Working the land, searching the soil:
developing a geophysical framework for Neolithic land-use studies
Project introduction, -methodology, and preliminary results at 'Valther Tweeling'

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1. Project introduction

1.1. Archaeological prospection of Neolithic sites

At the end of 2020, an interdisciplinary research project, entitled "Working the land, searching the soil. A geophysical framework for diachronic land-use studies" was started at Ghent University (UGent) in collaboration with the cultural heritage agency of the Netherlands and the Department of Geomagnetism at the Institute of Geophysics of the Czech Academy of Sciences.

The project aims to redress current understanding of Neolithic land use in sand, sandy loam and loam soils of the Netherlands and Belgium by developing a geophysical framework to map related land-use traces. Although many Neolithic settlement sites have been revealed on these soils through the collection of ploughed-up surface-finds, little is known about their spatial layout and structural organization, such as the construction of timber houses, wells and enclosures. As methodological innovations over the past decades have led to adaptive minimally invasive mapping strategies for such archaeological sites (*e.g.*, Bats, 2007; Verhagen *et al.*, 2013; Crombé & Verhegge, 2015), our project does not focus on mapping artefact scatters. Rather, the project aims to optimize use of geophysical techniques to map and characterize Neolithic soil features in combination with widely applied invasive survey approaches such as trial trenching and borehole sampling. While the project addresses Neolithic land use, the targeted methodological developments will be transferable to geophysical approaches to archaeological prospection of any period.

1.2. Archaeogeophysical context

In the past, geophysical surveys of Neolithic feature sites have enabled to accurately map, for instance, Linear Band Keramik (LBK) settlement sites (Sevenants *et al.*, 2011) and (causewayed) enclosure sites (*e.g.*, Schofield *et al.*, 2021), due to the significant size and geophysical contrast of the archaeological features of such sites, particularly when dug into a solid geological sub soil. Smaller and subtler features, such as post holes or pits in the unconsolidated soils of the Low Countries form an important share of the Neolithic features (Lange, 2014) but are harder to detect. As such, they receive far less attention of archaeological geophysicists and no proper studies, geared towards optimizing geophysical survey of these often-subtle archaeological features, currently exist. This subtlety is mainly due to a significant homogenization of the archaeological features into the natural subsoil matrix, through post-depositional soil forming processes such as bioturbation, and eluviation-illuviation and into the anthropogenically altered topsoil, for example through soil working (Wood & Johnson, 1981).

Traditionally, geophysical survey methods in archeology, mainly magnetometry, electrical resistance, electromagnetic induction, and ground penetrating radar survey, target mapping buried cultural remains, after which geophysical anomalies are characterized qualitatively through archaeological feedback (Boucher, 1996). More recently, advanced modelling approaches are starting to be deployed to investigate the geometry or composition of the archaeological feature (Pickartz *et al.*, 2019). Such endeavors complement studies into the influence of seasonal variations as those investigating the influence of moisture variations on the discrimination potential of electric and electromagnetic survey methods (Boddice, 2014; Schneidhofer *et al.*, 2017). Although these strategies help build the much-needed framework for investigating elusive types of, most often prehistoric, land use, they remain rare and, mostly experimental and site-specific. A more fundamental, and generally applicable framework rooted in archaeological practice as well as geophysical theory currently remains absent. Research lags such as these not only affect archaeological prospection, but burdens the use of geophysical methods in other applications as well. Soil structure characterization (Romero-Ruiz *et al.*, 2018) is only one example where the geophysical complexities of the subsurface target are fundamentally identical to those of buried (prehistoric) archeology. Therefore, to provide a more comprehensive framework for prospection of subtle archaeological variations, our project aims to provide a future-oriented methodological basis for geophysical approaches to archaeological and environmental studies.

2. Project methodology

2.1. Methodological context

Since the archaeological discrimination potential of geophysical survey methods is largely determined by the contrast between the geophysical properties of the targeted feature fills and the surrounding natural soil matrix (Gaffney & Gater, 2003), characterizing the potential contrasts between natural soil profiles and Neolithic archaeological soil features of the Low Countries is a first step in developing better survey strategies and interpretation schemes. If the signal caused by this contrast is larger than the data noise, caused by the factors such as underlying geology, instrument specifications, or mode of data collection (Schmidt *et al.*, 2020), the targeted archeology should be detectable with the deployed instrument type. Further complicating detection, some geophysical soil properties, such as electrical conductivity and dielectric permittivity, are inherently dynamic. As these are determined by soil moisture content and influenced further by temperature, electrical and dielectric contrasts exhibit temporal variations due to precipitation or seasonality. Our project aims to provide an interpretative framework the understand and predict these variations through a combination of theoretical studies, of which preliminary results are presented in Mendoza Veirana *et al.* (2021), and experimental field work. An overview of the latter is the subject of the following sections.

2.2. Site selection and sampling approach

To provide a broad empirical basis for understanding and predicting geophysical contrasts of Neolithic features, we target two types of sites. A first group comprises so-called natural soil profiles (*i.e.* soil profiles without archaeological features), with some degree of soil development, representing the entire range of soil textures (from sandy to clayey). Site selection for these partly overlaps with study locations selected for past soil-physical studies in Flanders detailed in van der Bolt *et al.* (2020) (Fig. 1-A). The second group comprises profiles across preserved Neolithic features, taking into account the archaeological variation as well as the surrounding natural soil matrix (Fig. 1-C, Fig. 2).

The field work consists of three steps: [1] soil description; [2] profile geophysical measurements, and [3] soil sampling. First, sampled profiles are described macroscopically

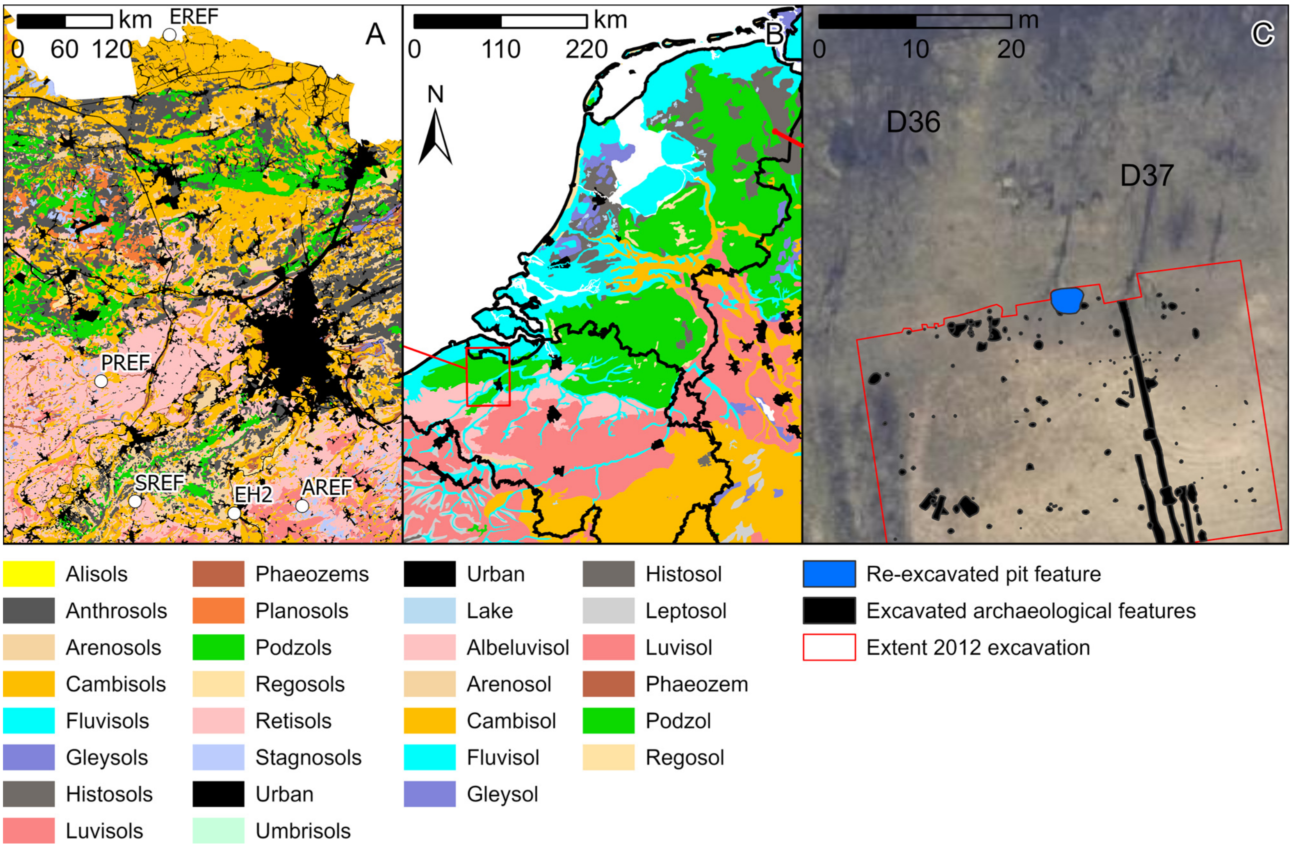


Fig. 1 – A: Locations of the studied natural soil profiles with labels from van der Bolt *et al.* (2020), background: WRB Soil Units 40k (Informatie Vlaanderen); B: Overview map, background: Soil reference group code of the STU from the World Reference Base (WRB) for Soil Resources (ESDAC); C: Location of the archaeological features excavated by Fens and Arnoldussen (2015) and the location of the selected pit feature for re-excavation, geophysical measurements, sampling and installation of the monitoring station (see Fig. 2).

according the code of good practice for archeology (S.N., 2019) and orthophotographed (De Reu *et al.*, 2014). In the second step, geophysical properties that are straightforward to record along exposed profiles (magnetic susceptibility, electrical conductivity and dielectric permittivity) are collected along regular vertical intervals. These data are collected with a small but highly sensitive magnetic susceptibility meter (SM-30 by ZH Instruments), and a coaxial impedance dielectric reflectometer probe (Hydraprobe, Stevens Water Monitoring Systems Inc.), which registers real dielectric permittivity as well as bulk electrical conductivity. The Hydraprobe's standard data processing assumes that the relaxation component of the soil is negligible. Consequently, the provided bulk electrical conductivity is commonly overestimated. This issue has been resolved using the correction by Longsdon *et al.* (2010), which considers the relaxation component non-negligible. Lastly, soil samples, *i.e.* undisturbed (Kopecky) rings and bulk samples are collected from the soil horizons identified within the natural soil profiles, and from observed archaeological layers within archaeological feature, to enable quantifying relevant physical and chemical properties that give rise to geophysical responses. As such, one to two samples are collected centrally within the identified soil horizons or archaeological layers. For a single natural profile, this fieldwork can be done in approximately one working day by a team of two. Fieldwork on a natural and archeological soil profile pit requires an extra person, particularly when a monitoring station needs to be installed.

To monitor and account for temporal changes in the bulk electrical conductivity and dielectric permittivity, permanent monitoring stations (Teros 12 by Meter Group) are installed with capacitance sensors inserted within the soil horizons and, if present, archaeological layers of five natural soil profiles [Aref, Eref, Pref, Sref, EH2 from van der Bolt *et al.* (2020)] and at least two archaeological feature profiles of which 'Valther Tweeling' (NL) is the first (see section 3). The Teros 12 sensors monitor soil temperature, bulk electrical conductivity and volumetric water content at least once per hour. At the soil profiles by van der Bolt et al. 2020, the sensors were already installed at three depths, *i.e.* within the ploughed topsoil layer (0-30 cm), the compacted subsoil layer (30-40 cm) and the deeper subsoil (40-80 cm) . At the archaeological feature profiles, they are installed centrally within the soil horizons or archaeological layers, in proximity to the collected samples. The resulting geophysical data with a timestamp are downloaded at a later stage for further analysis.

Basic soil properties (bulk density, porosity, water content, soil texture, organic matter content, cation exchange capacity, electrical conductivity and permittivity phases) of the collected soil samples are determined in the laboratory. These can be interrelated using pedotransfer functions and introduced into pedophysical models to predict geophysical soil properties theoretically (Mendoza Veirana *et al.*, 2021). In turn, these geophysical soil properties will to be forward modelled to possible sensor responses of synthetic archaeological features and soils to determine optimal survey strategies and survey times.

3. First results at the archaeological site of 'Valther-Tweeling'

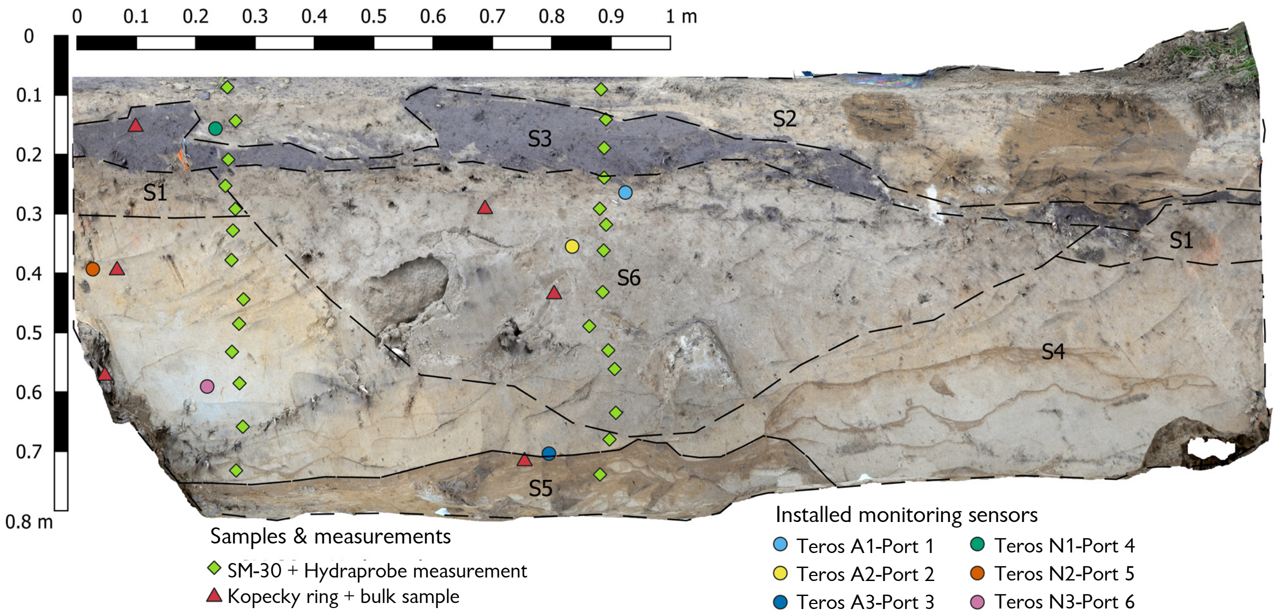
3.1. The site of 'Valther-Tweeling'

In 2012, a rescue excavation was completed on a parcel directly to the south of the listed site of Dolmen D36 and D37 (van Giffen, 1925), locally known as the 'Valther Tweeling', in the village of Valthe (Province of Drenthe, the Netherlands). Aside from many scattered finds, various soil features were excavated by Fens and Arnoldussen (2015). In addition to several Late Bronze age and/or Early Iron age soil features, the most significant finds are dated to the Middle Neolithic period, attributed to Funnelbeaker material culture, and interpreted as related of the construction or funerary use of the Dolmen. Particularly relevant for this study, an irregularly shaped pit feature with a diameter of ca. 3 m was partially excavated along the northern edge of the excavation (Fig. 1). This pit was interpreted as a boulder extraction pit used in the construction of the Dolmen (Fens *et al.*, 2016). The partiality of the excavation provides a rare opportunity of an already identified and accurately located Neolithic soil feature, which, more importantly, remains preserved *in situ*. In addition, traces of Neolithic land-use around the monument have been recorded during the 2012 excavation, but are still largely unknown in the wider surrounding landscape.

For these reasons, the 'Valther Tweeling' site provided an excellent opportunity in the context of this research project. On July 5th 2021, a single fieldwork day was organized by Rijksdienst voor het Cultureel Erfgoed and UGent to sample and record the excavated profile as described above, after which a monitoring station was installed.

3.2. Qualitative exploration of the results

The excavated profile (Fig. 2) was visually interpreted and divided into different natural and archaeological feature units (S1-S6 on Fig. 2). The topsoil (S3) is largely disturbed and is covered with a layer of sediment (S2) that was added after the 2012 excavation. Below this topsoil, bioturbation traces of an older Ap horizon are present (S1), which



Soil features

S1: Yellow, weakly silty, moderately fine sand, weakly gravelly; gradually transitioning lower limit (BC horizon: mollenlaag/bioturbated)

S2: Yellow mottled, weakly silty, moderately fine sand, weakly gravelly; sharply transitioning lower boundary sharp (recent disturbance)

S3: Grey, weakly silty and weakly humiferous, moderately fine sand, weakly gravelly; sharply transitioning lower boundary sharp (Ap horizon; plough soil)

S4: Light yellow, weakly silty sand, moderately fine with some humus infiltration veins, sharply transitioning lower boundary sharp (C-horizon)

S5: Brown yellow, moderately silty sand, moderately coarse with thick humus infiltration vein (C-horizon: top boulder clay)

S6: Grey, weakly silty sand, moderately fine with some larger cobbles; vaguely transitioning lower boundary (extraction pit?)

Fig. 2 – Orthophoto of the section wall of the excavated profile pit at 'Valther Tweeling' with descriptions and delineations of the interpreted natural and archaeological soil features, location of the profile measurement and sampling positions, and location of the installed monitoring stations.

overlie the parent material (S4). These deposits are made up of silty sand, with only a low silt content, and contain the remains of a subtle Bs horizon in the top. The archaeological pit feature (S6) can be recognized below the topsoil due to its greyish color, which contrasts visually with the natural soil profile.

Based on these field interpretations, two profile measurement lines were set out to collect the SM-30 and Hydraprobe data with a vertical interval of 10 cm. In addition, the different soil features were sampled through six Kopecky rings and adjacent bulk sampling, positioned as close as possible to the profile measurement lines. After the data collection and sample collection, six Teros 12 sensors were installed. Sensors A1 and A2 are located within the archaeological pit fill. Sensor A3 is located at the transition from the bottom of the archaeological fill to the parent material below. Sensors N1, N2 and N3 are located outside the archaeological feature, in the natural soil profile horizons.

Over the exposed profile (July 5th, 2021), volumetric water content and porosity of the sampled soil (Fig. 3-A) of the archaeological feature and the natural soil profile are practically indistinguishable. Combined with the sandy texture, this renders very low bulk electrical conductivities (Fig. 3-B), and relative dielectric permittivities (Fig. 3-C), whereby an observable geophysical contrast is almost entirely absent between the archeology and soil background. The differences in magnetic susceptibility (Fig. 3–E) are higher in the upper 15 cm, most probably due to the differing thickness and composition of S3 and S2 at the location of both profiles. Below this depth, the differences characterizing the targeted archaeological contrast are much smaller.

Combined, these *in situ* observations show the elusive nature of the targeted Neolithic feature. Practically no contrasts exists in the targeted geophysical properties, collected on the exposed profile (*i.e.* at a static point in time). However, for dynamic properties

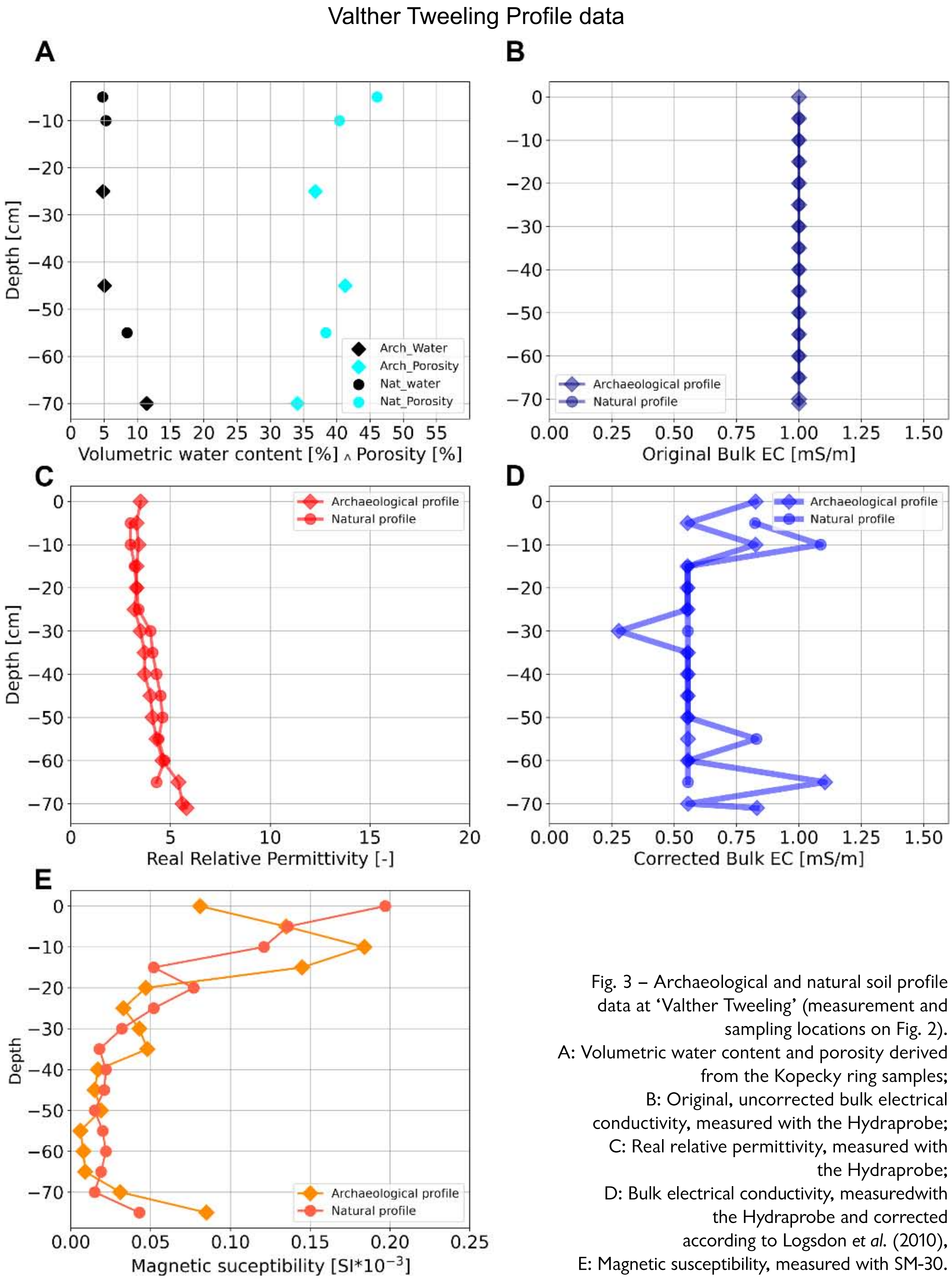


Fig. 3 – Archaeological and natural soil profile data at 'Valther Tweeling' (measurement and sampling locations on Fig. 2).
A: Volumetric water content and porosity derived from the Kopecky ring samples;
B: Original, uncorrected bulk electrical conductivity, measured with the Hydraprobe;
C: Real relative permittivity, measured with the Hydraprobe;
D: Bulk electrical conductivity, measuredwith the Hydraprobe and corrected according to Logsdon *et al.* (2010),
E: Magnetic susceptibility, measured with SM-30.

such as electrical conductivity and permittivity, the monitoring data collected after closing the exposed profile on July 6th shows how, for these properties, geophysical contrast is highly variable.

From late July to early September 2021, sensor A1 (upper fills of the archaeological feature), registered an increased bulk electrical conductivity and volumetric water content, while N1 (in the recent plough layer) registered shorter periods of increased bulk electrical conductivity and volumetric water content which seem a delayed response to precipitation (Fig. 4). The deeper N2 sensor (Bs horizon) only started to register an increased bulk electrical conductivity and increased volumetric water content since early October, a period which was not yet covered by precipitation data at the time of writing. Importantly, the increases in bulk electrical conductivity last for multiple days after the precipitation. A2, A3 and N3 currently don't exhibit significant variability in bulk electrical conductivity. The volumetric water content mainly indicates a gradual decrease and do not seem to be influenced by the registered precipitation events.

Further integration of the presented data with laboratory analysis conducted on soil samples from the site, and their integration into geophysical modeling procedures, is needed to fully grasp the relevance of these contrasts in terms of geophysical discrimination potential. However, the current observations already indicate how differences in specific soil properties and in electrical conductivity between soil and archaeological layers are, in this case, amplified under the influence of varying moisture and temperature, and that these differences cause a varying geophysical contrast between the natural soil background

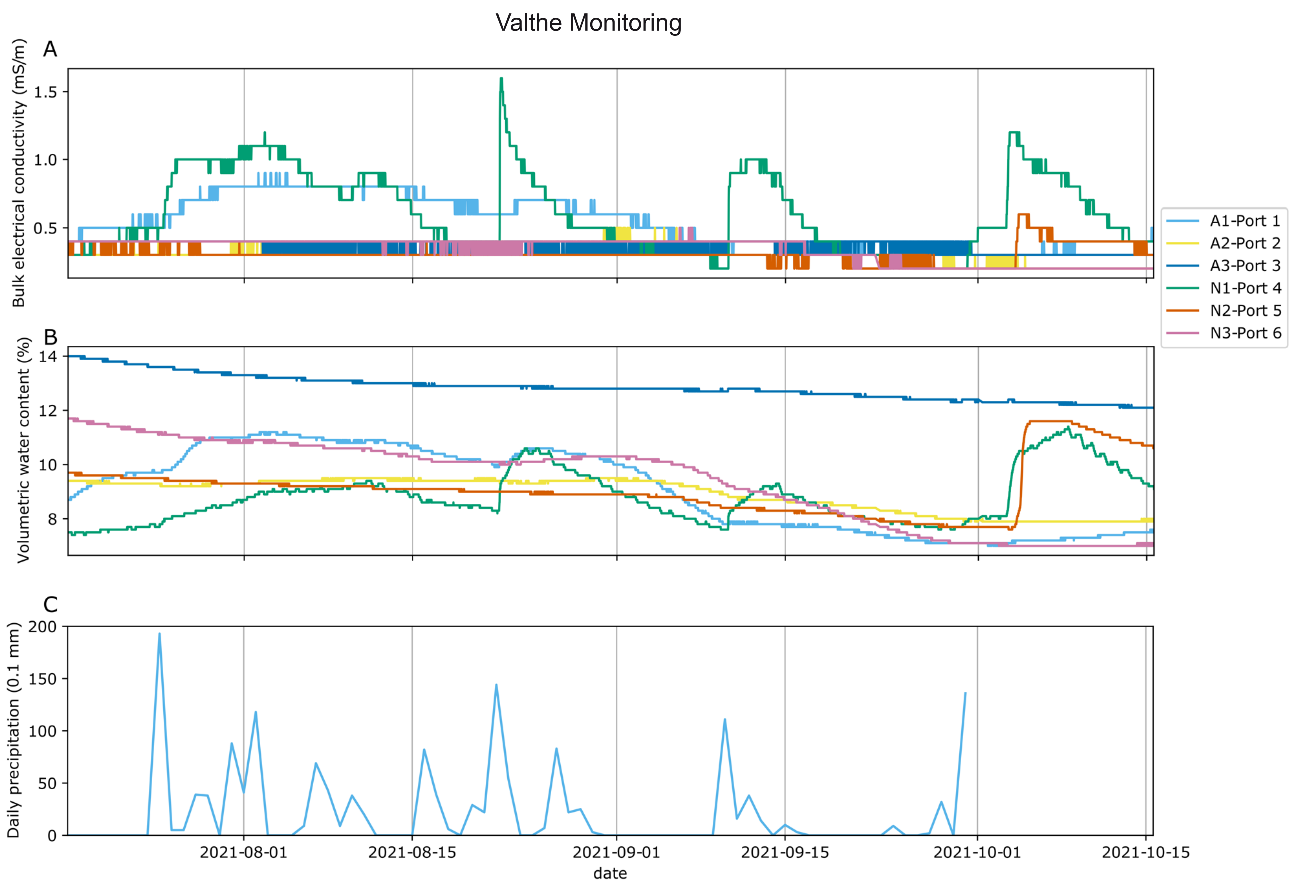


Fig. 4 – First three months of soil monitoring data at 'Valther Tweeling', measured with Teros 12 sensors. A: Original bulk electrical conductivity data. B: Volumetric water content. C: Precipitation data from the nearest weather station 333-Emmen (Royal Netherlands Meteorological Institute).

and the targeted archeology. The effect on the relative dielectric permittivity still has to be explored further, and will build on theoretical work by Mendoza Veirana *et al*. (2021). While short-term (*i.e.* annual and diurnal) changes in magnetic susceptibility are not expected (Lecoanet *et al*., 1999), more exhaustive magnetic analysis targeting factors such as magnetic remanence is needed to fully characterize (or discard) magnetic contrast at the site.

It follows that further monitoring, data analysis and geophysical forward modelling will reveal if, and under which circumstances these contrasts become detectable. This could inform us about an optimal timing for a landscape scale geophysical survey, maximizing detection of similarly contrasting archaeological features. Such a survey, whereby we will take into account the combined outcomes of the ongoing work as well as the influence of precipitation events, is scheduled in 2023.

4. Conclusion

We presented an approach to create a robust framework for detecting subtle soil features using geophysical methods. This framework is provided partly through experimental observations covering a wide range of natural soil profiles, as well as on representative prehistoric site locations. For the latter group, the 'Valther Tweeling' presented here is a first case study where an archaeological feature and natural soil profile are studied and monitored at the same location. The preliminary observations made at this location show how, through a straightforward fieldwork approach, data required to estimate basic geophysical contrast of prehistoric features can be collected within a short time- and budgetary framework, implying potential for more widespread application.

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Abstract

We are introducing the project 'Working the land, searching the soil. A geophysical framework for diachronic land-use studies' and present the first research results. By combining geophysical measurements with soil sampling and analysis on profiles of natural soils and archaeological features with long-term geophysical monitoring by sensors in the profile face, we aim to optimize the geophysical prospecting of subtly contrasting Neolithic (and other) soil features. The first results of the fieldwork on the cut of a Neolithic pit at 'Valther Tweeling' show the challenging conditions to register geophysical contrasts between soil traces and natural soils. The temporal changes in the electrical soil properties of the feature fill and the natural soil profile indicate that these react differently to precipitation, however. Therefore, subject to further data collection and analysis, an optimal contrast could be sought.

Keywords: Neolithic land-use, geophysical forward modelling, soil physics, *in situ* monitoring.

Samenvatting

We introduceren het project 'Landbewerkers en bodemspeurders. Een geofysisch kader voor diachroon landgebruikonderzoek' en presenteren de eerste resultaten van het onderzoek te 'Valther Tweeling'. Door geofysische metingen en bodemkundige monstername en analyse op profielen van natuurlijke bodems en archeologische sporen te combineren met langdurige geofysische monitoring met sensoren in de profielwand, willen we de geofysische prospectie van subtiel contrasterende Neolithische (en andere) bodemsporen optimaliseren. De eerste resultaten van het veldwerk op een gecoupeerde neolithische kuil te 'Valther Tweeling' wijzen op uitdagende omstandigheden om geofysische contrasten tussen bodemsporen en natuurlijke bodems vast te stellen, maar de temporele veranderingen in de elektrische bodemeigenschappen van de spoorvulling en de natuurlijke bodem wijzen erop dat deze op een verschillende manier reageren op neerslag en er mits verdere dataverzameling en -analyse dus potentieel naar een optimaal contrast kan gezocht worden.

Trefwoorden: Neolithisch landgebruik, geofysische voorwaartse modellering, bodemfysica, *in situ* monitoring.

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