Journal of Cultural Heritage xxx (2017) xxx–xxx

Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com/en

Original article

On the characterization of temporal and spatial patterns of archaeological crop-marks

Nicola Masini [a,d,*], Cosimo Marzo [b,d], Paola Manzari [c,d], Antonella Belmonte [c,d], Canio Sabia [a,d], Rosa Lasaponara [e,d]

[a] CNR-IBAM, C.da S. Loya, 85050 Tito Scalo, Italy
[b] ASI, Terlecchia, 75100 Matera, Italy
[c] INAF-IAPS, Via Fosso del Cavaliere 100, 00133 Rome, Italy
[d] CNR-ISSIA, Via Giovanni Amendola, 122 D/O, 70126 Bari, Italy
[e] CNR-IMAA, C.da S. Loya, 85050 Tito Scalo, Italy

ARTICLE INFO

Article history:
Received 12 September 2017
Accepted 23 December 2017
Available online xxx

Keywords:
Multitemporal remote sensing in archaeology
UAV
Crop-marks
Soil moisture-marks
Neolithic
Apulia

ABSTRACT

Crop-marks 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 expected features, land use, meteorological parameters, soil and vegetation types. The interaction of these factors is crucial for the major and minor visibility of crop-marks over seasons. Hence, the need to improve the knowledge of 'vegetation-mark phenomenology' by a multi-temporal investigation. This can be based on a holistic approach jointly using aerial prospection, information on meteorological conditions and in situ survey of soil and vegetation. Today, the availability of low cost Unmanned Aerial Vehicle (UAV) makes this approach feasible, as discussed in this paper. Herein, a multitemporal analysis from March to October 2014 has been conducted on a test site selected in the Tavoliere delle Puglie. It is one of the richest European areas in archaeological crop-marks because of the long and intense human frequentation (from Neolithic to Modern Ages) and the geo-pedological conditions which favoured the preservation of crop marks. In particular, results from the aerial observations evidenced not only during the spring season the expected crop-marks, due to cultivation, but, also, in August and October, weed marks linked to spontaneous herbaceous mainly growing due to favoured meteorological conditions (especially rain). Outputs from our investigations revealed new insights on the characteristics archaeological vegetation marks in relation with vegetation types and meteorological conditions.

1. Introduction

The detection of subsurface archaeological remains is one of the most challenging and complex research activities aimed at investigating the human past. This task can be addressed by observing the landscape from above [1,2] with a probability of success that depends on the state of conservation of archaeological features and physical interaction with their surroundings [3]. This interaction produces local variations in moisture content, organic soil, vegetation that can be detected by a variety of optical sensors mounted on aircrafts satellite platform and, unmanned aerial vehicles (UAVs) [4].

Crop-marks are linked to the presence of buried walls and/or filled ditches in vegetated areas: the first constrains, whereas the second favours the vegetation growth. In both of the two cases crop-marks are named positive and negative, respectively.

In case of bare ground, the commonly used proxy indicators are damp and soil marks. The first are variations in soil drainage induced by buried walls, moats, and ditches. The second appear as changes in soil colour caused by ploughing that can bring to light stony materials of shallow walls, or wet and organic clods of moats and/or earthworks. Finally, shadow marks caused by micro-relief, residues of eroded shallow remains, visible when the sun is low, are another useful archaeological proxy indicator.

The first who recognised the potential of aerial survey for archaeology were G.W.G Allen and O.S.G. Crawford [4], who investigated large areas in Britain and Middle East, and Antoine Poidebard,

* Corresponding author.
E-mail addresses: n.masini@ibam.cnr.it (N. Masini), cosimo.marzo@asi.it (C. Marzo), paola.manzari@iaps.inaf.it (P. Manzari), belmonte@ba.issia.cnr.it (A. Belmonte), c.sabia@ibam.cnr.it (C. Sabia), rosa.lasaponara@imaa.cnr.it (R. Lasaponara).

https://doi.org/10.1016/j.culher.2017.12.009
1296-2074/

who undertook extensive surveys in Syria. Crawford [5] identified three proxy indicators: "shadow-sites" related to "grass covered earth-works", "bare soils" and finally, "crop-sites", visible as color difference in presence of vegetation over earthworks. Crawford also analyzed the effects of weather, crop-type and soil moisture on the visibility of archaeological vegetation marks.

Scientific literature on crop-marks is very rich and mainly focused on case studies in England [6,7], France [8,9], and Italy [10–12].

Great attention is also paid to the: (i) relationships between the diverse parameters that can enhance or obscure crop-marks, and (ii) use of image enhancements.

About (i), several authors investigated the influence of soil, vegetation, climate and weather on archaeological crop-marks. Evans and Johns [13] observed that crop-marks appear when the "potential soil moisture deficit is greater than the amount of water in the soil available to the plant". Crop-marks appear also in very wet years but are less evident respect to drier years. In the Czech Republic, Gojda and Hejcman [14] found that in dry lowlands crop-marks are more visible on sandy than on loess or clay soils. According to them cropmarks were best developed in barley, followed by wheat, winter rape and alfalfa. In Bavaria, Stanjek and Faßbinder [15] put in relation the occurrence of crop marks, usually visible in July and August, with differences in soil bulk density which determines the water balance and thermal behaviour. Another investigated phenomenon is the transition from positive to negative crop-marks because plants above ditches and pit ripen faster, turning yellow earlier than adjacent crops which stay green longer [15].

About (ii), the advancement of satellite technologies made possible to use different data and processing methods to enhance crop-marks, making their discrimination easier [16,17]. Lasaponara and Masini [18] evaluated the detectability of crop-marks using multispectral satellite images to study medieval hilly settlements in Basilicata, Italy. They evidenced that (Near Infrared) NIR band and vegetation indices [19] emphasized marks linked to differential growth both in crop and weed. Today, Very High Resolution (VHR) satellite images offer a valuable alternative to the traditional aerial archaeology. Hyperspectral airborne sensors have been also used for archaeology. Despite the promising tentative [20,21] aimed at identifying the optimum spectral region for detecting crop marks [22] the high cost and low geometric resolution did not favour the use of hyperspectral airborne.

Other sensors such as Near Ultraviolet (NUT) and SAR have been applied to detect soil and crop-marks [23,24].

A real revolution in the detection of unknown archaeological sites is expected from the UAV. Nevertheless, the availability of very low cost and effective UAV tools is quite recent.

What is still today lacking in the literature is a focus on how crop marks vary on space and time. This is a crucial point because of the great variability of crop-marks over time in relation with climate, meteorological conditions, soil and vegetation.

A few attempts are in Crawford [5], Dassie [9], Wilson [2], who focused on inter-year observations of crop marks but they disregarded intra-year analysis, and in Agapiou et al. [22], who focused on the 'optimum temporal window'.

The different seasonal behaviour of archaeological proxy indicators can be depicted using multi-dates Google Earth images, which, unfortunately, rarely allow a systematic intra-year analysis, than can only be indirectly deduced by images taken in different years [25].

The reason of this lacuna is the high cost of air-space/borne images at high spatial resolution with at least a monthly image acquisition. Today, the availability of drones can strongly reduce these costs.

Herein we present the results from a systematic monitoring performed using a low cost drone for the acquisition of monthly aerial images (from April to October 2014). The aim of this study has been to analyse the spatio-temporal changes of crop-marks in relation with land use, vegetation and meteorological conditions. The analysis was conducted on a test site, Schifata (Apulia region, Italy), selected for the rich presence of archaeological marks, characterized by a large variety in typologies (crop and damp marks) and shapes (circular, curvilinear, linear, quadrangular).

2. Research aims

The paper deals with a methodological approach aimed to characterize for the first time spatial and temporal changes of archaeological crop-marks in relation to land use, vegetation, soil and meteorological conditions. The approach has been based on multitemporal observation conducted using UAV to analyse the spatial and temporal patterns of the typical archaeological proxy indicators linked to variations in growth of vegetation as well as in soil moisture content. The investigation has been performed in an area of Apulia (South of Italy) characterized by Neolithic settlements with the typical circular ditches built as defence systems [26,27].

The results showed that archaeological features are visible not only in spring, but also in summer and in autumn due to the physical interaction between archaeological residues, soil moisture, vegetation cover and meteorological conditions.

Our findings highlighted the usefulness of enlarging the temporal interval of aerial observations, to collect as much as possible the information about crop/damp/grass marks. Moreover, the availability of UAVs makes multitemporal prospection more feasible respect to the past also from the economic point of view.

3. Study area and methodologies

The investigated site is located in the Tavoliere, a large alluvial plain, in northern Apulia, gently sloping seaward, covering a surface of about 4.3 km^2 (Fig. 1). It is limited to the north by the Gargano Massif, by the Adriatic Sea to the East, to the west by the Daunian Pre-Apennines, by the Murge Highlands to the South. From the geological point of view, Tavoliere corresponds to the Northern part of the Southern Adriatic fore deep (Fossa Bradanica basin), which formed in the Lower Pliocene, between the Southern Apennine chain and the Apulian-Dinaric foreland [28,29].

The long human presence (from the Paleolithic to the present) in combination with the geo-pedological nature of soil, type of vegetation, agricultural practice created special conditions for the preservation of crop marks, still visible despite the mechanization of agriculture [29].

This area was investigated from 1949 to 1956 by Bradford [10,11], who discovered Arpi, the Neolithic settlement of Passo di Corvo and Masseria Villano. At the end of the 60s, Schmiedt [30] conducted studies on some Daunian and Roman settlements (Arpi, Ordona, Salapia) and medieval villages. Alvisi [31] performed investigations of Roman roads based on aerial photos.

In this paper, we focus on Schifata, located at 14 km NW from Foggia (Fig. 1), in a flat area characterized by intense agricultural cultivations, based on a system of crop rotation with annual shifts. The cultivations are generally cereals alternated with legumes and fallow field (resting). The soil is clayey-silty with a compact texture and poor content in organic matter.

In Schifata, vegetation and moisture changes evidence several curvilinear and linear marks, mainly related to Neolithic settlement [32]. They are characterized by two double ditched curvilinear enclosures (Fig. 1), surrounding circular and C-shaped

Please cite this article in press as: N. Masini, et al., On the characterization of temporal and spatial patterns of archaeological crop-marks, Journal of Cultural Heritage (2017), https://doi.org/10.1016/j.culher.2017.12.009