Veget Hist Archaeobot (2002) 11:155–168

Vegetation History
and Archaeobotany

Questioning the relevance of shifting cultivation to Neolithic farming in the loess belt of Europe: evidence from the Hambach Forest experiment

Amy Bogaard

Department of Archaeology and Prehistory, University of Sheffield, Northgate House, West Street, Sheffield S1 4ET, UK.
e-mail: A.M.Bogaard@sheffield.ac.uk

Received September 5, 2001 / Accepted February 26, 2002

Abstract. Despite widespread criticism, the shifting cultivation model continues to inform discussion of Neolithic farming in Europe, beginning with early Neolithic (*Linearbandkeramik* or LBK) communities concentrated in the loess belt of western-central Europe. Hundreds of LBK and later Neolithic sites have been excavated in this region and many of them sampled for charred plant remains. Archaeobotanical data on the weed floras harvested with crops provide the most direct archaeological evidence of crop husbandry practices, including the permanence of crop fields, but have played a limited role in the debate over shifting cultivation. The Hambach Forest experiment, conducted in the 1970s-80s near Cologne, Germany, provides valuable comparative data on the weed floras growing in newly cleared cultivation plots in an area of long-lived mixed oak woodland on loess-based soil. Correspondence analysis of the Hambach weed survey data suggests that weed floras of fields managed under a shifting cultivation regime would be rich in perennial species, including woodland perennials. Comparison of these results with Neolithic weed assemblages from the loess belt of western-central Europe strongly suggests that Neolithic crop fields were not recently cleared of woodland vegetation but were long-established.

Key words: Shifting cultivation – Hambach Forest – Experimental cultivation – Archaeobotany – Weed ecology

Introduction

Shifting cultivation refers to the use of newly cleared and burned woodland areas for short-term crop growing (c. 1-5 years) followed by a "shift" of cultivation to other newly cleared areas and woodland regeneration (over c. 20 or more years) on old plots. This system, also known as slash-and-burn, swidden, long-fallow or forest-fallow, is distinguished from cultivation regimes involving shorter fallow periods by the type of vegetation - primary or secondary woodland - which is cleared to create new fields (Dennell 1978, p 37). Burning releases nutrients from organic material into the soil, promoting high crop yields for a short period, and may damage the viability of potential "weed" seeds, rhizomes etc. present in the soil (Ellenberg 1996, p 770), reducing the need for tillage and weeding (Sigaut 1975, pp 18-29, 99). Shifting cultivation is attested historically in parts of Europe and North America (Grigg 1974, pp 62-63; Sigaut 1975, pp 18-29; Steensberg 1955, 1993, pp 15-16, 98-153; Larsson 1995; Lüning 2000, pp 52-54). It is also widely practised in tropical regions, where such techniques counteract the rapid leaching of soil nutrients by very high rainfall (Grigg 1974, pp 57-74; Steensberg 1993, pp 16-98).

Childe (1929, pp 45-46) first suggested shifting cultivation to explain the 'spread' of early Neolithic (*Linearbandkeramik* or LBK) farming communities across central and western Europe, principally in regions of loess-based soil between the North European Plain and the Alps, extending from Belgium to the Ukraine (Fig. 1; Bogucki 1996). The model was widely accepted for the LBK (Clark 1952, pp 92-98; Piggott 1965, pp 51-52) until the 1970s, when the alternative model of permanent fields cropped on a regular basis began to find favour (Modderman 1971; Kruk 1973). Nevertheless, shifting cultivation has contin-

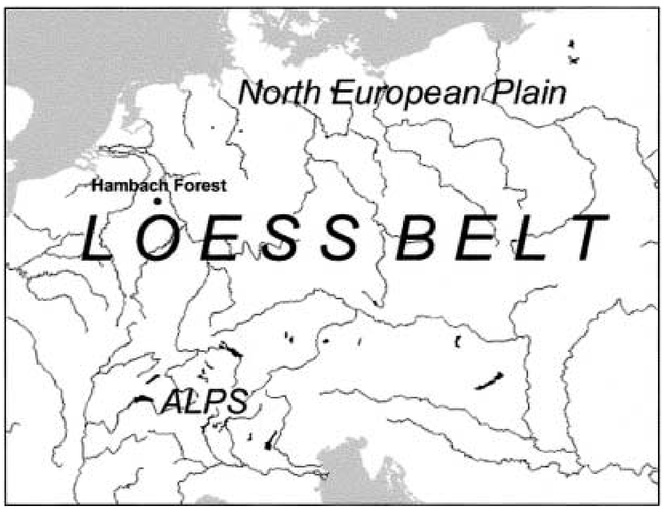

Fig. 1. Map of western-central Europe showing the loess belt and the location of the Hambach Forest

ued to influence more recent discussion of LBK and later Neolithic agriculture in the loess belt of western-central Europe (for example Wasylikowa et al. 1985; Beranová 1987, 1989; Godłowska et al. 1987; Kruk 1988; Milisauskas and Kruk 1989; Wasylikowa 1989; Rösch 1990; Rulf 1991; Whittle 1996, pp 160-162, 1997). Following the early pollen analyses of Iversen (1941) and Troels-Smith (1953), slash-and-burn farming has also long been associated with the later Neolithic *Trichterbecherkultur* or TRB in the North European Plain and Scandinavia (Midgley 1992, pp 384-393). Here again, shifting cultivation has continued to appear in recent accounts of TRB agriculture (for example Göransson 1988, p 70; Milisauskas and Kruk 1989; Andersen 1993; Kalis and Meurers-Balke 1998). Recent writing on the Neolithic period in the foothills surrounding the Alps (*Alpenvorland*) has also promoted the idea of shifting cultivation (for example Rösch 1996, 2000; Pétrequin 1996; Pétrequin et al. 1998). Similarly, shifting cultivation emerges in recent accounts of Neolithic agriculture in Britain (for example Barrett 1994, pp 143-148, 1999; Whittle 1997; Thomas 1999, pp 23-32). Despite sustained criticism of the model over several decades (Modderman 1971; Kruk 1973; Lüning 1980, 2000, pp 49-50, 187-189; Sherratt 1980; Rowley-Conwy 1981; Bogucki 1988, pp 79-82), therefore, shifting cultivation continues to thrive in the archaeological literature on Neolithic Europe. It has evolved from a model explaining the spread of Neolithic "farmer-pioneers" across Europe (Childe 1929) into one which emphasises the indigenous, "Mesolithic" (and hence "mobile") identity of Europe's first farmers.

Key arguments in support of shifting cultivation have included the supposed rapid exhaustion of soils (Childe 1929, pp 45-46, 1957, pp 105-106), the occurrence of sites in areas of relatively poor soils (Kruk 1973, 1980, pp 54-57, 1988; Rösch 2000), discontinuity in settlement occupation (Soudsky and Pavlu 1972) and pollen evidence for changes in woodland composition associated with clearance and burning (Iversen 1941; Troels-Smith 1953; Wasylikowa et al. 1985; Wasylikowa 1989; Godłowska et al. 1987; Göransson 1988; Rösch 1990, 1993; Andersen 1993; Kalis and Meurers-Balke 1998). All of these arguments are open to question. First, the claim of soil exhaustion in regions with relatively good soils, such as those based upon loess, is refuted by experimental evidence for the long-term stability of crop yields over decades of continuous cereal cultivation, even without manuring (Lüning 1980, 2000, p 174; Rowley-Conwy 1981; Reynolds 1992). Second, the relationship between basic soil quality and crop growing conditions may not be straightforward; intensive manuring, watering and weeding of cultivation plots, for example, can create a highly fertile garden soil (for example Jones *et al.* 1999). Third, more or less continuous occupation over several centuries has been demonstrated for some Neolithic settlements in western-central Europe (such as LBK sites in the Aldenhoven plateau, Stehli 1989), though there appears to be considerable variation, even within the LBK (Whittle 1996, p 166). In any case, the relationship between residential permanence and the permanence of cultivation areas may have been complex (Grigg 1974, p 60; Whittle 1997). Fourth, in addition to the fundamental issues of adequate dating and calculation of pollen diagrams (Rowley-Conwy 1981; Kalis and Meurers-Balke 1998), it has been emphasised that changes in woodland composition associated with clearance and burning do not necessarily reflect past *arable* land-use (Rowley-Conwy 1981; Brombacher and Jacomet 1997; Kalis and Meurers-Balke 1997, 1998).

It is striking that the most direct archaeological evidence for crop husbandry - the seeds of arable weeds harvested with ancient crops and associated with them in samples from archaeological deposits - has played a limited role in the debate over shifting cultivation (cf. Engelmark 1989; Dennell 1992). Within the loess belt of western-central Europe (Fig. 1), hundreds of Neolithic sites have been excavated and many of them sampled for charred plant remains (for example Kreuz 1990; Knörzer 1997). The significance of charred 'weed' seeds accompanying charred crop remains as evidence of crop husbandry has long been recognised (for example Knörzer 1971a; Willerding 1983) but their usefulness for distinguishing the cultivation of shifting versus permanent fields has been limited by the lack of comparative data on modern arable weed floras developed under a shifting cultivation regime. The repeated occurrence of a narrow range of weed taxa (the so-called Bromo-Lapsanetum praehistoricum weed community) in charred crop material from LBK-Rössen sites in the Rhineland, for example, has been interpreted by Knörzer (1971a) as evidence for permanent fields, whereas Bakels (1978, p 69) has argued that such weed assemblages could reflect shifting cultivation. While more recent archaeobotanical studies of LBK and later Neolithic crop husbandry in western central Europe have tended to favour a permanent field model, the difficulty of excluding shifting cultivation based on weed evidence has also been acknowledged (Brombacher and Jacomet 1997).

Descriptions of historical shifting cultivation in Europe and North America provide few observations on the weed floras growing with crops in shifting fields. There are indications that weed growth can be severely limited by burning and/or by exuberant crop growth in the first cultivation season of a shifting regime but that weed growth increases in the second and third cultivation sea-

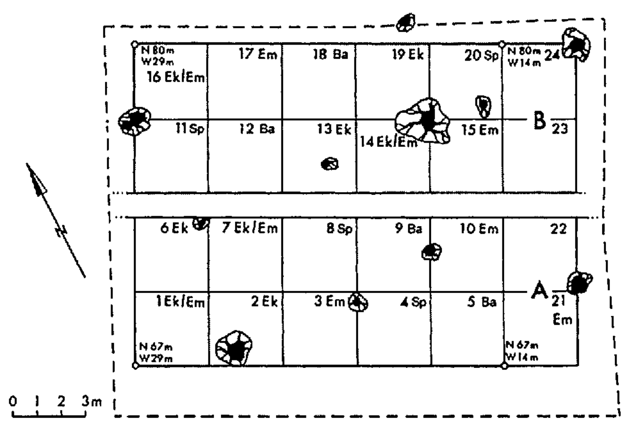

Fig. 2. The layout of experimental plots in the Hambach Forest and cereals grown on each plot (after Meurers-Balke and Lüning 1990: Fig. 2). Ba = Barley; Ek = Einkorn; Em = emmer; Sp = Spelt

Table 1. Outline of the Hambach Forest experiment from 1979-1984, showing weed surveys and soil disturbance measures

	1979	*1980*	*1981*	*1982*	*1983*	*1984*
Plots 1-10:						
Tillage prior to sowing	Hand weeding	Hand weeding	Rotavator	Rotavator	Rotavator/hoe	Rotavator
Weeding during crop growth	Hand weeding	Hand weeding	Hand weeding	-	Hand weeding/ hoeing	Hand weeding/ hoeing
Weed survey	Survey	Survey	Survey	Survey	-	Survey
Plots 11-20:						
Tillage prior to sowing	-	Ard-plough	Ard-plough	Ard-plough/hoe	Rotavator/hoe	Rotavator
Weeding during crop growth					Hand weeding/ hoeing	Hand weeding/ hoeing
Weed survey	Survey	Survey	Survey	Survey	-	Survey
Plot 21:						
Tillage prior to sowing	-	Burning	Burning	Rotavator	Rotavator/hoe	Rotavator
Weeding during crop growth					Hand weeding/ hoeing	Hand weeding/ hoeing
Weed survey	-	-	-	Survey	-	Survey

sons (Sigaut 1975, pp 18-29, 99; Engelmark 1995). Very little information is available from historical accounts on the floristic composition of these weed floras. Moreover, most of these accounts relate to coniferous woodland areas on poor soils; the weed floras of shifting cultivation in deciduous woodland may be quite different (Engelmark 1995).

A number of archaeologically-motivated experiments have included short-term cultivation of newly cleared fields in woodland areas: the Draved Forest experiment in southern Jutland, Denmark (Iversen 1956; Steensberg 1957, 1979), the Butser slash-and-burn experiment in Hampshire, England (Reynolds 1977), the Hambach Forest experiment near Cologne, Germany (Lüning and Meurers-Balke 1980; Meurers-Balke and Lüning 1990), the Chassemy experiment in the Aisne Valley, France (Firmin 1981, 1984) and the Umeå experiment in northern Sweden (Engelmark 1989, 1995; Viklund 1998, pp 27-28, 36-38). In addition, a new set of experiments was begun in 1994 near Stuttgart (Rösch 2000, Rösch et al. this volume). Of the completed experiments, the Hambach Forest experiment (Fig. 1) is particularly relevant to the interpretation of LBK and later weed assemblages in the loess regions of western-central Europe: the plots were laid out on newly-cleared, loess-based soil which had supported mixed oak woodland since early medieval times. Furthermore, the weed floras growing in experimental plots were surveyed just prior to harvest time over multiple cultivation seasons. Experimental conditions differed in some ways from those of the Neolithic, for example oak-hornbeam woodland rather than the lime-dominated woodland of the Atlantic period (Meurers-Balke and Lüning 1990). Nevertheless, the weed surveys conducted during the experiment provide comparative data of direct relevance to the interpretation of archaeobotanical weed assemblages. Three general observations on the development of the Hambach weed floras (Meurers-Balke and Lüning 1990; J. Meurers-Balke personal communication) deserve emphasis: 1. weed growth on the newly cleared soil was abundant, even by harvest time in the first cultivation season; 2. burning increased the vigour of both crop and weed growth; 3. floristically, the weed floras did not resemble the typical archaeobotanical weed assemblages known from LBK-Rössen sites in the Rhineland.

Thanks to the generosity of the scholars who conducted the Hambach experiment, the detailed weed survey data collected have been made available to the author for analysis. The aims of this analysis are to investigate how the weed floras on freshly cleared experimental plots developed over the first six years of cultivation and to compare the Hambach weed floras in ecological terms with the extensive archaeobotanical weed dataset available from Neolithic sites in the loess belt of western-central Europe. If the Hambach floras differ not only floristically but also ecologically from the archaeobotanical weed assemblages, the relevance of shifting cultivation to Neolithic farming in the loess belt should be seriously questioned.

Materials and methods

The Hambach weed survey data

The layout of experimental plots in the Hambach Forest and the cereal crops grown on each plot are shown in Fig. 2. Husbandry techniques used and the timing of weed surveys are shown in Table 1. Weed survey data were collected immediately prior to harvest time by Lohmeyer (1980; unpublished weed survey data) from 1979-1984. It should be noted that the seed corn used in the experiment was specially counted out for the calculation of seed yield ratios and thus virtually weed-free (J. Meurers-Balke personal communication). Soil disturbance measures - tillage prior to sowing and weeding during crop growth - varied over the course of the experiment, becoming more severe in response to increasing competition from weeds (Table 1). Thus, while some plots received no tillage or weeding in the first year, all plots were tilled by rotavator (rotary hoe) prior to sowing and weeded during crop growth in the last two years (Table 1). One plot (21) was burned prior to sowing for two consecutive years, followed by tillage by rotavator in subsequent years (Table 1). All surveys conducted on plots 1-21 (plots 22-24 were not surveyed) in 1979-1982 and 1984 (Table 1) were included in the

Table 2. Conversion of the cover/abundance scale used to record the weed surveys to a numerical scale

Cover/abundance scale	*Numerical scale*
v	1
r	2
+	3
I	4
II	5
III	6
IV	7

new analysis. Weed species occurring in at least 5% (five or more) of these plot surveys were included in analyses. These taxa are listed in Appendix 1. Trees and shrubs such as *Rubus* spp. were excluded because of their inability to set seed in disturbed conditions and so be harvested in seed; such taxa would not be present in archaeobotanical assemblages. Ferns and mosses were also left out because they do not produce seeds. In total, the analysis was based on 102 individual plot surveys (experimental plots surveyed in a given year) and 50 weed species. Lohmeyer (unpublished survey data) scored the weed species in each experimental plot survey on a phytosociological cover/abundance scale. In order to analyse these data, cover/abundance values were converted to a numerical scale as shown in Table 2.

Correspondence analysis was used to explore variation in the weed survey data. Like other ordination techniques, correspondence analysis arranges sites (here, experimental plots surveyed in a certain year) along axes on the basis of their species (here, their weed species) composition. CANOCO for Windows (ter Braak and Smilauer 1997-1999) was used to carry out the correspondence analysis and CANODRAW (Smilauer 1992) to plot the results. In all correspondence analysis diagrams, axis 1 was plotted horizontally and axis 2 vertically. In the correspondence analysis diagram of experimental plots, symbols were used to indicate husbandry practices. In the correspondence diagram of species, weed species were coded according to the general habitat categories (based on groupings of phytosociological classes - *Klassengruppen*) presented by Ellenberg et al. (1992). Life history information was taken from Rothmaler (1995).

Selection of archaeobotanical weed data for comparison with Hambach data

Archaeobotanical data from the loess belt (Fig. 1) were selected for consideration because of the extensive archaeobotanical dataset recovered from LBK and later Neolithic sites in the region. A review was carried out of archaeobotanical data (samples of charred plant remains) from Neolithic sites (c. 5500-2200 cal B.C. - Lüning 2000, Fig. 2) published up to and including 1999. This research was focused on the loess belt from Belgium to Hungary, Slovakia and Poland; few archaeobotanical data from Neolithic sites in the loess belt further east are available. Unpublished work by the author on archaeobotanical material from ongoing excavations at LBK Vaihingen/Enz in south-west Germany (Krause et al. 1998) was also considered. Because weed-rich samples are the most likely to give a representative picture of the original field weed floras, samples containing at least 30 charred seeds of wild/weed taxa identified to species or to small species groups (that is, containing up to three species) were selected. Samples from the same archaeological deposit which were also similar in their species composition were amalgamated so that each "sample" in the analysis represents a separate deposit or context; samples combining material from separate deposits were excluded. In some cases, original species identifications were adjusted in accordance with the accepted identifiability of the taxa concerned; thus, for example, seeds originally identified as *Rumex sanguineus* but lacking the distinctive perianth were put in the category *R. conglomeratus/sanguineus* since charred seeds of these species without the perianth cannot be reliably separated (Jacomet et al. 1989, p 303). Standardised identification categories for the "potential weed" taxa occurring in the selected archaeobotanical samples are listed in Appendix 2. The seeds of shrubs and trees unlikely to set seed in disturbed conditions (such as *Rubus* spp., *Prunus* spp.) were excluded from consideration as "weeds". General habitat category (Ellenberg et al. 1992) and life history information (Rothmaler 1995) were assembled for the "potential weed" taxa in the selected archaeobotanical samples.

A total of 262 weed-rich archaeobotanical samples from 57 Neolithic sites in the loess belt of western-central Europe were selected (Table 3). Most of the sites (46 out of 57, c. 81%) are in Germany (especially the lower Rhine, Baden-Württemberg and Bavaria); the remainder are in France (1 site), Belgium (1 site), The Netherlands (3 sites), Poland (2 sites) and Slovakia (4 sites) (Table 3). This very uneven distribution of sites with weed-rich samples reflects the uneven concentration of archaeobotanical

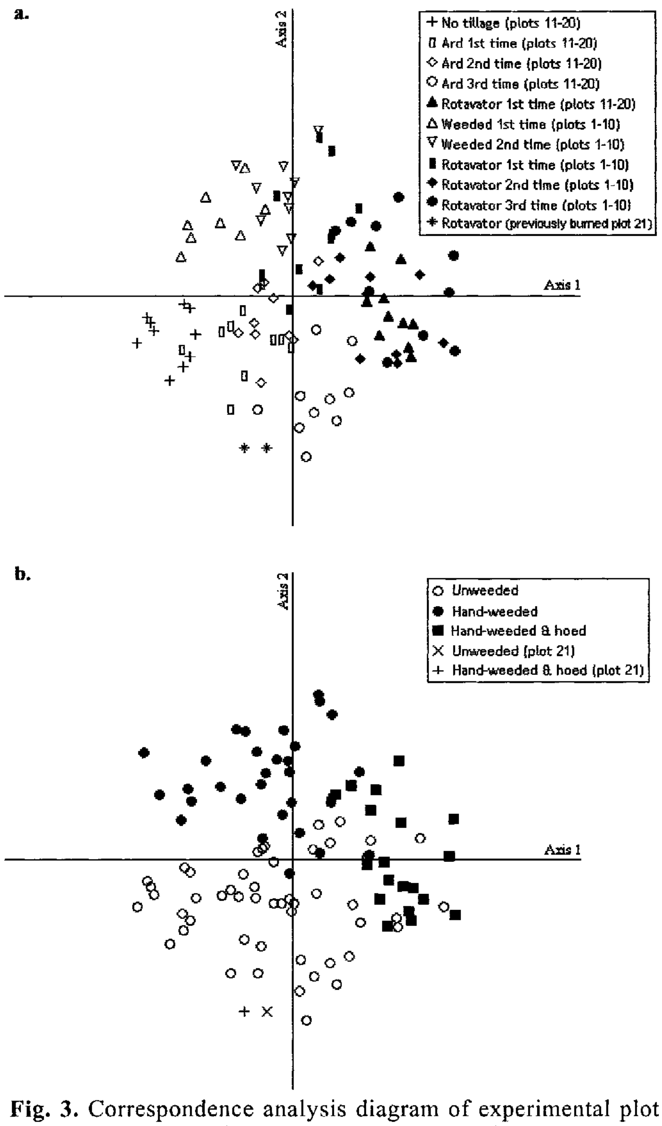

Fig. 3. Correspondence analysis diagram of experimental plot surveys coded by a, tillage method prior to sowing and b, weeding during crop growth

Table 3. The sites and samples selected. EN = early Neolithic; MN = middle Neolithic; LN = later Neolithic

Sites		Samples	
Location	**Source**	**Date**	**No.**
Belgium - Hainaut			
Aubechies	Bakels and Rouselle 1985	EN (LBK)	2
France - Aisne valley			
Villeneuve-St-Germain	Bakels 1984	MN (Villeneuve-St-Germain)	1
Germany - Baden-Württemberg			
Aldingen	Piening 1986a, 1992	LN (Schwieberdingen)	1
Ditzingen	Piening 1998	EN (LBK)	4
Ehrenstein	Hopf 1968	LN (Schussenried)	9
Endersbach	Piening 1979, 1982	MN (Großgartach)	2
Erbedingen-Hochdorf	Küster 1985	LN (Schussenried)	29
Freiburg-Geisingen	Piening 1988	LN (Schussenried)	2
Grossachsenheim	Piening 1986b	LN (Schussenried)	2
Heilbronn-Klingenberg	Stika 1996	EN (LBK), LN (Michelsberg)	2
Hilzingen	Stika 1991	EN (LBK)	6
Vaihingen/Enz	Bogaard unpublished data	EN (LBK)	58
Germany - Bavaria			
Aiterhofen	Bakels 1983/4	EN (LBK)	2
Altdorf	Bakels 1983/4	EN (LBK)	1
Enkingen	Kreuz 1990	EN (LBK)	1
Ergolding-Fischergasse	Küster 1989; Hinton 1995	LN (Altheim)	1
Galgenberg	Hinton 1999	LN (Altheim)	1
Hienheim/Donau	Bakels 1986	EN (LBK)	1
Meindling	Bakels 1992	EN (LBK)	11
Osterhofen-Schmiedorf	Küster 1995	MN (SBK/Oberlauterbach)	1
Schernau	Hopf 1981	MN (Bischheim)	1
Sengkofen „Pfatterbreite“	Hopf 1992	LN (Michelsberg)	1
Ulm-Eggingen	Gregg 1989	EN (LBK)	15
Germany - Lower Rhine			
Bedburg-Garsdorf	Knörzer 1974	EN (LBK)	4
Aldenhoven	Knörzer 1967	EN (LBK)	1
Aldenhoven 1	Knörzer 1997	MN (Rössen)	2
Hambach 260	Knörzer 1997	MN (Großgartach)	1
Inden 1	Knörzer 1997	MN (Rössen)	7
Inden 3	Knörzer 1997	MN (Rössen)	1
Köln/Mengenich	Knörzer 1967	EN (LBK)	1
Kückhoven	Knörzer 1998	EN (LBK)	2
Lamersdorf	Knörzer 1967	EN (LBK)	4
Langweiler	Knörzer 1971b	MN (Rössen)	2
Langweiler 16	Knörzer 1997	EN (LBK)	2
Langweiler 2	Knörzer 1973	EN (LBK)	1
Langweiler 3	Knörzer 1972	EN (LBK)	1
Langweiler 6	Knörzer 1972	EN (LBK)	1
Langweiler 8	Knörzer 1988	EN (LBK)	22
Langweiler 9	Knörzer 1977	EN (LBK)	5
Laurenzberg 7	Knörzer 1997	EN (LBK)	9
Laurenzberg 8	Knörzer 1997	EN (LBK)	4
Meckenheim/Bonn	Knörzer 1967	EN (LBK)	2
Rödingen	Knörzer 1967	EN (LBK)	2
Wanlo/Wickerath	Knörzer 1980	EN (LBK)	3
Germany - Lower Saxony			
Göttingen-Kleiner Hagen	Meyer and Willerding 1961; Willerding 1969	EN (LBK)	1
Lietfeld	Hopf 1957	LN (Bernburg)	1
Germany - Mosel valley			
Siebenborn „Vor Tonguich“	Bakels 1993	EN (LBK)	3
Germany - South Hessen			
Bruchenbrücken	Kreuz 1990	EN (LBK)	4
The Netherlands - Limburg			
Beek (Southern Limburg)	Bakels 1978, 1979; Bakels and Rouselle 1985	EN (LBK)	5
Geleen (Haesselderveld)	Bakels 1979; Bakels and Rouselle 1985	EN (LBK)	2
Maastricht-Randwijck	Bakels et al. 1990	MN (Rössen)	4
Poland - South (Krakow)			
Iwanowice-Klin	Litynska 1990	MN (Lengyel)	1
Mogiła 62	Gluza 1971, 1983; Gluza et al. 1988	MN (Lengyel)	2
Slovakia - South			
Blatné	Hajnalová 1988, 1989	EN (LBK)	2
Kamenin	Hajnalová 1989	LN (Baden)	1
Štúrovo	Hajnalová 1975, 1983	EN (LBK)	1
Svodín	Hajnalová 1986	MN (Lengyel), LN (Baden)	4

research in western-central Europe (Modderman 1988). Most of the sites are located on or near (c. <0.5 km) loess-based soil. Following the broad chronological divisions of the Neolithic in Lüning (2000, Fig. 2), most of the weed-rich samples (185 out of 262, c. 71%) date to the early Neolithic (LBK, c. 5500-5000 cal B.C.); c. 11% (29 out of 262) to the middle Neolithic (Rössen/Lengyel, c. 5000-4400 cal B.C.) and c. 18% (48 out of 262) to the later Neolithic (*Jungneolithikum* and *Spätneolithikum*, c. 4400-2800 cal B.C.) (none of the samples date to the final period, *Endneolithikum*) (see also Table 3).

The selected archaeobotanical samples were analysed to determine the crop processing stage(s) from which they derive as part of doctoral research by the author. About half of the samples appear to represent unmixed by-products and products of crop processing, while the remaining samples are of more mixed or ambiguous origin. In analyses of the archaeobotanical data presented here, all of the samples were included because the results were very similar when only unmixed samples were analysed. It should be noted, however, that the reconstruction of other aspects of crop husbandry, such as crop sowing time, is affected by the processing status of samples and so requires unmixed by-products and products.

Results and discussion

The impact of different husbandry measures on the Hambach weed floras

As noted above, the methods used to till experimental plots prior to sowing became increasingly severe over the course of the experiment, from no tillage or tillage by weeding only in 1979 through to tillage by rotavator in later years (Table 1). In Fig. 3a, data points representing experimental plots are shown distributed along correspondence axes 1 (horizontal) and 2 (vertical), with symbols indicating method of tillage. A clear horizontal trend is evident, from no tillage (+ signs) or tillage by weeding (open triangles) towards the negative (left) end of axis 1, through tillage by ard (open rectangles, diamonds and circles) in an intermediate position to tillage by rotavator (filled symbols) at the positive (right) end. Thus, the spread of points along axis 1 appears to represent a trend in tillage method, with increasing severity of soil disturbance from left to right. In addition, axis 1 seems to reflect the cumulative effect of tillage methods over time. Thus, plots tilled by weeding for the first time occur closer to the negative (left) end of axis 1 than the same plots tilled by weeding for the second time. Similarly, plots which were ard-ploughed for three consecutive years tend to be arranged sequentially along axis 1; such a trend is less evident among the plots tilled by rotavator for three years. Axis 1, therefore, appears to reflect increasingly severe tillage methods from left to right, the effect of most methods becoming more extreme when repeated through time. The major exceptions to the tillage trend along axis 1 are the surveys of plot 21 (asterisks in Fig. 3a); this plot was tilled by rotavator in both survey years but had previously been burned prior to sowing (see Table 1).

In Fig. 3b, symbols indicate whether or not plots were weeded (by hand or hand plus hoe) during the crop growing season, and weeded and unweeded plots are clearly separated on axis 2. The separation becomes less clear towards the positive (right) end of axis 1, suggesting that the additional impact of weeding during the crop growing season becomes less marked as tillage method becomes increasingly severe (cf. Jones et al. 1999). A partial separation of hoed and unhoed plots is also seen along axis 1 but this pattern may be an artifact of the association between hoeing and tillage by rotavator (Table 1). The exceptions to the patterning along axis 2 are again the surveys of plot 21. This plot was weeded in one survey year (+ sign) but this plot survey occurs at the extreme negative (bottom) end of axis 2 with the unweeded plots.

To summarise, it appears that axis 1 reflects a trend in the severity of pre-sowing disturbance (tillage) whereas axis 2 relates to disturbance during the crop growing season (weeding). The surveys of plot 21 (burned in 1980-1981), however, do not conform to the tillage trend on axis 1 or to the weeding trend on axis 2 (Figs. 3a-b). Field notes gathered during the experiment (J. Meurers-Balke personal communication) suggest that the release of nutrients by burning had a positive effect on crop and weeds alike, causing both to grow more vigorously on burned plots. The implication of these observations and of the position of plot 21 surveys in the correspondence analysis diagram (Figs. 3a-b) is that burning reduced the effectiveness of disturbance measures (tillage and weeding).

No other husbandry variables (such as type of cereal grown - diagrams not shown) showed any clear relationship with axes 1 and 2.

The development of the weed floras

In Fig. 4, data points representing experimental plots are shown as pie charts indicating the relative proportions of annual and perennial weed taxa present in each plot. It is evident that these proportions do not tend to change along either axis; throughout, plots are dominated by perennial weeds. In fact, based on all taxa in each plot survey (except trees, shrubs, ferns and mosses — see materials and methods section, above), the percentage of perennial weeds ranges from 57 to 100% (average 80%). Despite increasingly severe disturbance measures, therefore, conditions in the Hambach experimental plots remained favour-

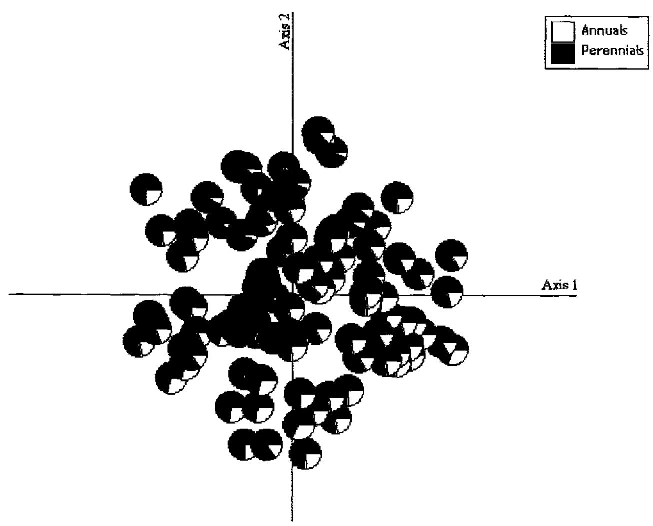

Fig. 4. Correspondence analysis diagram of experimental plot surveys showing proportions of annual and perennial weed species present

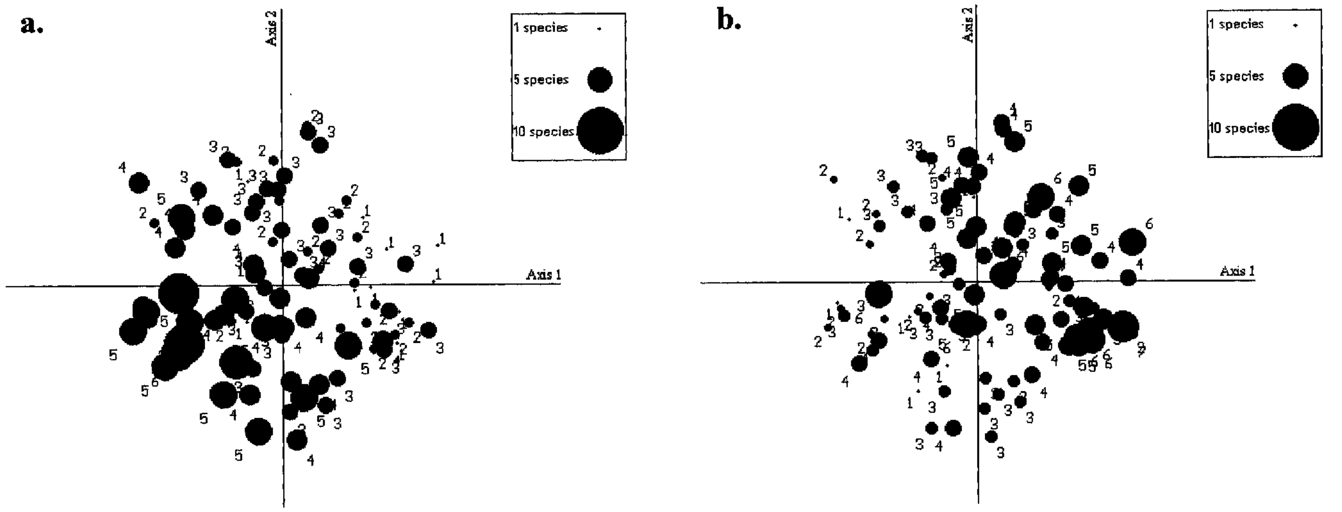

Fig. 5. Correspondence analysis diagram of experimental plot surveys showing numbers of a, perennial species of woodland and b, perennial species of disturbed habitats present.

able for perennials throughout the six-year period covered by the surveys. Annuals were able to colonise the plots from the first cultivation season onwards but were always outnumbered by perennials.

Whereas the proportions of annual and perennial weeds present in experimental plots do not appear to reflect variable levels of soil disturbance (tillage and weeding), trends are evident in the presence of perennials from different habitats. In Fig. 5, the size of points illustrates the number of woodland perennial taxa (Fig. 5a) or perennial taxa from disturbed habitats (Fig. 5b) present in each experimental plot survey; this number is also shown adjacent to each point. In Fig. 5a, woodland perennials are seen to be most numerous in plots of the bottom left quadrant, which received the least soil disturbance (no tillage or light tillage by ard and no weeding during crop growth - Fig. 3). The lowest numbers of woodland perennials occur in plots of the top right quadrant, which received the most soil disturbance (tilled by rotavator, with hand weeding or hand weeding plus hoeing during crop growth - Fig. 3). In terms of the number of woodland perennials per plot, therefore, the trend appears diagonal, decreasing from bottom left to top right. Fig. 5b, illustrating the number of perennials from disturbed habitats, such as pioneer, ruderal and arable ones, present per plot survey, shows a diagonal trend in the opposite direction, with numbers tending to increase from bottom left to top right, so from the least to most disturbed plots.

Trends in the presence of *annual* weeds from woodland versus disturbed habitats are less clear. Only one woodland annual species (*Moehringia trinervia*) occurred in the experimental plots, though, like the woodland perennials, it is particularly associated with the lowest levels of soil disturbance (diagram not shown). The remaining annual species - all of more or less disturbed habitats - do not show any clear trend in relation to disturbance level (diagram not shown). The appearance of annuals from non-woodland habitats in experimental plots during the first cultivation season was particularly noted by Lohmeyer (1980). These annuals were absent from the woodland flora prior to clearance and were probably brought to the experimental area on car tyres, shoes etc. (Lohmeyer 1980); as noted above, no weed seeds were present in the seed corn.

Discussion of Hambach results

Correspondence analysis of the weed survey data has demonstrated that the weed floras of newly cleared plots receiving low-level soil disturbance, that is no/light tillage and no weeding, are rich in perennial taxa, particularly woodland perennials. The latter could regenerate from roots/rhizomes in the soil or from the local seed bank or recolonise the cleared ground from adjacent woodland areas. Recently cleared plots receiving higher levels of disturbance are also dominated by perennial weeds but are characterised particularly by perennials of disturbed habitats. These may also derive, at least partly, from the local flora including the seed bank; Ellenberg (1996, p 768) has noted that the seeds of perennials from non-woodland habitats are often present in woodland areas on the soil surface or in the seed bank and germinate following clearance. Annuals occur at low levels in relatively undisturbed and highly disturbed plots alike and derive partly from the local woodland flora but mostly from highly disturbed anthropogenic habitats elsewhere (brought in on shoes etc.). In a shifting cultivation regime, with little or no tillage and weeding, it appears that the weed flora would be dominated by perennials, including woodland perennials, though possibly with some non-woodland annuals present (that is, brought in from other anthropogenic habitats, possibly via the seed corn). This outline of the weed flora associated with shifting cultivation agrees with general observations from other experiments on the weed floras in newly cleared and burned fields (Engelmark 1995; Rösch 2000). The least predictable influence on these floras is the proximity and character of non-woodland habitats from which plants could colonise plots, including any weed seeds in the seed corn (cf. Dierschke 1988; Engelmark 1989). The most predictable influence is the

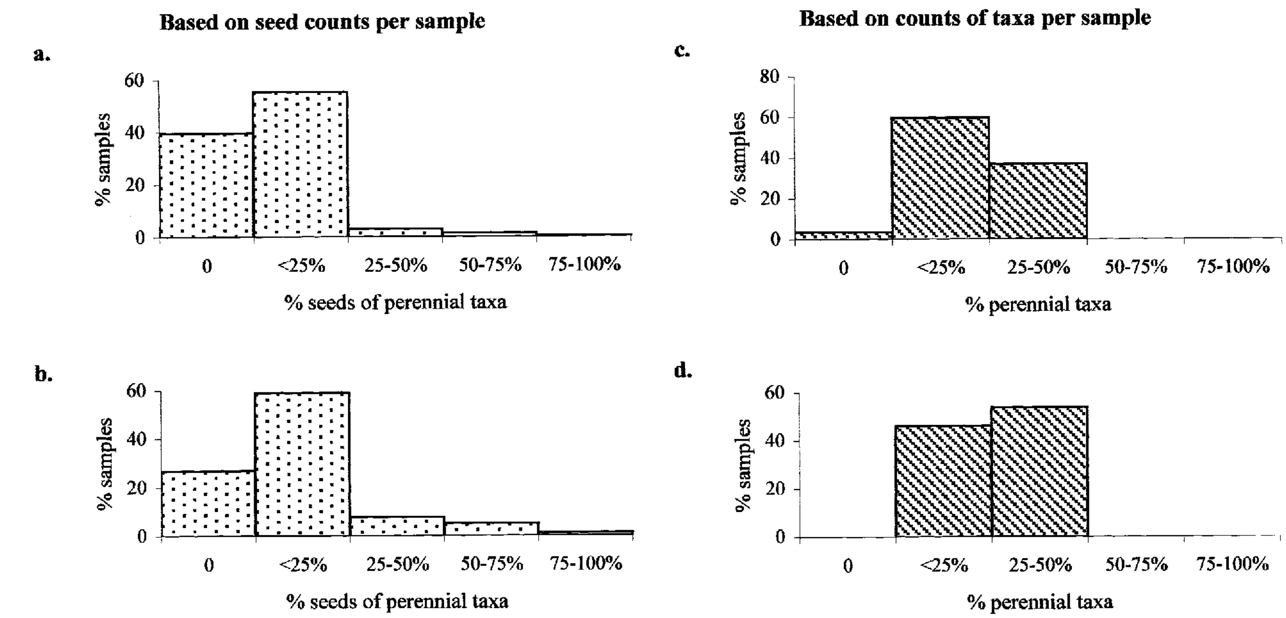

Fig. 6. Histograms showing proportions of perennial "weeds" in the archaeobotanical samples: a, all weed-rich samples (n=262); b, samples containing at least 30 weed seeds after the removal of *Chenopodium album* (n=156); c, weed-rich samples containing at least 10 weed taxa (n=57); d, samples containing at least 30 weed seeds and 10 weed taxa after the removal of *C. album* (n=39)

local woodland flora itself since, by definition, cultivation areas in a shifting cultivation regime are newly cleared of woodland (Dennell 1978, p 37).

While this general model of a weed flora dominated by perennials, including woodland perennials, is readily applicable to archaeobotanical data, there are two caveats. First, in order to be "visible" archaeobotanically, weeds must set seed and their seeds must be harvested with the crop. Perennial plants regenerating from seed or roots/rhizomes after clearance and burning, however, would vary in their ability to set seed in the first cultivation season after clearance. Indeed, the weed survey data from the Hambach experiment (Lohmeyer 1980; unpublished survey notes) suggest that trees and woody shrubs such as *Rubus* remained vegetative throughout the experiment; for this reason, they were excluded from the correspondence analysis (see materials and methods, above). Data on the length of the "pre-reproduction period" of herbaceous perennials are few but it is clear that some - including woodland perennials such as *Epilobium montanum* (Grime et al. 1988, p 246; cf. Ellenberg 1996, p 768) - can set seed within a few months of germination. Other newly germinated biennial/perennial species normally require at least a year of vegetative growth before they flower and set seed (such as *Cirsium* spp. - Grime et al. 1988, pp 198, 200). The archaeobotanical "visibility" of perennial weeds, therefore, would tend to increase in the second and later cultivation seasons of a shifting cultivation regime (cf. Steensberg 1979, p 23; Engelmark 1995; Rösch 2000). Assuming that prehistoric shifting cultivation allowed more than one cultivation season in newly cleared areas, as suggested by Reynolds (1977) based on the Butser slash-and-burn experiment and attested in many accounts of historical shifting cultivation in Europe (for example Sigaut 1975, pp 121-124; Steensberg 1993, pp 98-153), an abundance of perennials weeds ought to register archaeobotanically. A second and related complication is the severity of burning on newly cleared plots. Very intensive burning of the soil surface could potentially lead to virtual sterilisation of the soil (Ellenberg 1996, p 709), whereas less severe burning, as in the Hambach experiment, increases the vigour of crop and weed growth alike. A similar "positive" effect on weed growth has been observed to result from stubble burning in East Anglia (Evans 1969, p 20). Clearly, the effects of burning on weed growth could have been variable in the past, sometimes resulting perhaps in virtually 'weedless' harvests, in other cases leading to abundant weed growth. In summary, it seems reasonable to expect that widespread shifting cultivation in the Neolithic would have left some definite evidence behind in archaeobotanical weed assemblages, namely an abundance of perennial weeds, including woodland perennials.

Comparison of Hambach weed floras with archaeobotanical weed assemblages

Fig. 6a summarises the proportions of perennial 'weed' taxa in the archaeobotanical samples based on seed counts. Fig. 6b shows these proportions in samples containing at least 30 weed seeds after the removal of *Chenopodium album* - an annual species which appears to have been collected separately at some Neolithic sites and so may not always represent an arable weed harvested with crops (Knörzer 1967, 1988; Bakels 1979, 1983/4). Figs. 6a and b show very similar results: most samples contain only annual taxa or are dominated by annual taxa. A very small proportion of samples (ca. 2% in Fig. 6a,c, 6% in Fig. 6b) contain at least 50% perennial taxa. Fig. 6c,d shows proportions of perennial taxa present in samples containing at least 10 weed taxa in total. No samples in Fig. 6c,d contains 50% or more perennial taxa. In contrast to the proportions of perennials in the Hambach experi-

Table 4. Woodland species in the archaeobotanical samples. EN = early Neolithic; MN = middle Neolithic; LN = later Neolithic; TS = Total samples

Site Sample date	Aldenhoven 1 MN (Rössen)	Bedburg-Garsdorf EN (LBK)	Inden 3 MN (Rössen)	Langweiler EN (LBK)	Lietfeld LN (Bernburg)	Schernau MN (Bischheim)	TS
Woodland perennials							
Brachypodium sylvaticum	-	-	-	-	-	1	1
Stachys sylvatica	1	1	1	-	-	-	3
Stellaria holostea	-	-	-	-	1	-	1
Woodland annual							
Moehringia trinervia	-	-	-	1	-	-	1

mental plots (57%-100% of weed species present), therefore, the archaeobotanical samples appear richer in annual taxa.

As noted above, there may be a tendency for perennial weeds to be under-represented archaeobotanically, especially in the first cultivation year after clearance, since seed set may be delayed in some taxa. Even if a minority of perennial taxa in a sample were accepted as compatible with shifting cultivation, however, woodland perennials are extremely rare in the archaeobotanical samples. Only three woodland perennial species occur in a total of only five samples (c. 2 % of the total 262) (Table 4). The extreme rarity of woodland perennials *per se* is unlikely to be due to slow perennial seed set since there should be no particular bias against seed set in these perennials as opposed to perennials from other habitats. In contrast to the Hambach experimental plots receiving little soil disturbance, which tended to contain c. 3-6 woodland perennial species each (Fig. 5a), the five archaeobotanical samples each contain only one woodland perennial species (Table 4). Furthermore, none of these samples contains 50% or more perennials (based on either seed counts or counts of taxa).

A sixth sample contains a woodland annual species (*Moehringia trinervia* - Table 4) but, like the five samples containing woodland perennials, this sample is not dominated by perennial taxa. Though the general rarity of woodland annuals in the European flora (only a few are listed in Ellenberg et al. 1992) may explain the uniqueness of *M. trinervia* in both the Hambach experiment and the archaeobotanical samples, it does not explain the rarity of its seeds in archaeobotanical samples. Furthermore, because of their annual life-cycle, the rarity of these woodland taxa in the archaeobotanical samples cannot be explained by slow seed set.

Conclusions

The dominance of annual weeds and rarity of woodland taxa (in particular the rarity of woodland perennials) in the archaeobotanical samples under consideration strongly suggests that they do not derive from newly cleared fields as managed in a shifting cultivation regime, and that fallow periods, if used, were not long enough for woodland vegetation to re-establish itself. Even the few samples containing woodland taxa are not very convincing as evidence of shifting cultivation and could, in any case, reflect early phases in the establishment of "new" permanent fields. Indeed, even in the absence of widespread shifting cultivation, it is remarkable that such cases are so rarely represented.

Regardless of the possibly indigenous, "Mesolithic" heritage of early farmers in the loess belt of western central Europe, the clear implication of this study is that Neolithic crop fields were "fixed" in the landscape and that cultivated ground was carefully maintained and preserved for long periods of time. Similar views have recently been put forward on the basis of archaeobotanical weed data from lakeshore sites around the Alps (for example, Jacomet et al. 1989; Brombacher and Jacomet 1997; Maier 1999) and from Scandinavia (Engelmark 1995), areas where the "indigenous context" of early farming is widely accepted (for example Bogucki 1996). Based on this archaeological evidence, different forms of "fixed field" agriculture - including high-yielding cultivation of cereals on a garden scale (Charles et al. 2002) - deserve serious consideration through the development of analogies between archaeobotanical weed data and modern weed floras developed under known conditions. Further work on the ecological interpretation of archaeobotanical weed data (for instance, by application of the FIBS method - Charles et al. 1997, 2002; Bogaard et al. 1999, 2000, 2001; Jones et al. 2000) should permit a more detailed analysis of Neolithic husbandry practices and their social and economic implications.

Acknowledgements. I would like to thank W. Lohmeyer, J. Lüning and J. Meurers-Balke for the opportunity to analyse unpublished data from the Hambach Forest experiment; Mike Charles, Stefanie Jacomet, Glynis Jones and an anonymous reviewer for helpful comments on the manuscript; and Mia Broné for translation of Swedish text. This paper includes results from PhD research supported by a Social Sciences and Humanities Research Council of Canada Doctoral Fellowship, an Overseas Research Scholarship and the University of Sheffield.

References

Andersen ST (1993) Early- and middle-Neolithic agriculture in Denmark: pollen spectra from soils in burial mounds of the Funnel Beaker Culture. Journal of European Archaeology 1: 153-180

Bakels CC (1978) Four Linearbandkeramik settlements and their environment: a palaeoecological study of Sittard, Stein, Elsloo and Hienheim. Analacta Praehistorica Leidensia 11

Bakels CC (1979) Linearbandkeramische Früchte und Samen aus den Niederlanden. Archaeo-Physika 8: 1-10
Bakels CC (1983/4) Pflanzenreste aus Niederbayern - Beobachtungen in rezenten Ausgrabungen. Berichte der bayerischen Bodendenkmalpflege 24/25: 157-166
Bakels CC (1984) Carbonized seeds from northern France. Analecta Praehistorica Leidensia 17: 1-27
Bakels CC (1986) Früchte und Samen. In: Modderman PJR (ed) Die neolithische Besiedlung bei Hienheim, Lkr. Hienheim II-IV. Materialhefte zur Bayerischen Vorgeschichte A 57, pp 68-75
Bakels CC (1992) Fruits and seeds from the Linearbandkeramik settlement at Meindling, Germany, with special reference to Papaver somniferum. Analecta Praehistorica Leidensia 25: 55-68
Bakels CC (1993) Maring-Noviand, Siebenborn "Vor Tonguich", eine linearbandkeramische Siedlung mit Linsen. In: Schmidgen-Hager E (ed) Bandkeramik im Moseltal. Habelt, Bonn, pp 186-187
Bakels CC, Alkemade MJ, Vermeeren CE (1990) Botanische Untersuchungen in der rössener Siedlung Maastricht-Randwijck. In: Kalis AJ, Meurers-Balke J (eds) 7000 Jahre bäuerliche Landschaft: Entstehung, Erforschung, Erhaltung. Zwanzig Aufsätze zu Ehren von Karl-Heinz Knörzer. Rheinland-Verlag, Köln, pp 35-48
Bakels CC, Rouselle R (1985) Restes botaniques et agriculture de neolithique ancien en Belgique at aux Pays-Bas. Helinium 25: 37-55
Barrett JC (1994) Fragments from antiquity: an archaeology of social life in Britain (2900-1200 B.C.). Blackwell, Oxford
Barrett JC (1999) Rethinking the bronze age environment. In: Edwards KJ, Sadler JP (eds) Holocene environments of prehistoric Britain. Quaternary Proceedings 7: 493-500
Beranová M (1987) Zur Frage des Systems der Landwirtschaft im Neolithikum und Äneolithikum in Mitteleuropa. Archeologické rozhledy 39: 141-198
Beranová M (1989) On the problems of plant production and subsistence in the Neolithic and Eneolithic. In: Rulf J (ed) Bylany Seminar 1987 - Collected Papers. Prague, pp 273-277
Bogaard A, Palmer C, Charles M, Jones G, Hodgson JG (1999) A FIBS approach to the use of weed ecology for the archaeobotanical recognition of crop rotation regimes. Journal of Archaeological Science 26: 1211-1224
Bogaard A, Jones G, Charles M, Halstead P (2000) The scale and intensity of cultivation: evidence from weed ecology. In: Halstead P, Frederick C (eds) Landscape and land use in postglacial Greece. Sheffield Academic Press, Sheffield, pp 129-134
Bogaard A, Jones G, Charles M, Hodgson JG (2001) On the archaeobotanical inference of crop sowing time using the FIBS method. Journal of Archaeological Science 28: 1171-1183
Bogucki P (1988) Forest farmers and stockherders. Cambridge University Press, Cambridge
Bogucki P (1996) The spread of early farming in Europe. American Scientist 84: 242-253
Braak CJF ter, Smilauer P (1997-1999) CANOCO for Windows version 4.02. Centre for Biometry, Wageningen, NL
Brombacher C, Jacomet S (1997) Ackerbau, Sammelwirtschaft und Umwelt: Ergebnisse archäobotanischer Untersuchungen. In: Ökonomie und Ökologie neolithischer und bronzezeitlicher Ufersiedlungen am Zürichsee. Zürich und Egg, Zürich, pp 220-291
Charles MP, Bogaard A, Jones G, Hodgson J and Halstead P (2002) Towards the archaeobotanical identification of intensive cereal cultivation: present-day ecological investigations in the mountains of Asturias, NW Spain. Vegetation History and Archaeobotany 11: this volume
Charles M, Jones G, Hodgson JG (1997) FIBS in archaeobotany: functional interpretation of weed floras in relation to husbandry practices. Journal of Archaeological Science 24: 1151-1161
Childe VG (1929) The Danube in prehistory. Clarendon, Oxford
Childe VG (1957) The dawn of European civilization. Routledge, London
Clark JGD (1952) Prehistoric Europe: the economic basis. Methuen, London
Dennell R (1978) Early farming in south Bulgaria from the VI to the III millennia B.C. British Archaeological Reports (International Series) (Supplementary) 45
Dennell RW (1992) The origins of crop agriculture in Europe. In: Cowan CW, Watson PJ (eds) The origins of agriculture. Smithsonian Institution, London, pp 71-100
Dierschke H (1988) Pflanzensoziologische und ökologische Untersuchungen in Wäldern Süd-Niedersachsens IV. Vegetationsentwicklung auf langfristigen Dauerflächen von Buchenwald-Kahlschlägen. Tuexenia: 207-326
Ellenberg H (1996) Vegetation Mitteleuropas mit den Alpen in ökologischer, dynamischer und historischer Sicht. Ulmer, Stuttgart
Ellenberg H, Weber HE, Düll R, Wirth V, Werner W, Paulissen D (1992) Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica 18: 1-258
Engelmark R (1989) Weed-seeds in archaeological deposits: models, experiments and interpretations. In: Larsson TB, Lundmark H (eds) Approaches to Swedish prehistory. British Archaeological Reports (International Series) 500, pp 179-187
Engelmark R (1995) Experiments concerning prehistoric slash-and-burn agriculture (in Swedish with English summary). In: Larsson B (ed) Svedjebruk och röjningsbränning i Norden - terminologi, datering, metoder. Nordiska museet, Stockholm, pp 28-36
Evans G (1969) The farm and the village. Faber and Faber, London
Firmin G (1981) Une expérience d'agriculture de néolithique dans la vallée de l'Aisne. Les fouilles protohistoriques dans la vallée de l'Aisne 9: 361-384
Firmin G (1984) Agriculture expérimentale dans la vallée de l'Aisne. Revue archaéologique de Picardie 1-2: 95-102
Gluza I (1971) Neolithic plant remains from Kraków, Poland. Acta Museorum Agriculturae 6: 37-42
Gluza I (1983) Neolithic cereals and weeds from the locality of the Lengyel Culture at Nowa Huta-Mogiła near Cracow. Acta Palaeobotanica 23: 123-184
Gluza I, Tomczyńska Z, Wasylikowa K (1988) Uwagi o użytkowaniu drewna w neolicie na podstawie analizy węgli drzewnych ze stanowisk archeologicznych w Krakowie - Nowej Hucie (Remarks on the use of wood in the Neolithic based on the analysis of charcoals from archaeological sites in Kraków-Nowa Huta, in Polish with English summary). Materiały Archeologiczne Nowej Huty 12: 1-19
Godłowska M, Kozłowski JK, Starkel L, Wasylikowa K (1987) Neolithic settlement at Pleszów and changes in the natural environment in the Vistula valley. Przegląd Archeologiczny 34: 133-159
Göransson H (1988) Neolithic man and the forest environment around Alvastra pile dwelling. Lund University Press, Lund
Gregg SA (1989) Paleo-Ethnobotany of the Bandkeramik phases. In: Kind C-J (ed) Ulm-Eggingen: Die Ausgrabungen 1982 bis 1985 in der bandkeramischen Siedlung und der mittlalterischen Wüstung. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 34: 367-399
Grigg DB (1974) The agricultural systems of the world: an evolutionary approach. Cambridge University Press, Cambridge
Grime JP, Hodgson JG, Hunt R (1988) Comparative plant ecology: a functional approach to common British species. Unwin Hyman, London
Hajnalová E (1975) Archeologické nálezy kultúrnych rastlín a burinna Slovensku (Archäologische Funde von Kulturpflanzen und Unkräutern im Gebiet der Slowakei, in Slovak with German summary). Slovenská Archeologiá 23: 227-254
Hajnalová E (1983) Paleobotanické neolitické nálezy zo Štúrova (Paläobotanische Funde aus dem Neolithikum in Šturovo, in Slovak with Germany summary). Slovenská Archeologiá 31: 199-218

Hajnalová E (1986) Paläobotanische Reste aus Svodín. Slovenská Archeologiá 34: 177-184
Hajnalová E (1988) Analýza a hodnotenie rastlinných zvyškov z neolitickych objektov v Blatnom (Analyse und Bewertung der Pflanzenreste aus neolithischen Objekten in Blatné, in Slovak with German summary). Študijne Zvesti Archeologického Ústavu Slovenskej Akademie Vied 24: 11-28
Hajnalová E (1989) Katalóg svyškov semien a plodov v archeologických nálezoch na Slovensku (Catalogue of seed and fruit remains from archaeological finds in Slovakia, in Slovak with English summary). Acta Interdisciplinaria Archeologica 6: 3-192
Hinton P (1995) Die pflanzlichen Überreste. In: Ottaway BS (ed) Ergolding, Fischergasse - eine Feuchtbodensiedlung der Altheimer Kultur in Niederbayern. Materialhefte zur Bayerischen Vorgeschichte A68, pp 170-192
Hinton P (1999) Charred fruits and seeds. In: Ottaway BS (ed) A changing place: the Galgenberg in Lower Bavaria from the fifth to the first millennium B.C. British Archaeological Reports (International Series) 752: 227-235
Hopf M (1957) Botanik und Vorgeschichte. Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz 4: 1-22
Hopf M (1968) Früchte und Samen. In: Zürn HA (ed) Das jungsteinzeitliche Dorf Ehrenstein (Kreis Ulm). Veröffentlichungen des Staatlichen Amtes für Denkmalpflege Stuttgart, Reihe A, Vor- und Frühgeschichte 10/11, pp 7-77
Hopf M (1981) Die Pflanzenreste aus Schernau, Ldkrs. Kitzingen. In: Lüning J (ed) Eine Siedlung der mittelneolithischen Gruppe Bischeim in Schernau, Ldkrs. Kitzingen. Materialhefte zur bayerischen Vorgeschichte 44, 152-206
Hopf M (1992) Botanische Auswertung einer Sedimentprobe aus der Grube der Michelsberger Kultur in Sengkofen, Lkr. Regensburg. In: Matuschick I (ed) Sengkofen "Pfatterbreite", eine Fundstelle der Michelsberger Kultur im östlichen Alpenvorland. Bayerische Vorgeschichtsblätter 57: 30-31
Iversen J (1941) Land occupation in Denmark's Stone Age. Danmarks Geologiske Undersøgelse, Række II, 66: 1-68
Iversen J (1956) Forest clearance in the Stone Age. Scientific American 194: 36-41
Jacomet S, Brombacher C, Dick M (1989) Archaeobotanik am Zürichsee - Ackerbau, Sammelwirtschaft und Umwelt von neolithischen und bronzezeitlichen Seeufersiedlungen im Raum Zürich: Ergebnisse von Untersuchungen pflanzlicher Makroreste der Jahre 1979-1988. Orell Füssli, Zürich
Jones G, Bogaard A, Halstead P, Charles M, Smith H (1999) Identifying the intensity of crop husbandry practices on the basis of weed floras. Annual of the British School at Athens 94: 167-189
Jones G, Bogaard A, Charles M, Hodgson JG (2000) Distinguishing the effects of agricultural practices relating to fertility and disturbance: a functional ecological approach in archaeobotany. Journal of Archaeological Science 27: 1073-1084
Kalis AJ, Meurers-Balke J (1997) Landnutzung im Neolithikum. In: Richter J (ed) Neolithikum, Geschichtlicher Atlas der Rheinlande II/2.1-2.2. Rheinland-Verlag, Köln, pp 25-55
Kalis AJ, Meurers-Balke J (1998) Die "Landnam"-Modelle von Iversen und Troels-Smith zur Neolithisierung des westlichen Ostseegebietes - ein Versuch ihrer Aktualisierung. Praehistorische Zeitschrift 73: 1-24
Knörzer K-H (1967) Subfossile Pflanzenreste von bandkeramischen Fundstellen im Rheinland. Archaeo-Physika 2: 3-29
Knörzer K-H (1971a) Urgeschichtliche Unkräuter im Rheinland: ein Beitrag zur Entstehungsgeschichte der Segetalgesellschaften. Vegetatio 23: 89-111
Knörzer K-H (1971b) Pflanzliche Großreste aus der rössenerzeitlichen Siedlung bei Langweiler, Kreis Jülich. Bonner Jahrbücher 171: 9-33
Knörzer K-H (1972) Subfossile Pflanzenreste aus der bandkeramischen Siedlung Langweiler 3 und 6, Kreis Jülich, und ein urnenfelderzeitlicher Getreidefund innerhalb dieser Siedlung. Bonner Jahrbücher 172: 395-403
Knörzer K-H (1973) Pflanzliche Großreste. Rheinische Ausgrabungen 13: 139-152
Knörzer K-H (1974) Bandkeramische Pflanzenfunde von Bedburg-Gasdorf, Kreis Bergheim/Erft. Rheinische Ausgrabungen 15: 173-192
Knörzer K-H (1977) Pflanzliche Großreste des bandkeramischen Siedlungsplatzes Langweiler 9. Rheinische Ausgrabungen 18: 279-303
Knörzer K-H (1980) Pflanzliche Großreste des bandkeramischen Siedlungsplatzes Wanlo (Stadt Mönchengladbach). Archaeo-Physika 7: 7-20
Knörzer K-H (1988) Untersuchungen der Früchte und Samen. In: Boelicke U, Brandt D von, Lüning J, Stehli P, Zimmerman A (eds) Der bandkeramische Siedlungsplatz Langweiler 8, Gemeinde Aldenhoven, Kreis Düren. Rheinland-Verlag, Köln, pp 813-852
Knörzer K-H (1997) Botanische Untersuchung von 16 neolithischen Siedlungsplätzen im Bereich der Aldenhovener Platte, Kr. Düren und Aachen. In: Lüning J (ed) Studien zur neolithischen Besiedlung der Aldenhovener Platte und ihrer Umgebung. Rheinland-Verlag, Köln, pp 647-684
Knörzer K-H (1998) Botanische Untersuchungen am bandkeramischen Brunnen von Erkelenz-Kückhoven. In: Koschik H (ed) Brunnen der Jungsteinzeit. Rheinland-Verlag, Köln, pp 229-246
Krause R, Arbogast R, Hönscheidt S, Lienemann J, Papadopoulos S, Rösch M, Sidéra I, Smettan HW, Strien H-C, Welge K (1998) Die bandkeramischen Siedlungsgrabungen bei Vaihingen an der Enz, Kreis Ludwigsburg (Baden-Württemberg). Berichte der Römisch-Germanischen Kommission 79: 7-105
Kreuz A (1990) Die ersten Bauern Mitteleuropas - eine archäobotanische Untersuchung zur Umwelt und Landwirtschaft der Ältesten Bandkeramik. Analecta Praehistorica Leidensia 23
Kruk J (1973) Studies on the Neolithic settlement of the loess uplands (in Polish with English summary). Polska Akademia Nauk, Instytut Historii Kultury Materialnej, Warsaw
Kruk J (1980) The Neolithic settlement of Southern Poland. British Archaeological Reports (International Series) 93
Kruk J (1988) Zur Wirtschaft der Jungsteinzeit auf den Lössanhöhen des Oberweichselgebietes. Slovenska Archeologia 36: 141-151
Küster HJ (1985) Neolithische Pflanzenreste aus Hochdorf, Gemeinde Eberdingen (Kreis Ludwigsburg). In Küster H, Körber-Grohne U (eds) Hochdorf I. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 19: 13-83
Küster HJ (1989) Pflanzenreste in spätneolithischen Siedlungsschichten von Ergolding-Fischergasse, Lkr. Landshut. In: Schmotz K (ed) Vorträge des 7. niederbayerischen Archäologentages. Deggendorf, pp 17-27
Küster HJ (1995) Postglaziale Vegetationsgeschichte Südbayerns. Akademie, Berlin
Larsson B (1995) Slash and burn agriculture in the North - terminology, dating, methods (in Swedish with English summaries). Nordiska museet, Stockholm
Lityñska M (1990) Cereals and weeds from a Neolithic site at Iwanowice-Klin, Kraków province (in Polish with English summary). Sprawozdania Archeologiczne 62: 105-108
Lohmeyer W (1980) Flora und Vegetation. In: Meurers-Balke J, Lüning J Experimenteller Getreideanbau im Hambacher Forst, Gemeinde Elsdorf, Kr. Bergheim/Rheinland. Bonner Jahrbücher 180: 320-324
Lüning J (1980) Getreideanbau ohne Düngung. Archäologisches Korrespondenzblatt 10: 117-122
Lüning J (2000) Steinzeitliche Bauern in Deutschland - Die Landwirtschaft im Neolithikum. Habelt, Bonn

Lüning J, Meurers-Balke J (1980) Experimenteller Getreideanbau im Hambacher Forst, Gemeinde Elsdorf, Kr. Bergheim/Rheinland. Bonner Jahrbücher 180: 305-344

Maier U (1999) Agricultural activities and land use in a Neolithic village around 3900 B.C.: Hornstaad Hörnle IA, Lake Constance, Germany. Vegetation History and Archaeobotany 8: 87-94

Meurers-Balke J, Lüning J (1990) Experimente zur frühen Landwirtschaft. Experimentelle Archäologie in Deutschland 4: 82-92

Meyer B, Willerding U (1961) Bodenprofile, Pflanzenreste und Fundmaterial von neuergeschlossenen neolitischen und eisenzeitlichen Siedlungsstellen im Göttinger Stadtgebiet. Göttinger Jahrbücher 9: 21-38

Midgley MS (1992) TRB culture: the first farmers of the North European Plain. Edinburgh University Press, Edinburgh

Milisauskas S, Kruk J (1989) Neolithic economy in central Europe. Journal of World Prehistory 4: 403-446

Modderman PJR (1971) Bandkeramiker und Wandbauertum. Archäologisches Korrespondenzblatt 1: 7-9

Modderman PJR (1988) The Linear Pottery Culture: diversity in uniformity. Berichten van de Rijksdienst voor het Oudheidkundig Bodemonderzoek 38: 63-139

Pétrequin P (1996) Management of architectural woods and variations in population density in the fourth and third millennia B.C. (Lakes Chalain and Clairvaux, Jura, France). Journal of Anthropological Archaeology 15: 1-19

Pétrequin P, Arbogast R-M, Bourquin-Mignot C, Lavier C, Viellet A (1998) Demographic growth, environmental changes and technical adaptations: responses of an agricultural community from the 32nd to the 30th centuries BC. World Archaeology 30: 181-192

Piening U (1979) Neolitische Nutz- und Wildpflanzenreste aus Endersach, Rems-Murr-Kreis, und Ilsfeld, Kreis Heilbronn. Fundberichte aus Baden-Württemberg 4: 1-17

Piening U (1982) Botanische Untersuchungen an verkohlten Pflanzenresten aus Nordwürttemberg: Neolitische bis römische Zeit. Fundberichte aus Baden-Württemberg 7: 39-71

Piening U (1986a) Verkohlte Getreidevorräte von Aldingen, Gem. Remseck am Neckar, Kreis Ludwigsburg. Fundberichte aus Baden-Württemberg 11: 191-208

Piening U (1986b) Verkohlte Nutz- und Wildpflanzenreste aus Grossachsenheim, Gem. Sachsenheim, Kreis Ludwigsburg. Fundberichte aus Baden-Württemberg 11: 177-190

Piening U (1988) Neolithische und hallstattzeitliche Pflanzenreste aus Freiberg-Geisingen (Kreis Ludwigsburg). In: Der prähistorische Mensch und seine Umwelt. Festschrift für Udelgard Körber-Grohne. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 31: 213-228

Piening U (1992) Nutzpflanzenreste der Schussenrieder Kultur von Aldingen, Kreis Ludwigsburg. Fundberichte aus Baden-Württemberg 17: 125-142

Piening U (1998) Die Pflanzenreste aus Gruben der Linearbandkeramik und der rössener Kultur von Ditzingen, Kr. Ludwigsburg. Fundberichte aus Baden-Württemberg 22: 125-160

Piggott S (1965) Ancient Europe. Edinburgh University Press, Edinburgh

Reynolds PJ (1977) Slash and burn experiment. Archaeological Journal 134: 307-318

Reynolds PJ (1992) Crop yields of the prehistoric cereal types emmer and spelt: the worst option. In: Anderson PC (ed) Préhistoire de l'agriculture: nouvelles approches expérimentales et ethnographiques. CNRS, Paris, pp 383-393

Rösch M (1990) Vegetationsgeschichtliche Untersuchungen im Durchenbergried. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 37: 9-64

Rösch M (1993) Prehistoric land use as recorded in a lake-shore core at Lake Constance. Vegetation History and Archaeobotany 2: 213-232

Rösch M (1996) New approaches to prehistoric land-use reconstruction in south-western Germany. Vegetation History and Archaeobotany 5: 65-70

Rösch M (2000) Anthropogener Landschaftswandel in Mitteleuropa während des Neolithikums. Germania 78: 293-318

Rösch M, Ehrmann O, Herrmann L, Schulz E, Bogenrieder A, Goldammer JP, Hall M, Page H, Schier W (2002) An experimental approach to Neolithic shifting cultivation. Vegetation History and Archaeobotany 11: this volume

Rothmaler W (1995) Exkursionsflora von Deutschland (vol 3). Gustav Fischer, Stuttgart

Rowley-Conwy P (1981) Slash and burn in the temperate European Neolithic. In: Mercer R (ed) Farming practice in British prehistory. Edinburgh University Press, Edinburgh, pp 85-96

Rulf J (1991) Neolithic agriculture of central Europe - review of the problems. Památky Archeologické 82: 376-384

Sherratt AG (1980) Water, soil and seasonality in early cereal cultivation. World Archaeology 2: 313-330

Sigaut F (1975) L'agriculture et le feu. Cahiers des Études Rurales 1. Paris, Mouton

Smilauer P (1992) CANODRAW 3.0 user's guide. London

Soudsky B, Pavlu I (1972) The Linear Pottery Culture settlement patterns in central Europe. In Ucko P, Tringham R, Dimbleby G (eds) Man, settlement and urbanism. Duckworth, London, pp 317-328

Steensberg A (1955) In crackling flames (in Danish with English summary). Kuml 1955: 65-130

Steensberg A (1957) Some recent Danish experiments in Neolithic agriculture. Agricultural History Review 5: 66-73

Steensberg A (1979) Draved: an experiment in stone age agriculture. National Museum of Denmark, Copenhagen

Steensberg A (1993) Fire-clearance husbandry. Poul Kristensen, Herning

Stehli P (1989) Merzbachtal - Umwelt und Geschichte einer bandkeramischen Siedlungskammer. Germania 67: 51-76

Stika H-P (1991) Die paläoethnobotanische Untersuchung der linearbandkeramischen Siedlung Hilzingen, Kreis Konstanz. Fundberichte aus Baden-Württemberg 16: 63-104

Stika H-P (1996) Vorgeschichtliche Pflanzenreste aus Heilbronn-Klingenberg: Archäobotanische Untersuchungen zum Michelsberger Erdwerk auf dem Schlossberg (Bandkeramik, Michelsberger Kultur, Späthallstatt/Frühlatène). Materialhefte zur Archäologie in Baden-Württemberg 34

Thomas J (1999) Understanding the Neolithic. Routledge, London

Troels-Smith J (1953) Ertebølle culture - farmer culture (in Danish with full English translation). Aarbøger for Nordisk Oldkundighed og Historie 1953: 5-62

Tutin TG, Heywood VH, Burges NA, Moore DM, Valentine DH, Walters SM, Webb DA (1964-1980) Flora Europaea (vols 1-5). Cambridge University Press, Cambridge

Viklund K (1998) Cereals, weeds and crop processing in Iron Age Sweden: methodological and interpretive aspects of archaeobotanical evidence. Archaeology and Environment 14.

Wasylikowa K (1989) Paleoecological characteristics of the settlement periods of the Linear Pottery and Lengyel Cultures at Cracow-Nowa Huta. Prezegląd Archeologiczny 36: 57-87

Wasylikowa K, Starkel L, Niedzialkowska E, Skiba S, Stworzewicz E (1985) Environmental changes in the Vistula valley at Pleszow caused by Neolithic man. Przegląd Archeologiczny 33: 19-55

Whittle A (1996) Europe in the Neolithic. Cambridge University Press, Cambridge

Whittle A (1997) Moving on and moving around: Neolithic settlement mobility. In: Topping P (ed) Neolithic landscapes. Oxbow, Oxford, pp 15-22

Willerding U (1969) Pflanzenreste aus frühgeschichtlichen Siedlungen des Göttinger Gebiets. Neue Ausgrabungen und Forschungen in Niedersachsen 4: 391-403

Willerding U (1983) Paläo-Ethnobotanik und Ökologie. Verhandlungen der Gesellschaft für Ökologie (Festschrift Ellenberg) 11: 489-502

Appendix 1. Weed species recorded in Hambach experimental plots and included in analyses. Nomenclature follows Tutin et al. 1964-80

Agrostis canina
Agrostis stolonifera
Agrostis capillaris
Ajuga reptans
Anemone nemorosa
Calamagrostis epigejos
Carex sylvatica
Centaurium erythraea
Cerastium glomeratum
Cerastium fontanum
Cirsium arvense
Cirsium palustre
Cirsium vulgare
Convallaria majalis
Deschampsia cespitosa
Epilobium adenocaulon
Epilobium angustifolium
Epilobium montanum
Eupatorium cannabinum
Galeopsis tetrahit
Omalotheca sylvatica
Filaginella uliginosa
Hypericum humifusum
Hypericum maculatum
Hypericum pulchrum
Juncus bufonius
Juncus effusus
Lotus pedunculatus
Luzula multiflora
Chamomilla recutita
Milium effusum
Moehringia trinervia
Mycelis muralis
Oxalis acetosella
Plantago major
Poa annua
Poa trivialis
Polygonum hydropiper
Ranunculus repens
Scrophularia nodosa
Senecio sylvaticus
Senecio viscosus
Sonchus asper
Stachys sylvatica
Stellaria holostea
Stellaria media
Taraxacum officinale group
Tussilago farfara
Urtica dioica
Viola riviniana

Appendix 2. Standardised identification categories for the "potential weed" taxa occurring in the selected archaeobotanical samples

Agropyron caninum
Agrostemma githago
Ajuga genevensis/reptans
Aphanes arvensis
Arenaria serpyllifolia
Artemisia vulgaris
Asperula arvensis
Astragalus glycyphyllos
Atriplex patula/prostrata
Brachypodium pinnatum
Brachypodium sylvaticum
Bromus arvensis/hordeaceus/secalinus
Bromus erectus
Bromus racemosus
Bromus sterilis/tectorum
Carex muricata
Carex spicata
Centaurea jacea
Centaurea scabiosa
Chenopodium album group
Chenopodium ficifolium
Chenopodium glaucum
Chenopodium hybridum
Chenopodium polyspermum
Chenopodium urbicum
Cirsium vulgare
Conium maculatum
Cruciata laevipes
Daucus carota
Digitaria ischaemum
Digitaria sanguinalis
Echinochloa crus-galli
Erigeron acer
Erysimum cheiranthoides
Fallopia convolvulus
Fallopia dumetorum
Festuca pratensis
Festuca rubra
Galeopsis angustifolia/ladanum/segetum
Galium aparine
Galium boreale
Galium mollugo group/*verum* group
Galium palustre
Galium spurium
Hyoscyamus niger
Knautia arvensis
Lamium amplexicaule
Lapsana communis
Leontodon autumnalis
Leucanthemum vulgare
Linum catharticum
Lolium perenne
Lotus corniculatus group
Luzula campestris/multiflora
Malva sylvestris
Matricaria chamomilla
Moehringia trinervia
Myosotis arvensis
Nepeta cataria
Papaver rhoeas
Pastinaca sativa
Phleum pratense
Picris hieracioides
Pimpinella saxifraga
Plantago lanceolata
Plantago major
Plantago media
Poa annua
Poa compressa/nemoralis/palustris
Poa pratensis group/*trivialis*
Polygonum amphibium
Polygonum aviculare group
Polygonum lapathifolium
Polygonum minus
Polygonum mite
Polygonum persicaria
Potentilla anserina
Potentilla argentea
Potentilla reptans
Prunella vulgaris
Ranunculus acris
Ranunculus repens
Rhinanthus minor
Rumex acetosa/thyrsiflorus
Rumex acetosella
Rumex conglomeratus/sanguineus
Rumex crispus/obtusifolius
Sambucus ebulus
Saponaria officinalis
Scirpus setaceus
Scleranthus annuus
Senecio vulgaris
Setaria pumila
Setaria verticillata/viridis
Sherardia arvensis
Silene dioica
Silene latifolia
Silene nutans
Silene vulgaris
Sisymbrium officinale
Solanum nigrum
Sonchus asper
Stachys annua
Stachys sylvatica
Stellaria graminea/palustris
Stellaria holostea
Stellaria media
Trifolium arvense/campestre
Trifolium dubium
Trifolium hybridum/fragiferum
Trifolium montanum
Trifolium pratense
Trifolium repens
Urtica dioica
Urtica urens
Valerianella dentata
Valerianella rimosa
Verbascum nigrum
Veronica arvensis
Veronica hederifolia
Vicia hirsuta
Vicia sepium
Vicia tetrasperma
Viola arvensis/tricolor