrig	10	-	1296 - 1400	Bread wheat	*Triticum a*	P2	Good	4.3	2.7	2.4	0.007	2.03	5.28	60.94	-22.15	16.26	35.1	68.25
LB21 IS.2	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Good	4.4	2.6	2.4	0.007	2.12	7.59	46.66	-22.7	16.84	25.7	56.37
LB21 IS.2	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Borderline	5.2	2.6	2.9	0.009	3.53	7.06	67.89	-21.24	15.31	22.5	78.48
LB21 IS.2	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Borderline	6.1	2.7	2	0.009	2.92	7.29	62.18	-20.54	14.58	24.9	72.39
LB21 IS.2	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Good	5.1	2.3	2.1	0.009	1.94	5.83	64.25	-21.4	15.48	38.6	72.02
LB21 IS.2	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Borderline	4.2	2.1	1.9	0.004	1.97	5.60	61.49	-23.13	17.29	36.4	69.06
LB21 IS.2	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Good	4.9	2.3	1.9	0.005	3.31	8.22	63.34	-23.28	17.44	22.3	74.87
LB21 IS.2	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Borderline	4.6	2.3	1.9	0.006	1.37	3.28	54.7	-23.36	17.53	46.6	59.35
LB21 IS.2	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Good	6.8	2.9	2.5	0.013	3.28	6.77	63.55	-21.09	15.15	22.6	73.6
LB21 IS.2	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Good	4.4	2	1.9	0.004	2.05	6.63	64.24	-22.46	16.59	36.6	72.92
LB21 IS.3	Linbrig	10	-	1296 - 1400	Rye	*Secale cer*	P2	Borderline	4.7	1.9	1.8	0.006	3.35	5.53	63.95	-22.56	16.69	22.3	72.83
LB21 IS.3	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Borderline	5.2	2	2	0.006	2.49	3.52	60.81	-25.76	20.05	28.5	66.82
LB21 IS.3	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Good	5.5	2.1	1.6	0.006	3.29	7.03	65.51	-23	17.15	23.2	75.83
LB21 IS.3	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Good	5.7	2.2	1.8	0.007	3.28	1.89	66.69	-24.94	19.19	23.7	71.86
LB21 IS.3	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Good	5.1	2	1.9	0.005	3.97	5.00	58.12	-24.38	18.60	17.1	67.09
LB21 IS.3	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Borderline	6.1	2.5	1.9	0.007	2.26	5.67	53.21	-24.7	18.94	23.5	61.14
LB21 IS.3	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Good	5.8	2.6	1.5	0.006	3.66	4.56	66.81	-23.77	17.96	21.3	75.03
LB21 IS.3	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Borderline	4.8	2.2	1.7	0.005	2.74	4.03	63.02	-25.06	19.31	26.8	69.79
LB21 IS.3	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Borderline	4.5	1.9	2	0.005	3.35	0.47	63.87	-25.34	19.61	22.2	67.69
LB21 IS.3	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Good	6	2.2	1.8	0.008	2.98	1.45	56.42	-24.79	19.03	22.1	60.85
LB21 IS.4	Linbrig	10	-	1296 - 1400	Oat	*Avena spp*	P2	Good	5.8	2.3	1.6	0.008	3.12	0.67	59.44	-23.98	18.18	22.2	63.23
LB21 IS.4	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Good	7.4	2.1	2	0.012	5.39	2.56	71.09	-20.7	14.75	13.2	79.04
LB21 IS.4	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Good	6.8	2.7	2.1	0.012	4.48	4.93	63.68	-21.5	15.58	14.2	73.09
LB21 IS.4	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Borderline	6.7	2.2	1.7	0.013	4.1	4.31	71.23	-22.76	16.90	17.4	79.64
LB21 IS.4	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Good	7	2.1	1.9	0.011	3.96	3.13	69.01	-24.42	18.64	17.4	76.1
LB21 IS.4	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Good	7	2.3	2	0.01	3.72	3.98	69.84	-23.16	17.32	18.8	77.54
LB21 IS.4	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Good	6.7	2.4	2	0.013	4.8	2.81	65.73	-23.75	17.94	13.7	73.34
LB21 IS.4	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Borderline	5.8	2.1	1.7	0.007	2.62	4.01	62.02	-23.39	17.56	23.7	68.65
LB21 IS.4	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Good	5.9	2.2	1.9	0.007	2.81	3.90	58.69	-22.43	16.55	20.9	65.4
LB21 IS.4	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Good	7.1	2.2	1.7	0.011	3.6	2.52	64.21	-25.59	19.87	17.8	70.33
LB21 IS.5	Linbrig	13	-	1306 - 1424	Oat	*Avena spp*	P2	Borderline	6.4	2.3	2	0.012	4.24	5.36	65.27	-24.18	18.39	15.4	74.87
LB21 IS.5	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Good	6.7	2.3	2	0.01	3.37	4.05	64.89	-24.17	18.38	19.2	72.31
LB21 IS.5	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Good	4.9	1.7	1.7	0.006	3.39	1.88	64.48	-24.75	18.99	19	69.75
LB21 IS.5	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Borderline	5.2	2.1	1.8	0.004	3.08	1.16	55.71	-24.84	19.08	18.1	59.95
LB21 IS.5	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Good	6.8	2.9	2.2	0.011	2.85	1.91	55.35	-24.58	18.81	19.5	60.11
LB21 IS.5	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Bordrerline	3.8	1.5	1.4	0.002	3.61	2.33	65.59	-25.17	19.43	18.2	71.53
LB21 IS.5	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Borderline	6.4	2	1.8	0.005	3.5	4.19	65.74	-22.67	16.81	18.8	73.43
LB21 IS.5	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Borderline	5.6	2.2	2	0.005	3.01	2.09	62.49	-24.81	19.05	20.8	67.59
LB21 IS.5	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Good	4.3	1.6	1.4	0.006	3.66	1.64	67.19	-24.85	19.09	18.3	72.49
LB21 IS.5	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Borderline	4.6	1.6	1.6	0.004	3.07	5.31	60.09	-25.62	19.90	19.6	68.47
LB21 IS.6	Linbrig	13	-	1306 - 1424	Bristle oat	*Avena stri*	P2	Borderline	4.4	2.1	1.9	0.005	3	3.48	67.19	-24.62	18.85	22.4	73.67
LB21 IS.6	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Borderline	6.6	2.1	1.6	0.007	3.47	2.77	66.61	-22.53	16.66	19.2	72.85
LB21 IS.6	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Good	7.5	2.4	1.9	0.01	3.03	3.61	56.58	-22.6	16.73	18.7	63.22
LB21 IS.6	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Borderline	6.7	2.2	1.7	0.007	3.07	1.50	60.59	-22.64	16.77	19.7	65.16
LB21 IS.6	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Borderline	5.9	2.1	1.7	0.007	2.91	3.69	71.1	-23.19	17.35	24.5	77.7
LB21 IS.6	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Good	5.1	1.9	1.7	0.006	3.86	1.55	64.09	-23.07	17.22	16.6	69.5
LB21 IS.6	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Good	6.5	2.6	1.6	0.007	3.86	5.48	59.31	-25.11	19.37	15.4	68.65
LB21 IS.6	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Good	6.6	2.5	2.2	0.011	4.01	1.79	62.19	-22.68	16.82	15.5	67.99
LB21 IS.6	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Borderline	6.6	2.1	2	0.009	2.24	4.20	56.96	-24.74	18.98	25.4	63.4
LB21 IS.6	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Good	5.6	1.9	1.5	0.005	2.6	3.65	62	-23.46	17.63	23.8	68.25
LB21 IS.7	Linbrig	13	-	1306 - 1424	Common oat	*Avena sati*	P2	Good	7.6	2.7	2.4	0.013	3.68	2.13	58.89	-23.83	18.02	16	64.7
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley twisted	*Hordeum*	P2	Borderline	5.2	3.3	2.7	0.012	2.77	9.70	72.06	-24.78	19.00	30.3	26
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley twisted	*Hordeum*	P2	Borderline	6.1	3.5	2.9	0.016	2.13	8.91	57.3	-24.15	18.34	31.4	26.92
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley straight	*Hordeum*	P2	Good	5.8	3.3	2.5	0.015	2.61	4.72	65.92	-23.07	17.20	29.5	25.26
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley twisted	*Hordeum*	P2	Borderline	5.7	3.1	2.6	0.015	3.61	8.79	68.1	-24.3	18.50	22	18.89
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley twisted	*Hordeum*	P2	Good	4.9	3	2.3	0.012	1.8	8.41	61.42	-26	20.28	39.7	34.07
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley twisted	*Hordeum*	P2	Good	5.3	3	2.6	0.014	2.64	8.59	63.58	-25.22	19.46	28	24.05
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley straight	*Hordeum*	P2	Borderline	4.7	3.1	2.3	0.013	2.22	4.81	71.58	-25.49	19.75	37.6	32.26
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley straight	*Hordeum*	P2	Good	5.8	3.1	2.6	0.014	-	-	-	-	-	-	-
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley twisted	*Hordeum*	P2	Borderline	4.7	2.3	2.1	0.005	1.54	7.14	54.7	-23.07	17.20	41.5	35.6
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Barley twisted	*Hordeum*	P2	Borderline	4.4	2.5	1.9	0.009	2.18	6.03	73.71	-25.09	19.33	39.4	33.79
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Bristle oat	*A. strigosa*	P2	Borderline	5.1	1.3	1	0.004	3.92	8.12	77.9	-23.24	17.38	23.2	19.87
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Bristle oat	*A. strigosa*	P2	Borderline	7.2	1.8	1.2	0.009	4.44	9.13	75.93	-22.86	16.98	19.9	17.08
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Bristle oat	*A. strigosa*	P2	Good	7	1.9	1.6	0.009	2.88	8.88	68.07	-25.45	19.70	27.6	23.65
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Bristle oat	*A. strigosa*	P2	Borderline	6	1.4	1.2	0.005	3.46	9.41	79.17	-23.74	17.91	26.7	22.87
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Bristle oat	*A. strigosa*	P2	Borderline	5.5	1.5	1	0.005	2.88	11.26	80.07	-24.53	18.74	32.5	27.83
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Bristle oat	*A. strigosa*	P2	Borderline	4.3	1.7	1.7	0.004	3.06	8.84	62.93	-26.3	20.60	24	20.55
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Bristle oat	*A. strigosa*	P2	Good	4.4	1.3	1	0.004	3.35	10.73	70.97	-25.38	19.63	24.7	21.21
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Bristle oat	*A. strigosa*	P2	Borderline	4.3	1.2	0.8	0.002	4	8.95	77.8	-23.46	17.61	22.7	19.47
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Bristle oat	*A. strigosa*	P2	Borderline	6.6	1.5	0.8	0.004	3.99	10.60	73.89	-23.31	17.46	21.6	18.53
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Borderline	6.9	1.7	1.2	0.009	3.67	7.83	76.85	-24.42	18.62	24.4	20.95
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Borderline	7.2	1.9	1.5	0.007	3.19	7.86	75.15	-25.65	19.92	27.5	23.59
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Borderline	7.7	1.7	1.3	0.006	3.12	9.75	64.17	-23.72	17.89	24	20.54
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Borderline	6.8	1.8	1.2	0.008	1.16	7.87	20.54	-25.71	19.98	20.7	17.78
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Borderline	6.6	1.9	1.3	0.009	3.14	8.55	72.38	-25.81	20.08	26.9	23.05
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Good	5.6	1.6	1	0.007	3.66	8.65	63.34	-24.97	19.20	20.2	17.32
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Good	4.6	1.5	1.3	0.004	3.2	7.47	67.37	-25.12	19.36	24.5	21.03
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Borderline	6.4	1.6	1.2	0.007	3.23	8.68	79.88	-24.91	19.14	28.9	24.74
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Borderline	5.9	1.7	1.2	0.005	2.96	9.15	72.24	-26.2	20.49	28.4	24.37
DHS05 IS	Hallgarth	9	58	11th - 12th cer	Common oat	*A. sativa*	P2	Borderline	7.2	1.6	1.1	0.006	3.53	8.58	77.57	-24.53	18.74	25.7	22

(cont.)

SIBL ID	Site	Sample	Context	Period	Cereal type	Cereal species	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	%N	d15N	%C	d13C	Δ13C	CNatomic	C:N
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Good	6.6	2.1	1.3	0.011	2.79	9.56	75.62	-25.83	20.10	31.6	27.06
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Good	7.1	2	1.4	0.012	4.67	10.97	68.1	-23.21	17.35	17	14.57
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Borderline	6.8	2	1.5	0.012	3.54	8.99	65.73	-25.24	19.48	21.7	18.58
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Borderline	7.1	2	1.5	0.01	3.96	10.72	74.4	-23.65	17.81	21.9	18.78
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Borderline	6.4	2	1.4	0.009	2.86	8.15	72.21	-25.92	20.20	29.4	25.22
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Borderline	6.8	2.1	1.6	0.008	3.91	6.84	58.5	-24.82	19.04	17.5	14.97
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Good	6.6	2.1	1.7	0.009	3.09	10.45	63.56	-24.73	18.95	24	20.54
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Borderline	7.1	2.1	1.4	0.012	2.89	10.07	69.28	-26.34	20.64	28	23.99
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Good	6.3	2	1.4	0.01	3.1	8.13	64.28	-24.97	19.20	24.2	20.75
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Oat	*Avena sp*	P2	Borderline	6.5	2	1.2	0.01	5.15	9.08	80.98	-24.92	19.15	18.3	15.71
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley str	*Hordeum*	P2	Borderline	6.9	3.3	2.3	0.018	3.2	5.23	65.27	-22.11	16.20	23.8	20.41
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley twi	*Hordeum*	P2	Borderline	6.8	3.2	2.6	0.02	3.04	8.71	63.91	-24.67	18.88	24.5	21.01
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley twi	*Hordeum*	P2	Good	6.5	3.3	2.3	0.019	3.46	8.34	68.64	-23.76	17.93	23.1	19.83
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley twi	*Hordeum*	P2	Borderline	6.2	3.2	2.3	0.023	2.61	10.04	56.65	-23.84	18.01	25.3	21.67
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley twi	*Hordeum*	P2	Borderline	6.4	3.2	2.4	0.016	1.96	6.78	73.68	-25.41	19.66	43.8	37.54
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley twi	*Hordeum*	P2	Borderline	6.8	3.2	2.4	0.015	1.93	7.67	60.99	-24.72	18.94	36.8	31.57
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley str	*Hordeum*	P2	Good	5.7	3.1	2.3	0.017	2.79	6.44	64.08	-24.91	19.14	26.8	23
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley str	*Hordeum*	P2	Borderline	6.1	3.2	2.5	0.019	2.81	7.77	68.82	-23.85	18.02	28.5	24.47
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley twi	*Hordeum*	P2	Good	6.5	2.8	2.6	0.013	2.91	9.96	63	-24.47	18.67	25.2	21.65
DHS05 IS	Hallgarth	9	58	11th - 12th cen	Hulled barley twi	*Hordeum*	P2	Borderline	6.4	2.8	2.6	0.012	2.45	4.60	56.37	-23.75	17.92	26.8	23.01
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Good	6.2	2.5	2.2	0.009	3.52	6.44	53.21	-23.9	18.10	15.1	63.17
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Borderline	6.7	3.2	2.4	0.01	3.32	9.31	60.16	-25.17	19.43	18.1	72.79
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Borderline	6.1	2.1	2	0.012	2.21	9.03	35.37	-25.43	19.70	16	46.61
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Good	6.8	2.3	2	0.01	3.33	5.95	54.15	-23.51	17.69	16.3	63.43
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Good	6.3	2.9	2	0.008	4.08	9.11	56.39	-24.13	18.34	13.8	69.58
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Good	6.5	2.1	1.6	0.009	2.82	5.53	62.49	-25.56	19.84	22.2	70.84
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Borderline	6.3	2.5	2	0.009	2.7	5.92	49.7	-24.59	18.82	18.4	58.32
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Borderline	6.4	2.3	1.8	0.007	4.13	7.93	55.46	-22.77	16.91	13.4	67.52
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Good	6.3	2	1.9	0.005	3.95	8.89	58.83	-23.22	17.38	14.9	71.67
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Oat	*Avena sp*	P2	Good	5.2	2.2	1.9	0.004	4.11	6.72	64.3	-24.47	18.69	15.6	75.13
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Bristle oat	*A. strigos*	P2	Good	6.1	1.8	1.7	0.006	2.36	7.82	54.13	-24.41	18.63	22.9	64.31
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Bristle oat	*A. strigos*	P2	Good	6.2	1.9	1.5	0.009	3.31	16.91	55.24	-23.63	17.81	16.7	75.46
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Bristle oat	*A. strigos*	P2	Good	5.8	1.9	1.3	0.007	2.21	7.70	64.57	-24.41	18.63	29.2	74.48
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Bristle oat	*A. strigos*	P3	Borderline	5.5	1.8	1.1	0.002	2.57	8.72	43.94	-24.22	18.43	17.1	55.23
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Bristle oat	*A. strigos*	P3	Borderline	5.8	2	2	0.005	2.64	8.68	47.03	-22.96	17.11	17.8	58.35
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Bristle oat	*A. strigos*	P3	Bad	7.5	1.8	1.5	0.006	2.17	10.71	36.24	-25.48	19.76	16.7	49.12
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Bristle oat	*A. strigos*	P3	Good	7.3	2.3	1.8	0.008	3.01	8.11	51.16	-23.07	17.22	17	62.28
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Bristle oat	*A. strigos*	P3	Borderline	6	2.2	2	0.007	3.44	10.78	51.77	-22.89	17.04	15.1	65.99
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Common oat	*A. sativa*	P3	Borderline	5.8	2.1	2.1	0.006	2.58	8.83	39.32	-24.26	18.47	15.2	50.73
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Common oat	*A. sativa*	P3	Borderline	6.8	2.5	2.1	0.008	2.85	5.28	48.21	-25.19	19.45	16.9	56.34
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Common oat	*A. sativa*	P3	Borderline	6.4	2.3	1.9	0.007	2.78	6.85	48.41	-24.69	18.93	17.4	58.04
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Common oat	*A. sativa*	P3	Good	5.8	2.2	2.1	0.006	3.81	6.73	54.06	-23.79	17.98	14.2	64.6
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Common oat	*A. sativa*	P3	Bad	5.6	2	1.9	0.003	2.68	9.12	53.45	-25.06	19.31	19.9	65.25
LPL21 IS	Lightpipe	15	35	1305 - 1409 C	Common oat	*A. sativa*	P3	Bad	6	2.4	2.1	0.007	2.7	7.21	48.52	-24.49	18.71	17.9	58.43
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Good	6.5	2.6	2.2	0.013	3.6	8.19	57.41	-24.03	18.21	16	15.9472
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Borderline	6.5	2.4	1.9	0.012	3.4	8.44	61.82	-23.26	17.40	18.2	18.1824
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Borderline	6.2	2.3	1.8	0.012	3.48	7.50	55.19	-24.01	18.19	15.8	15.8592
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Good	6.5	2.3	1.8	0.011	4.05	9.44	60.6	-23.48	17.63	15	14.963
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Borderline	7	2.6	2.5	0.012	3.52	6.95	54.16	-23.73	17.90	15.4	15.3864
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Good	5.7	2.2	1.6	0.009	3.47	11.02	61.6	-24.63	18.84	17.7	17.7522
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Good	6.2	2.3	1.8	0.009	3.39	6.58	53.98	-25.06	19.29	15.9	15.9233
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Good	6.6	2.5	2	0.01	3.1	7.41	53.86	-24.68	18.89	17.4	17.3742
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Good	6.3	2.1	1.6	0.011	3.86	9.94	58.52	-24.09	18.27	15.2	15.1606
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Oat	Oat	P2	Borderline	6	2	1.4	0.007	3.18	7.74	58.41	-22.78	16.90	18.4	18.3679
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Good	5	1.8	1.8	0.006	3.06	6.95	55.71	-25.72	19.99	18.2	18.2059
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Good	4.8	1.4	1.3	0.004	2.93	5.53	54.12	-26.7	21.02	18.5	18.471
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Good	5.4	1.8	1.7	0.004	3.34	6.36	53.03	-25.7	19.97	15.9	15.8772
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Borderline	5.2	1.7	1.7	0.003	3.33	9.90	63.33	-25.55	19.81	19	19.018
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Good	4.8	1.5	1.4	0.004	3.29	10.63	59.59	-24.69	18.91	18.1	18.1125
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Good	5.5	1.5	1.3	0.006	3.16	9.07	65.61	-25.22	19.46	20.8	20.7627
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Good	5.3	1.7	1.4	0.003	4.25	10.27	52.91	-24.84	19.06	12.4	12.4494
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Borderline	5.6	1.9	1.7	0.005	3.82	8.34	55.76	-25	19.23	14.6	14.5969
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Borderline	5.1	1.5	1.7	0.004	3.09	7.13	58.22	-24.89	19.12	18.9	18.8414
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Bristle oat	*A.strigosa*	P2	Good	5.5	1.7	1.6	0.006	3.07	6.05	60.96	-25.45	19.70	19.8	19.8567
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Good	6.7	2.3	1.8	0.008	2.48	5.31	50.43	-25.14	19.38	20.3	20.3347
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Borderline	6	2.1	1.8	0.005	3.22	7.40	61.73	-24.12	18.31	19.2	19.1708
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Borderline	4.8	1.9	1.6	0.006	3	10.01	57.57	-23.38	17.53	19.2	19.19
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Good	5.8	2.1	1.7	0.009	3.91	7.55	59.55	-23.83	18.00	15.2	15.2302
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Borderline	7	2.2	1.9	0.008	3.31	7.95	61.89	-25.46	19.72	18.7	18.6979
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Borderline	5.7	2.1	1.7	0.006	3.56	7.45	59.68	-23.74	17.91	16.8	16.764
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Borderline	5.8	2.2	1.9	0.005	2.81	8.42	61.39	-23.63	17.79	21.9	21.847
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Good	5.3	1.9	1.5	0.007	4.22	6.00	60.39	-24.15	18.34	14.3	14.3104
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Good	5.7	1.9	1.7	0.005	2.74	11.34	62.73	-24.11	18.30	22.9	22.8942
BED21 IS	Belsay Ha	1	2449	1168 - 1265	Common oat	*A.sativa*	P2	Borderline	6.7	2.2	2.2	0.005	3.47	10.60	60.9	-23.36	17.51	17.5	17.5504

Appendix 3. Biomass data.

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Linbrig	10		1296 - 1400	Barley straight	P3	Borderline	4.9	2.5	2.3	0.008	LB21 IS.1
Linbrig	10		1296 - 1400	Barley twisted	P2	Good	5.9	3	2.6	0.012	LB21 IS.2
Linbrig	10		1296 - 1400	Barley twisted	P2	Borderline	5.1	3.2	2.3	0.01	LB21 IS.3
Linbrig	10		1296 - 1400	Barley straight	P2	Good	4.8	2.4	2.3	0.006	LB21 IS.4
Linbrig	10		1296 - 1400	Barley twisted	P2	Borderline	5.4	2.8	2.4	0.009	LB21 IS.5
Linbrig	10		1296 - 1400	Barley twisted	P2	Borderline	4.8	3	2.3	0.008	LB21 IS.6
Linbrig	10		1296 - 1400	Barley twisted	P2	Borderline	4.4	2.4	2.6	0.006	LB21 IS.7
Linbrig	10		1296 - 1400	Barley straight	P2	Borderline	5.5	2.7	2.3	0.008	LB21 IS.8
Linbrig	10		1296 - 1400	Barley straight	P2	Borderline	5.2	2.9	2.5	0.011	LB21 IS.9
Linbrig	10		1296 - 1400	Barley straight	P2	Borderline	5.5	3.2	2.5	0.011	LB21 IS.10
Linbrig	10		1296 - 1400	Barley	P2	-	4.6	2.2	2	-	-
Linbrig	10		1296 - 1400	Barley	P2	-	4.6	2.4	1.7	-	-
Linbrig	10		1296 - 1400	Barley	P2	-	4.8	2.4	2.1	-	-
Linbrig	10		1296 - 1400	Barley	P2	-	5.3	3	2.1	-	-
Linbrig	10		1296 - 1400	Barley	P2	-	5.1	3.1	2.2	-	-
Linbrig	10		1296 - 1400	Barley	P2	-	4.3	2.7	1.9	-	-
Linbrig	10		1296 - 1400	Barley	P2	-	5.5	3.3	2.5	-	-
Linbrig	10		1296 - 1400	Barley	P2	-	5.7	3.1	2.3	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	6.6	3.5	3	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.9	2.9	2.1	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	5.6	3.3	2.2	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.1	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.6	2.9	2.1	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	5.1	2.7	2.4	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	5	3	2.8	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	5.4	3	2.2	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	6.5	3.3	2.6	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.8	3.6	2.4	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	5.4	2.9	2.5	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.2	2.2	2	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.6	2.8	2.6	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.5	2.3	2.1	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	5.1	2.6	2.2	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.7	2.9	2	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.8	2.5	2	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.2	2.4	1.9	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.9	3.1	2	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	5.3	3	2.5	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	5.2	3.2	2.6	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.4	2.4	2.3	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	4.4	2.4	1.8	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	3.1	2.3	2	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	3.9	2.6	1.7	-	-
Linbrig	10		1296 - 1400	Barley	P3	-	5.1	3.7	2.7	-	-
Linbrig	10		1296 - 1400	Bread wheat	P2	Good	4.3	3.2	2.1	0.009	LB21 IS.11
Linbrig	10		1296 - 1400	Bread wheat	P2	Borderline	4.7	3	2.7	0.011	LB21 IS.12
Linbrig	10		1296 - 1400	Bread wheat	P2	Borderline	4.8	2.8	2.4	0.008	LB21 IS.13
Linbrig	10		1296 - 1400	Bread wheat	P2	Good	4.9	3.5	2.5	0.012	LB21 IS.14
Linbrig	10		1296 - 1400	Bread wheat	P2	Good	4.8	3.4	2.8	0.015	LB21 IS.15
Linbrig	10		1296 - 1400	Bread wheat	P2	Good	4.4	3.6	2.8	0.011	LB21 IS.16
Linbrig	10		1296 - 1400	Bread wheat	P2	Good	4.1	3.3	2.8	0.012	LB21 IS.17
Linbrig	10		1296 - 1400	Bread wheat	P2	Good	4.1	3.3	2.9	0.008	LB21 IS.18
Linbrig	10		1296 - 1400	Bread wheat	P2	Borderline	3.5	2.5	2.3	0.005	LB21 IS.19
Linbrig	10		1296 - 1400	Bread wheat	P2	Good	4.3	2.7	2.4	0.007	LB21 IS.20
Linbrig	10		1296 - 1400	Bread wheat	P3	-	4.3	3.4	2.7	-	-
Linbrig	10		1296 - 1400	Bread wheat	P3	-	4.4	3.1	2.7	-	-
Linbrig	10		1296 - 1400	Bread wheat	P3	-	4.4	3.2	1.9	-	-
Linbrig	10		1296 - 1400	Bread wheat	P3	-	5.1	3.1	2.5	-	-
Linbrig	10		1296 - 1400	Bread wheat	P3	-	5.2	3.5	2.6	-	-
Linbrig	10		1296 - 1400	Bread wheat	P3	-	4.8	3.6	2.7	-	-
Linbrig	10		1296 - 1400	Bread wheat	P3	-	4.5	2.5	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P2	Good	4.4	2.6	2.4	0.007	LB21 IS.21
Linbrig	10		1296 - 1400	Rye	P2	Borderline	5.2	2.6	2.9	0.009	LB21 IS.22
Linbrig	10		1296 - 1400	Rye	P2	Borderline	6.1	2.7	2	0.009	LB21 IS.23
Linbrig	10		1296 - 1400	Rye	P2	Good	5.1	2.3	2.1	0.009	LB21 IS.24
Linbrig	10		1296 - 1400	Rye	P2	Borderline	4.2	2.1	1.9	0.004	LB21 IS.25
Linbrig	10		1296 - 1400	Rye	P2	Good	4.9	2.3	1.9	0.005	LB21 IS.26
Linbrig	10		1296 - 1400	Rye	P2	Borderline	4.6	2.3	1.9	0.006	LB21 IS.27
Linbrig	10		1296 - 1400	Rye	P2	Good	6.8	2.9	2.5	0.013	LB21 IS.28
Linbrig	10		1296 - 1400	Rye	P2	Good	4.4	2	1.9	0.004	LB21 IS.29
Linbrig	10		1296 - 1400	Rye	P2	Borderline	4.7	1.9	1.8	0.006	LB21 IS.30
Linbrig	10		1296 - 1400	Rye	P2	-	5.7	2.3	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.2	2.1	1.8	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.3	2.1	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.2	2.2	1.6	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	6.4	2.9	2.7	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.1	2.6	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.7	3	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4	2.1	1.7	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.2	2.7	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.5	2.4	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.7	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.9	2.2	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.9	2.4	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.9	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.6	2.4	1.6	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.3	2	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.8	2.2	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5	2.3	2.4	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.6	2.5	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.3	2.8	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.7	2.1	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.5	2.4	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5	2.5	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	6	2.8	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.8	2.5	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.1	2.7	3	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.3	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.9	2.8	2.6	-	-

(cont.)

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Linbrig	10		1296 - 1400	Rye	P2	-	4.5	1.9	1.5	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.8	2.2	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	6.1	3	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.1	2.3	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	3.5	2.1	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.5	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.1	2.3	1.8	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.5	2.3	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.5	2.8	2.5	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.9	2	1.9	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.2	2.5	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.8	2	1.8	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.9	2.9	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.5	2.2	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.2	1.9	1.7	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.8	2.5	1.9	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.9	2.6	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5	2.7	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.4	2.1	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.8	2.6	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.7	2.2	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.2	2.5	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.3	2	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.8	2.5	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.8	2.8	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.1	2.7	2.5	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.7	2.3	2.4	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.2	2.8	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.4	2.4	2.4	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.4	2.8	3	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.8	2.5	2	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.6	2.7	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.4	2.3	2.5	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.1	2.2	1.9	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5.4	2.4	2.5	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.7	2.4	2.5	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5	2.7	2.5	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	4.9	2.1	1.8	-	-
Linbrig	10		1296 - 1400	Rye	P2	-	5	2.2	2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.4	2.5	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.6	2.2	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.3	2.3	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.5	2.3	2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.1	2	2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.2	2.3	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.5	2.5	1.9	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.7	2.4	2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.8	2.4	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.6	2.1	2.7	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.5	2.9	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	3.8	2.1	1.8	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.1	2.1	1.7	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.1	2.2	1.8	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.7	2.2	1.8	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.1	2.5	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	6.7	2.2	2.7	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.3	2.7	2.4	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.6	2.4	2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	3.3	2.1	1.8	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.4	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.4	2.8	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.4	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	6.8	2.7	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.5	2.3	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.1	2.4	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.8	2.4	2.4	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.6	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.6	2.5	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.5	2.1	1.7	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.3	2	1.8	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.1	1.5	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.2	2.9	2.5	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.2	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.9	2.9	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	6.4	2.5	1.9	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.4	2.7	2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.8	1.9	1.7	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.7	2.3	2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.4	2.5	2.4	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.3	2.2	1.7	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.6	2.6	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.3	2.7	2.8	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	6.3	2.8	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.7	2.4	1.9	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.3	2.7	2.4	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.2	2.2	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.9	2.4	2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.3	2.3	1.9	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.7	2.1	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.4	2.5	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.9	2.3	2.3	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	3.9	1.8	1.5	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.9	2.5	2.6	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.3	2.1	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.4	2.3	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.1	3.1	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.6	2.7	2.4	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.5	2.7	2.5	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.1	2.2	2	-	-

(cont.)

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Linbrig	10		1296 - 1400	Rye	P3	-	4.5	1.8	1.7	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	4.5	2.2	1.9	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.1	2.4	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	6.1	2.9	2.1	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5.2	2.7	2.2	-	-
Linbrig	10		1296 - 1400	Rye	P3	-	5	2.2	2.6	-	-
Linbrig	10		1296 - 1400	Oat	P2	Borderline	5.2	2	2	0.006	LB21 IS.31
Linbrig	10		1296 - 1400	Oat	P2	Good	5.5	2.1	1.6	0.006	LB21 IS.32
Linbrig	10		1296 - 1400	Oat	P2	Good	5.7	2.2	1.8	0.007	LB21 IS.33
Linbrig	10		1296 - 1400	Oat	P2	Good	5.1	2	1.9	0.005	LB21 IS.34
Linbrig	10		1296 - 1400	Oat	P2	Borderline	6.1	2.5	1.9	0.007	LB21 IS.35
Linbrig	10		1296 - 1400	Oat	P2	Good	5.8	2.6	1.5	0.006	LB21 IS.36
Linbrig	10		1296 - 1400	Oat	P2	Borderline	4.8	2.2	1.7	0.005	LB21 IS.37
Linbrig	10		1296 - 1400	Oat	P2	Borderline	4.5	1.9	2	0.005	LB21 IS.38
Linbrig	10		1296 - 1400	Oat	P2	Good	6	2.2	1.8	0.008	LB21 IS.39
Linbrig	10		1296 - 1400	Oat	P2	Good	5.8	2.3	1.6	0.008	LB21 IS.40
Linbrig	10		1296 - 1400	Oat	P2	-	8.1	2.6	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	7.9	2.2	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	7	2.5	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.7	2.3	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.9	2.2	2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.1	2.2	1.6	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	7.3	2.5	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.9	2.3	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.4	2.3	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6	2.3	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.1	2	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.6	2.1	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.8	2.2	1.3	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	7	2.3	2.4	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.9	2.3	1.4	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.6	2.1	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.3	2	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5	2.1	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.5	2.3	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	4.8	1.9	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.8	2.1	2.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.1	2.6	2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.1	2.2	1.5	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.2	2.2	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.2	2.3	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.6	2.6	2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.3	3	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.5	2.6	1.4	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.1	2.2	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	4.7	2.1	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.8	2.3	2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.2	2.2	2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.7	2.1	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.2	2	2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	4.7	2	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	4.8	2.1	1.5	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.4	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.1	2.1	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	4.5	2.6	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.6	2.2	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.4	2.2	1.4	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.3	2.5	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.4	2.2	1.6	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.7	2.4	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.5	2	1.5	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.6	2.2	1.6	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.3	2.1	1.5	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5	2	1.3	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	7.6	2.5	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.9	2.7	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6	2.3	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.9	2.4	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.9	2.1	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.4	2	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.4	2.2	2.6	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.8	3	2.3	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.7	2.2	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5	2.4	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.8	2.2	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.4	2.2	2.4	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	4.7	1.9	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.5	2.4	1.6	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.7	2.5	2.5	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.3	2.2	2.4	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.5	2.6	2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.4	1.8	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.6	2.3	2.3	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6.4	2.1	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	6	1.6	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5	2.2	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	4.7	2.2	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.2	2.2	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P2	-	5.1	2.1	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.1	2	2.3	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	5.4	2.6	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.4	2.2	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.2	2.2	1.6	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.5	2	2	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.7	2.4	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.8	1.9	2.5	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	5.9	2.4	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.1	2.4	1.6	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.7	2.6	2.1	-	-

(cont.)

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Linbrig	10		1296 - 1400	Oat	P3	-	5.7	2	1.4	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.5	2.2	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6	2.4	2	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	5.8	2.3	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	5.9	2.2	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	5.4	2.1	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.3	2.6	1.7	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.9	2.3	2.3	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	5.4	2.2	2.2	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	4.7	2.2	1.6	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.2	2.6	2.3	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	5.5	2	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	5.9	2.1	1.5	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	4.9	2.2	1.9	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	5.3	2.2	1.8	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.8	2.7	2.1	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.2	2.8	2.3	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.4	2.5	2.3	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.1	2.2	2.4	-	-
Linbrig	10		1296 - 1400	Oat	P3	-	6.6	2.5	2.5	-	-
Linbrig	13		1306 - 1424	Oat	P2	Good	7.4	2.1	2	0.012	LB21 IS.41
Linbrig	13		1306 - 1424	Oat	P2	Good	6.8	2.7	2.1	0.012	LB21 IS.42
Linbrig	13		1306 - 1424	Oat	P2	Borderline	6.7	2.2	1.7	0.013	LB21 IS.43
Linbrig	13		1306 - 1424	Oat	P2	Good	7	2.1	1.9	0.011	LB21 IS.44
Linbrig	13		1306 - 1424	Oat	P2	Good	7	2.3	2	0.01	LB21 IS.45
Linbrig	13		1306 - 1424	Oat	P2	Good	6.7	2.4	2	0.013	LB21 IS.46
Linbrig	13		1306 - 1424	Oat	P2	Borderline	5.8	2.1	1.7	0.007	LB21 IS.47
Linbrig	13		1306 - 1424	Oat	P2	Good	5.9	2.2	1.9	0.007	LB21 IS.48
Linbrig	13		1306 - 1424	Oat	P2	Good	7.1	2.2	1.7	0.011	LB21 IS.49
Linbrig	13		1306 - 1424	Oat	P2	Borderline	6.4	2.3	2	0.012	LB21 IS.50
Linbrig	13		1306 - 1424	Oat	P2	-	5.7	2.3	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.4	2.1	1.7	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7	2.3	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7	2.2	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.7	2.5	1.7	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.4	2.3	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.9	2.3	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.9	2.6	2.3	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.7	2	1.5	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.6	2.9	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.3	2.1	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.3	2	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.5	2.3	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.3	2.3	1.7	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6	2.4	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.4	2.4	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.5	2.1	1.7	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.3	2.5	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.7	2.2	1.7	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.1	2.3	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.2	2.2	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.5	2.4	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7	2.3	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.1	2.4	2.3	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.2	2.3	1.7	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.6	2.3	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.8	2.4	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.8	2.5	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.3	2.1	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.8	2.2	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.1	2	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.9	2.4	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.2	2.1	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.7	2.3	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.1	2.4	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.1	2.2	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.3	2.9	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7	2.3	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.9	2.4	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.8	2.4	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.9	2.1	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.8	2.2	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.8	2.5	2.3	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.6	2.3	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.2	2.1	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7	2.4	2.4	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.8	2.3	2.2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.1	2.4	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.6	2.1	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.8	2.3	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.6	2.2	1.5	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.9	2.1	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.1	2.1	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.2	2.2	2.2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.7	2.2	1.6	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7	2.2	2.2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.9	2.7	2.2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6	2.2	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.6	2.5	2.4	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.3	2.6	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.4	2.1	1.5	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.6	2.1	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.4	2.5	2.2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.4	2.1	1.6	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.4	2.1	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.6	2.1	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.2	2.5	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.6	2.1	1.6	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.7	2.1	1.9	-	-

(cont.)

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Linbrig	13		1306 - 1424	Oat	P2	-	6.4	2.6	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.7	2.2	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.9	2.6	2.2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.3	2.2	1.7	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.6	2.1	1.7	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.5	2.4	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	4.6	2	1.7	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	4.2	2	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.5	2.2	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	4.8	2	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	4.8	2	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5	2.1	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	4.9	2.1	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.1	2	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.5	2	1.5	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.3	2.1	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	4.7	2.1	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	4.8	2.1	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.4	2.4	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.2	2.5	2.2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.6	2.7	2.2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.1	2.4	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.7	2.4	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.6	2.3	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.6	2.1	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.6	2	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.3	2	1.5	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.5	2.3	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.6	2.1	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.1	2.3	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.4	2.1	1.6	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7	2.3	2.6	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.7	2.3	1.9	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.3	2.2	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.6	1.9	2.2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6.7	2.5	2.3	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	6	2.2	2.1	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	5.9	2.2	1.8	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	4.9	2.1	2	-	-
Linbrig	13		1306 - 1424	Oat	P2	-	7.5	2.5	1.9	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Good	6.7	2.3	2	0.01	LB21 IS.51
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Good	4.9	1.7	1.7	0.006	LB21 IS.52
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Borderline	5.2	2.1	1.8	0.004	LB21 IS.53
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Good	6.8	2.9	2.2	0.011	LB21 IS.54
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Bordrerline	3.8	1.5	1.4	0.002	LB21 IS.55
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Borderline	6.4	2	1.8	0.005	LB21 IS.56
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Borderline	5.6	2.2	2	0.005	LB21 IS.57
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Good	4.3	1.6	1.4	0.006	LB21 IS.58
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Borderline	4.6	1.6	1.6	0.004	LB21 IS.59
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	Borderline	4.4	2.1	1.9	0.005	LB21 IS.60
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	5.1	1.9	1.6	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	6.6	2.2	2	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	4.9	1.7	1.4	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	4.9	1.9	1.9	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	4	1.4	1.2	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	4.6	1.9	1.7	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	4.5	1.6	1.4	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	3.9	1.3	1.3	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	4.3	1.6	1.5	-	-
Linbrig	13		1306 - 1424	Oat (*A. strigosa*)	P2	-	4	1.9	2	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Borderline	6.6	2.1	1.6	0.007	LB21 IS.61
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Good	7.5	2.4	1.9	0.01	LB21 IS.62
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Borderline	6.7	2.2	1.7	0.007	LB21 IS.63
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Borderline	5.9	2.1	1.7	0.007	LB21 IS.64
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Good	5.1	1.9	1.7	0.006	LB21 IS.65
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Good	6.5	2.6	1.6	0.007	LB21 IS.66
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Good	6.6	2.5	2.2	0.011	LB21 IS.67
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Borderline	6.6	2.1	2	0.009	LB21 IS.68
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Good	5.6	1.9	1.5	0.005	LB21 IS.69
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	Good	7.6	2.7	2.4	0.013	LB21 IS.70
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	6.7	2.5	1.7	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	6.3	2.4	2.1	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	5.9	2.3	1.5	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	5.8	2	2.1	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	6	2.3	2.2	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	6.4	2.7	2	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	6.3	2.4	1.7	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	6.3	1.9	1.7	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	6.5	2.5	2.1	-	-
Linbrig	13		1306 - 1424	Oat (*A. sativa*)	P2	-	7.1	2.2	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley twisted	P2	Borderline	5.2	3.3	2.7	0.012	DHS05 IS.1
Hallgarth St.	9	58	11th - 12th centuries	Barley twisted	P2	Borderline	6.1	3.5	2.9	0.016	DHS05 IS.2
Hallgarth St.	9	58	11th - 12th centuries	Barley straight	P2	Good	5.8	3.3	2.5	0.015	DHS05 IS.3
Hallgarth St.	9	58	11th - 12th centuries	Barley twisted	P2	Borderline	5.7	3.1	2.6	0.015	DHS05 IS.4
Hallgarth St.	9	58	11th - 12th centuries	Barley twisted	P2	Good	4.9	3	2.3	0.012	DHS05 IS.5
Hallgarth St.	9	58	11th - 12th centuries	Barley twisted	P2	Good	5.3	3	2.6	0.014	DHS05 IS.6
Hallgarth St.	9	58	11th - 12th centuries	Barley straight	P2	Borderline	4.7	3.1	2.3	0.013	DHS05 IS.7
Hallgarth St.	9	58	11th - 12th centuries	Barley straight	P2	Good	5.8	3.1	2.6	0.014	DHS05 IS.8
Hallgarth St.	9	58	11th - 12th centuries	Barley twisted	P2	Borderline	4.7	2.3	2.1	0.005	DHS05 IS.9
Hallgarth St.	9	58	11th - 12th centuries	Barley twisted	P2	Borderline	4.4	2.5	1.9	0.009	DHS05 IS.10
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	6.1	3.2	2.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	5.4	3.3	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	5.6	2.9	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.8	2.9	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.9	2.4	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	5	2.8	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	5.5	3	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	3.8	2.6	1.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.9	3.1	2.2	-	-

(cont.)

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	5	2.7	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.7	3.3	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	5.2	3.1	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.5	2.9	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.8	3	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.7	2.4	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.9	2.6	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4	2.7	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.8	3.1	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	4.1	2.3	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Barley	P3	-	3.6	3	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley straight	P2	Borderline	6.9	3.3	2.3	0.018	DHS05 IS.40
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley twisted	P2	Borderline	6.8	3.2	2.6	0.02	DHS05 IS.41
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley twisted	P2	Good	6.5	3.3	2.3	0.019	DHS05 IS.42
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley twisted	P2	Borderline	6.2	3.2	2.3	0.023	DHS05 IS.43
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley twisted	P2	Borderline	6.4	3.2	2.4	0.016	DHS05 IS.44
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley twisted	P2	Borderline	6.8	3.2	2.4	0.015	DHS05 IS.45
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley straight	P2	Good	5.7	3.1	2.3	0.017	DHS05 IS.46
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley straight	P2	Borderline	6.1	3.2	2.5	0.019	DHS05 IS.47
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley twisted	P2	Good	6.5	2.8	2.6	0.013	DHS05 IS.48
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley twisted	P2	Borderline	6.4	2.8	2.6	0.012	DHS05 IS.49
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.3	3	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.6	3.2	2.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7	3.3	2.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.2	2.8	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	2.8	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.6	2.8	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.1	2.6	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.5	3.1	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	2.9	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	2.9	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.7	3	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	2.8	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.8	2.6	1.8	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.5	3	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.5	3.1	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.2	3.1	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.8	3.2	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	2.9	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.6	3.1	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.7	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.1	3.1	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.5	3.1	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.8	2.7	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.3	3.1	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.3	2.4	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.2	3.2	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.1	2.8	1.8	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.4	2.8	1.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	2.8	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.3	3.4	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.4	2.9	2.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.6	2.7	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.4	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.1	3	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.7	2.9	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.3	2.9	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7	2.8	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.6	2.3	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.6	3	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.5	3	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	2.7	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.1	2.9	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5	2.6	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.6	2.4	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	2.8	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.4	3.4	2.8	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.5	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	2.6	1.8	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.8	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	3.1	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.1	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.2	3	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.6	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.9	2.7	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.7	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.6	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.1	2.7	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.3	2.8	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.3	2.6	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	3	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	7.1	2.8	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	2	1.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.3	2.9	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	3.1	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.8	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.2	2.6	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.1	2.4	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.4	3.1	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.3	2.5	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	3	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.1	2.6	1.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.7	2.6	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	3	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.9	2.9	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.2	2.6	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.1	3.1	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.7	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5	2.8	2.1	-	-

(cont.)

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.5	3.3	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.9	3.1	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.1	2.5	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.7	2	1.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.1	2.8	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.8	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	2.9	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.5	3	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.1	2.5	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.7	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5	2.6	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	2.7	2.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.2	2.4	1.8	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	3	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.6	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.3	2.6	1.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.9	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.7	2.8	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.2	2.3	1.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.2	2.7	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.8	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.2	3	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.2	2.4	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.2	2.4	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.7	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.5	2.9	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.3	2.8	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.3	2.7	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.6	3.3	2.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.6	2.8	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.3	3.1	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.6	2.6	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.3	3.2	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.1	2.5	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.8	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.9	2.1	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.8	2.6	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.9	2.4	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.1	2.7	1.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.6	2.4	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.3	3.2	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.8	2.5	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.4	2.8	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.4	2.5	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.3	2.8	1.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.9	3.1	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.7	2.5	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	2.9	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.6	2	1.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.8	2.5	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.6	2.8	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	3.3	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	3.1	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5	2.6	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.8	2.5	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.1	2.8	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.6	2.4	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	3	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.2	2.6	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.3	1.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.6	2.1	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.2	2.7	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.8	2.2	1.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.6	2.8	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.8	2.5	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.8	3.2	2.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.4	1.8	1.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.2	2.8	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.9	2.5	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.6	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6	2.8	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.1	2.7	2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.5	2.3	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.5	3	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.1	2.6	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	6.1	2.7	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.8	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.9	2.5	1.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.6	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.4	2.3	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.5	2.5	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.2	2.5	2.2	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.7	2.4	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	3.7	1.9	1.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.5	2.9	2.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.7	2.4	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5	2.4	1.8	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.9	2.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.7	2.7	2.6	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	5.3	2.5	2.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Hulled barley	P2	-	4.4	2.2	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	*A. strigosa*	P2	Borderline	5.1	1.3	1	0.004	DHS05 IS.11
Hallgarth St.	9	58	11th - 12th centuries	*A. strigosa*	P2	Borderline	7.2	1.8	1.2	0.009	DHS05 IS.12
Hallgarth St.	9	58	11th - 12th centuries	*A. strigosa*	P2	Good	7	1.9	1.6	0.009	DHS05 IS.13
Hallgarth St.	9	58	11th - 12th centuries	*A. strigosa*	P2	Borderline	6	1.4	1.2	0.005	DHS05 IS.14
Hallgarth St.	9	58	11th - 12th centuries	*A. strigosa*	P2	Borderline	5.5	1.5	1	0.005	DHS05 IS.15
Hallgarth St.	9	58	11th - 12th centuries	*A. strigosa*	P2	Borderline	4.3	1.7	1.7	0.004	DHS05 IS.16
Hallgarth St.	9	58	11th - 12th centuries	*A. strigosa*	P2	Good	4.4	1.3	1	0.004	DHS05 IS.17
Hallgarth St.	9	58	11th - 12th centuries	*A. strigosa*	P2	Borderline	4.3	1.2	0.8	0.002	DHS05 IS.18

(cont.)

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Hallgarth St.	9	58	11th - 12th centuries	*A. strigosa*	P2	Borderline	6.6	1.5	0.8	0.004	DHS05 IS.19
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Borderline	6.9	1.7	1.2	0.009	DHS05 IS.20
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Borderline	7.2	1.9	1.5	0.007	DHS05 IS.21
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Borderline	7.7	1.7	1.3	0.006	DHS05 IS.22
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Borderline	6.8	1.8	1.2	0.008	DHS05 IS.23
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Borderline	6.6	1.9	1.3	0.009	DHS05 IS.24
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Good	5.6	1.6	1	0.007	DHS05 IS.25
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Good	4.6	1.5	1.3	0.004	DHS05 IS.26
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Borderline	6.4	1.6	1.2	0.007	DHS05 IS.27
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Borderline	5.9	1.7	1.2	0.005	DHS05 IS.28
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	Borderline	7.2	1.6	1.1	0.006	DHS05 IS.29
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	-	6.6	1.9	1.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P2	-	7.2	2	1.7	-	
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P3	-	4.5	1.2	0.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P3	-	6.5	2.2	1.9	-	
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P3	-	6.4	2	1.9	-	-
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P3	-	6.8	2	1.8	-	
Hallgarth St.	9	58	11th - 12th centuries	*A. sativa*	P3	-	6.4	1.9	1.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Good	6.6	2.1	1.3	0.011	DHS05 IS.30
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Good	7.1	2	1.4	0.012	DHS05 IS.31
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Borderline	6.8	2	1.5	0.012	DHS05 IS.32
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Borderline	7.1	2	1.5	0.01	DHS05 IS.33
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Borderline	6.4	2	1.4	0.009	DHS05 IS.34
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Borderline	6.8	2.1	1.6	0.008	DHS05 IS.35
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Good	6.6	2.1	1.7	0.009	DHS05 IS.36
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Borderline	7.1	2.1	1.4	0.012	DHS05 IS.37
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Good	6.3	2	1.4	0.01	DHS05 IS.38
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	Borderline	6.5	2	1.2	0.01	DHS05 IS.39
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	-	6.7	2	1.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	-	7.1	2	1.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	-	6.1	2.2	1.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	-	6.9	2.1	1.7	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	-	6.8	2.1	1.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	-	6.5	2	1.1	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P3	-	7.3	2	1.5	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P3	-	7.3	2	1.4	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	-	7.1	2	1.3	-	-
Hallgarth St.	9	58	11th - 12th centuries	Oat	P2	-	6.4	2	1.5	-	-
Lightpipe Farm	15	35		Oat	P2	Good	6.2	2.5	2.2	0.009	LPL21 IS.1
Lightpipe Farm	15	35		Oat	P2	Borderline	6.7	3.2	2.4	0.01	LPL21 IS.2
Lightpipe Farm	15	35		Oat	P2	Borderline	6.1	2.1	2	0.012	LPL21 IS.3
Lightpipe Farm	15	35		Oat	P2	Good	6.8	2.3	2	0.01	LPL21 IS.4
Lightpipe Farm	15	35		Oat	P2	Good	6.3	2.9	2	0.008	LPL21 IS.5
Lightpipe Farm	15	35		Oat	P2	Good	6.5	2.1	1.6	0.009	LPL21 IS.6
Lightpipe Farm	15	35		Oat	P2	Borderline	6.3	2.5	2	0.009	LPL21 IS.7
Lightpipe Farm	15	35		Oat	P2	Borderline	6.4	2.3	1.8	0.007	LPL21 IS.8
Lightpipe Farm	15	35		Oat	P2	Good	6.3	2	1.9	0.005	LPL21 IS.9
Lightpipe Farm	15	35		Oat	P2	Good	5.2	2.2	1.9	0.004	LPL21 IS.10
Lightpipe Farm	15	35		Oat	P3	-	6.8	2.2	2.4	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.2	2.2	2.1	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.3	2.2	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	7	2.5	2.3	-	-
Lightpipe Farm	15	35		Oat	P3	-	4.2	2.1	1.6	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.2	2.1	1.5	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.2	2.1	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.1	2.3	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.3	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.4	2.3	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.6	2.2	2.2	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.3	1.7	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.3	2.9	2.2	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.5	2.1	-	-
Lightpipe Farm	15	35		Oat	P3	-	7.1	2.2	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.3	2.2	1.6	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.6	2.2	1.7	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.1	2.1	1.7	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.4	2.1	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.5	2.7	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.1	1.6	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.1	2.8	2.1	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.2	1.6	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.2	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.9	2.5	2.4	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.3	1.7	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.4	2.5	2.2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.3	2.2	2.2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.5	2.2	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.2	2.1	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.4	2	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.2	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.6	2.5	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.5	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	7	2.5	2.2	-	-
Lightpipe Farm	15	35		Oat	P3	-	7.1	2.6	2.2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.3	2.1	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.6	2.5	2.2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.1	2.3	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.4	1.6	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.5	2	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.4	2.4	2.3	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.4	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.8	2.1	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.2	1.6	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.4	2.5	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.2	2.2	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.8	2.2	1.6	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.3	2.1	2.1	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.6	2.8	1.7	-	-

(cont.)

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Lightpipe Farm	15	35		Oat	P3	-	5.5	1.8	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.4	2.3	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.3	1.5	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.1	2.1	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.7	2.3	2.1	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.8	2.2	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.7	2.3	2.2	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.7	2.2	1.7	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.2	2.1	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	4.9	2	1.3	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.2	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.2	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2	2.1	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.8	2.3	2.1	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.8	2.2	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	4.7	2	1.6	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.2	2.4	2.3	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.3	1.5	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.2	2.2	2.2	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.7	2.1	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.3	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.8	2	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	4.6	2	1.7	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.7	2.3	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	6	2.2	1.9	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.8	2.3	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.3	2.2	1.8	-	-
Lightpipe Farm	15	35		Oat	P3	-	5.9	2.4	2	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.1	2	1.7	-	-
Lightpipe Farm	15	35		Oat	P3	-	6.3	2	1.7	-	-
Lightpipe Farm	15	35		*A. strigosa*	P2	Good	6.1	1.8	1.7	0.006	LPL21 IS.11
Lightpipe Farm	15	35		*A. strigosa*	P2	Good	6.2	1.9	1.5	0.009	LPL21 IS.12
Lightpipe Farm	15	35		*A. strigosa*	P2	Good	5.8	1.9	1.3	0.007	LPL21 IS.13
Lightpipe Farm	15	35		*A. strigosa*	P3	Borderline	5.5	1.8	1.1	0.002	LPL21 IS.14
Lightpipe Farm	15	35		*A. strigosa*	P3	Borderline	5.8	2	2	0.005	LPL21 IS.15
Lightpipe Farm	15	35		*A. strigosa*	P3	Bad	7.5	1.8	1.5	0.006	LPL21 IS.16
Lightpipe Farm	15	35		*A. strigosa*	P3	Good	7.3	2.3	1.8	0.008	LPL21 IS.17
Lightpipe Farm	15	35		*A. strigosa*	P3	Borderline	6	2.2	2	0.007	LPL21 IS.18
Lightpipe Farm	15	35		*A. sativa*	P3	Borderline	5.8	2.1	2.1	0.006	LPL21 IS.19
Lightpipe Farm	15	35		*A. sativa*	P3	Borderline	6.8	2.5	2.1	0.008	LPL21 IS.20
Lightpipe Farm	15	35		*A. sativa*	P3	Borderline	6.4	2.3	1.9	0.007	LPL21 IS.21
Lightpipe Farm	15	35		*A. sativa*	P3	Good	5.8	2.2	2.1	0.006	LPL21 IS.22
Lightpipe Farm	15	35		*A. sativa*	P3	Bad	5.6	2	1.9	0.003	LPL21 IS.23
Lightpipe Farm	15	35		*A. sativa*	P3	Bad	6	2.4	2.1	0.007	LPL21 IS.24
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Good	6.5	2.6	2.2	0.013	BED21 IS.1
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Borderline	6.5	2.4	1.9	0.012	BED21 IS.2
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Borderline	6.2	2.3	1.8	0.012	BED21 IS.3
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Good	6.5	2.3	1.8	0.011	BED21 IS.4
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Borderline	7	2.6	2.5	0.012	BED21 IS.5
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Good	5.7	2.2	1.6	0.009	BED21 IS.6
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Good	6.2	2.3	1.8	0.009	BED21 IS.7
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Good	6.6	2.5	2	0.010	BED21 IS.8
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Good	6.3	2.1	1.6	0.011	BED21 IS.9
Belsay Hall	1	2449	1168 - 1265	Oat	P2	Borderline	6	2	1.4	0.007	BED21 IS.10
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.6	2.4	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.9	2.4	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.7	2.4	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.2	2.2	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.1	2.3	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	7	2.3	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.7	2.5	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.6	2.1	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.4	2.1	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.5	2.1	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.9	2.4	2.2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.5	2.1	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.7	2.8	2.2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.9	2.5	2.4	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.3	2.3	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.4	2.3	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.7	2.4	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6	2.3	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.4	2.2	2.2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.4	2.4	2.1	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	4.9	2.1	1.6	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.7	2.5	2.1	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.3	2.2	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.4	2.1	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.1	2	1.5	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.2	2.5	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	7	2	1.5	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6	2.7	2.2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.9	2	1.3	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.5	2.6	2.2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.7	2.3	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.1	2.2	1.5	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.4	2.1	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	7	2	1.5	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.6	2.1	1.6	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.3	2.2	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6	2.3	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5	2.1	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.3	2.2	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.3	2.1	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.5	2.3	2.2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.5	2.3	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.6	2.2	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.2	2	1.9	-	-

(cont.)

Site	Sample	Context	Period	Grain ID	Preservation (external)	Preservation (internal)	Length (X-mm)	Width (Y-mm)	Depth (Z-mm)	Mass (mg)	SIBL ID
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.9	2.2	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.7	2.4	1.6	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.3	2.1	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.9	2.2	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.4	2.2	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.6	2.3	1.5	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.5	2.1	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6	2	1.5	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.5	2.2	1.6	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6	2.1	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5	2.1	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.1	2.1	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.4	2.1	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.3	2	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	7	2.5	2.3	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.2	2.1	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.6	2.4	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	4.6	2.3	1.5	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.1	2.2	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	7.1	2.4	2.3	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.7	2.5	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	7.1	2.5	2.3	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.6	2.1	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.9	2.3	2.1	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.6	2.4	2.2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.9	2.3	1.6	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.8	2.4	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.5	2.3	2	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.8	2.1	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.3	2.2	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.2	2.2	2.3	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6	2.2	2.1	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.1	2.3	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.9	2	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.3	2.2	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.7	2	1.8	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	4.9	2	1.9	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	6.8	2.2	1.7	-	-
Belsay Hall	1	2449	1168 - 1265	Oat	P2	-	5.9	2.2	1.6	-	-
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Good	5	1.8	1.8	0.006	BED21 IS.11
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Good	4.8	1.4	1.3	0.004	BED21 IS.12
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Good	5.4	1.8	1.7	0.004	BED21 IS.13
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Borderline	5.2	1.7	1.7	0.003	BED21 IS.14
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Good	4.8	1.5	1.4	0.004	BED21 IS.15
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Good	5.5	1.5	1.3	0.006	BED21 IS.16
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Good	5.3	1.7	1.4	0.003	BED21 IS.17
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Borderline	5.6	1.9	1.7	0.005	BED21 IS.18
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Borderline	5.1	1.5	1.7	0.004	BED21 IS.19
Belsay Hall	1	2449	1168 - 1265	*A.strigosa*	P2	Good	5.5	1.7	1.6	0.006	BED21 IS.20
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Good	6.7	2.3	1.8	0.008	BED21 IS.21
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Borderline	6	2.1	1.8	0.005	BED21 IS.22
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Borderline	4.8	1.9	1.6	0.006	BED21 IS.23
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Good	5.8	2.1	1.7	0.009	BED21 IS.24
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Borderline	7	2.2	1.9	0.008	BED21 IS.25
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Borderline	5.7	2.1	1.7	0.006	BED21 IS.26
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Borderline	5.8	2.2	1.9	0.005	BED21 IS.27
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Good	5.3	1.9	1.5	0.007	BED21 IS.28
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Good	5.7	1.9	1.7	0.005	BED21 IS.29
Belsay Hall	1	2449	1168 - 1265	*A.sativa*	P2	Borderline	6.7	2.2	2.2	0.005	BED21 IS.30