Veget Hist Archaeobot (2003) 12:177–185
DOI 10.1007/s00334-003-0007-6

ORIGINAL ARTICLE

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Rye cultivation in the Danish Iron Age – some new evidence from iron-smelting furnaces

Received: 4 December 2002 / Accepted: 30 June 2003 / Published online: 15 August 2003

Abstract Analyses have been carried out on well-preserved carbonised rye and barley plants and associated plant remains preserved in iron smelting furnaces from southern Jutland, Denmark. The furnaces are dated archaeologically to the transition between the Roman and Germanic Iron Ages (ca. A.D. 400). The results of the analyses allow detailed reconstruction of the contemporary fields, revealing them as having been well tended with a dense stand of crop plants and few weeds. The composition of the weed assemblages suggests that the rye was autumn-sown. Analysis of the culm bases and roots showed that rye had probably been broadcast sown, followed by a light harrowing to cover the sown grain.

Keywords Archaeobotany · Secale · Hordeum · Iron-smelting furnaces · Winter crops · Yield · Sowing depth

Introduction

Iron smelting in Denmark in the period from A.D. 100 to A.D. 700 was carried out in slag-pit furnaces (Voss 1993). These furnaces comprised a chimney just over a metre in height, in which roasted bog iron ore and charcoal was packed, and an underlying pit of about 60 cm in depth, into which the molten slag ran during the smelting process (Fig. 1). The slag pit was dug first and filled prior to building the chimney, in order to prevent the charcoal and iron ore from falling into the pit prior to the smelting process. In Denmark the most common filling material was straw, but occasionally heather or small wooden billets were used. The use of wood as filling materiel in the slagpit is also known from northern Germany (Dörfler and Wiethold 2000).

During smelting, the molten slag ran down into the pit, and sometimes resulted in the straw being compacted and carbonised at the base of the pit rather than being burnt away (Voss 1993).

Samples of straw from iron-smelting furnaces differ from most other archaeobotanical samples in that there is precise information about the origin of the material; in almost all cases it comprises ripe cereal plants pulled up by the root. During iron smelting, the plant material in the pit is slowly warmed up and dried under anoxic conditions. This creates ideal conditions for carbonisation without the risk of cereal grains "popping" due to their water content (Mikkelsen 1997). Accordingly, it is sometimes possible to find perfectly preserved plant material at the base of the slag pits, where it has been encapsulated by the overlying slag block. This plant

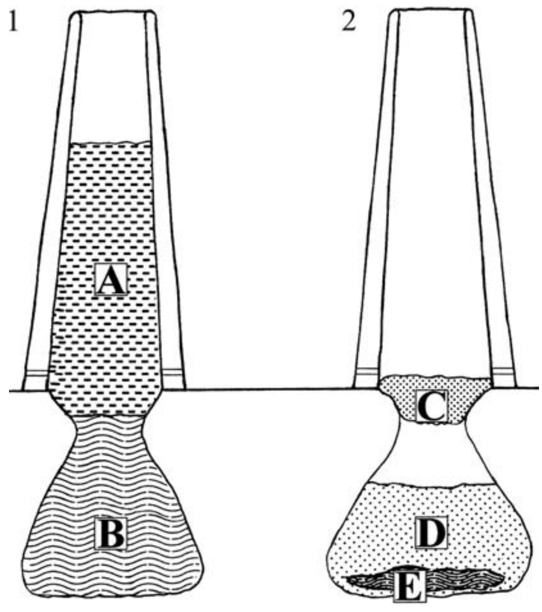

Fig. 1 Iron-smelting furnace before (*1*) and after (*2*) the smelting process. *A* roasted bog ore and charcoal; *B* straw; *C* iron "bloom"; *D* slag and *E* carbonised straw (after Voss 1993)

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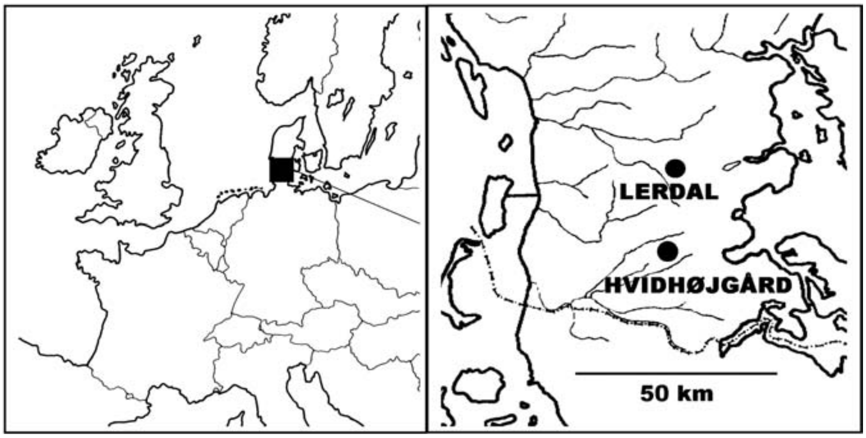

Fig. 2 Maps showing the location of the two investigated sites in southern Jutland, Denmark

material typically comes from a single field from a single year and there is no risk of contamination by earlier or later material. As a consequence, it gives a "snapshot" of a small area of a particular field, in contrast to samples of waste from postholes and pits for example, where the archaeobotanical material can derive from many different sources (Willerding 1991).

In recent decades, many iron-smelting furnaces have been excavated in Denmark, primarily in the southwestern part of Jutland. A series of archaeobotanical samples has been analysed from these features, producing much new information on Iron Age agriculture (Mikkelsen 1997, 1998, 1999, 2000a, 2000b, 2002). These analyses, which focused on material from slag pits containing primarily either rye (*Secale cereale*) or hulled six-rowed barley (*Hordeum vulgare var. vulgare*), showed that there were differences in the respective weed assemblages associated with these two crop species. On the basis of numerical analyses performed on the weed seed assemblages, Mikkelsen concluded that rye was cultivated as a winter crop (Mikkelsen 1998). According to Behre (1992), rye as a crop plant probably evolved from wild rye growing as a weed of winter crops in central and eastern Europe.

Analyses of soil preserved on the roots of the barley and rye plants revealed a higher content of nutrient in the soil from the barley roots. Combined with the weed seed assemblages in the slag pits, Mikkelsen (2002) interpreted this as showing that the contemporary crop rotation comprised first manured barley followed by a number of years of rye cultivation.

The present author has subsequently investigated many archaeobotanical samples from four Danish sites. The sites, which are archaeologically dated to the transition between the Roman and Germanic Iron Ages around A.D. 400, were excavated by Haderslev Museum. The analyses comprised carbonised material from a large number of house remains and pits, in addition to that from three iron-smelting furnaces. This article describes the investigation of the latter, in which new and more detailed analyses were able to provide an even more detailed and subtle picture of the contemporary fields.

The sites

Hvidhøjgård

At Hvidhøjgård (Fig. 2), Haderslev Museum excavated a settlement from the early Germanic Iron Age; a well in the settlement is dated dendrochronically to about A.D. 460. The settlement comprised seven houses and three small economy buildings. Around the settlement there were also 71 slag pits from iron-smelting furnaces (Andersen 1996).

Lerdal

At Lerdal (Fig. 2), Haderslev Museum excavated a settlement spanning the period between A.D. 200 and A.D. 600. The settlement comprised up to 10 farm units. Around the settlement there were numerous slag pits from iron-smelting furnaces (Ethelberg 1999).

Materials and methods

The archaeobotanical samples from the iron-smelting furnaces comprise compacted cereal straw with the ears attached. This material can be very well preserved but it is also very fragile. This means that pieces of root and stem will often fragment further if samples are processed by flotation. As a consequence, only unprocessed samples were examined, as an important aim of the investigation was to find out what these plant parts could reveal.

All of the archaeobotanical samples were examined under a low-power binocular microscope, and any identifiable plant remains were picked out and identified with the aid of a reference collection comprising recent plant material, and by reference to relevant literature (for wild plants see Anderberg 1994; Beijerinck 1947; Berggren 1981; Körber-Grohne 1991). The nomenclature of the plant names follows Hansen (1981).

All the grains, rachis segments (each segment counted as one) and weed seeds were counted. All the stems (each basal part of a stem counted as one stem) and nodes (thickened attachment points for leaves on the stems of grasses) were counted in order to establish whether parts of the cereal plants were absent. This can be seen from the relationship between the number of nodes and stems, as this ratio is very constant in cereal plants at ear formation (Andersen 1980). The number of stems (tillers) arising from each

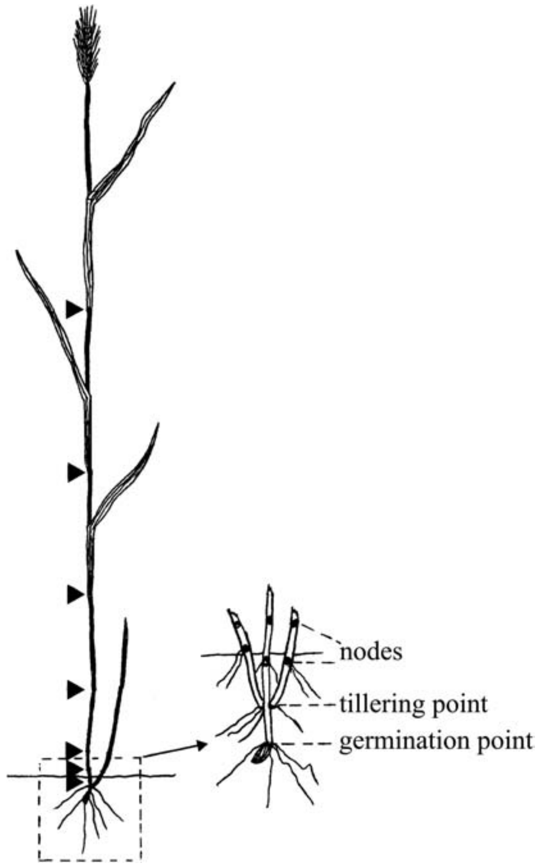

Fig. 3 Schematic drawing of a rye plant shows the nodes on the stem

root was counted in order to establish plant density, as tillering is dependant on the density at which the plants have been sown.

It was assumed that the stems or parts of the stems (nodes, etc.) derive from the same plant from which ears were found.

The distance between the germination point, at the base of the coleoptile, and the tillering point was also measured (Fig. 3). This distance is dependant on the depth at which the grain has been sown. Its measurement enables the depth of sowing to be calculated, as tillering normally occurs approximately 1.5 cm under the soil surface (Andersen 1980).

Hvidhøjgård

During excavation of iron-smelting furnace no. 11, a sample comprising 5.5 l (x539) was taken. Most of this sample was subsequently processed by flotation, but a sample of 2 l was retained intact, and this is the material that was examined in its entirety.

A sample of 11 l was taken from iron-smelting furnace no. 148 (x692). An unprocessed part of the sample comprising 0.5 l was examined. Seven samples have previously been analysed from the site (Mikkelsen 2000b).

Lerdal

A sample of 0.675 l/293 g (x4653) was taken from iron-smelting furnace no. 4149. The sample was unprocessed and a sub-sample of 83 g was analysed. The sub-sample was produced by dividing off approximately one quarter of the whole sample, which was very homogeneous.

Three samples, processed by flotation, from iron-smelting furnaces no. 168 (sample x253), no. 169 (sample x238) and no. 4159 (sample x5823) were analysed by H. Kroll, Kiel University. In these analyses, the number of stems and nodes were not counted. The results of these (unpublished) analyses are presented in this article by kind agreement with H. Kroll.

Results

The results of the analyses are presented in Table 1. The samples from Hvidhøjgård contained rye (*Secale cereale*) with roots, stems and intact ears. 12–14 rachis segments per ear could be counted on the intact ears preserved in the samples (Fig. 4). There were a number of weed seeds in the samples, but virtually no stems or leaves of these plants, with exception of a number of stems of *Spergula*

Fig. 4 Intact rye ear from Hvidhøjgård. The ear is 30 mm long (Photo P.S. Henriksen)

Table 1 Carbonised plant macrofossils from Hvidhøjgård and Lerdal. The volume of and the number of nodes and roots from x238, x253 and x5823 from Lerdal were not recorded

		2 l	0.5 l	83 g	Analysed by H.Kroll (Kiel)		
		x539	x692	x4653	x238	x253	x5823
Cultivated plants	Part						
Avena sativa	Caryopsis				8	12	1
Avena sativa	Glume				4	8	1
Avena sp.	Caryopsis sp.				123	94	1
Hordeum vulgare var. *vulgare*	Caryopsis				712	1028	6
Hordeum vulgare	Rachis segment				126	7	1
Secale cereale	Caryopsis	424	89	243			478
Secale cereale	Rachis segment	358	171	5380			35
Secale cereale	Root	267	169	5			
Secale cereale	Node	1357	638	17			
Arable weeds							
Chenopodium album	Seed	6			109	104	7
Digitaria sanguinalis	Caryopsis				75	36	
Euphorbia helioscopia	Seed				1		
Fallopia convolvulus	Fruit				1	1	
Galeopsis segetum	Nutlet				72	69	
Galeopsis tetrahit/bifida	Nutlet				2		
Galeopsis sp.	Nutlet	8	14				
Galium spurium	Seed						1
Juncus bufonius	Seed	16					
Lapsana communis	Achene						6
Odontites verna coll.	Seed	28			1		2
Odontites verna coll.	Capsule	3	2				
Persicaria hydropiper	Fruit	8					
Persicaria maculosa/ lapath. s.l.	Fruit	9			193	424	5
Poa annua	Caryopsis	4					
Polygonum aviculare s.l.	Fruit	138			13	1	
Polygonum sp.	Fruit	16					
Ranunculus cf. *repens*	Achene	9					
Raphanus raphanistrum	Capsule				32+12	14+3	
Rumex acetosella	Fruit	36	24		3	1	2
Scleranthus annuus	Pseudocarp	12			2		
Stellaria media	Seed					1	
Spergula arvensis	Seed		971		1147	671	103
Spergula arvensis	Capsule		388				
Trifolium repens	Seed	4					
Tripleurospermum inodorum	Achene	8	16				9
Veronica arvensis	Seed		41				2
Vicia hirsuta	Seed	4	5				50
Grassland plants							
Bromus arvensis	Caryopsis						2
Leontodon autumnalis	Achene	4					
Lolium perenne	Caryopsis	16					
Lycopus europaeus	Nutlet				1		
Plantago lanceolata	Seed				1		1
Poa cf. *trivialis*	Caryopsis	352	187				
Ranunculus acris type	Achene					2	
Heath plants							
Calluna vulgaris	Shoot	5					
Diverse							
Asteraceae	Achene		4				
Brassicaceae	Seed		4				
Carex sp.	Nutlet	4				1	
Caryophyllaceae	Seed		8				
Cerastium sp.	Seed		4				
Cerastium sp.	Capsule	1					
Chenopodium sp.	Seed	8					
Fabaceae	Seed	8					
cf. *Festuca* sp.	Caryopsis				87	74	689
Hieracium sp.	Achene		4				
Lamiaceae	Nutlet		8				
cf. *Lolium* sp.	Caryopsis				9	1	18

Table 1 (continued)

		2 l	0.5 l	83 g	Analysed by H.Kroll (Kiel)		
		x539	x692	x4653	x238	x253	x5823
cf. *Poa* sp.	Caryopsis				19	15	
Poaceae	Caryopsis	28			19		20
Trifolium sp.	Seed		4				
Indet.	Seed	12	38				
Indet.	Leaf	3					
Indet.	Bud	2					
Collected food plants							
Corylus avellana	Nutshell fragment	1					

Table 2 Results of measurements of the distance between the germination and tillering points on rye roots from Hvidhøjgård, together with the estimated depth of sowing

Sowing depth (distance between germination and tillering points+1.5 cm)	cm	0–1.5					2					2.5			3
Distance between germination and tillering points	cm	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
Measurements	No.	5	7	8	9	13	11	8	1	5	3	0	0	0	1

arvensis in x692. The weed seed assemblages in the two samples were very different; x692 was dominated by *Spergula arvensis*, whereas this species did not occur at all in x539. Similarly, there were a large number of seeds of *Polygonum aviculare* s.l. only in x539. The only species which occurred in large amounts in both samples was *Poa* cf. *trivialis*.

Sample x4653 from Lerdal comprised rye (*Secale cereale*) ears with only a small number of grains, only a little straw, a few roots and no weed seeds.

Of the three straw samples investigated by H. Kroll, two mainly contained grains from hulled six-rowed barley (*Hordeum vulgare* var. *vulgare)* but also many grains from oat (*Avena* sp.) and one contained grains from rye (*Secale cereale*). The weed seed assemblages in the two barley samples were broadly similar, dominated by *Spergula arvensis*, *Chenopodium album*, *Galeopsis segetum*, *Persicaria lapathifolia* s.l./*maculosa* and *Digitaria sanguinalis*. Of these species, only *Spergula arvensis* occurs in large numbers in the rye sample. In contrast, this latter sample contained many caryopses of a species of cf. *Festuca* sp. and many seeds of *Vicia hirsuta*.

The results of the measurements of the distance between the germination point and the tillering point on the rye plants are shown in Table 2. Most of the measurements lay between 3 and 5 mm, corresponding to a sowing depth of about 2 cm.

The tillering of the rye plant could be estimated from the number of stems arising from one plant. The intact plants had up to six tillers per plant, but the majority had only one or two (Fig. 5). Most of the stems were, however, broken apart. It could, however, be established that the majority of plants had only had two stems as they were broken apart with only one broken surface on the flat side lacking roots, whereas there were very few roots with more than one broken surface.

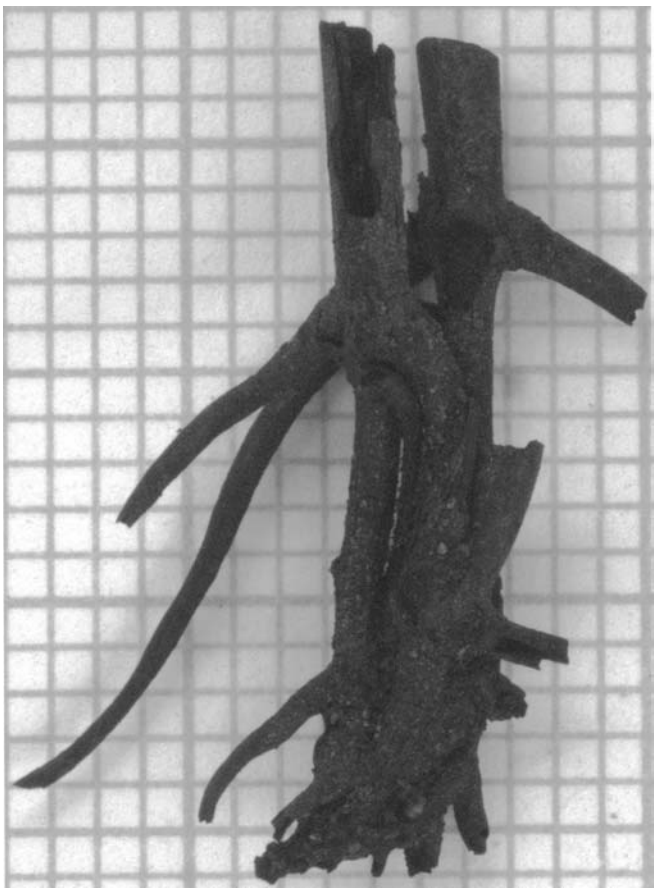

Fig. 5 Rye root from Hvidhøjgård. The scale is 1 mm (Photo P.S. Henriksen)

Discussion

Hvidhøjgård

The samples from Hvidhøjgård contained almost exclusively straw of rye (*Secale cereale*) with whole ears and roots intact. This indicates that the pits under iron-smelting furnaces were filled with rye plants that had been pulled up from the field in connection with the iron-smelting process. A number of roots had earth attached to them, which suggests that the cereals came directly from the fields, rather than having been taken home and stored in order to be used some time later for filling the slag pits. The soil at the site is so sandy that the earth would not have remained on the roots after drying and transportation. The grains were fully developed, which indicates that iron smelting took place in August when the rye was ready to harvest.

The weed flora

The composition of the weed flora in the two samples is very different, which shows that there could be a great variation between different parts of the fields or from year to year. It will therefore be a matter of chance as to which species occur in the individual furnaces, which each probably only represent a small area of a few square metres (see yield, approx. 4 m^2). A species such as *Spergula arvensis* is, accordingly, totally dominant among the weeds in sample no. x692, whereas this species does not occur at all in sample no. x539. This should, however, be seen in the light of the fact that although a very large number of seeds and fruits of some weed species do occur, these can represent the production of a single or only a very few plants. The weed species in question are great producers of seeds or fruits. This shows that the rye field from which the straw comes, was very "clean", presumably with only very few weed plants (10–20) per square metre; this is a clean crop, even in modern agriculture. Confirmation of this is given by there being virtually no remains of weed species together with the straw, with the exception of a number of *Spergula* stems and seed capsules in sample no. x692. The low number of weed plants also indicates that the rye grew in a dense stand that could out-compete the weeds. However, one has to consider that cereals and weeds of a sample represent only a small area of the field.

These results correspond well to the situation described by Mikkelsen (2000b) for samples from the same locality. He, too, found great variation between the different samples and recorded numbers of seeds or fruits corresponding to the normal production of single plants.

Spring-/autumn-sown crops

A number of weed species in the samples indicate that rye was cultivated as a winter cereal. In sample no. x539 there were a large number of seeds of *Polygonum aviculare* s.l. that were seen both in summer and winter crops, but most commonly abundant in autumn-sown fields. The seeds germinate early in the year and, as a result, the young plants are often destroyed by soil preparation in spring (Jessen and Lind 1922–1923).

There were also a substantial number of seeds and seed capsules of *Odontites verna* coll. In archaeobotanical investigations, this species is found almost exclusively together with rye, for example at Aggersborg dated to the end of the first millennium A.D. (Jessen 1954) and Haithabu (A.D. 800–1000) (Behre 1983). It also often occurs with rye in iron-smelting furnaces (Mikkelsen 1998, 2000b). According to Hansen (1981), *Odontites verna* is the only occurring *Odontites* species in Denmark, and the only subspecies of *Odontites verna* to be found in cornfields in Denmark is *Odontites verna* ssp. *verna*. According to Hegi (1974), this subspecies occurs primarily as a weed in autumn-sown crops. However, it was not possible to identify the subspecies in the archaeological material.

The samples contained a small number of seeds of *Vicia hirsuta*. This species is a rare find in Danish Iron Age material, but was found in large numbers in material from Haithabu, where it is linked with winter rye (Behre 1983). However, it can also occur rarely with summer-sown cereals.

Both samples also contained a large number of caryopses of *Poa* cf. *trivialis*, which as a weed in cereal fields only occurs in damp places in autumn-sown fields (Danmarks Jordbrugsforskning 1998). However, *P. trivialis* also grows on damp meadows, pastures and roadsides and the caryopses could, therefore, also have come from the edge of the field, from where it can be expected that the straw was also taken.

In contrast to the above, *Spergula arvensis* dominates sample no. x692. This plant is often seen in spring-sown fields, but also occurs in winter crops (Behre 1983; Sepstrup 1975).

To conclude, based on the weeds found in the two samples it is not easy to reconstruct the sowing time, and neither did Mikkelsen (2000b) reach a sure conclusion concerning this topic. This is mainly because the two species that are most often used as indicators of winter cultivation of rye, *Agrostemma githago* and *Centaurea cyanus* (Behre 1983), do not occur in the two samples investigated. Their absence cannot, however, be used to exclude winter cultivation of rye as many other of the weed species present indicate that this was the case.

Presumably, *Centaurea cyanus* was first introduced to Denmark in Viking or early Medieval times, when it appeared in cereal finds (Jensen 1985), and *Agrostemma githago* was introduced in the Germanic Iron Age, the first find from Denmark is dated to A.D. 500 (Helbaek 1957).

Analyses of roots, stems and ears

The roots of the rye plants were well preserved, as can be seen from Fig. 5. Accordingly, it could be established that the majority of plants had formed between one and three tillers. Such limited tillering only occurs if rye has grown in a dense stand of about 300 stems/m^2 (Andersen 1980). This result refers to modern rye races, but as the breeding of cereals in the last century has always been in dense stands, the ability to produce tillers has not been promoted, and there is therefore no reason to believe that the tendency to produce tillers should have been smaller in former times.

This almost corresponds to the density of modern fields and the possibility that the plants were collected from a fallow field can therefore be excluded; on a fallow field, where lost grain has germinated, it would be usual to find up to 20–30 stems per plant (Andersen 1980). Very limited tillering could also occur if the rye plants had grown in a dense stand of weeds, but the small quantities of weed stems in the samples shows that this was not the case here.

In both of the investigated samples the basal part of the plants was over-represented relative to the upper parts. Accordingly, a comparison of the number of stems (based on the number of roots with the stem base preserved intact) and the number of nodes shows that there are 5 and 3.8 nodes per stem in samples x539 and x692, respectively. At the time of ear formation in a cereal crop. there will, on average, be 7–9 nodes per stem, with 6–7 nodes/stem as a minimum figure. Of these, the internodes (stem sections) between the penultimate node and the ear comprise half of the total height (Andersen 1980) (see Fig. 3). This shows that the uppermost half to two thirds is missing from the samples; this is also reflected in the small number of rachis segments (chaff) and grains relative to the number of stems. However, it cannot be determined whether some of the upper stems and the ears were removed before the straw was placed in the pit, whether they were burnt away in connection with the iron-smelting process or whether the unprocessed sub-samples are unrepresentative of the complete samples.

The possibility that the rye had been threshed before being placed in the two iron-smelting furnaces can be excluded, as the numbers of rachis segments and grains are of the same order of magnitude. If the crop had been threshed before the straw was used as fill, there would have been many more rachis segments than grains. Accordingly, Mikkelsen (1998) found that in threshed rye from an iron-smelting furnace there were 57× as many rachis segments as there were grains, and in the present investigation, a sample from Lerdal proved to have 22× as many rachis segments as grains.

Yield

On the basis of the amount of straw in sample x692 it can be estimated that the crop from at least 4 m^2 was used to fill the pit below this iron-smelting furnace. The calculations are as follows:

- stems/m^2 (estimated from modern rye) (Andersen 1980): 300
- roots/0.5 l subsample (Table 1): 169
- total sample size in litres: 11

As the sample only contained 3.8 nodes per root, and a minimum of seven were expected, the uppermost 2/3 of most of the straw must be missing. This is also confirmed by the low number of grains and rachis segments, 89 and 171, respectively. With 12–14 rachis segments (see below) per ear, and one ear per root, more that 2,000 rachis segments could be expected if the rye plants were intact. That is to say that to the roots and straw in the 0.5-l sub-sample investigated belongs a further 1 l of stems, that is 169 roots corresponding to 1.5 l of sample. In total, there were 11 l of straw in the furnace, and on the basis of this, it can be estimated that in the whole sample there were 11/1.5×169=1,239 roots.

With an estimated stem density of 300/m^2 this corresponds to the use of crops from about 4 m^2 to fill furnace x692. In a modern rye crop, which grows with a moderate level of manuring, there will be an average about 24 grains per ear (Andersen 1980), which also corresponds well to the 12–14 rachis segments per ear which could be counted on the intact ears preserved in the samples, as rye normally produce two grains per rachis segment. Combined with the estimated number of ears of 300/m^2, and the fact that the majority of the grains measured 5–6 mm in length and 2–3 mm in diameter, corresponding to small-grain modern rye cultivars with a thousand-grain weight around 25 g (Andersen 1980; Høst 1982), this indicates that the yield could have been on the order of 1,800 kg/ha according to the following calculation:

- ears/m^2 (estimated from modern rye) (Andersen 1980): 300
- grains/ear (estimated from modern rye and intact ears in the find): 24
- 1,000-grain weight (estimated from modern rye) (Andersen 1980) (in grams): 25
- m^2 of crop used in furnace: 4
- 300 ears/m^2 × 24 grains/ear=7,200 grains/m^2 (modern estimation)
- 25 g/1,000 grains × 7,200 grains/m^2=180 g grains/m^2 corresponding to 1,800 kg/ha
- loss of grain: 180 g grains/m^{2}x4 m^2/furnace=720 g

such a small loss would not in itself give reason to thresh the cereals prior to placing them in the iron-smelting furnace. This result is estimated according to modern preconditions, but as both the grain size and the number of rachis segments/ear in this study corresponds to modern small-grained cultivars under poor growing conditions, the result is probably in the right order.

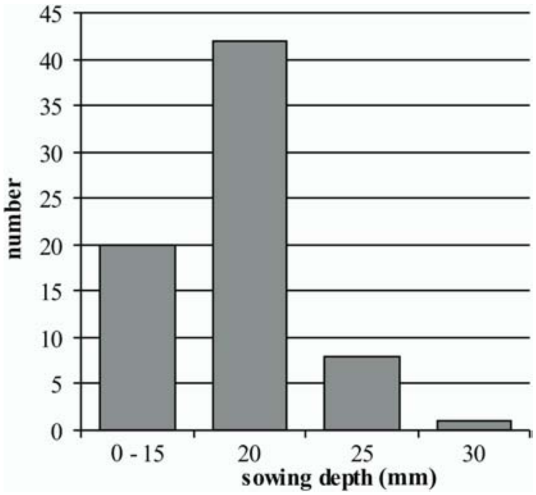

Fig. 6 Depth of sowing for 71 measured cereal plants, calculated on the basis of the distance between the plants' germination point (base of coleoptile) and tillering point, cf. Table 2

Depth of sowing

On a large proportion of roots it was possible to find the point from which the plant had germinated and the point from which tillering was initiated (that is, where the plants divide into several stems). The tillering point normally lies about 1.5 cm under the soil surface (Andersen 1980), which means that the depth of sowing can be estimated from the distance between the germination point (base of the coleoptile) and the tillering point. Measurements of this distance can be seen in Table 2 and the estimated depth of sowing is shown in Fig. 6. The average sowing depth of 2 cm corresponds to the recommended sowing depth for modern rye, as a yield decrease can be expected when sowing deeper than 3–4 cm (Andersen 1980).

A sowing depth of 0–2.5 cm indicates that the crop was broadcast sown followed by light harrowing, as sowing in rows in ard furrows or covering of broadcast seed by ard ploughing would result in a greater and more variable depth of sowing.

Lerdal

The sample x4653 (see Table 1) from Lerdal contained very compacted rye ears almost lacking grains, together with a little straw, which suggests that the fill used in the pit must have been threshing waste. The sample also contained a good quantity of charcoal pieces, including *Quercus sp*., measuring 10–40 mm (identified by Claus Malmros, NNU). This presumably originates from the charcoal fill in the chimney of the slag-pit furnace (Voss 1993). The analysed sample contained only a few roots and nodes and around 22 rachis segments for every rye grain. There were no weed seeds in the sample.

Modern rye normally forms two grains per rachis internode, which means that there were originally around 10,760 grains in the counted rachis segments. Of these grains, only 2.3% remained with the rachis segments. A composition such as this must represent refuse from very efficient threshing. This sample is a complete equivalent to that from Snorup in which Mikkelsen (1999) found that in a slag pit with threshing waste only 1% of the original grains remained with the rachis segments.

The whole sample contained around 19,000 rachis internodes, which corresponds to around 1,400 stems or the crop from 4–5 m^2, if it resembled that from Hvidhøjgård. It is very unlikely that such a large quantity of straw could be placed so that precisely the uppermost end with the ear from the entire crop was preserved. This suggests that the ears were separated from the straw before they were placed in the furnace, and presumably also before they were threshed. This can also explain the absence of weed seeds. The separation of the ears and the straw can either have occurred by the rye being harvested by cutting just below the ears, or that the top of the straw (that is, the ears) was removed after the whole plant had been harvested, a practice which has been demonstrated from the end of the pre-Roman Iron Age at Overbygård in northern Jutland (Henriksen and Robinson 1996).

The three samples from the iron-smelting furnaces analysed by Kroll in 1999 comprised un-threshed cereals; two slag pits contained barley straw with ears and grains and one contained rye straw with ears and grains. There is very little coincidence between the weed seed assemblages from the barley slag pits and the rye slag pit respectively. Barley is accompanied by *Spergula arvensis*, *Chenopodium album* and *Persicaria lapathifolia* s.l./*maculosa*; species which are common in grain finds from the whole of the Iron Age. In addition, there are many capsules of *Raphanus raphanistrum*, a species linked with spring crops (Danmarks Jordbrugsforskning 1998). With the exception of a good number of seeds of *Spergula arvensis*, the above species are virtually absent from the rye sample, which, in contrast, contains many seeds of *Vicia hirsuta*, a species which, as mentioned previously, can be linked to winter cultivation. On the basis of these differences in weed assemblages between the rye and the barley samples H. Kroll has suggested that rye was cultivated as a winter cereal (H. Kroll, personal communication).

Conclusion

The analyses of plant material from iron-smelting furnaces has shown that this type of find has great potential. This is due in part to the material often being extremely well preserved and not being contaminated either by earlier or later material, and in part because the plant material, in contrast to samples of waste from post holes and pits, originates from a particular field in a particular year and has in most cases not undergone any processing beyond being uprooted. The samples can therefore give a very precise picture of conditions in a little area—according to my results, approx. 4 m^2—of the cereal field from which the material originates. The great variation between samples from the same locality also shows that a large number of analyses is required if an overall picture is to be drawn of the ecological conditions in the fields around a settlement.

Collectively, the weed seed assemblages in the samples may indicate that rye was cultivated as a winter crop, even if very typical winter crop weeds such as *Agrostemma githago* and *Centaurea cyanus* are missing. The analyses sketch a detailed picture of the contemporary rye fields at Hvidhøjgård as being well cultivated with a dense stand of crop plants and few weeds. The analyses indicate furthermore that the sowing was accomplished by broadcast sowing followed by light harrowing to cover scattered cereal grains.

Acknowledgements This investigation was carried out at the Environmental Archaeology Unit of the National Museum as part of the project "Kost og Kultur" ("Food and Culture"), the project leader is Sabine Karg. The project was financed by a grant from the Ministry of Culture's research pool. Thanks to Helmut Kroll (Kiel) for making available the result of his analyses from Lerdal, and to Claus Malmros (NNU) for his identification of charcoal from Lerdal. Thanks to museum curators Sabine Karg and David Earle Robinson and to Jan Harrild (NNU) for help with identifications and inspiring discussions, and a special thanks to David Earle Robinson for comments on this manuscript. The manuscript has been translated by Anne Bloch Jørgensen and David Earle Robinson.

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