Analysis of RGB Images to Enhance Archaeological Cropmark Detection: the Case Study of Nuceriola, Italy

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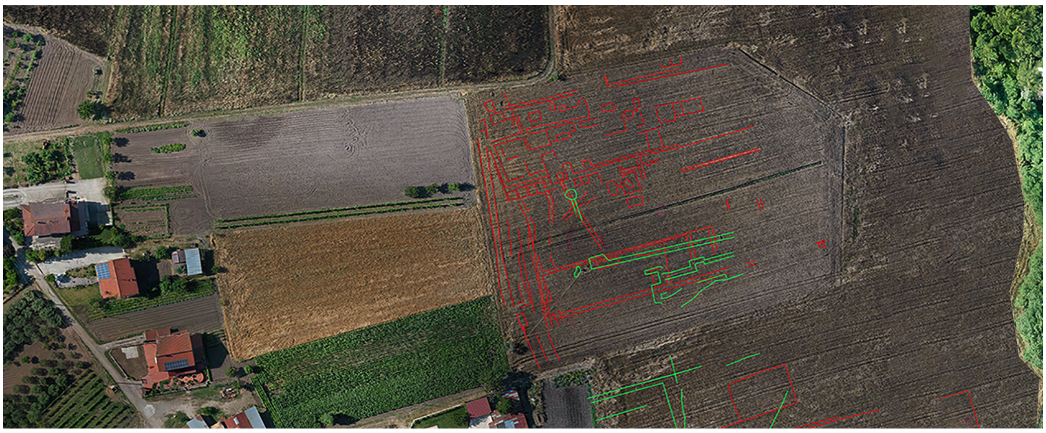
Abstract

This work presents an experiment conducted on the settlement of Nuceriola, an archaeological site identified along the ancient via Appia, the road that starting from Rome passed through the city of Beneventum (Italy) in the direction of Brindisi. Different tools have been applied to enhance the detection of archaeological cropmarks. Since 2011, the Ancient Appia Landscapes Project has been working on the detection of the dynamics and the network of ancient settlement located along the Appia road in the east of Benevento, along with the cyclical elements and the human activities that influenced the evolution of landscapes. Starting from the photogrammetric results obtained from the processing of images from UAV, this document compares different types of mapping applying vegetative indices (VI) on raster data in order to point out archaeological evidence on land cultivated with wheat. For aerial image shots, a commercial quadcopter with RGB camera was used to identify the buried remains in archaeological settlements by means of visual recognition. The aim was to verify which types of mapping with VI can produce the best results for the display of archaeological finds, especially in terms of cropmarks. The case study shows that the use of only RGB cameras, without the addition of multispectral or thermal cameras, already allows the digital recording of buried archaeological remains through the application of appropriate filtering procedures of the colorimetric data and the vegetative indices.

Keywords
landscape archaeology, aerial photogrammetry, vegetation indexes, RGB.



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Introduction

In the agricultural landscape of many countries, archaeological features are most frequently buried under a modern arable layer, but they can still be identified thanks to the different chemical and physical properties of the sub-soil. One of the most rapid and cheapest systems to identify hidden archaeological sites has always been the archaeological survey. With this technique, by collecting the artefacts found on the surface, it is possible to hypothesize the existence and the location of an archaeological site, the extension and stratification of which must subsequently be verified through prospecting and/or excavation. Preliminary, or sometimes subsequently, to the surface survey is advisable to read the aerial or the satellite images (if available), to identify traces and alignments caused by the buried structures and therefore visible from above. The most common phenomena recognizable by aerial or satellite prospections are the shadow marks, walls or embankments visible from oblique images with grazing sunlight, and the cropmarks, that appear as lower height of vegetation, allowing to distinguish buried walls, or filled ditches indicated by higher and more luxuriant vegetation. The phenomena of shadow marks and cropmarks are often coupled together; they are often visible simultaneously as a non-uniformity of colouring and of vegetation height essentially due to the difference in the soil moisture (fig. 1). The cropmarks

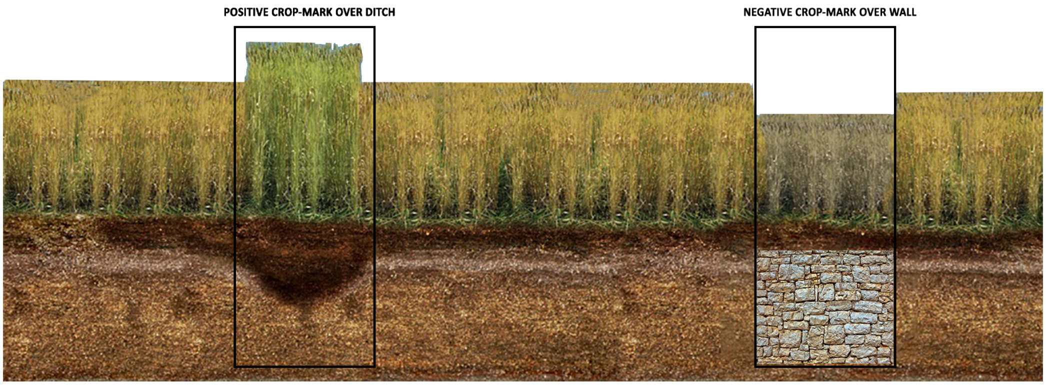

Fig. 1. Cropmarks formation principle.

are the most important proxy indicators of the presence of archaeological buried remains. Their characteristics and information provided on human past depend on the nature of the expected features, the land use, the meteorological parameters, the soil and the vegetation types. Until the past decade, archaeologists traditionally used images from planes and satellites, whose ultimate purposes were not purely dedicated to the archaeological sphere, but to cartographic, geomorphological, topographical, and urban studies. Nowadays, Preventive or Landscape archaeology need to acquire images in short times, at a moment of the year, where buried archaeological evidences are most evident. For this reason, applications of Unmanned Aerial Vehicles (UAVs) are increasingly frequent for the acquisition of images useful to intercept and locate invisible traces. The main reasons for the increase in UAV applications for preventive and landscape archaeology are the technological development of these vehicles, which have proven to be increasingly simple and reliable to pilot, and the improvement of the image quality [Barba et al 2019; Florio et al 2018, Russo 2017]. The advantages of UAVs compared to classic aerial photogrammetry are essentially a lower cost of the images and the fact that the UAVs are non-invasive, and able to survey an archaeological site without altering it in any way. In literature, applications of aerial photogrammetry from UAV for the identification of cropmarks mostly use Hyper and Multi-Spectral or Thermal cameras, with sensors able to return more information on the vegetative state of the crops and to detect the points of discontinuities caused by the submerged structures [Agudo et al. 2018; Koucká et al. 2018; Šedina et al. 2019]. The elaborations carried out in this study start from a classic RGB sensor, integrated in the gimbal of a commercial UAV. The flight was carried out in June, during the ripening phase of a wheat field. The aim of the work was to verify whether, from the RGB data, information on the spatial location of the submerged structures could be drawn, mapping the Red, Blue and Green channels together and using some of the most famous vegetative indices in the literature.

Archaeological site

The case study presented here is part of the major Ancient Appia Landscapes Project (AAL), carried out by the University of Salerno – Department of Cultural Heritage Sciences and Department of Civil Engineering – [Santoriello et al 2016]. The project aims to investigate the topographical development of the via Appia near Benevento, to reconstruct settlement patterns and the evolution of ancient landscapes up to the present day. The context analysed is located near one of the most important cities of the Roman period, along one of the fundamental roads of the time. Unfortunately, archaeological traces on the surrounding territory are faint or invisible. Therefore, it was decided to try out a series of different approaches that could most likely enhance the buried traces of the past. One of these methods is the aero photo interpretation, carried out on some of the most significant sites identified in the outlying areas of Benevento. In detail, the investigations were conducted in the area of masseria Grasso, 6 km away from Benevento, where archaeologists have found an important settlement of about 7 ha, dated between the middle of the fourth century BC to the VI-VII century AD. It is one of the main sites in the countryside of Benevento, where the ancient Nuceriola has been recognized, located 4 Roman miles away from Beneventum (fig. 2). Recent excavations have identified part of the route of the via Appia, for a length of


Fig. 2. The case study of Nuceriola, Benevento, Italy.

about 14 m, and also the remains of a ceramic workshop from the 1st century B.C. - 1st century A.D., consisting of at least 6 rooms, 3 kilns for the production of ceramics and a series of service areas. A further excavation has made it possible to identify the remains of a Samnite fortification in yellow tuff blocks (this was later dismantled by the Romans). The site remained unknown until today and does not give back significant monumental remains, because ancient evidences are buried underground, inside private properties exploited as agricultural land. The ceaseless ploughing has strongly compromised the ancient structures, determining the thinning of the archaeological stratigraphy. Due to the impossibility of excavation on the whole surface, it was necessary to perform a series of interventions to define the extension and the articulation of the settlement; among the different operations carried out, photointerpretation showed a good success for the particular conditions of the site. Cereal crops, including barley, wheat and spelt, are present on the plateau. These plants have a different ripening period, therefore the presence of any traces to be found on the photographic supports will be conditioned by the moment in which the flight is made. It was decided to operate in mid-June, when most of the fields were ripening, including the wheat field analysed. The flight was scheduled over the entire surface of the masseria Grasso plateau.

Equipment used

The UAV system used for this application is a DJI Mavic 2 Pro with a net weight of the sensor of about 900 g. The installed camera has a sensor of 1'', with resolution of 20 megapixel (5472 × 3648 pixels, 12.8 x 9.6 mm, Pixel Size of 2.33 μm) and focal length of 10 mm, Field of View - FOV 77°.
For the acquisition of the nadiral photogrammetric shots, it was chosen a single capture with an automatic flight plan. The results showed that the GSD obtained from the UAV images is 2.3 cm at the flying height of 100 m, using an 80% along-track image overlap and a 60% across-track overlap. The number of images acquired and subsequently processed is 153, detecting an area of about 0.27 km^2.
To support the photogrammetric project, 6 Ground Control Points (GCP) were measured to georeference and assess the accuracy of the generated 3D model. The GCPs were materialized on the ground using photogrammetric targets (60 x 60 cm) and topographic nails. The reference system adopted is UTM/ETRF00 with ellipsoidal height. The precision achieved in the planimetry is on average centimetric while in altimetry it reaches about 2.5 cm.
For the generation of the nadiral orthophoto of the surveyed area, it was used the software Agisoft Metashape (ver. 1.5.3 build 8469). The following parameters were set for the processing of the point clouds: in the 'Align Photos' phase, Accuracy = High (original images), Key-Point limit = 40000, Tie-Point limit = 4000. To optimize the camera alignment process, f (focal length), cx and cy (principal point offset), k1, k2, k3, k4 (radial distortion coefficients), were fitted. In the computation of the Dense Cloud, the parameters used were: Quality = High (1/4 of the original images), Depth filtering = Disable; once the complete elaboration of the photogrammetric shots was done, the software gave back the texturized 3D model and finally, the orthophoto, in a GeoTIFF format and the DSM - Digital Surface Model (fig. 3).

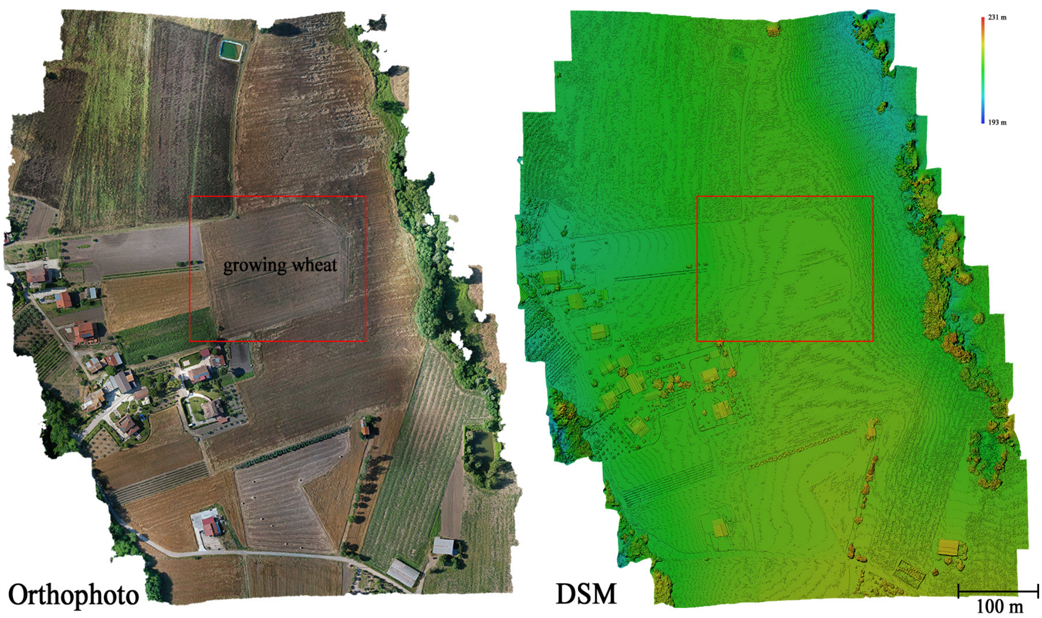

Fig. 3. Orthophoto and DSM. In the red rectangle, the study area.

Cropmarck visibility from orthophoto

Further analysis on the ortho-mosaic were conducted applying colour filters, in order to improve the photointerpretation of the images. These simple techniques can improve the display of archaeological evidence from the ortho-image alone [Agapiou et al 2017].
The orthophoto was imported in the Python environment, to compute the equations and make changes in the RGB colours to simplify the analysis of the area. In detail, it was used scikit-image, an open-source library dedicated to image processing that employ natively NumPy arrays as image objects.
A NumPy array is a grid of values, all of the same type, and is indexed by a tuple of nonnegative integers. To plot the processed images, it was used a plotting library called Matplotlib. Matplotlib is a Python 2D plotting library which produces publication quality figures in a variety of hardcopy formats and interactive environments across platforms.
Matplotlib is designed to work the same way MATLAB does, with the possibility to use Python and the advantage of being free and open source. The conversion of an image with RGB channels into an image with a single grayscale channel, is a reduction of the complexity of the model, from three dimensions to a single dimension colour space. The value of each grayscale pixel is calculated as the weighted sum of the corresponding red, green and blue pixels. Usually, objects in images have distinct colours (hues) and luminosities, so the transformation from RGB to HSV can be used to separate different areas of the image. In the RGB representation the hue and the luminosity are expressed as a linear combination of the RGB channels (tab. 1). HSV colour space describes colours in terms of the Hue (H), Saturation (S), and Value (V). In the HSV colour space, the colour distribution of a single-coloured object is invariant with respect to brightness variation. Then to have a new coloration map, the channel R was swapped the B one from the original RGB image and proceeding again to calculate the HSV values (fig. 4).

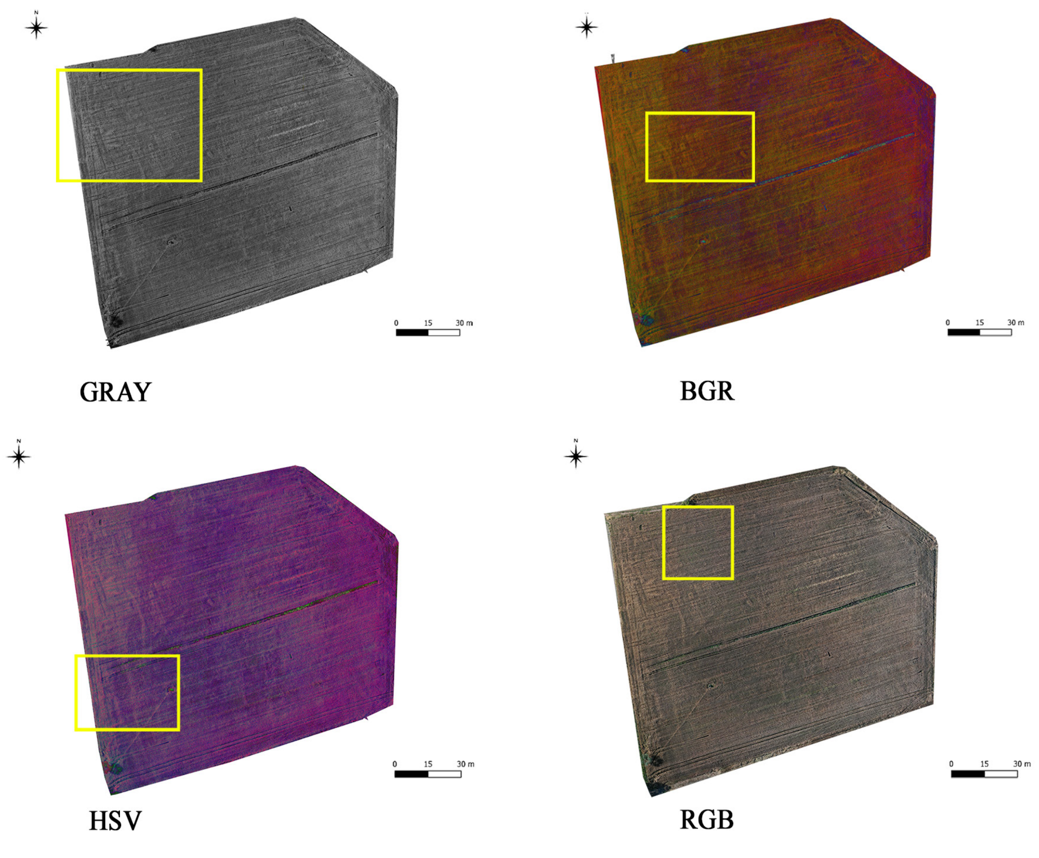

Fig. 4. RGB filters and possible cropmarks zones on the orthophoto (in yellow).

Tab. 1 - RGB filters used in the study.

Filters	CHs	Equations	References
Gray	G	$0.2125 * R_{RED} + 0.7154 R_{GREEN} + 0.0721 * R_{BLUE}$	Poynton, (2003)
HSV	H	$0, if\ X_{max} = X_{min} \leftrightarrow R_{RED} = R_{GREEN} = R_{BLUE}$ $60°.\left(0 + \frac{R_{GREEN} - R_{BLUE}}{C}\right), if\ X_{max} = R_{RED}$ $60°.\left(2 + \frac{R_{BLUE} - R_{RED}}{C}\right), if\ X_{max} = R_{GREEN}$ $60°.\left(4 + \frac{R_{RED} - R_{GREEN}}{C}\right), if\ X_{max} = R_{BLUE}$ $C = \max(R_{RED}, R_{GREEN}, R_{BLUE}) - \min(R_{RED}, R_{GREEN}, R_{BLUE})$	Smith, (1978)
	S	$0, if\ X_{max} = X_{min} \leftrightarrow R_{RED} = R_{GREEN} = R_{BLUE}$ $\frac{C}{V}, otherwise$	
	V	$V = \max(R_{RED}, R_{GREEN}, R_{BLUE})$	

Vegetation indices from RGB information

The application of vegetation indices derived from UAV or satellite images to predict cropmarks (positive and negative) have been investigated in literature using almost exclusively a multi or hyperspectral approach. As a matter of fact, most of the band combinations in the multispectral and hyperspectral imagery provide some archaeological information. For example, the band combinations in the near infrared part of the spectrum tend to give the best archaeological results, using NDVI maps (Normalized Difference Vegetation Index). Our study aims to verify whether the vegetative indices deriving from RGB information, can be able to identify cropmarks in growing wheat conditions. The following RGB-based vegetation indices (VI- tab. 2) were computed in Pix4Dfields 1.6.1 on a pixel basis coming from the orthophoto, previously calculated in Agisoft Metashape: Visible Atmospherically Resistant Index (VARI), Triangular Greenness Index (TGI), Greean Leaf Index (GLI), Red-Green-Blue Vegetation Index (RGBVI), Normalized Green Red Difference Index (NGRDI) and Excess of green (ExG).
The VI indices were averaged over each plot with the tool Index Generator. Once the VIs had been generated, the pixel frequency histogram was reduced for each map, and the gray-scale maps were finally built (fig. 5).
The results of the study of aerial images from UAV are interesting because the anomalies identified confirms extension and complexity of the settlement network of Nuceriola. To the north, at least one residential block has been detected with the short side of about 35m (i.e. 1 actus, i.e. a Roman unit of measurement) arranged along what remains of the ancient Via Appia. The residential block is delimited by two probable paths that extend for at least 100 m. The blocks inside show a complex articulation, with rooms organized along the perimeter walls or probably around inner spaces according to a more or less constant orientation of 70°. To the south, for reasons of visibility, the anomalies detected are fewer in number and mostly attributable to other secondary roads. From the images, it seems however possible to confirm the step of 1 actus for the short side of at least one other block, while towards the centre of the town it seems to change, while remaining regular and with measurements referable to the multiples of the actus (fig. 6).

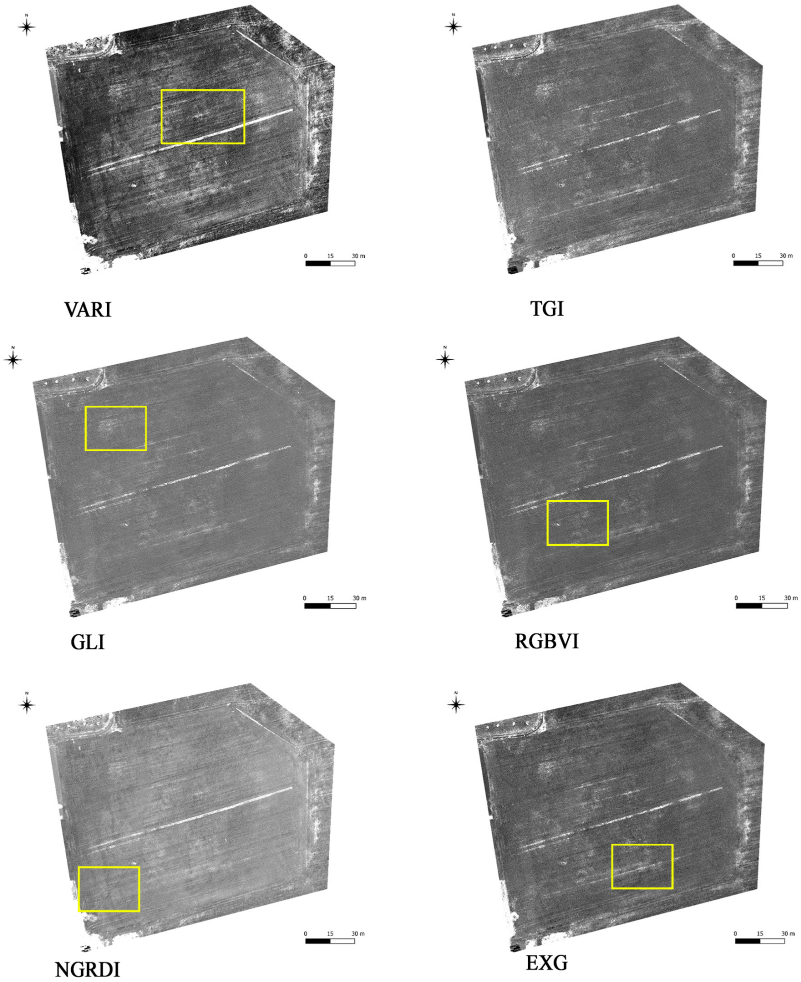

Fig. 5. V.I. maps and possible cropmarks zones on the orthophoto (in yellow).

Tab. 2 - Vegetation Indices used in the study.

V.I.	Equations	References
VARI	$\frac{R_{GREEN} - R_{RED}}{R_{GREEN} + R_{RED} - R_{BLU}}$	Gitelson et al. (2002)
TGI	$R_{GREEN} - 0.39 * R_{RED} - 0.61 * R_{BLU}$	Hunt et al., (2005)
GLI	$\frac{2R_{GREEN} - R_{RED} - R_{BLUE}}{2R_{GREEN} + R_{RED} + R_{BLUE}}$	Louhaichi et al., (2001)
RGBVI	$\frac{R_{GREEN}{}^2 - (R_{RED} * R_{BLUE})}{R_{GREEN}{}^2 + (R_{RED} * R_{BLUE})}$	Bendig, et al., (2015)
NGRDI	$\frac{R_{GREEN} - R_{RED}}{R_{GREEN} + R_{RED}}$	Tucker (1979)
EXG	$2R_{GREEN} - R_{RED} - R_{BLU}$	Bendig, et al., (2015)

Conclusion

The RGB orthophoto of the archaeological site can be used for the detection of buried archaeological features. Such features can be detected mainly from linear cropmarks. Despite the fact that the specific flight had limited spectral range (i.e. visible bands), and composed only of nadiral images, some particularly interesting have been identified from the maps generated by VI. known in the literature without the use of near infrared information, therefore without the use of multi spectral cameras. The tests carried out show that there is not just one single VI viable for all the traces identified, even in case of equal ground conditions. The indices seem to variably enhance the traces, given the respond to different burial phenomena. Therefore, the winning method is to overlap multiple techniques (e.i. VI. and RGB filters) and to verify persistence and variations.
For the case study analysed, the most important information was provided by the VARI (for the evidence on the west ridge), the GLI (that improves the visibility of collapses and empty spaces), the TGI (which point out evidence of hydraulic works in the east) and the EXG (that highlights the possibility of a road south) indices.
The results are partially confirmed by other remote sensing technique (geophysics) employed in this area [Rizzo et al. 2017], where the same linear features shown in the ortho-mosaic, as well their orientation, are highlighted.

Fig. 6. Cropmarks anomalies: the settlement network of Nuceriola.

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