Journal of Archaeological Science 42 (2014) 390–398

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Identifying ancient manuring: traditional phosphate vs. multi-element analysis of archaeological soil

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ARTICLE INFO

Article history:
Received 23 October 2012
Received in revised form
21 October 2013
Accepted 16 November 2013

Keywords:
Multi-element soil analysis
ICP-MS
Total P analysis
Ancient fields
Manuring
Principal Component Analysis (PCA)

ABSTRACT

Elevated soil phosphorus levels are often used as indicators for prehistoric manuring. However, in this article it is argued that though P is indeed a good anthropogenic marker, multi-element analyses can provide more insight into former fertilisation practices and land use.

Here, we compare the ability of both traditional total P analysis and multi-element analysis by ICP-MS to identify prehistoric manuring on soil samples from a well-preserved prehistoric Celtic field system in Denmark. The ICP-MS data set of 58 soil samples was furthermore analysed by multivariate analysis (PCA). Results show that the stronger extraction for the multi-element analysis releases significantly more P than the traditional analysis but similar archaeological interpretations based on relative P enrichments can be made. Among the 42 analysed elements, 11 were significantly ($P < 0.01$) enhanced in the fields relative to a reference soil, namely Na, P, K, Ca, Mn and Sr and the rare earth elements (REE's), Nd, Sm, Eu, Gd and Dy. Cobalt was the only element which was depleted within the field system. Enhanced P levels show that manuring was practiced, while elevated concentrations of Sr indicate that not only animal manure but also bones/domestic waste was added. Furthermore, the enhancement pattern of some major and minor elements indicate that unweathered subsoil was incorporated into the topsoil – probably through tillage erosion until approximately 2000 years ago. The study also indicates that the banks demarcating the individual fields were made of the same material as the field plough-layers, which makes within-field soil relocation the most likely cause of the banks.

1. Introduction

Manuring practices are important for understanding prehistoric agriculture and prehistoric cultures in general. This is first of all because manuring improves crop yields and helps in preventing soil deterioration, but also since the practice of manuring – in combination with fallowing – enables more permanent field systems, require byres or enclosures for collecting the manure, and is a very labour intensive practice, which therefore influenced people's daily lives. Prehistoric manuring has accordingly been the subject of many archaeological studies during the last decades focussing on when it was introduced, what kind of manure was used, and the intensity of manuring (e.g. Bakels, 1997; Guttmann et al., 2005, 2006). The practice of manuring is usually inferred archaeologically on the basis of ceramics, charcoal, bone, etc. found on prehistoric fields, but soil micromorphology and analysis of soil lipids have also proven very useful (Guttmann et al., 2005). However, the two latter approaches rely on good preservation conditions and time consuming laboratory investigations.

Analyses of the essential plant-nutrient soil phosphorous – usually reported as phosphate (PO_4^{3-}) – have been used since the 1930s with great success in archaeology as it is fast and applicable in a wide range of settings (Holliday and Gartner, 2007). Animal dung, bones, food remains, etc. are highly enriched in P and when deposited, the largest fraction of the added P is usually irreversibly bound to the minerals and soil organic matter while only a smaller fraction is removed with crops (Blume et al., 2010). The relatively simple analytical determination of P has facilitated its widespread use in archaeology, but extractions and determination techniques have varied greatly in time and among researchers, which makes it difficult to compare results in absolute terms (Holliday and Gartner, 2007). Thus phosphate has long been considered a good proxy for human activity, although P accumulation patterns should always be interpreted cautiously.

In the 1950s it was recognized that elements other than P can be useful in archaeological contexts (e.g. Lutz, 1951). Within archaeology, multi-element analyses have increasingly been applied for identifying

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http://dx.doi.org/10.1016/j.jas.2013.11.013

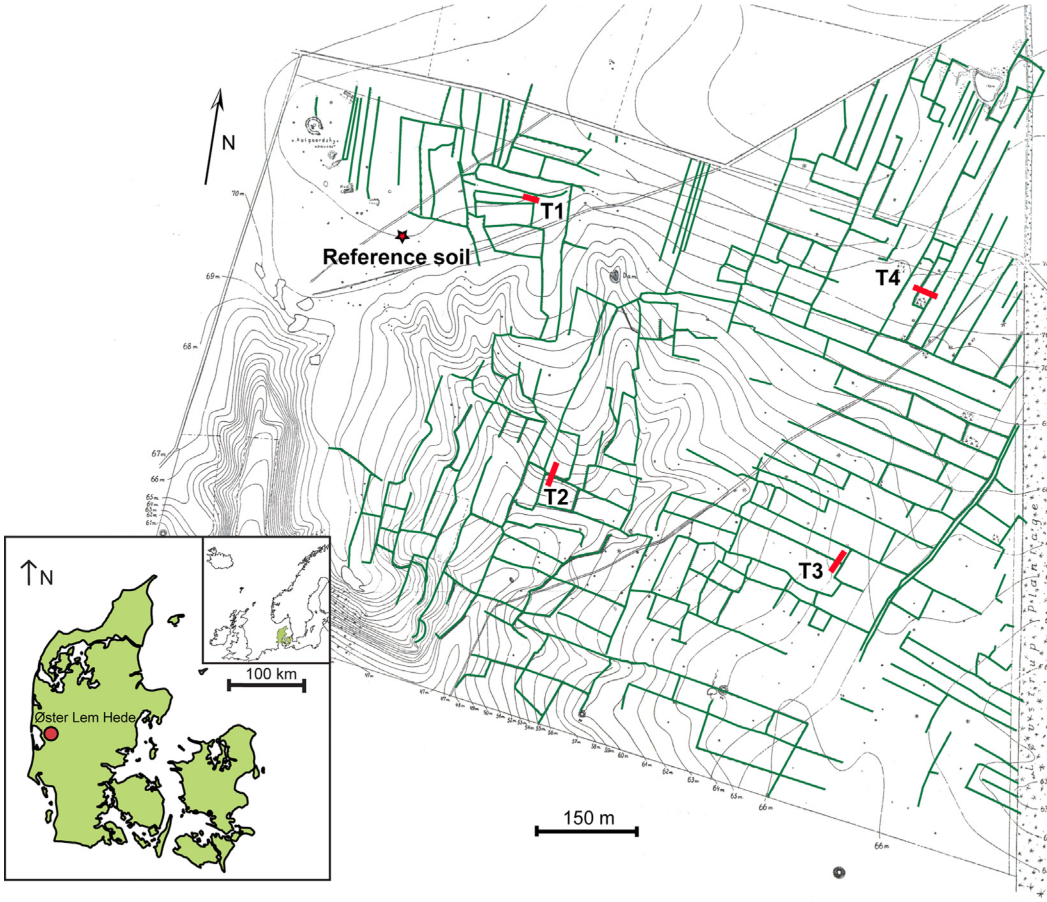

Fig. 1. Location of the study site Øster Lem Hede, Denmark. Originally the prehistoric field system stretched further to the north where there are now modern fields and to the east where there is now a plantation. The location of the four excavated trenches (T1–T4) and the reference soil are marked on a map of the Celtic fields based on Hatt (1949).

different activity areas in connection with settlements as reviewed by Holliday et al. (2010). This is driven by recent technical developments, especially inductively coupled plasma-mass spectrometers (ICP-MS) with superior detection capabilities that can carry out simultaneous analyses of multiple elements at ultra-low concentrations. Based on ICP techniques, the elements most often found to be associated with human settlements are P, K, Ca, Mn, Cu, Zn, Sr, Ba and Pb, but elements such as Mg, Rb, Cs and Th have also proven useful in some instances (Entwistle et al., 2000; Oonk et al., 2009; Wilson et al., 2005, 2008, 2009). Ancient fields have hitherto received less attention in multi-element analysis although some studies of historical sites have indicated that elements other than P can be useful. For instance, Sr and Ca – probably deriving from shell sand, bones or fish refuse – were found in fields in a study from Isle of Skye (Entwistle et al., 2000), while Ba, P and to some degree Ca, Zn and Sr were enhanced in a study in Scotland (Wilson et al., 2005). Element enhancement in fields will naturally vary with manuring practices and it will generally be much less pronounced compared to settlements.

Understanding what the enhancement of certain elements in soils represents is still problematic (Walkington, 2010), and interpretation of multi-elemental data is complicated by the fact that one has to take into consideration factors such as length and intensity of human activity, topography, parent material shifts and natural and cultural post-depositional processes (e.g. Woodruff et al., 2009). Nevertheless, each group of elements has unique vertical distributions in undisturbed soils depending on soil types (e.g. Tyler, 2004), which may be used to trace possible anthropogenic disturbances or additions. In some studies it has been possible to ascribe particular elements to specific anthropogenic features, but these elements usually vary from site to site and generally it is varying concentrations that reflect different activity areas at a given site (e.g. Wilson et al., 2005).

The aim of this paper is to evaluate and compare how both traditional total P analysis and multi-element analysis of abandoned ancient fields can be used to identify prehistoric manuring strategies. This will be done by examining a well-known Danish prehistoric field system where manuring is indicated by e.g. ceramics, charcoal and allochthonous soil particles. A Principal Component Analysis (PCA) is applied for multivariate data description and structure exploration, allowing us to discover grouping of samples and/or variables which may otherwise be obscured by individual sampling and analytical errors (Esbensen, 2010).

2. Material and methods

2.1. Site description

The site investigated is the Celtic fields at Øster Lem Hede (56° 3′ N, 8° 27′ E) partly situated in a protected heathland in Western Jutland, Denmark (Fig. 1) (Hatt, 1949). The field system dates from the late Bronze Age and the Pre-Roman Iron Age (ca. 800 BC–AD 1). It is > 1 km^2 and one of the best preserved Danish prehistoric field systems – the low earthen banks and lynchets demarcating the individual fields can still clearly be seen. The area has subsequently been used for extensive grazing, but only minor areas within the protected area have been physically disturbed by later activities.