ipaast-czo case study: Montalcino (SI, Italy)

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The Estate and the farmer/landowner:

This case study focussed on a vineyard which is part of the Banfi estate (https://www.banfi.it/it/), near Montalcino, in Val D'Orcia Valley, Tuscany. Established in 1978, today the Banfi estate encompasses 2830 ha, 800 of which are vineyards to produce Brunello di Montalcino wine and other well-known products, including the Rosso of Montalcino and Super-Tuscan wines. The rest is covered in woodlands, olive and plum grooves, wheat, and other open-field crops. Thanks to these American investors, the Banfi estate and brand developed quickly, enabling the revaluation of the area of Brunello and Poggio alle Mura, the castle that is the headquarters of the estate today. Today, Banfi plays a vital role in the world of wine making and is considered an important part of the local community. It is owned by the Mariani family, the same family that created it in the '70 through their company, Banfi Vinteres, a company that has exported wine from Italy to the US since 1922. Through the Banfi Foundation (https://fondazionebanfi.it/en/), multiple projects are financed and carried out, like the Sanguis Jovis – School for Sangiovese (a project to spread knowledge and raise awareness on Sangiovese vine) and Balena Brunella, a project focussed on the fossil of a whale founded near Poggio alle Mura castle.

While the US investment and subsequent success saved the area from abandonment (a widespread problem the countryside of Tuscany in the '70s and '80s, and particularly problematic in Val D'Orcia), and while current activities deliver value in the community, the exploitation of the landscape for wine production has caused multiple problems, discussed below.

Figure 1: The Banfi Estate manages the vineyard surveyed in this case study.

Further stakeholders in land management at Poggio Casalini

Poggio Casalini is part of the municipality of Montalcino, a city well-known for wine production, located near Siena, IT, in the Val D'Orcia Valley. Poggio Casalini is inside one of the Tuscany Region's seven UNESCO world heritage areas, the Val D'Orcia natural heritage site (https://whc.unesco.org/en/list/1026/), and therefore protected by UNESCO's preservation policies.

The Tuscany Region (https://www.regione.toscana.it/documents/10180/12604324/17_Val_d_Orcia_Val_d_Asso.pdf/b023b4b7-968f-4372-ab4d-6eb8b4862ac9) and *Sopraintendenza Archeologica e delle Belle Arti della Provincia di Siena, Arezzo e Grosseto* (http://www.sabap-siena.beniculturali.it/index.php?it/235/tutela-paesaggistica) are the two main policy stakeholders. These organisations cooperate to create preservation plans and schemes which are fundamental to land management in the area. In particular, the Tuscany Region creates a "*Piano di indirizzo territoriale – PIT* "(Territorial planning), for each notable sub-region. This system defines multiples objectives for landscape preservation, for example in preservation of the *Crete Senesi (*Siena's clays), a particular kind of soil, or the promotion of project for the maintenance and valorisation of the landscape. The *Consorzio del Brunello di Montalcino DOP* (Brunello of Montalcino Consortium - https://www.consorziobrunellodimontalcino.it/it/home/home) is another important stakeholder. Being part of this consortium and of the *Disciplinare di Produzione* (Production specification) of the Brunello of Montalcino wine, limits the kind of vines that is possible to grow, the number of plants per hectare and other elements that influence the character and use of the landscape.

Current land use:

Figure 2: The case study area: A vineyard set in a landscape managed for its natural heritage.

This case study focussed on a field currently managed as a vineyard. Vines are cultivated with a spacing of 0.8*2.5 m, using cordon spur canopy management, mechanical inter-row weeding in alternate rows, and chemical weedkillers applied directly under the plants. The vineyard produces red grapes used in the Brunello di Montalcino DOP wine production. Before 2019 the field was used for arable cultivation (wheat and other cereals). To establish the new vineyard, deep tillage (>1 m) was carried

out. This process disturbed archaeological deposits in the field, evidenced by the sherds present on the surface today. This process may have shifted the position of deposits and redistributed artefacts.

What we know about archaeology on the farm:

From 1999 to 2003, the Department of Archaeology and History of Arts of the University of Siena surveyed the district of Montalcino within a broader initiative to develop the archaeological map of the Province of Siena. Intensive survey started in 1999 when the team recognised a large artefact scatter (Figure 3, red polygon on the bottom of the picture). When this survey was carried out, the field was not under cultivation. The archaeological finds identified on the surface were distributed over a rather large area (approx. 1 hectare) and included fragments of tiles, stones and coarse ware, table ware, kitchen ware, jars and amphorae. Any architectural feature was identified based on the presence of mosaic tiles, architectural terracotta, and other building materials. The artefacts were all medium size and were in a good state of conservation. Because the field was not being tilled, visibility was very low, preventing the team from distinguishing different functional areas within the site. The dimensions, the association of the surface artefacts, and the overall characteristics of the assemblage suggest an interpretation of a mid-size productive settlement site complex, probably next to a villa dated to the early Roman Imperial Period, with evidence of reuse in Late Antiquity.

How precision agriculture is being used:

Precision agricultural methods are not yet in use within the estate.

Management Challenges:

Multiple problems affect the field and the wider area. Climate change is particularly problematic in Tuscany, which is facing desertification and unstable distribution of rain during the year, causing increasing difficulties for agriculture and wine production. While summer droughts are normal in the region, in recent years this phenomenon has increased in duration and frequency, reducing the yield and causing problems in vinification (i.e., acid and sugar content, unstable polyphenols). Phytosanitary treatments and the management of pests are other important problems in the area: wine is one of the most polluting agrarian products, and a great number of plant protection products are distributed each year (Román et al.; 2020). Other problems include soil erosion due to poor surface water management: intensifying rainfall events, with a high probability of intense and destructive rains that cause the erosion of the surface and the most fertile layers of the soil, with negative impacts on productivity and soil management. In Poggio Casalini in particular, deep furrows and rapid water flows within them which are created in the inter-row strips cause problems for machine operation and workers' safety.

Sources of existing data:

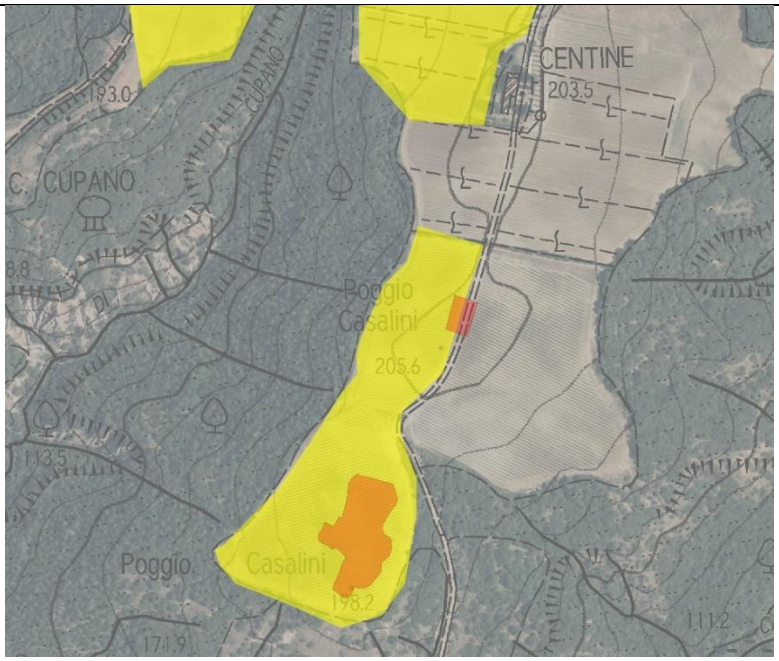


Figure 3: Yellow polygons delimit the areas surveyed. Light red polygons highlight archaeological areas.

In 2003, the Department of Archaeology and History of Arts of the University of Siena carried out a magnetic gradiometry survey to collect further data on the site identified through fieldwalking survey. The results revealed a concentration of anomalies which corresponded closely with the area of the surface scatter, but which lacked a clear, interpretable shape.

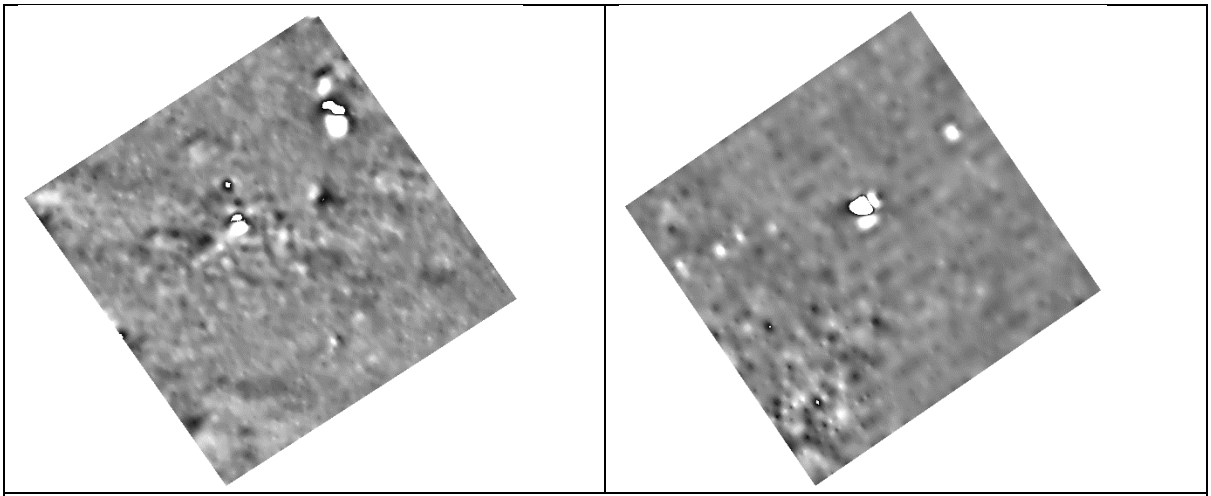


Figure 4: Magnetic maps (+/10 nT) showing some anomalies (dipoles) possibly associated with buried archaeological deposits.

New data collected for the case study:

Multispectral data:

The OptRx® Crop Sensors (AgLeader Technology, Ames, IO, USA) measure the reflectance in the 630–685 nm (red), 695–750 nm (RE red edge) and 760–850 nm (NIR—Near InfraRed) wavebands. Using those wavebands, NDVI and NDRE indexes are calculated. NDVI and NDRE are vegetative indexes obtained from the red, red-edge and NIR wavebands with formulas 1 and 2:

$$NDVI = \frac{NIR - RED}{NIR + RED} ; NDRE = \frac{NIR - RE}{NIR + RE}$$

The two index values range from -1 (bare ground or water) to 1 (highly vigorous vegetation).

To collect data, the sensor was mounted on a Kubota B2420 tractor. The sensor was paired with a GNNS receiver, the GPS 6500 from AgLeader Technology (Ames, IO, USA). The sensor and GNSS were coupled with a data collector (Panasonic ToughPad FG-Z1, Panasonic Core). A metal bracket positioned on the front of the tractor was used to install the sensor facing the ground. The sensor was positioned 1.15 m from the ground, emitting a beam with a rectangular footprint of 1.14 m in length and 20cm in width. The data were collected every 30 cm in alternate rows. 12 rows in total were surveyed, covering an area of 1.07 ha. The data collected were processed in QGIS. First, pointe measurements were interpolated using the Inverse Distance Weighting (IDW) method, with a distance coefficient P=4, 40 rows and 98 columns. Subsequently, a Gaussian filter with a standard deviation value of 2 and a range of 3 was used to create a representative raster.

Drone data:

On March 3rd a Parrot ANAFI (Parrot Drone SAS) was used to carry out a photographic survey to evaluate the presence of visible crop marks in the field. A flying height of 120 m resulted in a nominal 4 cm/pixel resolution in 103 photos. Pix4d (Pix4D S.A., Prilly, Switzerland) was used to produce a high-resolution orthophoto of the field, which shows an distinctive area of darker coloured soil corresponding to the location where the artefact scatter and magnetometry survey indicated the presence of buried archaeological deposits.

ARP data:

On March 8th 2023, GeoCarta (https://geocarta.net/) conducted a new survey to assess variations in soil resistivity using an automatic on-the-go recording resistivity meter, the ARP© (Automatic Resistivity Profiling of Geocarta). The instrument configuration includes:

1) Four pairs of rolling electrodes arranged in V-shaped configuration. One pair of rolling electrodes is used to inject current in the soil and the other three pairs function as receiving electrodes. Those electrodes are set at 0.5, 1 and 2 m from injecting electrode wheels, to measure apparent soil electrical resistivity for a depth of investigation up to 0.5, 1 and 2 m respectively.
2) Resistivimeter, designed for optimized synchronous measurement of three channels with a quick time response (44 ms) and a high tolerance to contact resistance that allows high-speed measurements.
3) Doppler radar to trigger the electrical resistivity measurements at 20 cm intervals along each transect. A computer, to display and store the values of apparent electrical resistivity, which is equipped with the GIS software Geocarta Office (Geocarta, Paris, France), allowing data to be processed in real time.
4) Positioning system (DGPS) for real-time data referencing.

Data was collected across the vineyard (1.98 ha), between vine rows at three depths: 0.5 m, 1 m, and 2m. Further technical details of the data collection and processing were not provided by GeoCarta. Three raster maps were produced and delivered by GeoCarta which document local variations in soil resistivity and related properties.

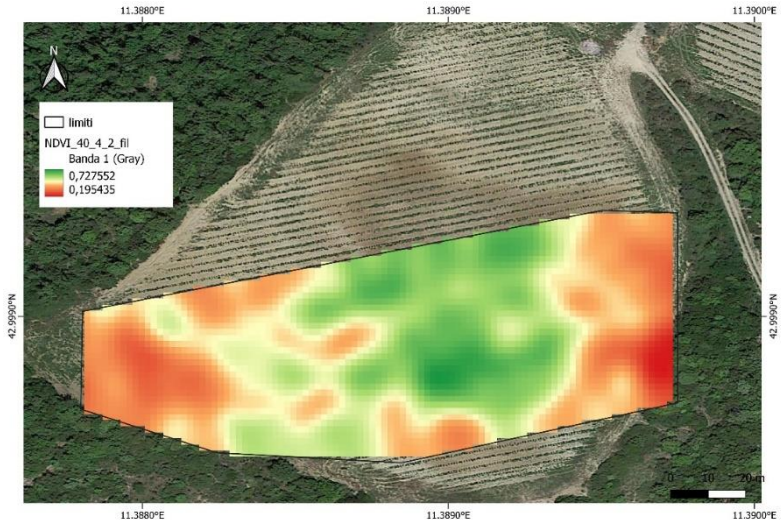


Figure 5: NDVI raster maps from the Optrx data collection

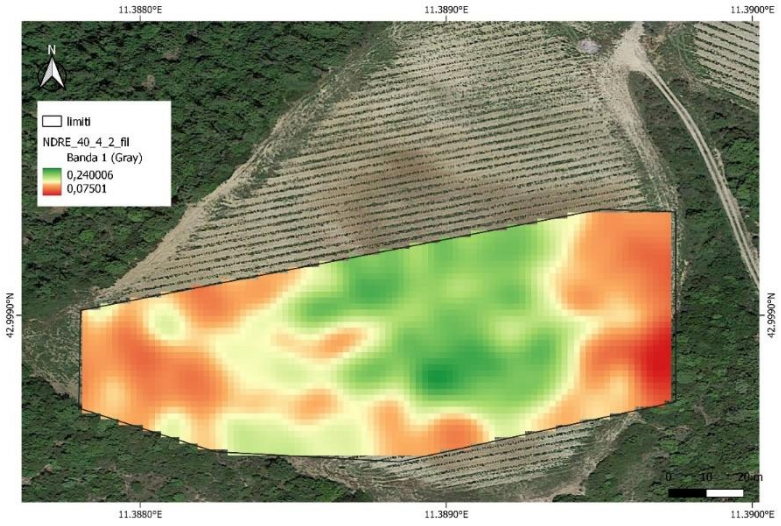
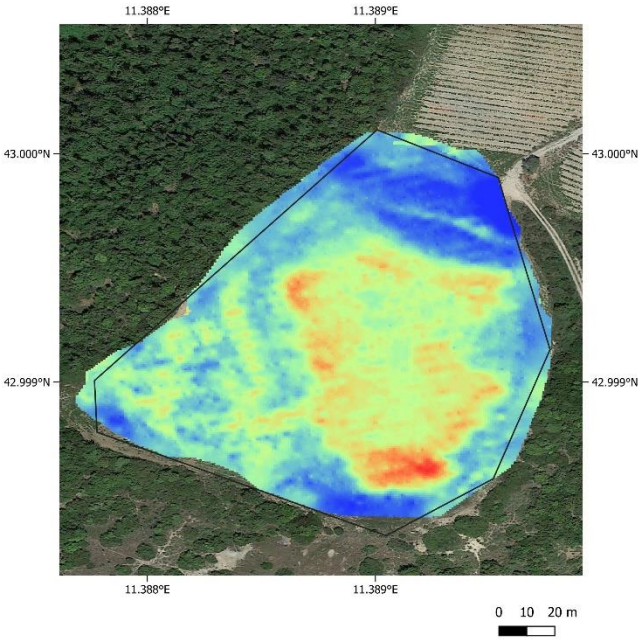


Figure 6: NDRE raster maps from the Optrx data collection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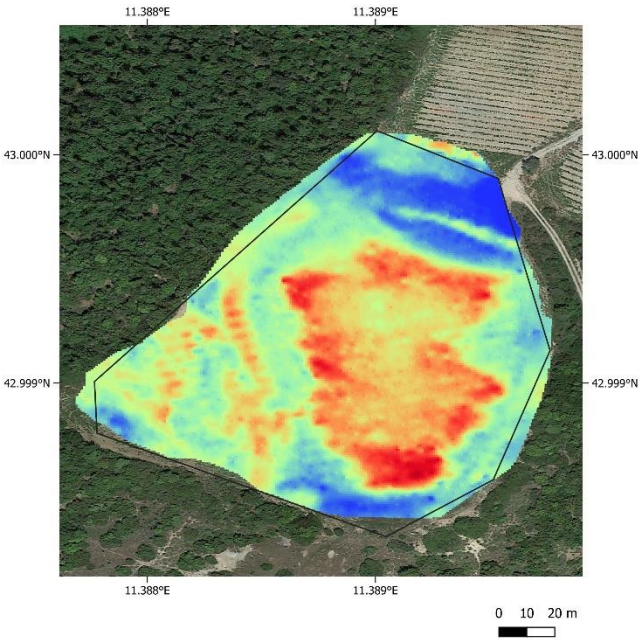
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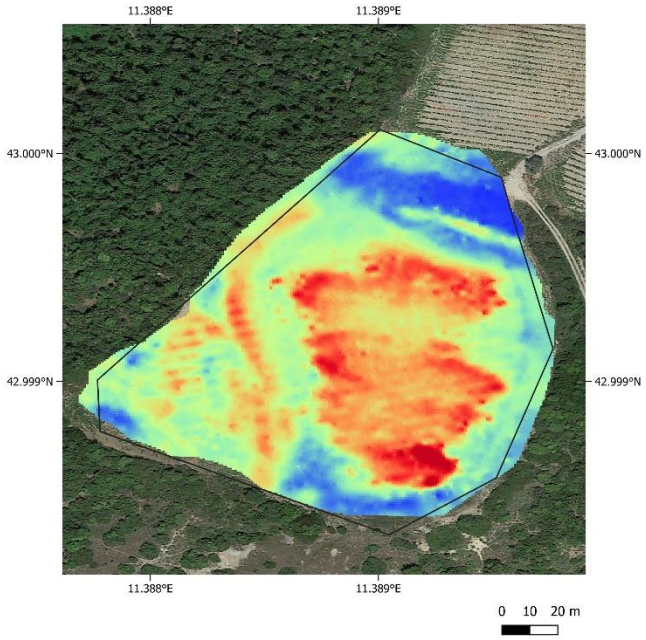

Figure 7: Resistivity variations at three depths (0.5 m, 1 m, 2 m)

Figure 8: An orthophoto of the survey area produced using photos collected with a UAV.

Insights from joint analysis and interpretation:

Analysis and interpretation to evaluate spatial variability in soil properties and assess the influence of buried archaeology in the soil led to several conclusions:

- Terrestrial multispectral survey of spontaneous winter cover crops in vineyards can document local spatial variability in soil-plant interactions, providing a useful proxy for spatial variations

in soil conditions when vines have dropped their leaves. This information is important because it can inform variable rate operations and guide management practices in vineyards in winter.

- In this context, it is likely that the presence of buried artefacts positively influences the plants' vigour and greenness, observed in the multispectral survey data.
- This interpretation is supported by the "crop marks" visible in the RGB aerial imagery collected, which are characterised by greener vegetation, which typically corresponds to vegetation with higher NDVI and NDRE values.
- The ARP data can usefully inform agricultural management, for example by supporting variable depth tillage, guiding cover crop seeding based on soil variations, and informing water management. These data also indicate the location of buried archaeological materials. In practice, however, joint use for applications across these sectors remains limited by data resolution, as normally agricultural surveys would be carried out at a lower spatial resolution than that used here.
- The typical spatial resolution of multispectral OptRx data collection is also a barrier to joint analysis or data reuse in current practice, as is unusual to collect data every 0.3 - 0.2 m for commercial agricultural applications.

Soil Health and Heritage Futures:

This case study's data showed variability in cover crop development that is correlated with the presence of buried archaeology. The range of vegetative index values in the OptRx data is higher in the area containing buried archaeological deposits detected through geophysical survey when compared to the surrounding area. Further, there is a measurable difference in the range of values between the area overlapping with the artefact scatter and the surrounding area. How these data can inform future management requires careful consideration. The presence of buried archaeological remains is creating spatial variability in crops that should be addressed and managed by the farmer. In this case, to address ongoing erosion in the field, variable rate cover crop seeding should be considered, informed by the combined dataset. Based on the data, seeding in the lower part of the field would be recommended, both for blocking surface water flow and for enhancing organic matter and, consequently, resistance to soil erosion (Pantani et al., 2022). The ARP data showed differences in soil resistivity that can be interpreted as the presence of buried archaeological deposits: this information is fundamental for planning the establishment of a new vineyard or an orchard, as the deep tillage usually used to create the optimum substrate for the plant to grow can mix buried archaeological deposits into the soil. Planning these interventions carefully using sensing data is essential to minimise problems not only for heritage management, but for agricultural management. Without planning using appropriate data, damage to potentially important archaeological remains can occur without them being documented and the mixing of buried materials into the subsoil can cause problems for fertility, erosion, and soil management.

To better evaluate the interaction between cover crop roots and buried artefacts, further data are needed, notably multispectral OptRx data with higher temporal resolution. In this case study, data were collected only during winter, a rainy and cold-humid season in Tuscany. Is not clear how the cover crop, and the vine, respond to the presence of buried archaeology during the dry season, and this information is necessary to understand interactions across the year. For the same reason, multi-temporal soil moisture data should be integrated into the analysis.

References:

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