2 Lessons from Laxton, Highgrove and Lorsch: Building Arable Weed-Based Models for the Investigation of Early Medieval Agriculture in England

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Introduction

Arable weed ecology provides a means of comparing farming systems in terms of crop growing conditions. A useful 'short-cut' to summarizing key ecological characteristics of arable weeds is to measure their functional ecological traits. These are morphological or behavioural characteristics that have been shown experimentally to predict weed species' potential in relation to major habitat variables. Thus, for example, specific leaf area (the ratio of leaf area to leaf dry weight) and related traits reflect growth rate, and hence species' potential to flourish in fertile soil conditions (Díaz et al., 2004; 2016; Wright et al., 2004; Reich, 2014).

The approach of estimating species' potential by measuring functional traits, known as functional ecology, also lends itself to framing comparisons between present and past farming systems. The weed floras of present-day crop fields can be recorded through survey, while those from past agricultural systems are attested through archaeobotanical assemblages of crops and their associated weeds. The advantage of using functional ecology as the basis of comparison between weed floras is twofold: it enables comparison of weed floras (e.g., modern and ancient) that have few or no species in common;

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and the 'functional' nature of the traits means that similarity or difference in weed floras can be assessed in terms of underlying ecological processes. In other words, use of functional ecology makes it possible to set up a 'relational analogy' (Wylie, 1985) between modern and ancient weed communities: assessments of similarity (or difference) are based on an understanding of relevant causal (here, ecological) mechanisms. The aim of such comparisons is therefore *not* to stumble upon an exact modern 'match' for ancient weed floras and farming systems, but rather to identify meaningful ecological *contrasts*, as a means of reconstructing past land use systems that may have no close modern analogue (Charles et al., 2002; Jones, 2002; Bogaard, 2004, 8).

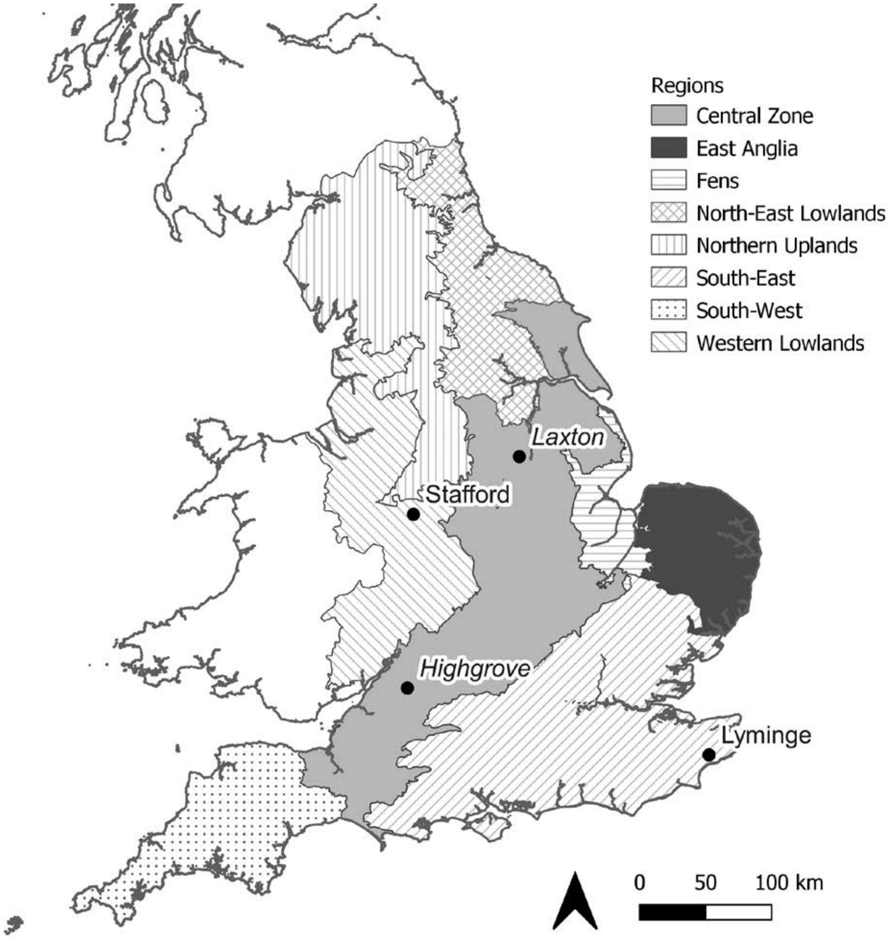
In this paper we consider the usefulness of functional weed ecology to shed light on early medieval agriculture in England by framing comparisons between archaeobotanical weed assemblages and present-day farming systems. We do this in two steps.

First, we consider a previously published weed ecological model for distinguishing 'low-input' and 'high-input' cereal production systems on the basis of a set of functional ecological traits that reflect species' potential in relation to fertility and disturbance (Bogaard et al., 2016). 'Disturbance' in plant ecology refers to the destruction of plant biomass, for example by mechanical perturbation of the soil, which in arable fields is effected through tillage and weeding (Grime et al., 1988). The weed ecological model was derived to discriminate between low-input production of cereals in present-day Haute Provence, south-eastern France (e.g., little/no manuring or hand-weeding) and high-input cultivation in Asturias, northern Spain (e.g., intensive manuring and hand-weeding) on the basis of such traits (Bogaard et al., 2016). The model provides an axis of combined fertility and disturbance to assess the labour intensity of past farming systems. We review a worked example of the application of this model to an early medieval archaeobotanical assemblage, from Stafford in the West Midlands of England (Hamerow et al., 2020), dating primarily from the late ninth to mid-twelfth centuries, and then consider a second case study, that of sixth- to twelfth-century Lyminge, Kent (Thomas, 2013; Thomas and Knox, 2013). We use these assemblages to illustrate how application of the Provence/Asturias 'intensity model' relates to the general hypothesis of extensification in early medieval England: that is, expanding cereal production with diminishing inputs per unit area (Hamerow, this volume).

While the 'intensity model' provides a means of situating early medieval arable weed assemblages on an input/intensity spectrum, it combines traits relating to fertility *and* disturbance, since this combination achieved the best discrimination of low-input cereal production in Haute Provence from high-input cultivation in Asturias. For the purposes of understanding developments in early medieval farming, however, it is desirable also to consider soil disturbance separately. The hypothesized nature of early medieval husbandry is that it achieved 'extensification' in part through use of the mouldboard plough, which enabled expansion onto heavier soils and promoted effective tillage by turning over the soil (Fussell, 1966; Hamerow, this volume). The tillage regime in Haute Provence incorporated spring harrowing, and the disturbance contrast between the Haute Provence and Asturias regimes was not sufficiently strong to construct a model on the basis of disturbance traits alone (Bogaard et al., 2016). The second step in our functional weed analysis, therefore, was to construct a new model on the basis of two regimes that differed *primarily* in terms of disturbance, in order to monitor disturbance levels in early medieval fields. We did this using relevant ecological traits of weed floras surveyed in two present-day English cereal production systems: the persisting open-field system at Laxton, Nottinghamshire, and organic cereal fields at Highgrove's Duchy Home Farm, Gloucestershire (Figure 10; Plate I).

The well-known open-field system at Laxton (Orwin and Orwin, 1938) as it exists today is a conventional farming system incorporating herbicides and thus lacking a fully expressed arable weed flora. Alongside arable fields, however, the open-field landscape incorporates substantial meadow verges, known locally as 'sykes', that have remained unploughed for centuries, and are not sprayed with herbicides (Plate Ia). While the 'sykes' are thus outside the arable regime per se, they offer valuable evidence of the flora that develops in the absence of substantial disturbance from ploughing. The 'sykes' can be contrasted with the arable weed floras that persist in unsprayed arable field edges at Laxton (Hamerow et al., 2020). Highgrove's Duchy Home Farm established organic cereal production near Tetbury, Gloucestershire in 1985. The farm offers a good sample of cereal field weed floras developed under moderate management intensity (Plate Ib), supplementing the fragmentary arable field weed flora at Laxton. Here we combine the botanical survey and ecological trait data for the Laxton 'sykes' and fields with data from the Highgrove fields to produce a new model for discriminating between low- and high-disturbance conditions.

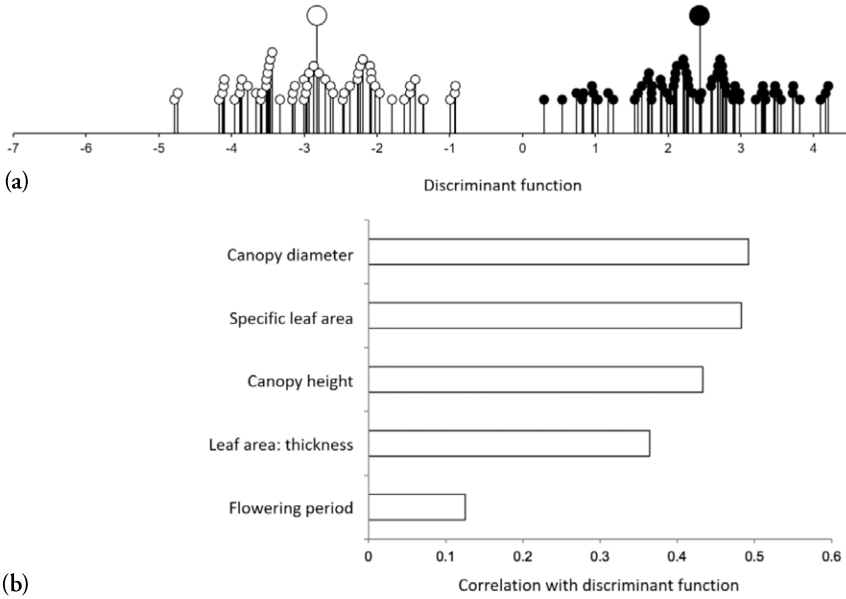
Before applying the Laxton-Highgrove model to archaeobotanical data, we take the additional step of introducing a comparison with a unique weed dataset from experimental mouldboard ploughing at the Lauresham Open-Air Laboratory for Experimental Archaeology



10 Map showing the locations of the two present-day English cereal production systems considered here (italics), and the two archaeological case studies. Regional divisions by Rippon et al. (2015). Map created with QGIS (http://www.qgis.org; accessed 08/03/2022).

in Lorsch (Kropp, this volume). In recent years, the Lauresham team has established a three-field rotation system (an autumn cereal followed by a spring cereal and then a fallow year) using (re) constructed early medieval mouldboard tillage powered by oxen. Surveys of the weed floras growing on three main experimental ridge-and-furrow fields (north-east, south and north-west) at Lorsch in 2019 and 2020 (Sonnberger, 2020; see also Kropp, this volume) provide a key opportunity to assess disturbance levels achieved with the mouldboard plough.

Finally, using the archaeobotanical examples of Stafford and Lyminge, we assess arable disturbance levels and consider to what extent use of the mouldboard plough successfully maintained – or even enhanced – disturbance levels as part of early medieval 'cerealization'.



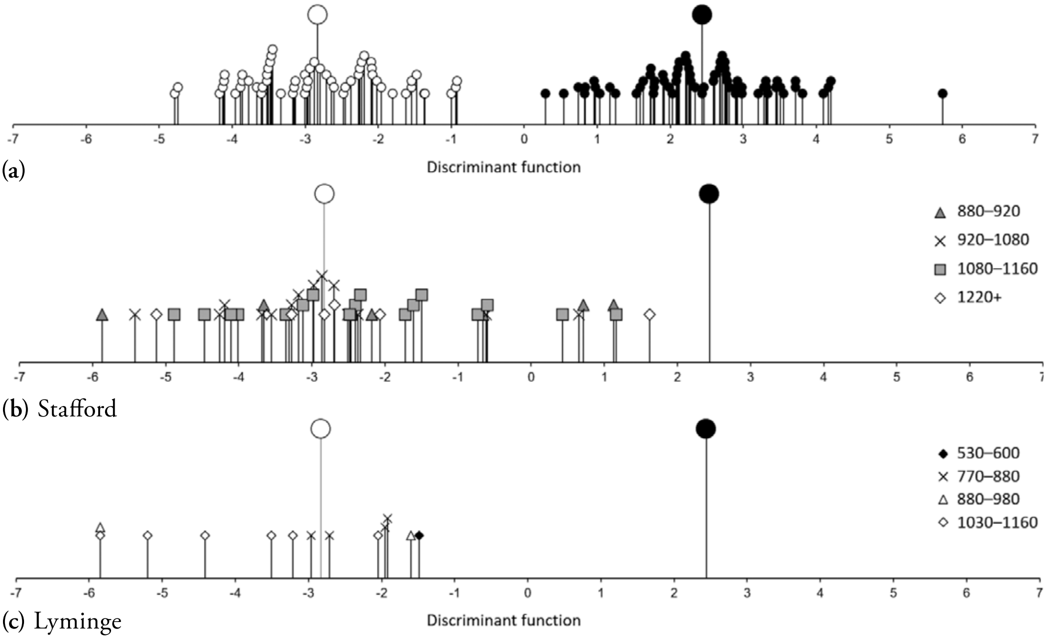
11a–b (a) The relationship of Haute Provence fields (open circles) and Asturias fields (filled circles) to the discriminant function extracted to distinguish these two groups (larger symbols indicate group centroids); (b) correlations between the functional attribute scores used as discriminating variables and the discriminant function.

A model for assessing the labour-intensity of cultivation: Haute Provence and Asturias

A functional ecological study of weed floras developed under traditional agricultural regimes in Asturias and Haute Provence successfully discriminated between high- and low-input farming methods, respectively (Bogaard et al., 2016). This separation was achieved using discriminant analysis on the basis of five functional traits of weed species that predict their response to soil fertility (e.g., manuring) or disturbance (tillage and weeding): specific leaf area (leaf area/leaf dry weight), canopy height and diameter, the ratio of leaf area per node to fresh leaf thickness, and flowering duration. Figure 11 shows the separation of surveyed fields in Asturias and Provence along the discriminant function, and the functional traits of weed species used as discriminating variables. This analysis was conducted on the basis of species' presence/absence per field (rather than frequency in quadrats), making the model applicable to archaeobotanical weed data (Bogaard et al., 2016).

Application of the intensity model: Stafford and Lyminge

In order to assess similarity to the modern high- versus low-input regimes, the 'intensity model' was applied to archaeobotanical weed data from Stafford, as set out by Hamerow et al. (2020). Stafford, in



(a)

(b) Stafford

(c) Lyminge

12a–c (a) The relationship of the modern fields in Haute Provence and Asturias to the discriminant function; the relationship of archaeobotanical samples from (b) Stafford and (c) Lyminge to the discriminant function (larger symbols indicate centroids for the modern groups).

the West Midlands of England, was established as a *burh* (fortified settlement) in 913, and later developed as a town at the intersection of land- and river-based transport routes; its hinterland, at the interface of lighter river terrace soils and heavier clays, provided a setting well suited to crop production (Figure 10; Carver, 2010; Hamerow et al., 2020, 587).

Archaeobotanical samples from Stafford containing at least ten seeds of weed taxa identified to species level were entered into the classification phase of the discriminant analysis, as unknown cases. The results (Figure 12b) show that late ninth- to early tenth-century samples have variable scores on the discriminant function, but from the early tenth century onwards, the Stafford samples increasingly conform to 'low-input' growing conditions. Thus, the great majority of cereals benefited from little to no manuring or hand-weeding from the early tenth century. These results, combined with palynological evidence for largely open, arable landscapes around Stafford through this period (Hamerow et al., 2020), suggest that cereal cultivation featured low-input management within an extensive, large-scale system.

A second case study, that of Lyminge, opens another 'window' onto the extensification process, in a very different setting. Lyminge lies in south-east Kent (Figure 10), on chalk bedrock overlain in places by silts, clays, sands and gravels (McKerracher, 2017, 130). The archaeobotanical assemblage from Lyminge dates from the sixth through to the twelfth century, offering a sequence that begins much earlier than that at Stafford (McKerracher, 2017). Following the establishment of a royal centre/hall complex at Lyminge in the sixth to early seventh century, a royal monastery existed from the mid-seventh to late ninth century (Thomas, 2013). Lyminge was subsequently an archepiscopal possession of Canterbury through the tenth to twelfth centuries (Thomas and Knox, 2013). A seventh-century plough coulter excavated at Lyminge – the earliest known example from Anglo-Saxon England – raises the possibility of precocious adoption of mouldboard plough technology in a high-status context under Frankish influence (Thomas et al., 2016). The actual implication of this find for agricultural practice, however, has as yet remained unclear.

The assemblage of 'weed-rich' archaeobotanical samples at Lyminge (containing at least ten weed seeds identified to species level) is smaller than that at Stafford, but their distribution along the discriminant function (Figure 12c) has interesting implications. First, *all* of the Lyminge samples fall at the low-input end of the spectrum, from the sixth century onwards, in contrast to Stafford, where a 'tail' of high-input samples persists throughout the sequence. Second, the chronological distribution of Lyminge samples on the discriminant function suggests progressively lower input conditions through time: the single sixth-century sample has the highest score, while the later eighth- to ninth-century samples mostly have higher scores than those of eleventh- to twelfth-century date. In sum, the results from Lyminge suggest that its farming system already 'began' as a low-input regime, but underwent further extensification through time, paralleling developments at Stafford.

A model for assessing soil disturbance levels: Laxton and Highgrove

A second weed-based model, focused on contrasting mechanical soil disturbance levels, enables us to factor out the influence of soil fertility and to build a complementary perspective on tillage regimes, especially the use of the mouldboard plough. This model is based on a combination of two modern botanical survey datasets: from Laxton and Highgrove's Duchy Home Farm (Figure 10; Plate I).

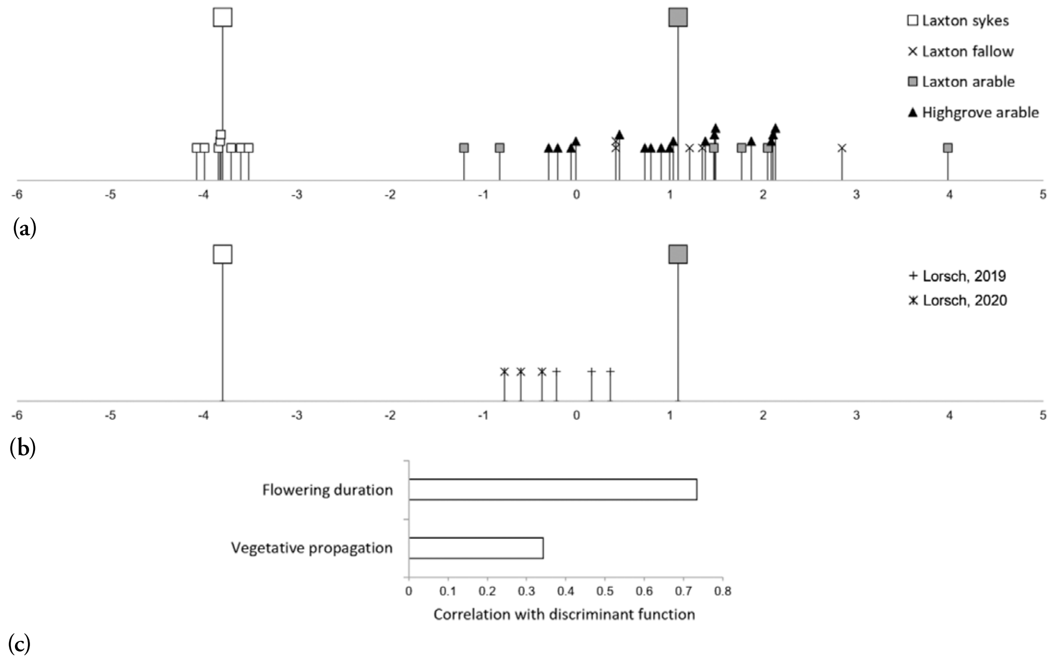
Botanical survey at Laxton in June 2018 encompassed three types of site/habitat: (a) eight unploughed but periodically grazed and annually cut 'sykes' (hay meadow areas, unsprayed by herbicides, between or on the edges of the open fields); (b) unsprayed six-metre edge strips of six cereal fields; and (c) five fallow fields – i.e., in the third, fallow year of the rotation scheme – that had not recently been sprayed.

At Highgrove in June 2019 we surveyed 17 organic cereal fields managed as part of a rotation system: typically two to three years of ley (grass/clover) followed by one year each of bread wheat, oats, barley and rye. The cereals notably included tall, locally adapted populations of 'heritage' rye and wheat developed by John Letts that have been grown at Highgrove for over ten years; and a similarly unimproved, 'traditional' landrace of barley.[1]

In each field, the weed species present were recorded in each of five one-metre-square quadrats distributed along a transect from one end of the field to the other, as in other recent studies (Bogaard et al., 2018). For the purposes of archaeobotanical application, the data were converted to a semi-quantitative form of weed species' presence/absence per field. The average score of each functional trait per field was calculated as the sum of attribute values for the species in the cultivated field divided by the number of species in each field. IBM® SPSS® (Statistical Package for the Social Sciences) version 27 was used to perform discriminant analysis, using the 'leave one out' option. The success of the discriminant analysis was measured in terms of the percentage of fields correctly reclassified as 'low-disturbance' or 'high-disturbance', using the discriminant function extracted in the analysis.

Discriminant analysis was used to separate the Laxton 'sykes', on the one hand, from the Laxton and Highgrove arable fields (including those under fallow at Laxton), on the other (Figure 13a). This successful discrimination (94 per cent correctly reclassified) was achieved on the basis of two functional attributes relating to species' tolerance of mechanical disturbance: flowering duration (which patterns with germination time, and hence the ability of seeds to germinate following a disturbance event) and (for perennials only) vegetative propagation, i.e., the ability to regenerate from fragments of root/stolon/rhizome following disturbance (Figure 13a, c). This model is similar to that described by Hamerow et al. (2020) but is more robust in that it incorporates a larger set of fields, including those at Highgrove.

1 A landrace is a crop population adapted to a specific local environment. The terms 'heritage', 'traditional' and 'unimproved' highlight the contrast between these crops and modern commercial monocultures which do not adapt to local environmental conditions.



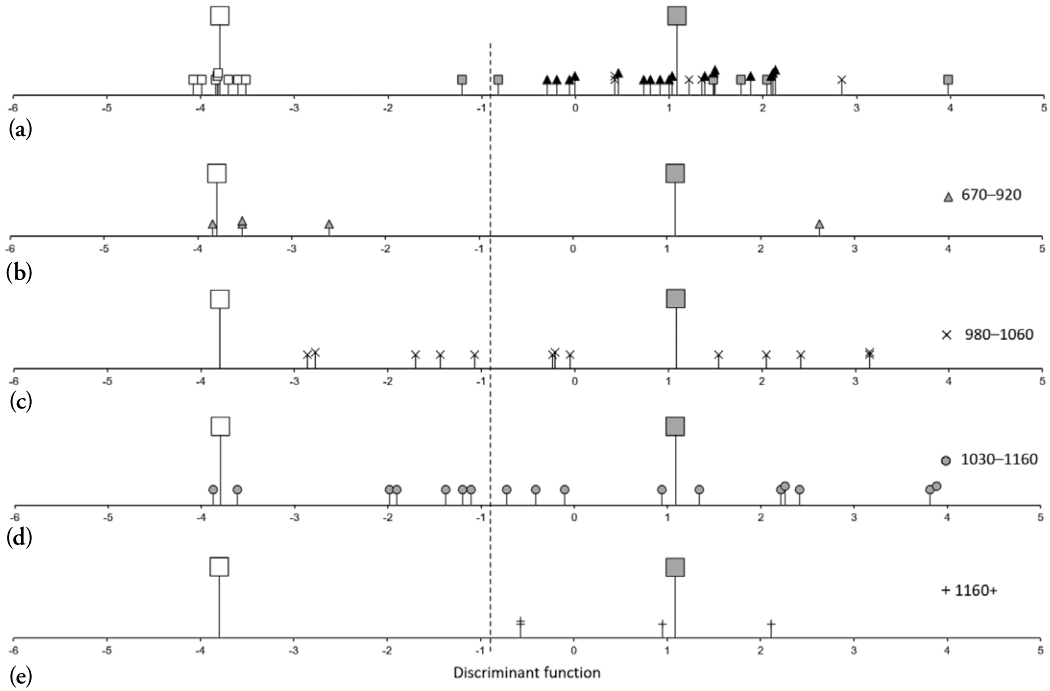
13a–c (a) The relationship of the Laxton sykes (open squares) and arable fields at Laxton and Highgrove (other symbols) to the discriminant function extracted to distinguish these two groups (larger symbols indicate group centroids); (b) the relationship of the Lorsch mouldboard-ploughed fields to the discriminant function; (c) correlations between the functional traits used as discriminating variables and the discriminant function.

Application of the disturbance model: experimental mouldboard ploughing at Lorsch

Botanical survey of three experimental ridge-and-furrow fields was conducted at Lorsch in June 2019 and June 2020 (Sonnberger, 2020; see also Kropp, in this volume). The lists of weed species present in each field at survey time were entered into the classification phase of the discriminant analysis, as unknown cases. The discriminant scores of the Lorsch plots (Figure 13b) place them within the arable field range. Relative to the tractor-ploughed fields at Laxton and Highgrove, the Lorsch fields fall at the lower end of the arable group. Lorsch therefore offers a plausible baseline of disturbance levels to be expected under effective mouldboard ploughing.

Application of the disturbance model: Stafford and Lyminge

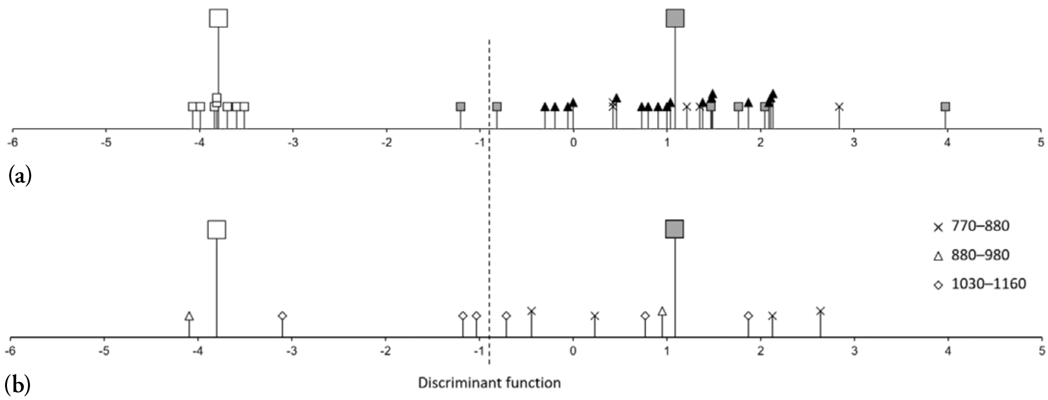
Archaeobotanical samples from Stafford containing at least ten seeds of weed taxa identified to species level were entered into the classification phase of the discriminant analysis, as unknown cases. As observed in a previous application of the Laxton-only disturbance model to the Stafford data (Hamerow et al., 2020), the discriminant scores of the Stafford samples, organized by phase (Figure 14a–e), show an increasing tendency through time towards more disturbed



14a–e (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; (b–e) the relationship of archaeobotanical samples from Stafford to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

conditions resembling the modern arable fields. None of the samples dating to the twelfth century or later resembles the undisturbed grassland of the 'sykes', whereas in earlier phases some samples were more similar to the sykes, perhaps because they represent the intermittent cultivation of land normally used for pasture (see Hooke, 1981, 207) or the interface of arable and grassland. The implication is that, *within* the extensification process, arable fields at Stafford were more consistently and comprehensively disturbed from the twelfth century onwards than in earlier periods. This observation is consistent with a more systematic use of the mouldboard plough in this final phase, when all cereal farming apparently took place in heavily disturbed conditions. The plausibility of this interpretation is supported by the 'Lorsch baseline' (the dotted line in Figure 14), which suggests the minimal discriminant scores and disturbance levels to be expected under effective mouldboard ploughing.

Archaeobotanical samples from Lyminge containing at least ten seeds of weed taxa identified to species level were similarly entered into the classification phase of the discriminant analysis, as unknown cases. In addition, samples lacking seeds of perennial weeds were excluded, since one of the functional traits used as a discriminating variable – vegetative propagation – only applies to



15a–b (a) The relationship of Laxton sykes versus Laxton and Highgrove arable fields to the discriminant function; (b) the relationship of archaeobotanical samples from Lyminge to the discriminant function (larger symbols indicate centroids for the modern groups). The dotted line represents the 'Lorsch baseline', the minimum discriminant score to be expected under effective mouldboard ploughing.

perennials.[2] The results (Figure 15) show that the earliest eligible samples (of late eighth- to late ninth-century date) all fall at the arable/high-disturbance end of the spectrum, and above the 'Lorsch baseline'. In disturbance terms, this phase at Lyminge, contemporary with the royal monastery, resembles the samples of twelfth-century and later date at Stafford, and is consistent with mouldboard ploughing. Later phases at Lyminge, when it was an archepiscopal possession of Canterbury, are more variable in terms of disturbance, though most are more or less comparable with disturbance levels under mouldboard ploughing. We consider the implications of these findings further below.

Discussion: interpreting the results from Stafford and Lyminge

The application of weed-based models, one focused on intensity (high versus low inputs, combining fertility and disturbance) and one on disturbance levels only (contrasting unploughed meadow with annually tilled arable), to medieval archaeobotanical assemblages from Stafford and Lyminge has revealed similarities as well as differences between the two archaeological case studies. Taking the similarities first, application of the intensity model suggests that cereal production at both Stafford and Lyminge reflects a general process of 'cerealization' through increasingly extensive farming, with low inputs per unit area. Within this trend, there is subtle differentiation between the two sites: whereas the Stafford results include a minor proportion of relatively high-input (presumably infield) cereal production throughout the late ninth- to twelfth-century and later

2 At Stafford, this step did not exclude any samples since all contained some perennials.

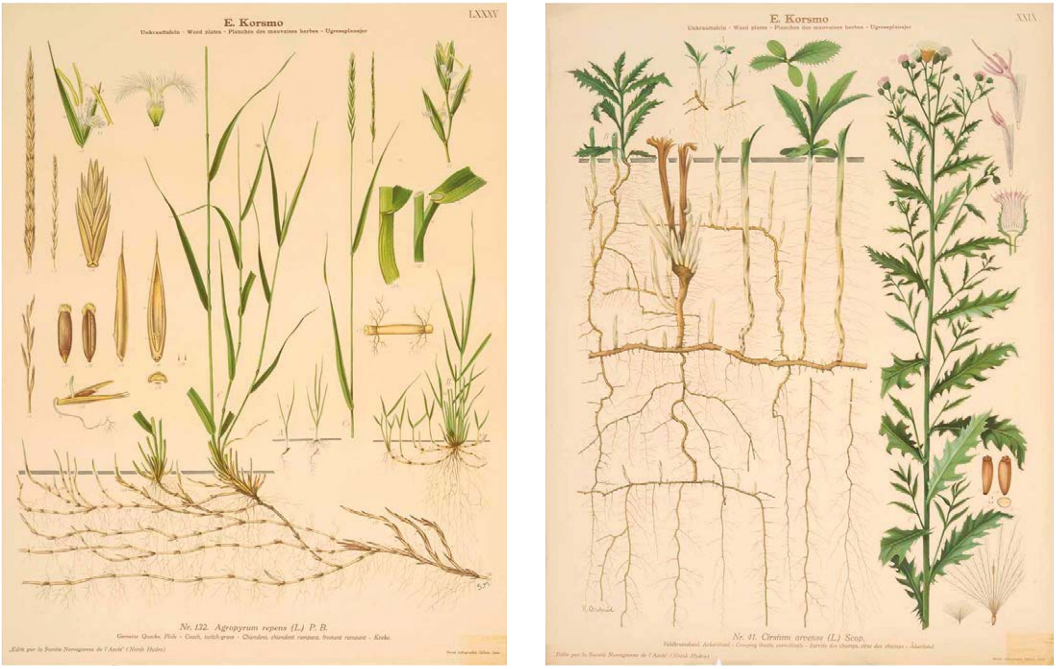
sequence, at Lyminge the weed signal is distinctively 'low-input' from the sixth century onwards, without a 'tail' of higher-input samples.

Application of the disturbance model also reveals some divergence between the two sites. The heavier clay soils at Stafford were effectively disturbed to levels comparable with modern arable fields from the twelfth century onwards, probably reflecting pervasive use of the mouldboard plough at this time. At Lyminge, by contrast, high disturbance comparable with modern annually cultivated arable and mouldboard ploughing is apparent much earlier, from the late eighth century.

The seventh-century coulter discovered at Lyminge (Thomas et al., 2016) indicates that the mouldboard plough could have been in use here from the beginning of the sequence reflected in the archaeobotanical samples classified by the disturbance model. The results of the application of the disturbance model to experimental mouldboard-ploughed fields at Lorsch, on the one hand, and to the Lyminge archaeobotanical samples, on the other, support the inference that the coulter was a powerfully symbolic object in part because it reflected actual agricultural practice (Holmes, this volume).

It appears that early medieval farmers achieved levels of mechanical soil disturbance comparable to the modern tractor-ploughed arable fields at Laxton and Highgrove, and above the 'mouldboard baseline' provided by Lorsch. This similarity, however, may obscure differences in soil conditions and agricultural practice. Laxton is surrounded by heavy clay soils, while those at Highgrove are more variable but include very heavy clays; the soils around Lyminge were chalk-based and hence lighter to work. Another difference between modern and ancient practice may be how many times fallow fields in the rotation were ploughed. Nowadays the fallow in Laxton is ploughed only once, in March, for ground-nesting birds, in accordance with Natural England's Higher Level Stewardship scheme. In the early twentieth century, in the absence of herbicides, the fallow was ploughed up to six times in summer to control weeds (Haigh, 2016, 16). Repeated ploughing discouraged some weeds but not others; one Laxton farmer recalled that the roots (rhizomes) of twitch or couch grass (*Elymus repens* (L.) Gould; Figure 16a) were particularly troublesome, being 'propagated rather than killed by ploughing' (Allison et al., 2017, 109). This capability of certain perennial weeds to regenerate from fragments of root/rhizome/stolon is exactly what we seek to capture by including that functional trait in the disturbance model (Figure 13).

It is possible that early medieval farmers at Stafford and Lyminge ploughed multiple times in the fallow year to control weeds, maintaining high levels of disturbance. Experimental farming at



16a–b (a) Couch grass (*Elymus repens* (L.) Gould) and (b) creeping thistle (*Cirsium arvense* (L.) Scop.), showing in each case rhizomes that readily regenerate when fragmented by ploughing. Illustrations from Korsmo, 1934, obtained from www.plantillustrations.org (accessed 26/07/21). Images are in public domain, reproduced under Creative Commons Licence. https://creativecommons.org (accessed 26/07/2021).

Lorsch includes mouldboard ploughing a minimum of two times in the fallow year, using a reduced furrow depth. That medieval farmers did seek to plough fallow multiple times to control weed levels is suggested by Walter of Henley's 'Husbandry', written 1276–90. In a section headed, 'To free lands from too much water', he recommended that the fallow field be ploughed twice, in April and again after midsummer (St John's Day) and justified the timing of the second ploughing as follows: 'Let your land be cleaned and weeded after St John's Day; before that is not a good time. If you cut thistles fifteen days or eight before St John's Day, for each one will come up two or three' (Cunningham and Lamond, 1890).

The timing of ploughing after midsummer echoes early twentieth-century practice in Laxton of ploughing multiple times through July (Haigh, 2016, 14), as does a particular concern with thistles (Allison et al., 2017, 106). Like twitch or couch grass mentioned above, creeping thistle (*Cirsium arvense* (L.) Scop.) has rhizomes that readily regenerate when fragmented by ploughing (Figure 16b). The instruction to plough after St John's Day, the driest part of the summer, suggests an attempt to minimize the probability of any rhizome fragment detached by the plough producing roots and subsequently establishing into a new plant.

A further possible contrast between ancient and modern practice is two- versus three-course rotation. Evaluation of these two rotation scenarios is beyond the scope of this paper (Schroeder, this volume; Hamerow et al., in prep.), but it stands to reason that a two-course rotation, with repeatedly ploughed fallow every *second* year (rather than every third), would result in more frequent ploughing events (cf. Campbell and Robinson, 2010). Two-course rotation may help to explain how early medieval farmers achieved high levels of disturbance comparable to annual cultivation with modern tractor ploughing and exceeding the Lorsch baseline.

A more general inference, stemming from application of both intensity and disturbance models to Stafford and Lyminge is that, within the process of 'cerealization through extensification', high disturbance levels were frequently maintained. This finding underlines the distinctiveness of early medieval farming, which, on the one hand, suffered from diminishing inputs in terms of fertility while, on the other, achieving remarkable levels of weed control through mouldboard tillage. This 'decoupling' of trends in inputs (predominantly fertility) and disturbance in some sense paved the way for later developments in cereal farming in England – and more widely across western Europe – which variously promoted intensive approaches to restoring fertility *despite* expanding scales of cultivation (Bloch, 1931; Bayliss-Smith, 1982; Williamson, 1998 and this volume). This stands in contrast to the kind of extensification apparent in Romano-British farming. As shown by Lodwick (this volume), there are signs of low-input crop husbandry in Roman Britain, but no definitive evidence for a mouldboard plough: extensive farming in the Roman period may therefore have entailed both low fertility *and* low disturbance, with their decoupling coming only when the mouldboard plough came into more widespread use in the early medieval period. Hence, while there may be a consistent trend towards extensification through the Roman and medieval periods – as also seen in the Rhineland (Hamerow et al., forthcoming) – the particular means and mechanisms of extensive farming may have been different in each era.

Conclusions

The arable weed-based models considered here provide complementary means of assessing the overall intensity of arable land management and growing conditions, and the specific role of mechanical soil disturbance. Application of these models to two contrasting case studies – Stafford in the lowlands of the West Midlands, and Lyminge among the chalk downs of Kent – illustrates some of the variety we might expect across England (see McKerracher, this volume, for another archaeobotanical application of the disturbance model). On the one hand, the ecological setting, chronology and social geography of each site clearly shape its uptake and deployment of innovations such as the mouldboard plough. On the other hand, even in two such distinct cases it is possible to discern variations on similar agroecological themes: the cerealization of local landscapes through extensive management, and effective tillage through the mouldboard plough and bare fallow. The wider emerging picture suggests that these processes played out through the early medieval period, resulting in a tendency towards diminishing fertility alongside consistent levels of disturbance comparable to mouldboard ploughing, at least in the Central Zone where most available archaeobotanical data are concentrated (Hamerow, this volume; Hamerow et al., in prep.). Given this bias, the western and south-eastern case studies considered here are instructive in suggesting the wider relevance of these trends.