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Understanding complex soil variability: the application of archaeological knowledge to precision agriculture systems in the UK.

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Abstract. *As higher resolution datasets have become more available and more accessible within commercial agriculture, there has been an increasing expectation that more data will bring more answers to questions surrounding soil, crop and yield variability. When this does not happen, trust and confidence in data can be lost, affecting the uptake and use of precision agriculture.*

This research presents a novel approach for understanding complex soil variability at a variety of different scales. It seeks to understand the impact that archaeological sites may have on soils and how those impacts might be relevant in precision agriculture systems?

From one case study site in the UK, preliminary results indicate that there are a number of ways that archaeological sites impact agricultural soils. Geophysical variations show changes in soil depth relating to archaeological features, but also outline where past activity may be expected. Some past activities such as habitation increase the likelihood of geochemical variation in key agricultural elements like phosphorus. NDVI satellite imagery have some correlations with parts of an archaeological site relating to previous human occupation, yet is irregular over time.

This highlights the need to understand both the archaeological site as well as the agricultural context, to be able to add understanding to areas of complex variation, which may not appear regularly over a number of years, but clearly impact certain crops, in certain conditions.

Keywords. *Archaeology, soil variation, geophysics, geochemistry, agricultural soils.*

Introduction

Knowledge of the spatial variability of soils is an essential component of precision agriculture. In order to vary nutrient application, or identify the causes of crop variation, how and where the soil varies is one of the first questions to be asked. Comparably, in archaeological studies of past remains, the soils of the site need to be evaluated before and alongside geophysical, satellite based, or geochemical surveys. This is crucial in understanding whether anomalies are being caused by natural variations in the soil, or by disturbances due to possible human activity (English Heritage 2008).

There is a significant body of research into how soils vary and how agricultural soil sampling can take that spatial heterogeneity into account (Oliver & Frogbrook 1998; Frogbrook et al. 2002). There are a whole host of different approaches used in research, from point sampling on a grid basis, to 'W' shape patterns within defined areas, to area based grid sampling. The geostatistical work done by Kerry and Oliver (2004) further clarified the need to work from the variability of the soil or soils as the starting point, determining the sampling interval based on the variogram. Despite much work in the area, it seems that farmers and precision agriculture service providers still tend to implement the same approach (whether grid based or other) across their client base for simplicity of operations.

The interface between earth sciences and archaeology has produced a field known as geoarchaelogy (Holliday & Gartner 2007). Geoarchaeologists work to understand the important connections between archaeological sediments and natural deposits. Often concentrating on vertical soil profiles, the geomorphology of the landscape, catenas and soil pits. Micromorphology has also grown as a very important contribution to the study of how objects, sediments and debris become deposited and mixed into existing soils and sediments at microscopic resolution. In between these two fields, at opposite ends of the scale, is the work of archaeological geophysicists. Surveying large areas such as at Stonehenge, where 100s of ha were covered, at comparatively high resolutions in the order of 10s of centimetres (Gaffney & Gater 2003).

Of these two, the agricultural and the archaeological communities, both cover a range of scales. Agriculture traditionally, and until recently, has usually thought about the larger scale, the farm scale, the field scale, and now the within-field scale. Archaeological researchers however have most often worked at the very fine scale, from centimetres to metres. Yet in the last 10 years development in technology and the accessibility of data have led to an overlap in the resolution. This overlap in resolution opens up questions of how archaeological data could be used to aid precision agriculture systems and how might precision agriculture data impact archaeological investigations?

Archaeological Knowledge

Less common archaeological data

Archaelogical Excavation

Due to the high cost, time requirement, and its destructive nature, archaeological excavations do not occur over extensive areas and thus have less relevance for overlap with precision agriculture. However some small excavations and test pits can be found on many known archaeological sites in the UK if archaeological work has occurred on the site. Excavations can reveal information about the soil profile, the cultivation patterns and the variations that might occur over 1 or 2m (e.g. peri-glacial features). However they occur generally only once, and cover a very limited spatial area.

Geoarchaeogical Survey

Geoarchaeological surveys mainly consist of transects of soil cores. These cores can take a variety of forms, depending on the questions being asked, but will often give very detailed analysis of the stratigraphic layers across a particular site or area. Spatially these do not provide much detailed information on the variability of soils within the top metre but can give good indications of how the soils have developed in the area.

Multi-elemental Analysis

Multi-elemental soil analysis has increased in the last decade due to the capability of ICP-MS and the substantial use of Portable X-Ray Fluorescence analysis of soils (Canti & Huisman 2015). Recent research has focused on the typical elemental signatures of archaeological sites, from farms to floor surfaces to rubbish middens (Oonck et al 2009).Important elements include Ba, Ca, P, Sr, Pb and Zn (Wilson et al. 2008). The application of multi-element techniques in commercial archaeological work is however limited, usually only focusing on detailed studies of particular buildings, deposits and artefacts. It has had limited impact on commercial work involving topsoils and subsoils and even less at the larger scales normally associated with modern agriculture (although one example of a study that has potential cross-over was presented by Dungworth (Dungworth et al. 2013).

More common archaeological data

Aerial photography

For many years pioneers of archaeological prospection have been taking and searching out historic aerial photographs of sites. Often these are taken at opportune moments in the year when the crop has moisture stress and is most likely to be showing sharp differences that are visible to the naked eye. Collections of historic aerial photographs in the UK can come from a number of sources but over time, new work under the National Mapping Programme project run by Historic England has produced a consistent dataset across the whole of the UK. This contains many archaeological sites and features of all sizes, from the Neolithic to the Twentieth century, that appear as crop marks or soil marks.

Archaeological Geophysics

Near-surface geophysical surveys have traditionally been of small scale and specifically focused on the most interesting/evidenced archaeological areas. Increasingly though, with more integrated equipment and data collection methods, larger arrays of sensors and fast methods of acquisition, larger areas have been surveyed. In the UK, with 67 registered companies practicing archaeological geophysics, collectively there is estimated to be 100,000 hectares of existing data at standard archaeological resolutions (pers. comm. Thomas). This does not also take into account the areas surveyed by small archaeological groups, University departments and Historic England. Surveys often may involve repeated geophysical assessments with a variety of geophysical methods. The most common method is Magnetic Gradiometry, followed by Resistivity and Ground Penetrating Radar. Magnetic Gradiometry has become the most commonly applied due to its functionality over a number of geologies, and ability to produce detailed maps of the magnetic variation at a site.

These magnetic anomalies can show ditches, pits, metal artefacts, pipelines, building outlines, areas of burning and sometimes, depending on the geology and background noise, soil marks, land drains and agricultural cultivation marks. Resistivity and Ground Penetrating Radar surveys are less common, although with the advances in mobile platforms and multiple-sensor arrays this may not be the case in the future.

Methods

Case study site

The case study site presented here lies in the southwest of the UK. The site was chosen due to its mixture of archaeological and agricultural data as well as its varying soil types that flow across the site. It lies in a chalk dominated landscape with higher areas covered by clay soil with flints. The soils over chalk are thin, varying between 20 and 30cm in depth whereas the clay with flints is considerably deeper. There are two fields that will be included specifically within the whole farm. The farm collects a number of datasets, some average for all farms in the UK, some more focused towards precision agriculture. These include cropping records, weather data, NDVI satellite imagery, zoned soil sample records and fertiliser applications. The archaeological context to the site has had reasonable attention over the past 20 years. Survey work and excavation has been carried out on the farm, along with aerial photography collection and archaeological geophysics by a number of different teams, some University led and some commercially led.

Methods

Collation of existing data took place first in Arc GIS to visually compare datasets together. This was followed by detailed soil sampling on a 20 x 20m grid to a depth of 15cm to gain a much clearer idea of the topsoil variability at this resolution. Soil samples were oven dried, sieved and ground to < 2mm removing large flint flakes or chalk nodules. Samples were then analysed via a Thermo Niton XL3t GOLD+ Portable X-Ray Fluorescence for 150 seconds in a stand for consistent measurement of prepared samples.

Satellite images are common throughout the UK in precision agriculture systems. With a number of images throughout the year it will be possible to test how these relate to archaeological features. To do this all images provided by a commercial provider, as to a farmer, were visually inspected. To look further into long term variation from these images, thus reducing the effects of very short term temporal events such as pest impacts and machinery impacts, images from each year were combined with an equal weighting to give an average image of NDVI variation over a particular year for a particular crop. This was done in Arc GIS using the weighted sum tool.

Results and discussion

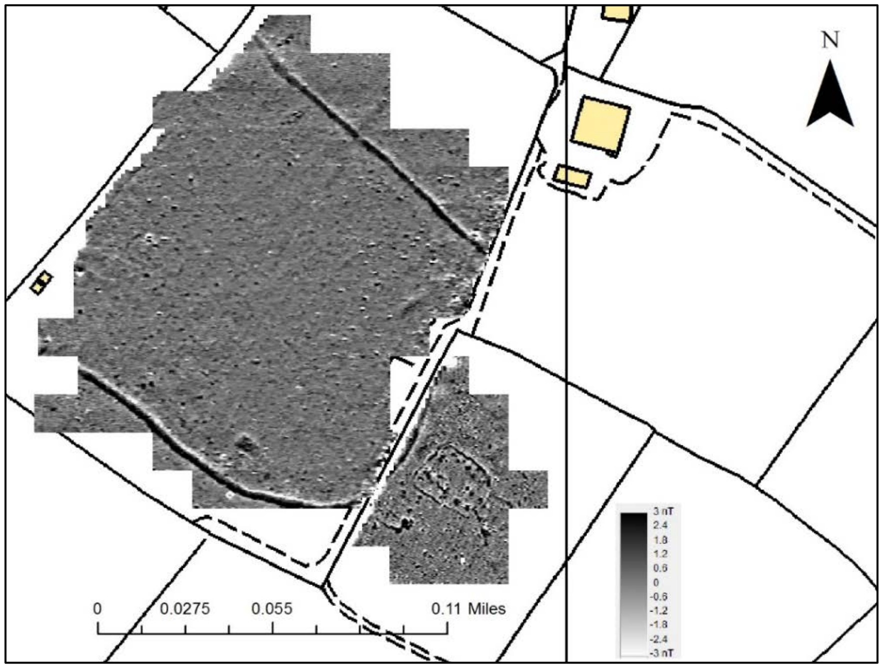
Initial results

Archaeological Geophysics

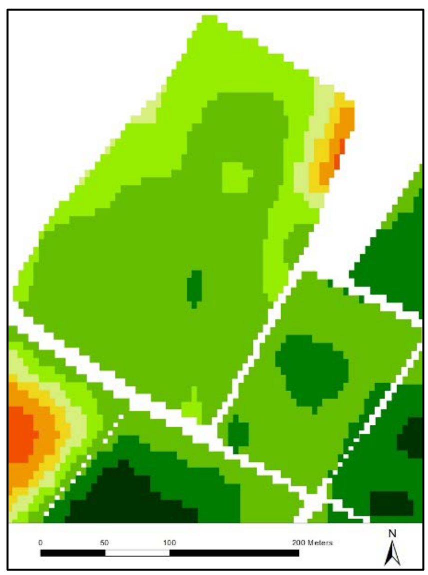
The results from a fluxgate magnetic gradiometer survey, shown in Figure 1, can be used to clarify certain subsurface anomalies. Some are archaeological and some are less interpretable. The key archaeological features that exist consist of two parallel ditches on each side of the larger field, that are interpreted as a large enclosure, most probably for livestock due to the lack of other archaeological features in between the two ditches. Further to the south east, in the smaller field, there are a number of archaeological features. These are formed of a number of circular pit features, a surrounding linear boundary and connecting linear anomalies that head east from the main boundary. These are common types of archaeological site in the UK and represent small Iron Age (*circa.* 500BC - 100AD) enclosures that were inhabited for a period of time (due to the presence of midden pits).

This data set gives some direct inferences about the abrupt changes in the soil profile in relation to topsoil depth. These anomalies are however broadly in the order of only a few metres in size. Ditches being long and thin, pits being relatively small. Hence from a precision agriculture perspective, this information seems of limited use as the resolution of management is not at that level. Yet from an archaeological perspective, these ditches have enclosed certain areas for certain uses at certain periods of time. Some of these, such as where humans have inhabited for a period of time, will be foci for a concentration of nutrients such as phosphorus. Soils that may be enhanced in nutrients could also be buried below the topsoil and periodically, in subsoiling or ploughing scenarios, be mixed in with existing topsoil. This cultivation mixing, along with topography, enhances the likelihood of soil movement spatially, as has been proven in a number of archaeological experiments. Thus potentially small 20 x 20m could have potentially a larger impact than might previously have been thought.

The NDVI image in Figure 1 is shown to link the effects of this inhabited part of the archaeological site to responses visible in a commercially provided satellite image (5m pixel size). This image was the only one for that year that showed such a response out of a total of 12 images. There are many reasons for this, such as weather, timing of the image, crop type and growth stage as well as inherent soil properties. However it exemplifies that archaeological sites can in certain circumstances produce significant areas of variation but that this is more complex and dynamic than most soil variation is assumed to be.



A



B

Fig I. a: shows a survey conducted by Bournemouth University (Credit: Amy Green) using a fluxgate magnetic gradiometer, b: shows an NDVI image courtesy of Intelligent Precision Farming and Simon Meaden.

Soil analysis

In addition to just collecting existing information and data about the case study site, further soil samples were also collected to clarify whether archaeological sites do indeed impact on the soils natural variation in certain elements. Figure 2 shows a proportionately sized circle map of the site, showing the phosphorus variation across the site.

This map shows significant variation within the field, but also is correlated well with the geologies that change across the site. There are generally larger values of total phosphorus to the north and south of the case study site matching the chalk based soils. This is expected due to the numerous forms that phosphorus can take when measuring the total elemental values via PXRF. The small Iron Age enclosure however lies upon the soils characterized by clays with flints. The average value of total phosphorus within this zone is 1127ppm with a standard deviation of 146ppm. Further sampling form 28 samples within the enclosure present an average level of 1362ppm with a standard deviation of 122ppm.

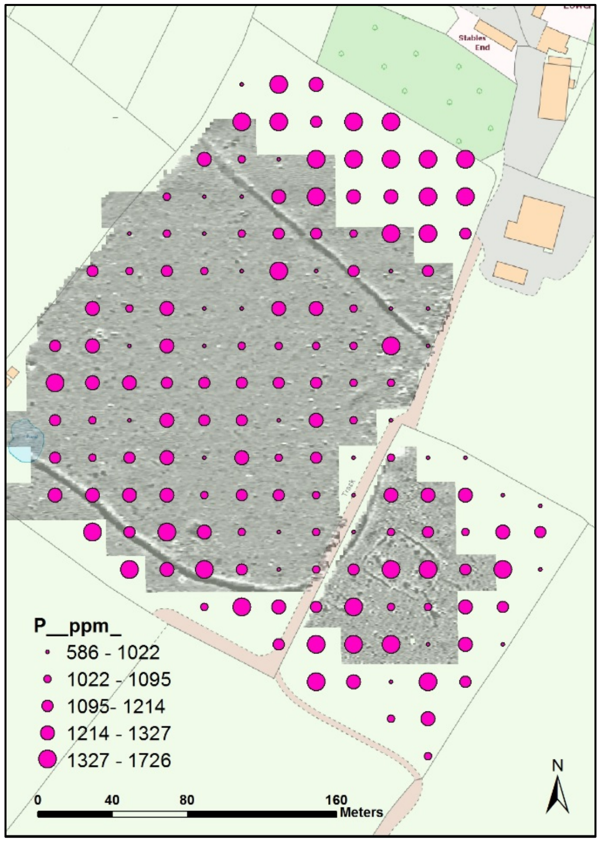


Fig II. Shows the variation in total phosphorus across the case study site, overlaid with the archaeological geophysical survey. © Crown Copyright and Database Right 2015. Ordnance Survey (Digimap Licence).

So preliminary results do show an increase in total phosphorus in comparison to the variation of the soils. However it is not possible to confirm the source of that phosphorus. For example is the phosphorus from sources such as excreta and human waste, or is it combined with possible calcium sources? These could potentially be from bone deposition within the soil, or from the excavation of midden pits/ditches that have enhanced the amount of soft chalk in the topsoil, therefore contributing to a likely increase in phosphorus similar to the chalk based soils on the site. There is also variation in the clay with flints soils, thus it will be necessary to quantify the source of that variation before concluding about archaeological enhancement in this case.

Satellite Imagery

With a number of satellite images throughout the year it was possible to question whether and why archaeological impacts might be visible within the recorded imagery from 2012 to 2016. The results from this showed one clearly attributable correlation with the smaller Iron Age enclosure shown in Fig 1 B. Other images and the weighted sum analysis of each year did not show this clear distinction. This was due to the individual timings of the images taken throughout each year. It was found that images at earlier growth stages, during crop establishment for Oilseed Rape, proved better at showing variations than images taken later on in the crops life cycle (due to canopy closure and green area index).

Another clear distinction to be drawn from these results also indicate that from analysis of a number of images from each year and each crop type within that year, there are patterns that re-occur throughout the crop rotation. It is known that crops will differ in their responses to certain soil variables and at particular times in their growth cycle. Initial results from this analysis suggest that there may be consistent variations that can be identified through NDVI imagery that occur only when this crop is grown and is likely to relate to specific areas of soil variation not traditionally visible.

Archaeologists have before only concentrated on prospecting for crop marks during the late summer after a particular drought stress and when crops are ripening. Specific concentration is on cereals due to their clear response to variation in most years. This research is beginning to highlight the need to look at other crops, such as Oilseed Rape, for particular periods of time where they may exhibit senilities to certain soil variables, such as phosphorus during establishment. These results display potential for learning not just on how archaeological sites impact agriculture, but also on how archaeologists can learn more about archaeological sites from mutual analysis of archaeological and agricultural data.

Conclusions

This research, although at an initial stage, shows a number of interactions that have not been considered before from both an archaeological and an agricultural perspective. It has highlighted the importance of considering archaeological sites in the context of precision agriculture. Yet it is not clear how widespread many of these interactions are across other geologies, other archaeological sites and under other management regimes. Clearly archaeological impacts are not seen regularly if their impact on the soil is marginal, however archaeology could account for much variation that is infrequently observed and cannot be understood purely in an agricultural context. It is hoped that further research will clarify more of these initial concepts with deeper analysis to allow precision agriculture specialists to be able to gather and understand available and existing archaeological data to help inform better management and understanding of soils.

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