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Palaeo-ecological and archaeological analysis of two Dutch Celtic fields (Zeijen-Noordse Veld and Wekerom-Lunteren): solving the puzzle of local Celtic field bank formation

Stijn Arnoldussen¹  · Marjolein van der Linden²

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Abstract Celtic fields are the best preserved and most widely distributed type of prehistoric agricultural landscape in the Netherlands, and occur throughout north-western Europe. In this contribution, data from two excavated Dutch Celtic fields are used to explain the process of bank formation and to unravel the agricultural regime of Celtic fields. To this end, traditional archaeological methodologies and geochemical analyses are combined with detailed palaeo-ecological analyses. It is shown that Celtic field banks were constructed from a mixture of non-local soil, wetland vegetation, dung and settlement debris such as charcoal and sherds. A system was in place in which sods and plants were cut in lower-lying wetland landscapes and which were transported to the settlement, where they were presumably used as byre-bedding, became enriched with dung and were mixed with settlement debris. This mixture was carted to the fields, most likely to be spread across fallow plots as a manuring agent. From this primary, functional location, a composite sediment of agricultural sediments and the added manure was incorporated into the field banks. This process of incorporation was very slow and probably started with the uprooting of arable weeds

from the fields, which were tossed to the side against the wattlework fences—together with minute quantities of soil attached to their root clusters. As a consequence of this chain of events, over the course of centuries, banks of anthropogenic sediment came to enclose fields within the Celtic field landscapes.

Keywords Celtic fields · Embanked fields · Prehistoric agriculture · Palynology · Spores · Non-pollen palynomorphs

Introduction

Celtic fields are agricultural field systems of embanked field plots that are traditionally dated between the Late Bronze Age and the first two centuries of the Roman Period (c. 1000 cal BC–AD 200). They are native to the north–west European sandy soils and abundantly present in the Netherlands, Belgian Kempian plateau, Northwest Germany and Denmark (Brongers 1976; Zimmermann 1976; Klamm 1993; Behre 2002; Spek et al. 2003; Kooistra and Maas 2008; Arnold 2011; Meylemans et al. 2015). They are akin to the co-axial fields of the United Kingdom (Curwen and Curwen 1923; Johnston 2005; Yates 2007) and southern Scandinavia (Hatt 1931, 1937, 1949; Nielsen 1984; Widgren 1987, 1989), but differ from those in morphological details (i.e. more rectangular than coaxial, lynchets rather than banks; Klamm 1993; Yates 2007) and composition (generally poor in stones, unlike the United Kingdom reave systems and Swedish Iron Age field systems; cf. Widgren 1986, 1987; Hedeager 1988; Klamm 1993, p 44). Despite a remarkably early start to their investigation (Picardt 1660; Janssen 1848; van; Giffen 1918; cf. van der Sanden 2009), there has been limited recent detailed

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analysis aimed at understanding the genetic processes of Dutch Celtic field banks (but see Spek et al. 2003, 2009). Multiple hypotheses have been forwarded to explain bank development (Table 1), but as such hypotheses were unfortunately seldom based on actual fieldwork on Celtic fields, the ways in which Celtic field banks evolved has been studied much less (but see Gebhardt 1976; Spek et al. 2003; Nielsen and Kristansen 2014 for exceptions). To this end, a long-term research project into the nature and dynamics of Dutch Celtic fields has been initiated (Arnoldussen 2012; Arnoldussen and Scheele 2014). As part of this project the sites of Zeijen-Noordse veld and Wekerom-Lunteren have been archaeologically investigated (Fig. 1). In this

contribution, we report on the results of the archaeological and palaeo-ecological analysis of the Zeijen and Wekerom excavations, in order (1) to determine how the banks around the Celtic field plots evolved and (2) to try and explain the agricultural regime of Celtic fields.

Methods

In the sections below, a brief outline of the archaeological sites and their geogenetic settings is given, which serves as an introduction and contextualisation to the procedures of

Fig. 1 Distribution map showing **a** the regional occurrence of later prehistoric field systems (*dark brown* regions; after Fig. 1 in Brongers 1976, p 28; Klamm 1993; Yates 2007; Arnold 2011; Meylemans et al. 2015) across Europe (their dominant form is shown in regions with *dashed outlines*), and **b** the locations of the Dutch Celtic fields (*dark brown* regions) shown on a simplified palaeogeographical map of the Netherlands around 3,800 BP (after Fig. 143 in De Mulder et al. 2003, p 228), with the locations of Zeijen-Noordse veld and Wekerom-Lunteren indicated as *outlined stars*

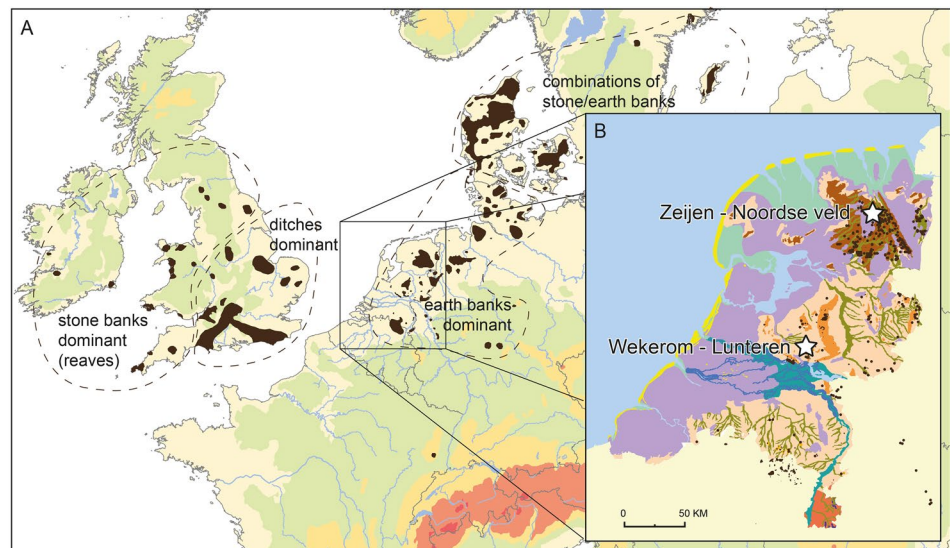


Table 1 Hypotheses for the development of Celtic field banks, principal references and relation to fieldwork evidence

Cause of bank formation	References	Based on fieldwork observations
Tree clearance/removal of stumps	Toms (1911); Harsema (1980); Brongers (1976)	No
Fieldstone clearance	Kristensen (1933); Hatt (1949); Brongers (1976); Harsema (1980); Kooi and De Lange (1987); Johnston (2013), 319; van der Heijden et al. (2009); Widgren (2010), 76	Yes (Scandinavia/United Kingdom), no (Netherlands, example of stones cleared and placed near bank known)
Drift-sand catchment	van Giffen (1944); Hatt (1949); Groenman-van Waateringe (1979)	No
Drift-sand protection	van Ginkel (1987)	No
Tillage-displaced soil	Müller (1911); Hatt (1931); Jensen (1982)	No
Deposition of depleted soil from fields	van Giffen (1950); Kooi and De Lange (1987); Spek et al. (2003)	Partly (Spek et al.: yes), others: no
Banks as composting sites	Fokkens (1998)	No
Banks as preferred cultivation locations	Gebhardt (1976, 1982); Brongers (1976); Zimmermann (1976, 1995); Spek et al. (2003); Behre (2008); Groenman-van Waateringe and van Geel (2017)	Yes (high phosphorus content, no ard marks)
Combinations of factors	Klamm (1993); Sørensen (1984); Spek et al. (2003)	Partly (Spek et al.: yes), others: no

sample taking, sample preparation and analysis described thereafter.

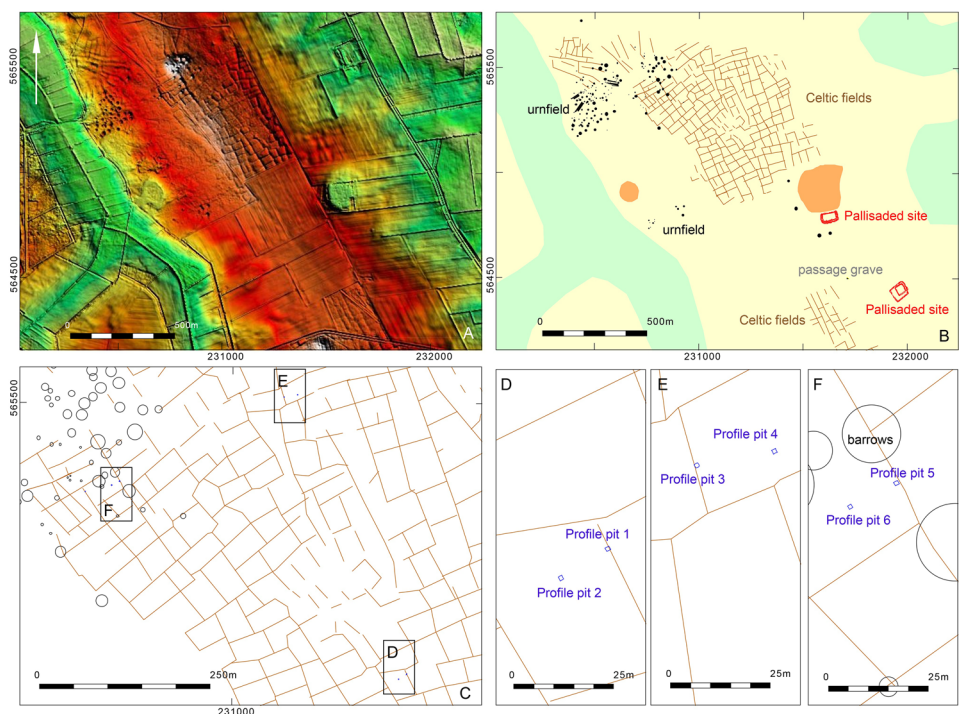
Site information: Zeijen-Noordse veld

The site of Zeijen (Fig. 2) is situated on a central part of the ice-pushed Hondsrug-complex (Rappol 1984). After Saale-period glaciation, the top of the locally deposited boulder-clay moraine has eroded into a sediment known as locally as *keizand*, i.e. a cryogenically sorted sediment of low loam-content and with local deflation zones (Rappol and Kluiving 1992; Berendsen 1997; De Mulder et al. 2003). Locally, thin aeolian sand-deposits of Weichselian Age (coversand) may cover this *keizand* layer (Castel and Rappol 1992; De Mulder et al. 2003). Presumably between 1200 cal BC and 1 AD an extensive (over 50 ha) Celtic field complex developed (Arnoldussen 2012). This field system was by no means placed on a blank canvas (Fig. 2b), as Funnel Beaker Period (c. 3500–2900 cal BC) remains such as a passage grave, flatgraves and various flint and ceramic artefacts are found close by (van Giffen 1924, 1930; van der Sanden 2009). Moreover, an alignment of Bronze Age tumuli may have delimited the Celtic field to the west (Waterbolk 1977a). More towards the west, a large urnfield cemetery is visible, but during the Iron Age some cinerary barrows were also placed on top of the Celtic field banks. In the late Iron Age, two palisaded settlements were constructed to the southeast of the Celtic field (van Giffen 1936, 1950; Waterbolk 1977b).

Site information: Wekerom-Lunteren

The Celtic fields of Wekerom-Lunteren are situated on the Saale-period glacial deposits known as the Oud-Reemst ice-pushed ridge (De Mulder et al. 2003; Pierik 2010). Albeit classified as glacial deposits belonging to the Drenthe Formation, this comprises reworked pre-Saalian deposits of the river Rhine and Meuse precursors (van der Meer et al. 1985; De Mulder et al. 2003). Here too, a thin (<1 m) aeolian sand deposit of Weichselian Age may locally cover parts of the Saalian-period reworked sediments (van der Meer et al. 1985; Oude Rengerink 2004). This landscape was used throughout prehistory, but main focal periods appear to be the Neolithic (for which various barrows in the vicinity are known; Bursch 1933; Modderman 1963; Hulst 1972; Lanting 2013) and the Iron Age (Arnoldussen and Scheele 2014). The presence of a Celtic field was first noted in the 19th century, when its provisional extent was mapped (Brongers 1976), yet present-day LiDAR imagery suggests that the aggregate complex may have exceeded 210 ha. Remarkably, in the 1940s excavations had already been undertaken in the Wekerom Celtic field (De Vijf-sprong), but they were never published in full (Verwers 1972; van Klaveren 1986). In this unpublished excavation, Iron Age house-plans and outbuildings were uncovered amidst the Celtic field banks and plots. A Late Iron Age well was also excavated nearby (Peen 2011). Unfortunately, the archaeological remains discovered did not permit the dating or understanding of the construction of the Celtic field banks. Therefore, a targeted excavation campaign was

Fig. 2 LiDAR altimetry map (a) and archaeological overview (b) of the Zeijen-Noordse veld cultural landscape. The locations of the profile pits dug in both banks and fields are indicated in c, whereas insets d, e and f (all to same scale) show the extents and exact locations of the profile pits (blue outlines) in relation to the Celtic field banks (brown outlines) and barrows (f black outlines)



undertaken to investigate sets of Celtic field banks and their adjacent field plots (Fig. 3; Arnoldussen and Scheele 2014).

Archaeological fieldwork and sampling: Zeijen and Wekerom

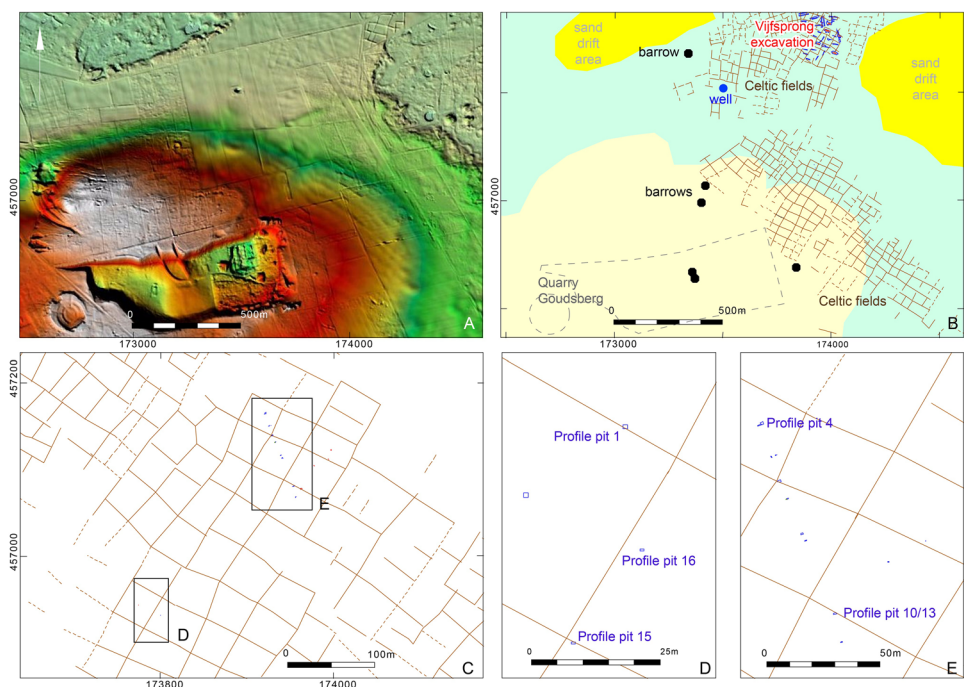
Archaeological fieldwork involved the manual digging of profile pits of c. 1 by 1 m at surface level down to a depth of 90–120 cm. Their (small) size reflects both the minimum size required to understand, document and sample the sections, and the regulations permitting research set by the landscape managers. Moreover, for the detailed strategies of sampling and sieving described below, the types of information derived from the 1 by 1 m test-pits would not benefit from larger trenches, as the labour investment would be disproportionate to the results obtained. Also, the small size (and thus limited representativeness) of the excavation pits implies that extrapolation is only possible when several trenches yield similar results within a given Celtic field. Therefore, a minimum of three bank and three field plots was investigated at each location. Moreover, the process of selecting the optimal sample locations was important, and at both sites many more profile pits have been dug than are reported on in this paper (in total 24 profile pits for both sites). To optimally reflect intra-site variability, test-pits were—where possible—situated in parts of the Celtic field with different bank orientations. Principally, the initial locations of the profile pits at bank locations was determined by LiDAR analysis to identify areas of better bank preservation, after which coring and test-pits were

used to identify the best possible sample locations. Field plot profile pits were generally situated at 8–15 m distance from bank profile pits in the middle of suspected field plots. Depth of the profile pits was determined by the presence of recognisable unaffected natural soil (at least 30 cm) at the base of the sections. During the archaeological fieldwork, levels were lowered by hand in 10 cm spits (hand-collecting any artefacts) at Zeijen and by 5 cm spits at Wekerom. For each spit 12 l of sediment were sieved with 4 mm mesh (retaining all objects, i.e. also natural unworked stone). In profile pits 10/13 and 15 at Wekerom, no sieving took place (only hand-collecting). The soil profiles in the profile pits were sampled with Kubiena soil monolith tins (mostly measuring 40×5×5 cm). Secondary soil formation (podzolisation) of the tops of the sections may have masked macroscopically visible clues that could allow the identification of an anthropogenic (agricultural) layer at both Zeijen and Wekerom.

At Zeijen, six profile pits were dug in three parts of the Celtic field with a different orientation of the banks (see Fig. 2, C–F for locations) and in all three areas both a bank (odd profile pit numbers) and adjacent field plot (even profile pit numbers) were investigated. The geogenetic interpretations, OSL ages, and sample locations for palaeo-ecological analysis are indicated in Fig. 4.

At Wekerom, 17 profile pits were dug at various parts of the Celtic field to determine the nature and degree of preservation of the banks and field plots (Arnoldussen and Scheele 2014, for locations see Fig. 3c–e). As various parts of the Wekerom Celtic field were disturbed by

Fig. 3 LiDAR altimetry map (a) and archaeological overview (b) of the Wekerom-Lunteren cultural landscape. The locations of the profile pits dug in both banks and fields are indicated in c, whereas insets d and e (not to same scale) show the extents and exact locations of the profile pits (blue outlines) in relation to the Celtic field banks (brown outlines)



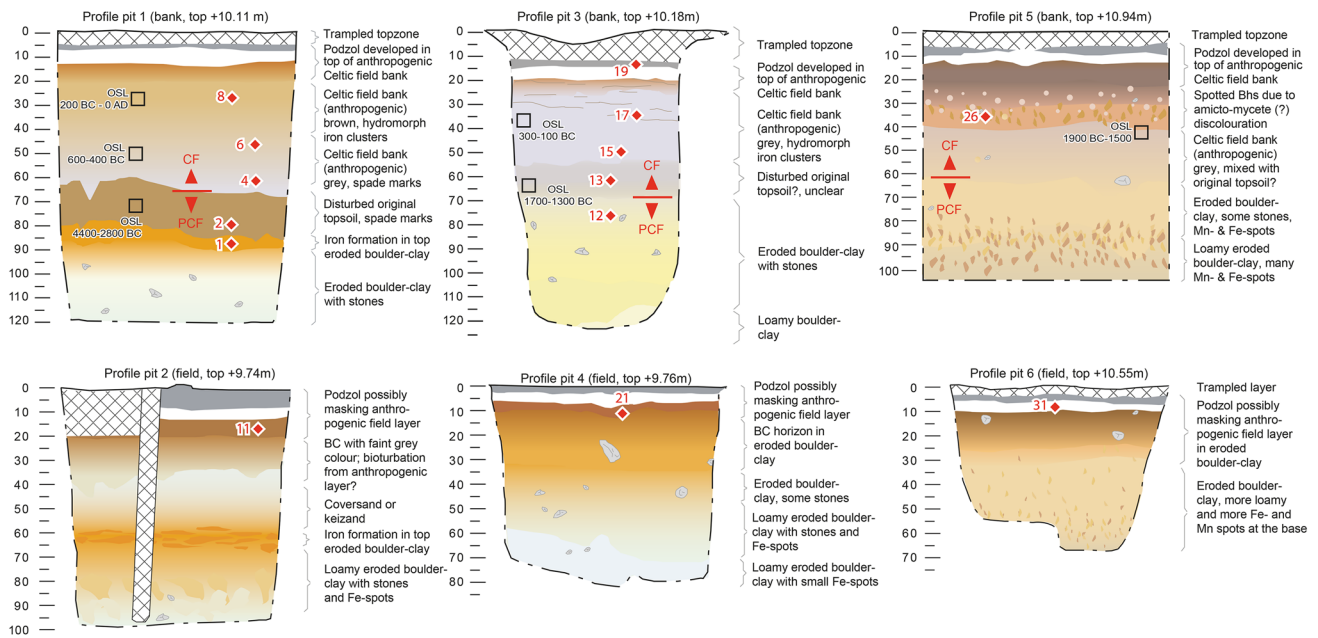


Fig. 4 Interpretative drawings and geogenetic interpretations for the sections of the banks (profile pits 1, 3 and 5) and their adjacent field plots (profile pits 2, 4 and 6) of the Zeijen-Noordse veld Celtic field (sections all to the same scale, *top* indicated in metres above Dutch Ordnance Datum). The locations of the various sub-samples inside

the Kubiens tins are indicated as red diamonds and are labelled with their analysis number (cf. Fig. 7). For the banks, the transition between Pre-Celtic field (PCF) layers and Celtic field layers (CF) is indicated in *red*. The location and age of OSL samples is indicated in *black*

forestry activities around AD 1900 and/or by agricultural activities taking place up to AD 1995 (Arnoldussen and Scheele 2014), this paper only discusses a selection of bank and field locations where preservation conditions were best and that were chosen for detailed analysis. The geogenetic interpretations, OSL ages, and sample locations for palaeoecological analysis of these profile pits are depicted in Fig. 5.

OSL-dating

In order to support archaeological dating based on the material culture recovered, Optically Stimulated Luminescence (OSL) dating was undertaken. For Zeijen and Wekerom, six samples from sections of Celtic field banks were dated (Wallinga and Versendaal 2013a, b; Arnoldussen and Scheele 2014). The positioning of the samples within the banks was carefully chosen to (a) avoid base- and topmost locations of layers to reduce bioturbation effects, and (b) to offer a vertical distribution that allows detection of chronological trajectories within the banks. The location and age of the OSL samples is indicated in Fig. 4 (Zeijen) and Fig. 5 (Wekerom).

Geochemical analysis and soil micromorphology

Samples for geochemical analysis were taken vertically across the sections from each recognised layer, at intervals with a maximum of 5 cm. These samples were dried during post-excavation analysis and analysed with a Thermo Scientific NitonXL3t portable XRF (GOLDD detector; measurement of up to 25 simultaneous elements in the analytical range between S and Ur as well as light elements—Mg, Al, Si, P, S and Cl). To optimise performance for light elements by preventing secondary X-ray absorption by air, the source and detector were purged with helium gas. All analyses were performed in bulk mode (mining mode). The device is factory calibrated and additional (ISE; <http://www.wepal.nl>) soil standards were measured for external standardization.

Various bank and field plot locations at Zeijen and Wekerom were sampled for soil micromorphological thin-section analysis (preliminary results: Arnoldussen 2012, pp 64–47; Arnoldussen and Scheele 2014, pp 61–64), but these samples will be discussed in full in a separate paper.

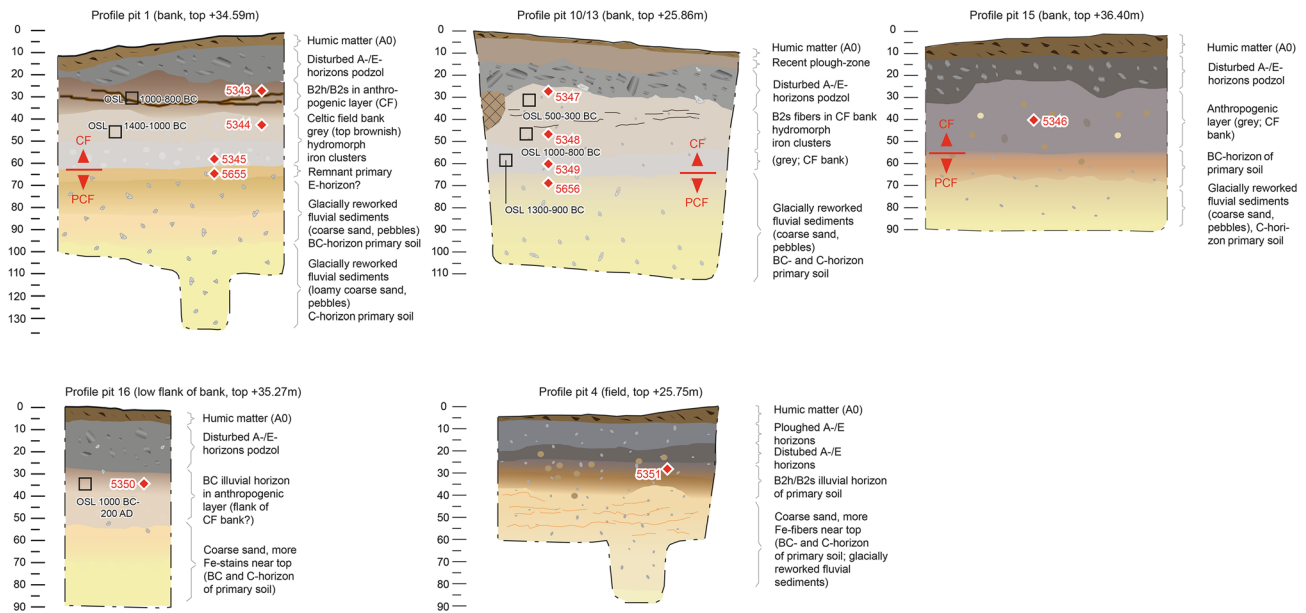


Fig. 5 Interpretative drawings and geogenetic interpretations for the sections of the banks (profile pits 1, 10/13 and 15), lower bank flank (profile pit 16) and field plot (profile pit 4) of the Wekerom-Lunteren Celtic field (sections all to same scale, *top* indicated in metres above Dutch Ordnance Datum). The locations of the various sub-samples

inside the Kubiena tins are indicated as *red diamonds* and are labelled with their analysis number (cf. Fig. 9). For the banks, the transition between Pre-Celtic field (PCF) layers and Celtic field layers (CF) is indicated in *red*. The location and age of OSL samples is indicated in *black*

Analysis of (charred) macro remains and charcoal

The soil samples for macro remains analysis were dried and sieved over 2, 1 and 0.5 mm sieves. Seven samples from profile pit 3 (bank) and nine samples from profile pit 5 (field) from Zeijen-Noordse veld were scanned preliminarily (van der Velde 2010). From Wekerom in total six samples from profile pits 1, 13 and 15 (banks) and two from profile pit 4 and 16 (field plots) were analysed by O. Brinkemper. Identification follows the standard identification literature for seeds and plant remains (e.g. Anderberg 1994; Cappiers et al. 2006; Jacomet 2006).

Four samples from Zeijen-Noordse veld from profile pits 1 and 3 were selected and charcoal and other charred remains were fully analysed by L. I. Kooistra. Before analysis the samples were sieved (0.5, 1 and 2 mm fractions). For Wekerom, charcoal analysis was undertaken by J. van der Laan for fourteen samples from profile pit 1, three samples from profile pit 10/13, one sample from profile pit 15 and eight samples from profile pit 16 (Arnoldussen and Scheele 2014). See the ESM for the entire dataset.

Palynological analysis

In the laboratory, subsamples for palynological analysis were taken from the Kubiena tin soil monoliths. Two of the banks (profile pits 1 and 3) from Zeijen-Noordse veld

were sampled in five locations distributed vertically across the section, whereas the bank uncovered in profile pit 5 was only sampled once (Fig. 4). As anthropogenic (field) layers could not be unambiguously identified macroscopically in the field plots, it was decided to sample these contexts only once (one sample for each field plot; profile pits 2, 4 and 6). For Wekerom, two banks (profile pits 1 and 10/13) were each sampled with 3 samples across the anthropogenic layer and one in the underlying natural primary soil (Fig. 5). Only a single sample was analysed for an additional third bank location (profile pit 15). Despite, or because of, the absence of visual indicators of agricultural layers in the field plots, two samples were taken to investigate their nature (in profile pits 4 and 16). These samples were taken below the level of the disturbed (presumably c. AD 1900) A-/E-horizon, to give a better chance of containing a preserved later prehistoric signal. All the anthropogenic layers of both field and banks locations were sampled to study the Celtic field phase (CF). In some profile pits deeper layers were also sampled, which represent the Pre-Celtic field phase (PCF; Figs. 4, 5).

The subsamples, of which the volumes ranged between 1 and 6 ml, were prepared according to the standard acetolysis method (Erdtman 1960; Fægri and Iversen 1989; Konert 2002) at the pollen laboratory of the Free University of Amsterdam and were mounted in glycerine oil. To each sample *Lycopodium* spores were added to allow the

calculation of the pollen concentration (Stockmarr 1971). The pollen slides were analysed using an Olympus BH2 microscope with magnifications from 400× for counting, and 600× or 1,000× for identification of problematic pollen. In total 14 subsamples from Zeijen - Noordse veld were analysed by M. van der Linden and 11 subsamples from Wekerom by M. van Waijjen. Pollen identification and nomenclature follow Beug (2004) and the Northwest European pollen flora (Punt et al. 1976–2003), indicated by the suffix “B” or “P”. Non-pollen palynomorphs (NPPs) were identified after van Geel (1972, 1976), and van Geel et al. (1981, 1983, 1989, 2003). The microscopic charcoal particles were counted on the pollen slides by estimating the surface area of microscopic charcoal particles in relation to the surface area of one *Lycopodium* spore. This resulted in a fictive value (a number of surface area units) for the microscopic charcoal fragments which was used to calculate the percentage in relation to the pollen sum and the microscopic charcoal concentration (surface area units/ml) per sample. Although this method does not reflect the exact amount of microscopic charcoal in the sample, it does reflect the approximate amount and gives information about the ratio between pollen and microscopic charcoal particles. During the preliminary scan of the soil samples macro remains of Ericaceae (charred and waterlogged) and mosses (waterlogged) were found (van der Velde 2010). The presence of waterlogged remains of heath vegetation may indicate contamination or infiltration with recent material since heath is present to dominant in the present-day vegetation of the sites studied. The finds of recent macro remains within the deeper samples reflect bioturbation, suggesting that infiltration of more recent pollen may also have occurred (cf. Dimbleby 1985). Such possibilities were kept in mind when interpreting the results of the pollen analysis. Indications for infiltration of pollen are large spikes in percentages (and high concentration) of certain pollen types such as Ericaceae (usually in the top soil) or the occurrence of pollen types which are normally found in recent layers (for example cultivated species *Secale* and *Fagopyrum*). To ensure that the pollen data reflect the ancient vegetation, Ericaceae pollen and spores of ferns and mosses were excluded from the pollen sum. However, since Ericaceae were also part of the ancient vegetation, for comparison the pollen percentages were also calculated based on a total pollen sum and on an upland pollen sum (excluding *Alnus* and marsh vegetation and including Ericaceae). Samples were counted up to 250 pollen grains or more (606 grains in sample 31) in the total pollen sum if possible. Dimbleby (1985) showed that the number of recorded species increases during the pollen count, but all those pollen types which have a final percentage of 1 or more are represented within the first 250 grains. To ensure that all present pollen types were noted, after the pollen count was

finalized the total pollen slide was scanned for new pollen types which were scored with ‘+’ if present (the so-called rare types). The results are summarized in pollen diagrams created with the software program TILIA v.1.7.16 (Grimm 2011). The entire dataset including the percentages based on upland pollen sum and total pollen sum and pollen concentration data can be found in the ESM.

Results and interpretation

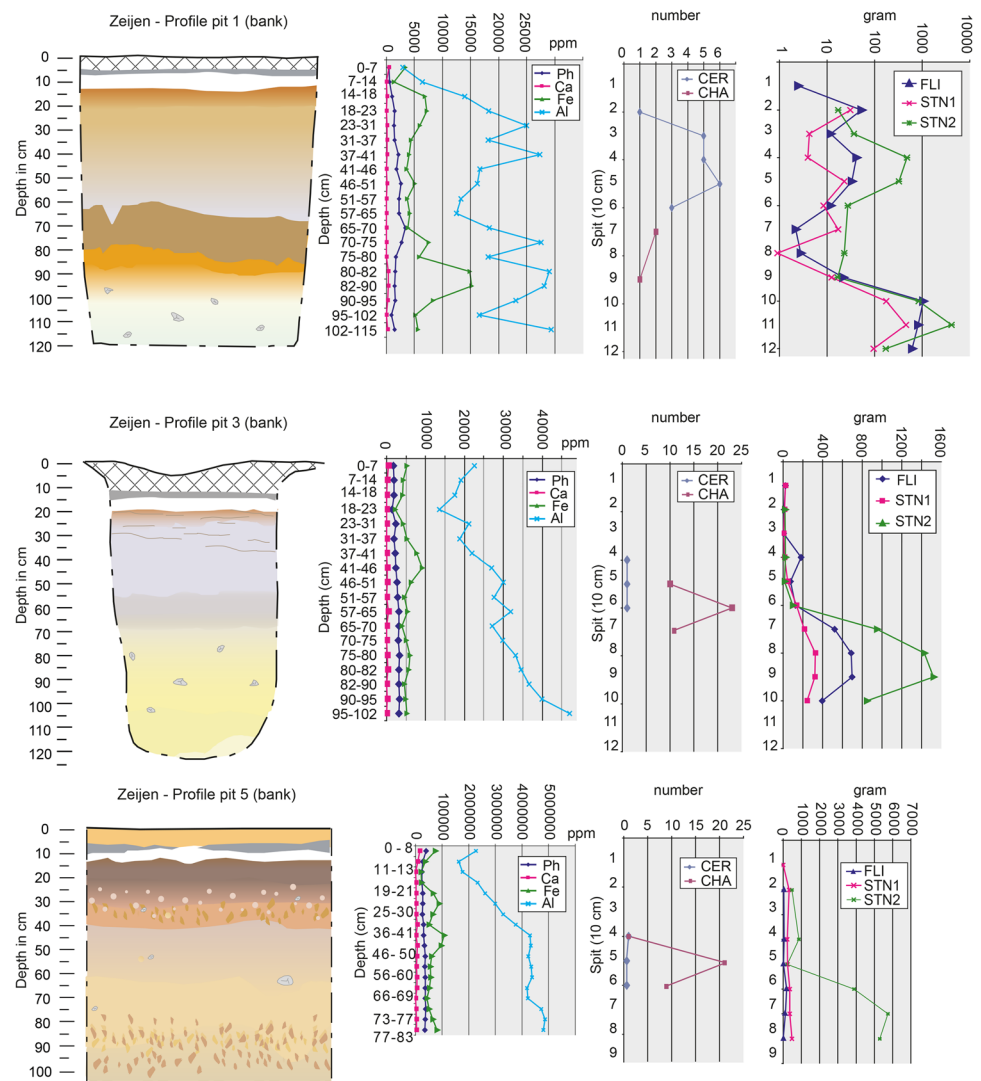
In the sections below, the archaeological and palaeo-ecological results are discussed for the two studied sites. In these discussions, the archaeological data obtained during the sieving of the bank sediments and the geochemical analyses of the sediments are discussed first, followed by the description of the palaeo-ecological evidence.

Archaeology: Zeijen-Noordse veld

The bank sediments at Zeijen contain many fragments of pottery (Fig. 6). In profile pits 3 and 5 these fragments occur more towards the base of the bank, but profile pit 1 yielded sherds from 20 to 60 cm depth. Possibly, more intense weathering (thaw-frost cycles) has left sherds in the upper layers more prone to degradation. In general, the sherds tend to be small (mean weight 4.2 g) and are therefore unlikely to reflect in-situ (domestic) debris. Due to their small size they are difficult to date, but presumably date to the Iron Age (Arnoldussen 2012). In profile pits 3 and 5, larger (i.e. hand-collected) charcoal fragments occur roughly at the same depths as the pottery. In profile pit 1 the charcoal appears to be correlated to a disturbed (Fig. 4; hoe- or spade cultivated?) PCF layer. From the distribution of unworked flint and stones it is clear that the banks comprise some smaller pebbles, but the majority of larger boulders originated from the eroded boulder-clay sediments underneath the banks (by weight, the stones from anthropogenic layers account for a mere 12.7% (profile pit 1), 9% (profile pit 3) and 13% (profile pit 5) of the profile pit totals; Fig. 6; Arnoldussen 2012). Fieldstone clearance can thus be ruled out as the prime cause of bank formation in the investigated Dutch Celtic fields. Moreover, the marked increase in stone content below the anthropogenic-natural interface, suggests that the banks cannot have been constructed solely from the local soil (cf. Behre 2002), as in that case stone-content of the banks would have been more similar to those of the underlying natural soil.

Remarkably, the geochemical characterisation also suggests a (partly) non-local origin for the bank composition. The low aluminium content of the anthropogenic parts banks in profile pits 3 and 5, with respect to that of the underlying natural soil (below 30 cm (profile pit 5)

Fig. 6 Schematic section drawings (see Fig. 4 for interpretation) and geochemical composition as determined with p-XRF (in ppm), numbers of sherds (CER) and charcoal (CHA) particles recovered, as well as weight (in g) of unworked flint (FLI), and stones (stones < 2 cm = STN1, stones 2–5 cm = STN2) for Celtic field banks at Zeijen-Noordse veld (for location of the profile pits see Fig. 2c–f). Distribution graphs are aligned to match with recovery depth in depicted sections



to 60 cm (profile pit 1)), argues against the use (solely) of local soil for bank construction. In a similar vein, the high iron content of the natural glacial soil underlying the anthropogenic sediments in profile pit 1, suggests—even if allowing for sesquioxide displacement during primary podsolization—that the high iron content of the natural soil is unmatched higher-up in the section, despite theories that interpret bank construction as resulting from amassing local soil to the sides of fields (Table 1).

The archaeological finds from the field plots testify to a former anthropogenic influence, but due to their lower numbers they are—unlike for the banks (Fig. 6)—not visualised here as distribution graphs. The field plots adjacent to profile pits 1 and 3 (profile pits 2 and 4 respectively) both yielded some Late Bronze Age to Iron Age sherds (profile pit 2: one sherd in spit 2, four sherds in spit 3, profile pit 4: one sherd in spit 1). Charcoal was recovered from spits 2 (3 fragments) and spit 7 (one fragment) of profile pit

2 and from spit 3 in profile pit 4 (10 fragments). Although it is clear from the cultural material recovered from the field plots that they were anthropogenically influenced, the nature of this influence remains unclear. Podsolization has rendered macroscopic visual identification of the fields as past agricultural layers (i.e. colour, homogenization, possible ard-marks) impossible. Moreover, it cannot be excluded that somewhere between the cessation of the Celtic field system and the present investigations, some of the soil has been removed, either by wind erosion or the cutting of sods (e.g. Medieval *Plaggenwirtschaft*).

Palaeo-ecology: Zeijen-Noordse veld

The two pre-Celtic field (PCF) samples underneath the banks differ in pollen composition (Fig. 7). The PCF in profile pit 1 (sample 2) contains more than 87% tree pollen. *Alnus* is the dominant tree pollen type (46.2%). Most

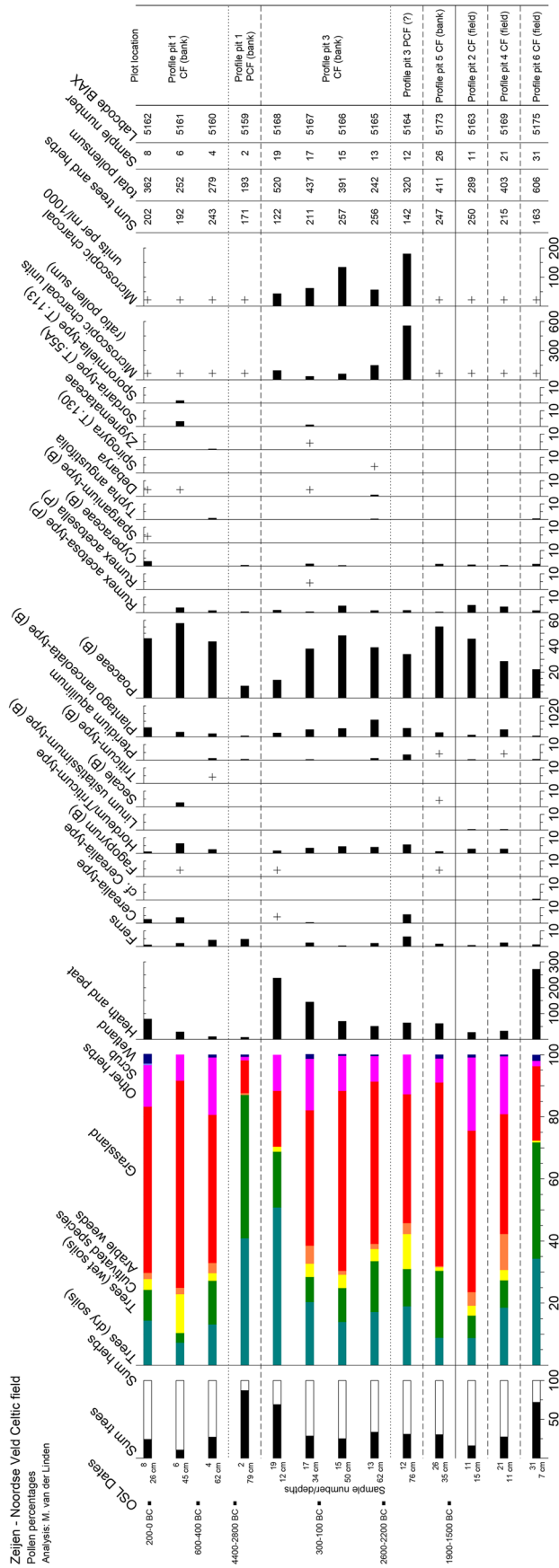


Fig. 7 Selection of pollen percentages, spores, algae and microscopic charcoal for the Zeijen-Noordse veld samples

of the *Alnus* pollen probably originates from the nearby marshy area west of Zeijen. Grasses (Poaceae) form 11% of the pollen sum. Arable weeds are barely present in the PCF sample from profile pit 1 and pollen of cultivated species is absent. Pollen of Ericaceae is barely present. In profile pit 3 (sample 12) the PCF pollen percentage of trees is only 31%. Non-arboreal pollen is dominant. Over 40% of the pollen sum consists of grassland species. Cultivated species have a remarkably high percentage (11.3%) which consists of Cerealia-type and *Hordeum/Triticum*-type. Also, in comparison to sample 2, a relatively high amount of *Plantago lanceolata* pollen and *Pteridium aquilinum* spores are present. Both these species occur on fallow arable land. *Plantago lanceolata* is an indicator of trampled or disturbed soil and grazing activity, whereas *Pteridium aquilinum* mainly occurs on fields, which have been recently cleared of woody vegetation (Weeda et al. 1985, 1988). The high *Pteridium aquilinum* values in sample 12—underneath the bank of profile pit 3—could reflect an initial woodland clearance at the start of the Zeijen Celtic fields.

In the Celtic field (CF) samples from the banks in profile pits 1, 3 and 5 the arboreal pollen ranges between 10–34%. The top CF sample of profile pit 3 (sample 19) seems to be an outlier because it contains 68.9% tree pollen and a very high percentage of Ericaceae (237%, which would be 74% of the pollen sum if Ericaceae were included and *Alnus* excluded). All CF samples (except no. 19) have high Poaceae percentages ranging between 37.9 and 57.8%. All contain pollen of Cerealia-type and *Hordeum/Triticum*-type. *Secale* and *Fagopyrum* are present in the top of the anthropogenic layers. When *Secale* is found in pre-Roman age layers it traditionally is interpreted as a weed (Behre 1992). The earliest indications of cultivation of *Secale* date from the Late Iron Age to Early Roman period at Noordbarge (100 cal BC–AD 100; van Zeist 1981) and Ede-Veldhuizen (about AD 100; van Zeist 1976), both not far from Zeijen and Wekerom. Pre-late medieval finds of *Fagopyrum* are also rare, but not uncommon, and it has been suggested that there has been small scale, but widespread cultivation from Roman times onwards (De Klerk et al. 2015). On a large scale cultivation and consumption of *Fagopyrum* has occurred in the Netherlands since the 14th century (van Haaster 1997). At Zeijen, the presence of both *Secale* and *Fagopyrum* in sample 26 (and most probably in the other samples as well) was probably caused by infiltration of pollen from upper layers. Downwash of pollen of the (sub) recent heath vegetation is suggested by the low pollen counts of Ericaceae deeper in profile pits 1 and 3—compared to extremely high levels (percentages as well as concentration) in near-surface samples (e.g. samples 8, 19

31; Fig. 7) at Zeijen. It is however not unlikely that heath vegetation also increased in the Zeijen area in the Iron Age due to land use changes.

Arable weeds and other herbs part of pollen types that do not have a characteristic environmental envelope were numerous in all CF samples. The base of the bank in profile pit 3 (sample 12) contains more than 10% *Plantago lanceolata*-type pollen and the highest concentration of microscopic charcoal units (179 k units/ml). It probably reflects initial cultivation/fallow cycles, during which prior soil formation was truncated and homogenised. Higher-up in the Zeijen CF banks pollen grains of wetland plants (i.e. *Sparganium*-type, *Typha latifolia* and Cyperaceae) are present in low numbers. Microscopic remains of green algae *Debarya*, *Spirogyra* and Zygnemataceae were also found. Coprophilous fungi *Sporormiella*-type (T.113) and *Sordaria*-type (T.55A) indicate the presence of animal dung. From the base to the top of the CF layer, Ericaceae increase from c. 10 to 77% in profile pit 1 and from 50 to 237% at the top in profile pit 3. Conversely, the percentage of microscopic charcoal units decreases from the base to the top of the banks (yet shows a peak in the middle part of the anthropogenic layer in profile pit 3). The analysis of the charred macroscopic botanical remains from the base of the CF of profile pit 1 and 3 showed that the samples were very poor (see ESM for tables with charred seeds and charcoal data). One charred cereal grain was found in profile pit 1 (51–65 cm depth), but due to poor preservation it could not be identified to genus-level. Macroscopic charcoal fragments of *Quercus* and *Alnus* dominate, *Fraxinus excelsior* and cf. *Populus/Salix* were present in the 5 and 2 mm fraction. The 1 mm fraction contained many small fragments of unidentifiable charcoal (345 in profile pit 1 and 65 in profile pit 3). Four stems of *Calluna vulgaris* were found in profile pit 1. In profile pit 3 (depth 38–50 cm) a charred flower of *Calluna/Erica* was also found as well as charcoal of *Quercus*, *Alnus* and *Fraxinus*. The sizes and surfaces of the charcoal fragments indicate that they are remains of coppiced or gathered firewood and not of in situ burned heath or woody vegetation. All charred remains point to an input of settlement waste into the banks.

The samples 11 (profile pit 2) and 21 (profile pit 4) from the possible anthropogenic layers (CF) of the field plots have a different species composition than sample 31 (profile pit 6), but otherwise resemble the bank CF samples. Samples 11 and 21 share a low percentage of tree pollen (resp. 16 and 27%). Both samples contain just over 3% pollen of cultivated species (i.e. *Hordeum/Triticum*-type and *Linum usitatissimum*-type, of which the latter is not present in the bank samples). Arable weeds and other herbs form a large part of the pollen sum. *Plantago lanceolata*-type reaches almost 5% in sample 21. Sample 31 has a very high tree pollen percentage (72%) compared to the other two

field samples. Cultivated species are absent except for one possible Cerealia-type. Ericaceous pollen peaks at about 270%. In this, the pollen composition of sample 31 resembles that of sample 19 (top of CF bank; profile pit 3). Both samples (19 and 31) are from the topmost (secondary podzol) layers and are more likely to reflect the (sub)recent to contemporary heathland vegetation rather than later prehistoric situations and are consequently not discussed further.

Archaeology: Wekerom-Lunteren

As at Zeijen, ceramics were recovered from all Celtic field banks (predominantly from the lower half of the remaining bank height; Fig. 8). The scarcity of ceramics in the upper parts of the sections may again relate to poorer preservation conditions higher-up in the sections. The sherds that are preserved in the banks are small (mean weight 2.05 g) and can only be dated to later prehistory in general, or possibly to the Early Iron Age (Arnoldussen and Scheele 2014). The similarities in distribution curves for pottery (CER) and charcoal (CHA) suggest that they ended up in the banks due to the same geogenetic process. Stone was systematically collected through sieving only in profile pit 1, allowing the inference that the stone content of the anthropogenic sediments is much lower than that of the underlying glacially reworked fluvial sediments (22% by weight; Arnoldussen and Scheele 2014). In profile pits 10/13 and 15, only a few larger stones were collected by hand. As in the case of Zeijen, the geochemical composition suggests that bank composition must have relied on (the addition of) non-local soil. Aluminium (in profile pits 1, 15 and to a lesser extent 10/13) shows a reduction in the anthropogenic layers as compared to the underlying natural sediments. Moreover, the high phosphorus oxide content of the natural soil in profile pit 1 (probably caused by apatite rather than manuring; Arnoldussen and Scheele 2014, p 34, cf. Banfield and Eggleton 1989) is unmatched by any location higher up in the section. Pronounced breaks in geochemical composition at the suspected natural-anthropogenic interface of profile pit 1 suggest that the original (primary) soil formation was truncated during, or at the start of, Celtic field usage.

The two suspected field plot locations investigated in profile pits 16 and 4 proved of unequal quality. The interpretation of profile pit 16 is hampered by the fact that it—in retrospect—had been situated too close to a Celtic field bank to reflect a clear ‘field plot’ location (cf. Fig. 3d) and by the fact that in its southern section a possible pit with ceramics was identified. This means that the finds recovered (Table 2; including amongst others sherds weighing up to 3.6 g and a spindle-whorl) cannot be held typical for ‘normal’ field plots, but may represent in situ settlement refuse.

Profile pit 4 better reflects the location and composition of a ‘normal’ field plot. The anthropogenic nature—whilst not pedologically visible—is evident from the sherds and charcoal recovered mainly from 30 cm depth. The finds are severely fragmented (pottery total weight 7.2 g, charcoal total weight 0.5 g; Arnoldussen and Scheele 2014). The scarcity of finds from higher-up in the section is presumably caused by more intense fragmentation due to the (sub) recent ploughing (cf. Fig. 5) as well as by frost-thaw cycles.

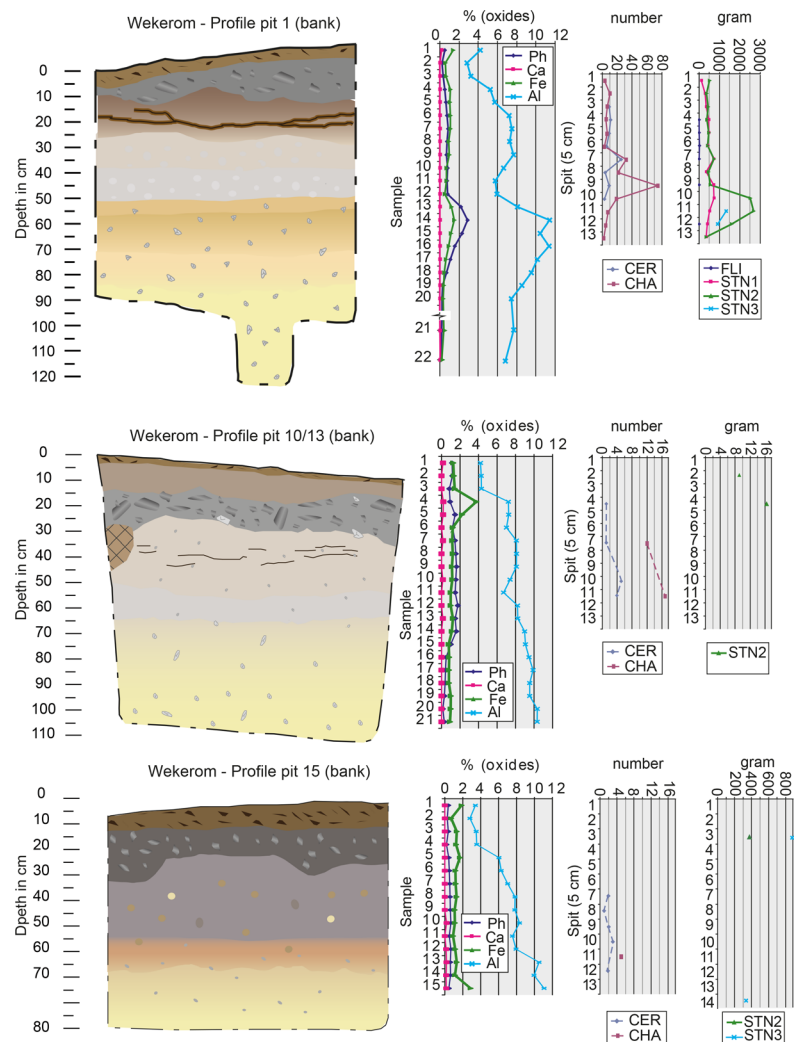
Palaeo-ecology: Wekerom-Lunteren

Sample 5655 from profile pit 1 reflects the PCF phase at Wekerom. This layer has a relatively low pollen percentage of trees (28.6%; Fig. 9). *Alnus* is the dominant tree pollen type (which in this dry sandy soil probably does not reflect the local vegetation but the pollen was probably blown in from marshy vegetation nearby). One pollen grain of *Salix* is observed as well as *Carpinus* pollen. The pollen spectrum is dominated by Poaceae (40.5%). Percentages of

cultivated species (in this layer only *Hordeum/Triticum*-type) and arable weeds (e.g. *Scleranthus* and *Spergula arvensis*) are relatively high. *Rumex acetosa*-type has a maximum value of 7.6%, the *Calluna vulgaris* percentage is 43%.

The CF samples from the banks have a lower tree pollen percentage than the PCF layers, ranging between 16 and 24%. Only the top of the bank in profile pit 10/13 (sample 5347) has a higher tree pollen percentage. Non-arboreal pollen dominates the CF samples. Poaceae form a large part of the pollen spectrum (34–53%). All samples contain cereal pollen, with *Hordeum/Triticum*-type amounting up to almost 8%. Some pollen grains could be identified as *Triticum*-type. Compared to Zeijen, a larger variation in arable weeds is present in the CF of Wekerom: *Artemisia*, *Convolvulus arvensis*-type, *Papaver rhoeas*-type, *Scleranthus* and *Spergula arvensis* are all present. The category of grassland plants (which can also grow on arable fields), such as *Plantago lanceolata*-type and *Rumex acetosa*-type (cf. Behre 1986), increases up to 9%. The top part of the

Fig. 8 Schematic section drawings (see Fig. 5 for interpretation) and geochemical composition as determined with p-XRF (in% of oxides), numbers of sherds (CER) and charcoal (CHA) particles recovered, as well as weight (in g) of unworked flint (FLI), and stones (stones < 2 cm = STN1, stones 2–5 cm = STN2, stones > 5 cm = STN3) for Celtic field banks at Wekerom (for location of the profile pits see Fig. 1c–e). Distribution graphs are aligned to match with recovery depth in depicted sections. Profile pits 10/13 and 15 have not been sieved, hence the discontinuous recovery



bank in profile pit 13 (samples 5347–5348) differs with 0.8 and 2.7%, respectively for these pollen types. In all the CF samples, wetland pollen types other than Cyperaceae are rare, yet some remains of green algae were found. Spores of coprophilous fungi—*Cercophora*-type (T.112), *Sporormiella*-type (T.113), *Podospora*-type (T.368) and *Sordaria*-type (T.55B)—are present throughout the CF banks, indicating the presence of animal dung. The pollen assemblage of the bank of profile pit 15 resembles that of the other banks, yet differs by the much lower percentage of Ericaceae and the higher microscopic charcoal units concentration (95 k/ml). The bank sediments of profile pits 1 and 10/13 contain a microscopic charcoal unit concentration of up to 86 k/ml, without evident vertical trends.

The charred macro remains are in agreement with the pollen results, and all finds are mentioned here. At 55 cm depth in profile pit 1 one charred spikelet fork of *Triticum dicocum* is found. Profile pit 10/13 contains one *Scleranthus annuus* fruit and one *Plantago lanceolata* seed (both charred and at c. 60 cm deep). Twenty-five cm higher-up in this bank, a grain of *Hordeum vulgare* is present. The charcoal fragments mainly consist of *Quercus* (n=40) and *Alnus* (n=14). This peculiar association, but also the straight trajectories of the tree rings across the fragments

suggests that they originate from heartwood. Like at Zeijen-Noordse veld, the Wekerom charred remains do not reflect the presence of slash-and-burn residues of local vegetation on the arable fields, but waste from a settlement site.

The field plot investigated in profile pit 4 (sample 5351) contained higher arboreal pollen percentages than the bank samples, but herbs still dominate the pollen assemblage. *Alnus* reaches percentages up to 34%. Poaceae are the largest component of the herbal vegetation in the pollen sum. The percentage of cultivated species is relatively low. Most of the cereal pollen grains are of *Hordeum/Triticum*-type, but in both samples a pollen grain of *Secale* is present as well. In profile pit 16, presumably the lower flank of a bank rather than a field, pollen of the marsh plant *Typha angustifolia* is found.

Discussion

Detailed combined archaeological and palaeo-ecological analysis of bank and field plots of samples from two Dutch Celtic fields has yielded high-resolution information on bank composition and development, which in turn facilitates reconstructions of the past agricultural regimes. First, the low number of stones recovered from the anthropogenically influenced parts of the banks compared to the number from the underlying natural soil, argues against fieldstone clearance as the main cause of bank development in these Dutch Celtic fields, despite being common elsewhere (e.g. Klammer 1993; Yates 2007). Bank formation here appears to reflect a combination of contributing factors that entail the admixture of dung (indicated by herbivore dung fungi; Figs. 7, 9), settlement debris (indicated by firewood charcoal and sherds; Figs. 6, 8) and non-local soil. The latter hypothesis of the non-local origin of at least part of the bank sediment is based on the observed discontinuities in the geochemical composition across the natural-anthropogenic interface (Figs. 6, 8) and the presence of non-local wetland landscape proxies (i.e. freshwater algae and wetland plants), non-local charcoal and small fragments of sherds (Figs. 6, 7, 8, 9). Moreover, micromorphological analysis of the bank sediment at both Zeijen and Wekerom provided indications (i.e. incorporation of not in-situ formed discrete nodules of hydromorphous iron formation; Arnoldussen 2012, pp 46–47; Arnoldussen and Scheele 2014, pp 61–64) of the admixture of clumps of soils from parts of the landscape wetter than the sample locations.

Evidently, mineroclastic and plant remains from wetland parts of the region ended-up in Celtic field banks. Presumably, sods from wetland areas such as wetter heathlands or meadows close to *Alnus* carrs were brought to the farmhouses as byre bedding, where they became enriched with manure and—after being mixed with additional household

Table 2 Numbers of sherds (CER) and charcoal fragments (CHA) from field plots locations at Wekerom-Lunteren (profile pits 16; low flank of bank rather than field plot proper) and profile pit 4 (field plot) tabulated per 5 cm spits

Profile pit	Spit	Ceramics	Charcoal
16	1	1	
16	2	5	
16	3	1	1
16	4	1	2
16	5	7	1
16	6	21	5
16	7	11	7
16	8	6	
16	9	3	
16	10	1	2
16	11		
16	12	1	
16	13		1
4	1		1
4	2		
4	3	1	
4	4	1	
4	5	2	1
4	6	3	7
4	7		2
4	8		1

For section interpretations see Fig. 5

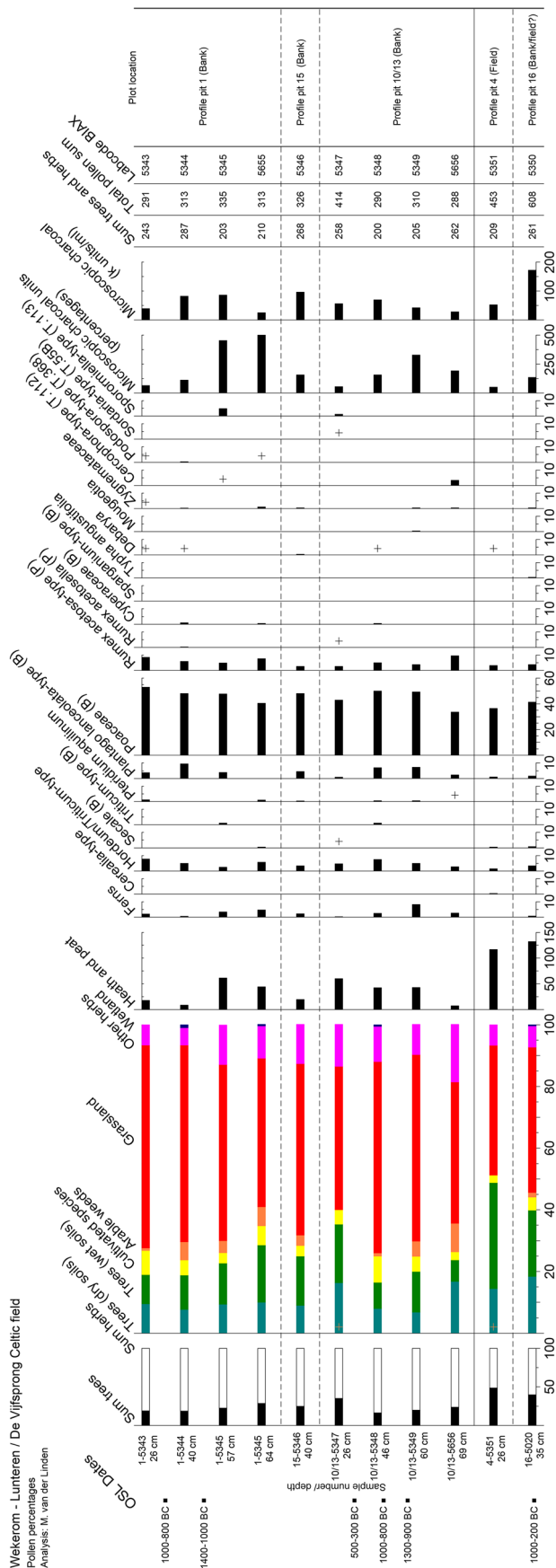


Fig. 9 Selection of pollen percentages, spores, algae and microscopic charcoal for the Lunteren-Wekerom samples

refuse (cf. Bakels 1997)—carted off to the fields (as was still practised in the Netherlands well into the 19th century AD; Heidenga 1988, cf. Kroll 1975). Alternatively, mud or muck from wetland areas could have been brought as manuring to the arable land directly (cf. Bakels 1997), or the wetland species represented could reflect a fodder signal. Here we favour the interpretation of sods being used as byre-bedding, later mixed with debris to be used as manure, as it best explains (a) the vertical aggradation of banks (i.e. net sediment input), (b) the composition (i.e. the concurrence of dung, charcoal and sherds in the banks) and ultimately, (c) the presence of dislocated clumps of wetland soil in the micro-topographic parts of the landscape, a presence otherwise devoid of explanation.

Based on the type and amount of humus in the banks, Brongers (1976), Behre (2008) and Spek et al. (2003) had already assumed “import of good quality organic topsoil or litter from outside the Celtic field” (Spek et al. 2003, p 166). Similarly, Gebhardt (1976, p 100) argues for the import of lamellic Luvisoil sediment to increase nutrient content of the soils at the Flögeln Celtic field. Investigations of banks of the, alas poorly dated, *oltidsagre* of Ælgaard Hede and Harild in Denmark also yielded evidence for (heather) sods (Hatt 1949; Klamm 1993). The presence of pollen from wetland vegetation (*Cyperaceae*, *Typha angustifolia*, *Sparganium*) can suggest the area of origin for such non-local soil, but it cannot be ruled out that the plants were gathered separately from the sods, either as fodder or as plant-manuring (cf. Bakels 1997; De Hingh 2000; Guttmann et al. 2005). The fact that the charcoal contained within the banks does not reflect local natural vegetation (e.g. selective combinations of upland (*Quercus*) and wetland species (mainly *Alnus*, which is not likely to grow on dry sandy soils), heartwood instead of twigs; (Arnoldussen and Scheele 2014, pp 54–58)) indicates that it reflects firewood selection criteria instead (full charcoal details in ESM). Unsurprisingly, recent fieldwork at a Celtic field near Hilversum has shown a similarly restrictive charcoal spectrum (dominated by oak in the banks, and some willow charcoal from the underlying natural soil; Hondelink and Brinkkemper 2014), confirming that this was a widely adopted system. The fact that Spek et al. (2003) did not analyse (e.g. age or species identification) the charcoal recovered from their test-pits at Zeijen, may have led to their probably erroneous assumption that this charcoal reflects the burning down of locally (re)grown vegetation upon initial clearance, or after fallow periods (Spek et al. 2003, pp 164–165).

The mixing of excrement-enriched dung with household debris to be used as fertilizer, leading to a veil of

sherds (*Scherbenscheier*; Klamm 1993, p 83) has been documented before at other prehistoric fields. For example, the ubiquitous presence of small sherds datable to the pre-Roman Iron Age and 1st century AD in the trenches and test-pits dug across the Flögel Celtic field (Zimmermann 1976, p 84), suggest that they represent an admixture to the dung-mix (Zimmermann 1976, p 86). At Telgte, a buried Bronze Age agricultural layer was similarly rich in small pottery fragments (Reichmann 1982). At Archsum and Rantum at Sylt, Bronze Age agricultural layers were shown to contain strongly fragmented and well-rounded sherds, charcoal and dung-enriched sods (Blume et al. 1987). At the Lodbjerg cliff site, an exposed Iron Age agricultural layer contained some flint fragments, possible dung and ashes as well as small fragments of charcoal and pottery (Liversage et al. 1987), suggesting it too was manured with a household debris and dung mixture. This tradition of using settlement debris as manure of course is widespread (Bakels 1997; De Hingh 2000; Guttman et al. 2005) and extends beyond the West-European lowland basin as well (Miller and Gleason 1994). For the Dutch case-studies discussed here, we have argued that that manure was intentionally mixed with mineroclastic materials (sods?) and settlement refuse, but the location of the mixing is unknown: it may have occurred in or near the byrehouse or on the fields (i.e. the dung documented may also or partly derive from livestock that was grazing or ploughing in the (fallow) fields).

It is moreover important to stress the paradoxical nature of the manuring evidence derived from Dutch Celtic field banks. Whereas the banks are generally the only remaining context in which anthropogenic layers from prehistoric field systems can be studied—with thinner anthropogenic layers in field plots being more severely affected by wind erosion, later ploughing, or Medieval or post-Medieval sod cutting and masking soil development (podsolization)—they represent the secondary position of manuring agents.

The primary objective in the past will have been to fertilize the field plots (Fokkens 1998), but due to the seasonally repeated agricultural cycles of uprooting and discarding arable weeds with sediment still attached to their root clusters at the sides of fields and the removal of sods from fallow fields, banks came to form a proxy repository of originally field plot sediments. As an alternative (or complementary) explanation, ploughing through (or after the removal of) grassy and shrubs vegetation after fallow periods may have been facilitated by the removal (as sods?) of the topmost layer containing most of the vegetation's root clusters and placing these along the field's edges—albeit that in such a scenario the most nutrient-rich part of the topsoil was removed from the field (cf. Brongers 1976, p 26). For Flögel, the high phosphorous values for the banks

as compared to the fields has been taken to suggest cultivation of the banks proper, rather than the fields (Zimmermann 1976, p 88; Behre 2008, pp 154–155; cf.; Behre and Kučan 1994, p 139). This suggests that—despite shared morphologies—supra-regional differences in bank width and composition may signal disparate usage traditions (Behre 2008, p 156).

Uprooting of arable weeds has been considered a component of bank construction before (Curwen and Curwen 1923; Harsema 1980; Klamm 1993), but we argue that it was the main cause of bank development in the two Dutch Celtic Fields studied, perhaps together with the removal of sods from fallow fields. That discarding arable weeds results in noticeable effects, is shown in historical times through a Danish law from 1779 that prohibited the tossing of remains of weeds and stones to the sides of arable fields (Bjerge and Sjøgaard 1904), indicating that this practice was quite common—yet one should note that such modern systems show a higher use-intensity compared to prehistoric systems, in which longer and shorter fallow periods play an important role (cf. De Hingh 2000, p 171). Understanding the generative force of bank development, however still leaves the distinct morphology of the bank (i.e. rectilinear, straight banks, plots embanked on all sides) in need of explanation. Uprooted weeds or clearance debris could have been disposed of in various ways, so what may have inspired this pattern of relatively straight banks to all sides of field plots?

The answer may be that in the initial phases of a Celtic field system, field plots were demarcated by wattlework fences (Liversage 1987; Klamm 1993; Spek et al. 2003). Large-scale field systems demarcating plots with wattlework fences are known for the period 1400–1000 cal BC from the Dutch river area (Fig. 10a; Arnoldussen 2008) and similarly shaped and dated systems (yet constructed with ditches) are known from the West-Friesland near-coastal area (e.g. Lohof and Roessingh 2014; Roessingh 2014). Tenure and land-use patterns underlying such Middle Bronze Age parcelling strategies (cf. Yates 2007) may have continued into, or have sparked, Celtic field planning. Excavation of the Bronze and Iron Age settlement of Hijken (Fig. 10b), situated within a Celtic field, has shown that fence-line systems are found at the locations of Celtic field banks (Arnoldussen and De Vries 2014). Such rare cases support the interpretation that originally, fence lines demarcating field plots were the targets against which agricultural refuse (amongst which were uprooted arable weeds) and possibly also composting dung/debris mixtures were deposited. Even if hypothesising a use of the banks as temporary compost repositories that were periodically spread onto the fields, there must have been a net sediment preservation at the borders. Over time, the demarcating function

Fig. 10 **a** Schematic overview of the excavation results of the Middle Bronze Age (c. 1400–1000 cal BC) settlement at Zijderveld (*red* houses, *orange* outbuildings, *black lines* fence-lines, the *darker green* zone is a filled-in residual gully, the *blue* bands indicate the general sub-rectangular layout marked with the various fence-lines; based on Fig. 6.23 in Knippenberg and Jongste 2005, p 63). **b** Part of the excavation results of the Iron Age habitation phase at Hijken (*yellow* houses, *blue* outbuildings, *black lines* fence-lines, the *light brown* bands indicate the location of Celtic field banks as indicated by aerial photography, the *darker brown* bands indicate the location of Celtic field banks as mapped during excavation (after Fig. 12 in Arnoldussen and De Vries 2014, p 101))



embodied by the fence, will have been taken over by the gradually rising volume of organic-rich sediment piled to both sides of the fences, thus very gradually developing into banks. Banks may therefore initially have, in following and substituting initial fence lines, developed

more as a consequence than by intent. The longevity of bank formation can be assessed through the OSL dates obtained, suggesting that bank accumulation took hundreds of years. The chronostratigraphic consistency of the samples combined with their similar age ranges

within and between the two individual Celtic field sites, shows that, despite the innate complexities of (OSL) dating agricultural soils, consistent and reliable results can be obtained. For the end of bank formation, the OSL dates of Zeijen profile pit 1 (200 BC–AD 1) and Wekerom profile pit 10/13 (500–300 BC) can only act as *terminus post quem* samples: they are located 30 cm from the top of the banks, which may very well have been higher originally. A combination of wind-erosion, Medieval and post-Medieval sod-cutting may have lowered the banks to their present-day heights, suggesting that bank development may well have continued into the Roman period. As the risk of contamination due to bioturbation of the topmost parts of the banks is considerable, the topmost layers were not OSL dated however.

The above explanation for bank construction could perfectly feasibly be executed at the scale of, and with the help of, a few households. This means that even if the initial planning was coordinated at supra-household level (but see Johnston 2005; Yates 2007 for nuanced views), seasonal cycles of subsistence agriculture of individual or small clusters of cooperating households were the main decentralised actors driving bank formation. Whereas its planar dimensions (i.e. the locations and orientations of the bank) may have resulted from landscape planning by a conglomerate of user communities, the vertical dimensions of the banks (i.e. their height) were the result of the shared and similar agricultural practices (e.g. the clearing of field weeds or other vegetation, fallow phases) that formed fixed elements of seasonal agricultural cycles, executed by the individual household members. Put more simply, the initial shape of a Celtic field resulted from a phase of deliberate planning executed as fences, followed by centuries of highly traditional, unchanged use that showed enough consistency in agricultural practice for the banks to grow to almost a metre in height. This may underlie the paradoxical uniformity of banks throughout a Celtic field (i.e. individual actors, yet within a set spatial framework, and all conforming to a shared agricultural practice). More important, however, is the conclusion that Celtic field banks can evidently act as chronostratigraphic repositories of (proxy) information on past agricultural strategies. OSL dating has shown that banks indeed have preserved (chrono)stratigraphies, which moreover span several centuries (Arnoldussen in press; Arnoldussen and Scheele 2014). This may comply with uprooting and vegetation clearance as being the very slow agents of bank heightening, and it shows that bank construction was far from instantaneous (Klamm 1993; Zimmermann 1995; Gerritsen 2003). Foremost future fieldwork on Celtic fields must acknowledge and exploit this chronostratigraphic potential in order to further our understanding of later prehistoric agricultural land use in more detail.

Conclusions

Our multi-proxy research on the archaeological and palaeo-ecological composition of banks and field plots within the Celtic fields of Zeijen and Wekerom provides new information about the formation of banks in these Dutch Celtic fields. It shows that there, banks were not formed as a result of fieldstone clearance, by tree stumps or through the accumulation of local soil, but rather are the result of gradual soil accumulation derived from soil input from uprooted arable weeds discarded at the sides of fields and the possible removal of vegetation or even sods from fallow plots then being placed at the sides of the fields. Geochemical analyses of the field sediments with p-XRF provided indications for the theory that banks were constructed using a mineroclastic input of non-local origin. This conclusion was supported by documented displaced, non-local, hydro-morphous iron clusters in thin sections, suggesting the incorporation of non-local soil. The origins of such non-local bank constituents were indicated through palynological analysis, plant macrofossil analysis, and charcoal analysis. At both sites, pollen of plant communities indicative of wetland areas (Cyperaceae, *Typha* and *Sparganium*) had become incorporated into the banks. Moreover, microfossils from algae indicative of such environments (*Debarya*, *Spirogyra*, *Zygnemataceae*) were recovered from the banks as well. The exact mechanism by which such non-local soil, presumably originating from wetland parts of the landscape, ended up in the banks can partly be reconstructed by combining the archaeological and palaeo-ecological evidence. The nature of the macroscopically recovered charcoal (i.e. combining restricted species of both dryland and wetland environments, but also the dominance of heartwood) reflects firewood preferences. The spatial correlation of this charcoal to small fragments of pottery indicates that both categories originated from settlement sites located elsewhere. The incorporation into the banks of microfossils of herbivore dung fungi (*Cercophora*, *Podospora*, *Sordaria*, *Sporormiella*) stresses that dung was part of the original bank sediment as well. We suggested an interpretation in which the above wetland signals resulted from the use of sods taken from wetland parts of the landscape as byre bedding, which was later mixed with settlement debris and carted to the fields for manuring (as it would better explain the mineroclastic input to banks), yet complementary or alternative explanations, such as their incorporation through fodder regimes or muck manuring, or the mixing of separate influxes of dung, refuse and soils at the field plots proper, remain possible as well. Irrespective of such choices, the bank composition reflects agricultural regimes in which non-local soil became mixed with dung and household debris (presumably during hearth clearance) of which only charcoal and sherds have now remained. We

argue that this mixture of soil, manure and domestic debris was carted from the settlements to the fields to be used as fertilizer. The frequency with which this was done and whether, in what ways, or how long this fertilizer was left to compost near the fields will remain unclear. At some point, presumably when fields lay barren after harvest or after repeated use, this mixture must have been spread across the fields to replenish soil nutrient values. The process through which this mixture of manure-enriched agricultural soil from the fields ended up in the banks, was most likely through the uprooting of arable weeds and removal of vegetation from fallow fields. These plants, and most notably their root-clusters and the encased soil within them, were dropped near fences initially demarcating the sides of the fields. This interpretation presently fits best the macro- and microscopical analysis of Celtic field sediments in the Netherlands and explains through what agricultural regime banks of increasing height could very gradually develop around later prehistoric field plots.

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