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UTILIZATION OF GEOPHYSICAL METHODS IN PRECISION AGRICULTURE AND ARCHAEOLOGICAL PROSPECTION

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Abstract

Connecting stakeholders in heritage, archaeology, and precision agriculture can help us to understand the impacts of and shape positive outcomes for this transformation by developing common ground and shared agendas. Technologies such as satellite imaging, drone-based imaging, and geophysical survey are used in the practice of precision agriculture to support farmers and land managers to make data-driven management decisions. Archaeologists use many of these same technologies to investigate the buried evidence for past human activities and make this evidence for the heritage of agricultural landscapes visible. Fundamentally, practitioners and researchers in both precision agriculture and archaeology are invested in developing a better understanding of soils, plants, topography, water, insects, current farming practices and anything else that shapes agricultural landscapes. Drone-based geophysical survey, still in development, has the potential to facilitate increased field access and improve survey timings, if the signal-to-noise ratio of the measurement is good and the depth of investigation sufficient. In agricultural geophysics, the relationship between measurements and the physical/chemical parameters of the soil under investigation needs to be identified and their spatial variation understood.

Key words: *soil, geophysics, agriculture, archaeology.*

INTRODUCTION

Absolutely, managing time effectively is vital in dynamic environments like arable land. It's a delicate balance between accessing fields at the right time for optimal survey conditions and ensuring minimal damage to the crop during its growth phase. Understanding the capabilities and limitations of different geophysical techniques is crucial in planning and executing surveys efficiently.

Choosing the right technique that can survey between crop rows during development can maximize field availability and provide better survey conditions. This might involve selecting instruments and array configurations that are compatible with the crop's growth stage and spacing. However, if certain techniques can only be employed when the crop is off, it necessitates careful scheduling to minimize disruption and maximize data collection opportunities.

In essence, timing is not just about when to conduct surveys but also about considering the impact on crop development and field accessibility. It requires a strategic approach to optimize both data quality and agricultural productivity (Blanchy et al., 2020).

Indeed, the development of drone-based geophysical survey technology holds significant promise for enhancing field access and improving survey timings in agricultural settings. Achieving a good signal-to-noise ratio and adequate depth of investigation are paramount for the success of such surveys. The ability to deploy drones can offer flexibility and efficiency, especially in dynamic environments like arable land.

Understanding the relationship between geophysical measurements and soil properties (Jigau, 2012) is a critical aspect of interpreting survey data effectively. For instance, apparent conductivity measurements are often correlated with soil properties like clay content, moisture levels, or salinity. However, this relationship can vary from site to site due to factors such as soil type, texture, and land management practices.

Calibrating geophysical measurements through soil sampling at specific points can provide valuable insights into local pedophysical relationships. Yet, extrapolating these findings to the entire field or management zones remains challenging due to spatial variability in soil properties. Overcoming this challenge may require integrating geophysical data with other sources of information, such as remote sensing data or historical field observations, to develop robust models for predicting soil properties at larger scales.

Continued research and development efforts in drone-based geophysical survey technology, coupled with advancements in data analysis techniques, hold the potential to address these challenges and unlock new opportunities for precision agriculture and soil management.

Figure 1. Poluted soil with hydrocarbons
(Tezkan et al., 2005)

The challenges faced in archaeo-geophysics indeed overlap with those encountered in agricultural geophysics, particularly regarding survey timing, methodological considerations, and the interpretation of geophysical data. Survey Timing: Like in agricultural geophysics, timing is critical in archaeological surveys. Post-harvest periods might be suitable for certain techniques like magnetics, but not for others that rely on moisture contrast, such as electrical conductivity surveys. Choosing the optimal time for surveying is essential for maximizing data quality. Methodological Challenges: Selecting the most appropriate geophysical technique for a given archaeological site depends on factors like soil composition (Figure 1), site conditions, and research objectives. Just as in agricultural settings, methodological considerations must account for the dynamic nature of the environment and adapt to seasonal changes. In both agricultural and archaeological contexts, understanding the relationship between geophysical measurements and soil or sediment properties is crucial. This involves identifying how physical and chemical parameters influence geophysical signals and interpreting these relationships to infer subsurface features or archaeological structures (Figure 2). Identifying Inconsistencies: Various factors can introduce inconsistencies in geophysical measurements, including instrument effects, calibration routines, operator proficiency, and environmental conditions. Just as in agricultural geophysics, it's essential to identify and account for these factors to ensure accurate interpretation of survey data in archaeological contexts. In summary, while agricultural and archaeological geophysics have distinct research goals and applications, they share common challenges related to survey timing, methodological considerations, and data interpretation. Addressing these challenges requires a comprehensive understanding of the relationship between geophysical measurements and subsurface properties, as well as robust quality control measures to minimize inconsistencies and maximize the reliability of survey results.

MATERIALS AND METHODS

Instigating a shift towards managing the subsoil as a large-scale resource at regional or national levels could indeed offer numerous benefits, but it also presents significant challenges.

Benefits

Pre-emptive Mapping: Similar to national lidar mapping programs, systematic mapping of the subsoil at high spatial resolutions would provide valuable data for various research purposes and land management practices. This would enable the identification of optimal measurement times for different geophysical techniques, enhancing the effectiveness of surveys.

Support for Research: The comprehensive mapping of subsoil properties would support both academic research and practical land management efforts, providing valuable insights into soil dynamics, fertility, and other key factors affecting agricultural productivity and environmental health.

Consistent Information: A coordinated mapping program would ensure consistent and complete information on core soil properties, facilitating informed decision-making in land management practices.

Challenges:
Funding: Implementing such a large-scale mapping program would require substantial financial resources. Securing funding from government agencies, private stakeholders, and other sources would be essential but challenging.
Coordination: Coordinating efforts among various stakeholders, including government agencies, landowners, farmers, and researchers, presents logistical and organizational challenges. Establishing effective communication channels and collaboration frameworks would be crucial.

Approachable Goals
Working with Farmers: Collaborating directly with farmers and land managers on issues like the impact of agricultural practices on geophysical survey results could serve as a tangible first step. Demonstrating the benefits of a coordinated approach through practical examples could incentivize broader participation.
Policy Integration: Identifying incentives and establishing policies to better coordinate work between heritage, environmental, and land management agencies is essential. This might involve updating existing stewardship schemes or creating new frameworks to integrate heritage concerns into agricultural land management policies.
In conclusion, while establishing a comprehensive program for managing subsoil as a resource presents challenges, addressing smaller achievable goals and fostering collaboration among stakeholders can pave the way for more coordinated and effective approaches to soil management at regional and national levels.
Combining data from archaeo-geophysical surveys with routine soil sampling analysis from agricultural practices presents a promising approach to improving soil mapping while reducing costs. By integrating higher resolution geophysical data with traditional soil analysis results, we can enhance our understanding of soil spatial variation over larger areas. This approach has been recognized as beneficial by experts in the field.

Figure 2. Building bridges between domains - understanding the impact of farming practice on geophysical measurements by sharing information

Benefits of Data Integration
Improved Spatial Understanding: Integrating geophysical survey data with soil sampling results allows for a more comprehensive understanding of soil properties and their spatial distribution across larger areas. This can provide valuable insights for both agricultural management and archaeological research.
Cost Reduction: By leveraging existing agricultural practices for routine soil sampling and combining them with archaeo-geophysical surveys, we can reduce the overall costs associated with soil mapping. This cost-effectiveness makes the approach more feasible for widespread implementation.
Technological Advancements:
Automated Data Collection: Advancements in automation, including robotics, are enabling more efficient and precise data collection in both agriculture and archaeology. This not only improves the quality of data but also reduces the time and labor required for fieldwork.
Real-Time Applications: Real-time applications, such as variable rate applications of fertilizers and irrigation based on sensor inputs, are becoming increasingly common in precision agriculture. Similarly, these technologies can be adapted for archaeological purposes, enhancing data collection efficiency and accuracy.
Machine Learning: Machine learning holds significant potential in both agriculture and heritage management. While still in its early stages, machine learning algorithms can streamline data processing, analysis, and interpretation by aggregating information from

various sources, including weather data, calibration routines, and sensor inputs.

Challenges

Cost Limitations: Despite the potential benefits, costs remain a significant barrier, particularly in the commercial sector. Developing and adopting new technologies, such as automated data collection and machine learning applications, requires investment in equipment, training, and infrastructure.

In conclusion, integrating data from archaeo-geophysical surveys with routine soil sampling analysis offers a cost-effective approach to improving soil mapping. Leveraging technological advancements, such as automation and machine learning, can further enhance data collection efficiency and analytical capabilities. However, addressing cost limitations is essential to widespread adoption and implementation of these approaches in both agriculture and heritage management.

RESULTS AND DISCUSSIONS

Changing agricultural practices and archaeological prospection

The spatial resolution of agricultural data, typically coarser by at least a factor of ten compared to archaeological prospection needs, poses challenges in identifying archaeological remains accurately within agricultural landscapes. The coarse resolution of agricultural data is primarily driven by associated costs and practical limitations related to the size of agricultural machinery and tramlines. This restricts the ability to collect higher resolution data.

Identifying archaeological features at the coarse agricultural scale is difficult due to the lack of detail. This can hamper efforts to locate and protect heritage sites within agricultural landscapes.

Despite the coarse resolution, agricultural data can provide valuable contextual information relating to geomorphology and palaeo-topography. Integrating this information into heritage management workflows can enhance understanding and decision-making.

Coarse-grain agricultural data can serve as a valuable tool for identifying areas of interest for more detailed and targeted archaeological surveying. This helps prioritize resources and focus efforts on areas with the highest potential for archaeological discoveries (Hølleland et al., 2017).

As agri-environment schemes evolve and incentives for farmers and land managers change, there's an expectation that collecting higher resolution data will become more viable. This could lead to opportunities for aligning agricultural data collection practices with the spatial resolution requirements of archaeological prospection.

In summary, while the discrepancy in spatial resolution between agricultural data and archaeological prospection needs presents challenges, there are also opportunities to leverage agricultural data for contextual information and targeted surveying. As technology advances and incentives evolve, there's potential for future alignment between agricultural practices and heritage management requirements (Figure 3).

Figure 3. Archaeological prospection position itself within changing land management reforms (Images: NAO; Institute for European Environmental Policy)

The structure of data delivery in precision agriculture, primarily in geo-referenced shapefile format, reflects the practical requirements of the agricultural industry. Here's a breakdown of the key points regarding data delivery and its potential implications:

Precision agriculture services typically provide clients with geo-referenced shapefiles containing field or management zone boundaries along with specific recommendations for agricultural applications, such as variable dosage rates for fertilizer application. These files are designed for direct upload into tractor control units, facilitating implementtation of recommended actions in the field.

The emphasis is on providing actionable recommendations rather than raw data. This approach streamlines decision-making for farmers and maximizes the utility of the information provided by precision agriculture service providers.

While raw data may not be included in the deliverables provided to clients, they are often stored by the service providers themselves. This creates a repository of valuable raw data that remains largely untapped.

The considerable stores of raw data held by commercial precision agriculture service providers represent an untapped resource. These datasets have the potential to yield valuable insights into soil variability, crop health, and environmental conditions over time. Access to raw data could enable further analysis and research into agricultural practices, soil dynamics, and environmental impacts. Researchers and analysts could leverage this data to develop new insights, refine models, and improve decision support systems in precision agriculture.

Encouraging data sharing and collaboration among precision agriculture service providers, researchers, and agricultural stakeholders could unlock the full potential of these raw datasets. Collaborative efforts could lead to the development of more sophisticated algorithms, predictive models, and decision support tools for sustainable agriculture.

Geophysical methods and properties

The relationship between magnetic properties and plant growth is complex and not yet fully understood. While some connections, such as those between iron/zinc content and plant growth, are recognized, the overall impact of magnetic minerals on plant growth is considered less significant compared to factors like water content and nutrient balance.

However, in specific environments where traditional geophysical methods like apparent conductivity measurements may be less informative, magnetic surveys could play a valuable role. Here are some scenarios where magnetic surveys could be useful:

Highly Conductive Environments: In environments where apparent conductivity measurements (Figure 4) may be masked, magnetic surveys can provide valuable information, especialy in identifying areas with high iron content in sandy soils.

Acidic Soils: In acidic soils where acidity dominates nutrient balance, magnetic properties could be useful in investigating phosphatelevels, providing insights into nutrient availability for plants.

Magnetometer Type Relevance: The choice of magnetometer type becomes crucial in such instances.

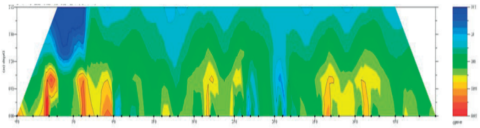

Figure 4. Apparent resistivity measurements (Kaufmann et al., 2020)

Total field magnetometers (Figure 5) may show greater potential for capturing subtler magnetic measurements compared to gradiometric configurtions, which may be more suitable for agricultural management zones.

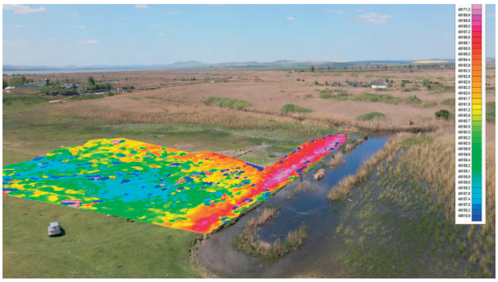

Figure 5. Magnetometric mapping in agriculture field

Related to Figures 6 and 7, the red zones represent the high soil magnetic susceptibility.

Experimental Applications: Experimental applications of magnetic susceptibility surveys (Kapicka et al., 1997) have shown promise, such as mapping soil copper content in viticulture or attempting to map soil organic content (Verdonck, 2021). These examples demonstrate the potential value of magnetic surveys in agricultural contexts.

UXO Detection: Magnetic surveys also have potential applications beyond agriculture, such as in the detection of unexploded ordnance (UXO), which remains a concern for many continental farmers.

Absolutely, magnetic surveys indeed have a wide range of applications beyond agriculture, and UXO detection is one of them. Unexploded ordnance, often remnants of past conflicts, pose significant risks to farmers and communities, particularly in areas where military activities have occurred.

Magnetic surveys (Figure 6) are effective in detecting buried ferrous objects, including UXO, due to their characteristic magnetic signature.

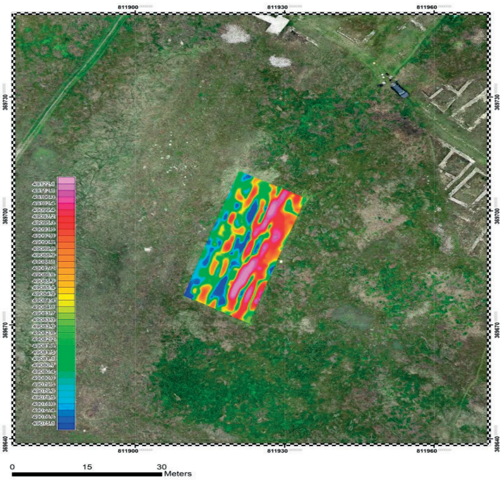

Figure 6. Magnetometric mapping in Argamum archaeological site

By measuring the variations in the Earth's magnetic field caused by subsurface anomalies, magnetic surveys can identify potential UXO locations (Figure 7), allowing for targeted investigation and clearance efforts (Cojocaru, 2015).

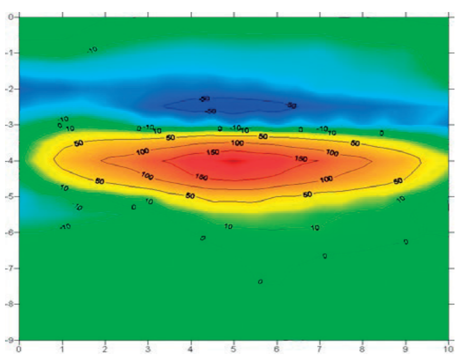

Figure 7. Magnetic mapping for detection of unexploded ordnance (UXO)

In areas with a history of military activity, conducting magnetic surveys can help identify and map potential UXO hazards, enabling authorities to implement appropriate safety measures and clearance operations.

These surveys can be conducted over large areas relatively quickly, making them valuable tools for assessing and mitigating UXO risks in agricultural landscapes.

Overall, magnetic surveys play a crucial role in UXO detection and contribute to ensuring the safety of farmers, landowners, and communities in regions affected by historical military activities.

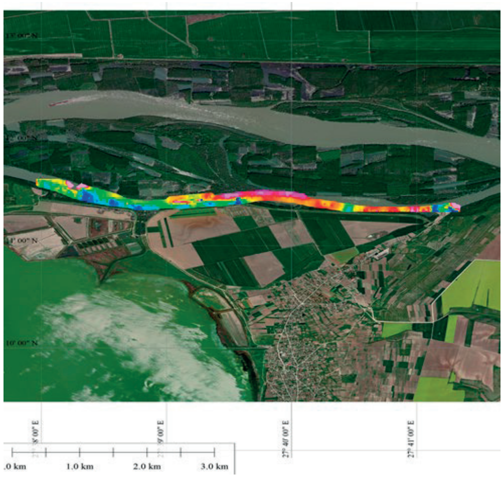

Figure 8. Danube river-magnetic mapping

Using magnetometry for identify the geological structure along the Danube river represent a good correlation with magnetometry results from the agriculture area (Figure 8). Ground-penetrating radar (GPR) is a non-destructive geophysical method used for soil investigation. It works by emitting electromagnetic pulses into the ground and measuring the reflected signals. These signals provide information about subsurface features, such as soil layering, moisture content, and the presence of buried objects or structures. Overall, GPR is a valuable tool for soil investigation because it provides detailed subsurface information without the need for excavation, making it efficient, cost-effective, and minimally disruptive to the environment. However, its effectiveness can be influenced by factors such as soil type, moisture content, and the presence of conductive materials (Figure 3).

Absolutely, developing mutually advantageous connections between different domains, such as agriculture and geophysics, can yield numerous benefits. Standardizing the storage of raw data from magnetic surveys is a crucial step in this process, as it creates an additional resource that can be leveraged by researchers in various fields.

Here's how standardizing the storage of raw data from magnetic surveys can facilitate collaboration and innovation:

- Standardized storage formats make raw data more accessible to researchers across different domains. This accessibility allows for greater collaboration and knowledge sharing, leading to the development of innovative solutions and insights.
- Researchers from agriculture, geophysics, and other fields can collaborate more effectively when raw data is standardized. This interdisciplinary approach encourages the exchange of ideas and methodologies, fostering creativity and innovation.
- Standardized raw data opens up new opportunities for exploring applications beyond the original scope of magnetic surveys. Researchers can analyze the data in novel ways to address emerging challenges or investigate previously unexplored research questions.
- Standardized storage formats often include metadata and quality control measures, ensuring the reliability and consistency of the data. This enhances the credibility of research findings and promotes confidence in the use of magnetic survey data for various applications.
- Standardization facilitates long-term preservation and archival of raw data, ensuring that valuable information remains accessible for future research and analysis.

Overall, standardizing the storage of raw data from magnetic surveys is a fundamental step towards fostering collaboration, driving innovation, and unlocking the full potential of magnetic survey data across diverse fields and applications.

This collaboration could lead to the development of more effective agricultural management strategies, improved environmental monitoring, and enhanced safety measures in agricultural landscapes.

CONCLUSIONS

The variable interest from the farming sector in preserving archaeological remains is often driven by economic considerations, which remain central in decision-making processes. While outreach and awareness programs can be successful with the public, including rural communities, their impact on the farming sector is often limited by economic imperatives. In the past, incentives for farmers to preserve heritage have been provided through EU schemes, but these have sometimes been viewed as insufficient. As policies are revised to address environmental and climate concerns (Filipciuc, 2019), the position of the historic environment needs re-evaluation. For instance, proposals to separate the natural and historic environments in valuations in the UK could potentially be counterproductive.

Adapting archaeological practices, such as geophysical prospection, to produce datasets more relevant to agricultural and environmental research and management could facilitate collaborations and highlight shared interests between domains. Focusing on the study of soil and its interactions with plants and water could serve as a common ground for cooperation. In soil investigation, GPR is commonly used for various purposes:

- GPR can map the soil layers beneath the surface, allowing engineers and geologists to understand the soil composition, thickness, and structure (Weihermueller et al., 2017).
- GPR can detect variations in soil moisture content, which is crucial for assessing soil stability and potential for erosion.
- GPR can identify underground anomalies such as voids, buried utilities, pipes, or archaeological artifacts, which are important considerations for construction projects or archaeological surveys.
- GPR can evaluate soil compaction levels by measuring changes in soil density (Chiriac, 2022), which is useful for assessing the suitability of soils for construction or agricultural purposes.
- GPR can be used to monitor changes in soil properties over time, such as subsidence, erosion, or groundwater fluctuations.

By demonstrating how archaeological data can contribute to agricultural and environmental research and management, collaborations between archaeologists and farmers could be fostered. Highlighting the potential benefits, such as improved soil management practices, increased crop productivity, and enhanced environmental sustainability, may incentivize greater engagement from the farming sector in preserving heritage sites (Cetinkaya, 2012). In conclusion, while the current focus in precision agriculture is on delivering actionable recommendations to clients, the raw data stored by service providers represent a valuable yet underutilized resource. Leveraging these datasets through collaboration, research, and data-driven analysis could drive innovation and improve agricultural practices in the future.

Ultimately, establishing connections between archaeology and agriculture requires finding common ground and aligning interests. By adapting archaeological practices to address the needs and priorities of the farming sector, collaborative efforts can be more effective in promoting heritage preservation while also supporting agricultural and environmental goals.

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