ACTA IMEKO
ISSN: 2221-870X
June 2024, Volume 13, Number 2, 1 - 9

Weed control in secondary archaeological sites by means of precision agriculture techniques

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ABSTRACT
The development of intervention approaches that lessen biodeterioration and enable the realization of cultural heritage is crucial for the improvement of secondary archaeological sites. A challenge faced by tiny archeological sites is the emergence of spontaneous vegetation, particularly ruderal plants. Here, we describe the development of a weeding system that applies precision agriculture techniques. Drones will be used to identify vegetation that is considered noxious and to apply herbicides where and when they are really needed. Additionally, the efficacy of the treatments can be tracked by using a multispectral sensor.

Section: RESEARCH PAPER

Keywords: multispectral sensor; weed control; precision agriculture; cultural heritage conservation

Citation: Fabio L., M. Leccisi, G. Schirripa Spagnolo, Weed control in secondary archaeological sites by means of precision agriculture techniques, Acta IMEKO, vol. 13 (2024) no. 2, pp. 1-9. DOI: 10.21014/actaimeko.v13i2.1753

Section Editor: Francesco Lamonaca, University of Calabria, Italy

Received January 20, 2024; **In final form** March 20, 2024; **Published** June 2024

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1. INTRODUCTION

Enhancing the administration, preservation, and utilization of minor archaeological sites is essential for maintaining our cultural legacy over time, sharing knowledge and culture, and growing the tourism and business sectors, particularly in small towns and rural areas [1].

Vegetation can occasionally be one of the primary causes of archaeological site degradation [2], [3], [4]. It is impossible to overstate the significance of vegetation development in the masonry and various artifact types of alterations (see Figure 1).

The vegetation found in archeological sites can have a major impact, particularly when considering certain substrate types and the local climate. Under some circumstances, the roots can spread out significantly in terms of depth, size, and distance traveled, and they can penetrate even on extremely dense substrates. Moreover, the mechanical action exerted by the subsurface components' growth must be complemented by the chemical activity produced by the radical synthesis of acid compounds [5], [6], [7], [8], [9], [10], [11]. Naturally, in certain circumstances [12], [13], the same vegetation might turn into a cultural treasure; consider the Ta Prohm temple in Cambodia, for example (see Figure 2). This denotes how vegetation can take on an important cultural and environmental value. Archaeological sites are often biodiversity hot spots [14], [15].

To prevent losing the cultural ruins entirely, it is crucial to manage the damage produced by vegetation even in these situations.

Weeds and ruderal plants are found in ancient sites. If spontaneous plants are not contained in a methodical manner, artifacts and archaeological sites are susceptible to rapid colonization or suffocation, the speed of which depends on the bioclimatic context in which they are located [16], [17], [18].

Figure 1. Monte Torretta di Pietragalla (PZ, Italy) archaeological site.

Figure 2. Angkor Wat - Ta Prohm Temple, Cambodia.

Figure 3. The Lokroi Epizephyrioi Theatre. In the fourth century BC, the Greek theatre was constructed close to what is now Locri in the Italian province of Reggio Calabria. utilizing a naturally occurring concave; Roman theatre was greatly altered. (a) A theatre with harsh vegetation present. (b) A nearly completely barren theatre.

The temple of Lokroi Epizephyrioi is depicted in Figure 3 both before and after a weeding operation.

Regular cleaning and weeding techniques are made more difficult within archaeological sites due to protection restrictions [19], [20], [21]. Put differently, you cannot use the processes and techniques that are typically employed to clean private driveways or the sides of roads. Due to this and the financial limitations of those tasked with maintaining and safeguarding secondary archaeological sites, these are frequently let to deteriorate. Due to its effectiveness and low cost and broad spectrum, glyphosate is the active ingredient present in the currently most used herbicides in the world [22].

Unfortunately, the use of glyphosate poses both environmental problems and for those who frequent the treated places (visitors, restorers, etc.); the molecule accumulates in the soil and aquifers [23], [24], [25]. Furthermore, there are studies, although not definitive, that consider glyphosate a probable carcinogen [26]. Unfortunately, to date, there are no herbicides available that are as effective and economical as glyphosate [27], [28]. For example, the use of acetic acid cannot be used in archaeological areas, because of its high probability of damaging the finds.

To increase the environmental and economic sustainability, it is necessary to have methodologies that allow intervention only when and where they are needed. In other words, in the case of weeds, treatments should be carried out according to the common precision agriculture practices.

As a result, public opinion has pushed for limitations on the use of glyphosate herbicides. All of this has led to some thought-provoking discussions on potential strategies for reducing the environmental dispersion of herbicides while simultaneously controlling the biodeterioration phenomenon caused by herbaceous, shrubby, and arboreal plants at archaeological areas.

Drones and rovers are commonly used in different fields. In agricultural use, various instruments are installed on them not only to monitor the conditions of the soil and plants, but also to provide spraying of fertilizer and/or pesticides. Obviously, it must be specified that the decision to use these products must be taken collectively only after the experts have evaluated all the possible implications, including the analysis and preservation of the biodiversity related to the vegetation.

Two examples of drones used in agriculture are shown in Figure 4: the first is a commercial drone with a 15-liter tank capable of spraying an entire crop; the second is a rover equipped with sensors capable of collecting information on the state of the water, productivity, the growth of vegetables or the composition, etc.

Although rovers are easily employed outside buildings and in open spaces, including amphitheatres, their usage in the archaeological field is still limited. In contrast, aerial drones are easier to use in the field of archaeology for information gathering, site mapping, archaeological site inspection, and video surveillance activities. Sensors and webcams are frequently mounted on rovers and drones.

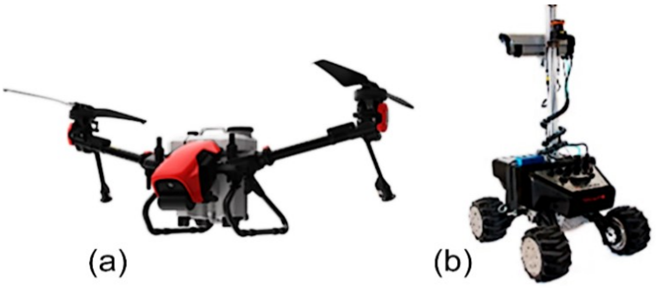

Figure 4. Two examples of commercial drones for agriculture. (a) XAG V40 drone with a 15 liters tank. (b) VINBOT an all-terrain autonomous mobile robot with a set of sensors capable of capturing data about water status, production, vegetable development, etc..

The weight and placement of these devices provide a constraint for aerial drones, although certain gadgets are so small and light that they don't affect the drones' ability to operate as intended.

In this paper, we suggest utilizing a drone (or rover) for early weed detection since rovers and drones are currently available for use in agriculture [29], [30], [31], [32]. Furthermore, with the same drone it is possible to intervene for weeding, applying a small quantity of herbicide only when and where necessary.

Obviously, drones can only be profitably used for the use of foliar biocides, which are effective for most herbaceous species. For woody species, other types of treatment are necessary, which cannot always be delivered via aerial sprays.

The system proposed consists of a rover capable of monitoring the site of interest. This rover should be designed in such a way that both during regular use and in the event of unintentional accidents, it cannot cause damages to the archaeological site. A camera, multispectral sensor, robotic arm, control computer, and wireless communication system will be included in the self-driving rover (or drone). The system will also georeference the noteworthy locations.

The suggested system is schematically shown in Figure 5. The system is a natural evolution of what is available on the market and what was developed in previous works [33], [34], [35].

The Rover should be reliable, run on electric motors and, possibly, with autonomously drive. Furthermore, since it must operate in areas of particular "value", it should be designed to minimize the risk of "damages" [36]. Therefore, particular care will be given to the batteries, both in terms of charging and discharging and safety against possible fires/explosions [37], [38], [39], [40], [41].

Given the importance of the sites of use, particular attention must be paid both to the control of the liquids used for weeding and those necessary for the operation of the rover. This check is essential to verify the correct administration of the products and to monitor any "spills" due to malfunctions [42], [43], [44].

In its normal use, initially the rover will carry out a preventive "reconnaissance" of the site. In this inspection, the areas that need weeding will be identified via video camera. Subsequently, the robotic arm will apply a "minimal" quantity of herbicide only to these areas. To subsequently confirm the effectiveness of the treatment or possibly repeat it, the treated zones will be georeferenced.

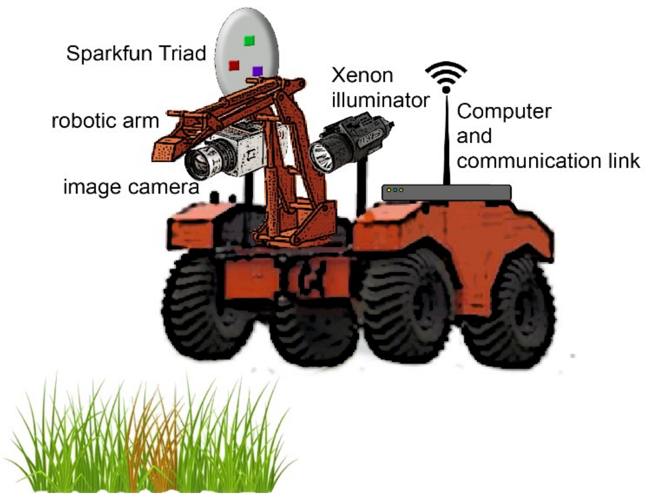

Figure 5. Proposed system shown schematically.

To allow the rover to work even in the absence of light (for example at night), it is equipped with an artificial light source; Xenon lamp with emission spectrum similar to the solar one. However, to have significant energy savings and reduce the batteries on board the rover, it is not excluded, in the near future, to implement a LED light source that simulates the solar spectrum [45], [46], [47].

From a technical point of view, creating a drone capable of operating in archaeological sites with this specific function is not simple. Indeed, there are problems with the hardware and dimensions of the structure, the selection of the drone's motion sensor and the environmental assessment. Additionally, certain algorithms must be used in the data collection and analysis processes to decide whether and how much product to spray. While many of these challenges are being worked on, this work specifically addresses how to assess and identify weeds in an archaeological context, as well as the changes that result after weeding.

Our study focuses on the use of a multispectral sensor, for collecting the spectral responses of weeds before and after a targeted weed control action. All this to allow a monitoring and control system to minimize the use of pesticides and verify whether the treatment carried out was effective. It is preferable to use a multispectral sensor, instead of a video camera, to lighten the work of the computer and the amount of data to be stored.

In fact, considering the normal extensions of an archaeological site and the desire to carry out localized interventions, the mapping by images, before and after the spraying of the herbicide, as well as the processing of the images to establish the effectiveness of the intervention, would require a system of image elaboration with very large memory and a large computing capacity.

After this introduction, the multispectral sensor used in our research will be described in section 2. Section 3 will illustrate the parameters used to identify correct weeding. In section 4 the results obtained will be presented. Finally, the Section 5 presents conclusions and future work.

2. THE MULTISPECTRAL SENSOR

Spectral approaches can now be used for sample analysis in portable systems at very low cost thanks to ongoing advancements in electronic devices and spectral sensors that are more affordable, more robust, and easier to use.

Precision agriculture is a field that makes use of multispectral sensors [48], [49]. Indeed, multispectral sensors can be used, for example, to examine the ripening of fruits or the amount of chlorophyll in plants [50], [51], [52], [53], [54], [55], [56].

The AS7265x multispectral sensor [57], which operates in the spectral range from 410 to 940 nm and covers 18 wavelengths or channels, is an example of a multispectral sensor suitable for monitoring the health of plants and fruits [58], [59], [60].

In this work we used the AS7265x SparkFun Spectral Triad sensor to verify the effectiveness of weeding [61]. Figure 6 shows the used SparkFun sensor.

The AS7265x sensor is made using detectors (AS72651, AS72652 and AS72653). It has 18 channels covering a spectral range between 410 and 940 nm (see Figure 7) accuracy of ±12%. The "Full Width at Half Maximum" (FWHM) of each channel is 20 nm. The sensor includes an MCU that enables two-way communications (I2C), a temperature sensor, and built-in interference filters on the detectors. Furthermore, the sensor is supplied already calibrated.

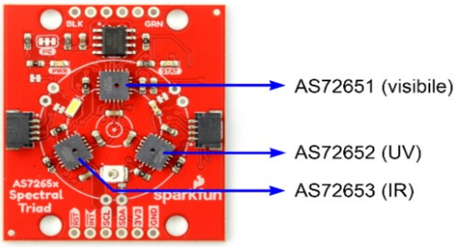

Figure 6. SparkFun Triad Spectroscopy Sensor.

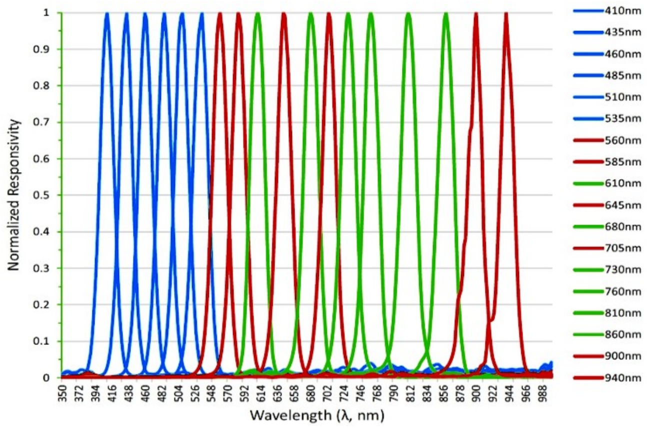

Figure 7. Spectrometric response of AS7265x

In our work, the area where weeding will be carried out is analyzed with the sensor before spraying the herbicide and after a few days to verify its effectiveness.

In other words, we use the information provided by the sensor AS7265x to check whether the desired effect has been achieved or whether a subsequent application is necessary. Having the possibility of verifying the effectiveness of the intervention in a simple and economical way, the herbicide can be used not only in a localized way but also in actually modest quantities.

To work in the field, our system is mainly composed of four different hardware modules: the sensor; a microcontroller (in our case Arduino board); a card for wireless remote data transmission; a computer for acquiring and processing information. Figure 8 shows a scheme of the proposed system.

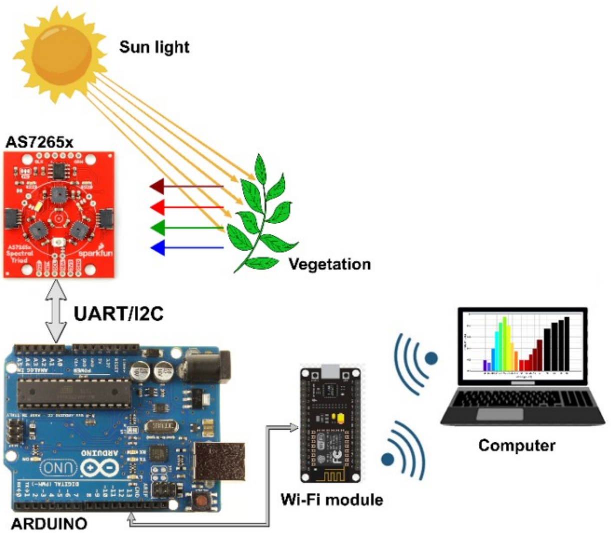

Figure 8. System diagram.

3. PARAMETERS FOR WEEDING CONTROL

Considering the spectral response of the sensor, the effectiveness of the weed control can be determined by obtaining the vegetative index of the treated area before spraying the herbicide and after a few days of treatment.

In the sun light spectral range, photosynthetically active radiation (PAR) is absorbed by plants and used as a source of energy for the process of photosynthesis. The leaf cells have evolved to disperse (reflect and/or transmit) solar radiation in the near-infrared spectral region, which carries about half of the total incoming solar energy. Robust absorption at these wavelengths could only lead to plant overheating and potential tissue damage. As a result, in the PAR and near-infrared, plants seem comparatively dark and bright, respectively. For usage in photosynthesis, the chlorophyll in leaves strongly absorbs visible light (400 to 700 nm). On the other hand, leaves' cellular structure is highly reflective of near-infrared light (700 to 1100 nm). As can be seen in Figure 9, a healthy plant has high absorption at the typical lengths of the colors Blue (435 – 485 nm) and Red 625 – 710 nm. Instead, it reflects Green (510 – 570 nm), which is why we see plants of this color, and above all it strongly reflects radiation with a wavelength greater than 740 nm (Near-Infrared - NIR).

Figure 10 represents the typical reflectance spectrum, comparing the curves for healthy vegetation, stressed vegetation and soil.

Given the multispectral response of our sensor, it is possible to obtain the vegetative indices that characterize a specific vegetation. One of the most used vegetation indices is the Normalized Difference Vegetation Index (NDVI). However, other indices are also used in research studies. In any case, all vegetative indices are obtained from the reflection spectrum of the analyzed vegetation [62], [63], [64].

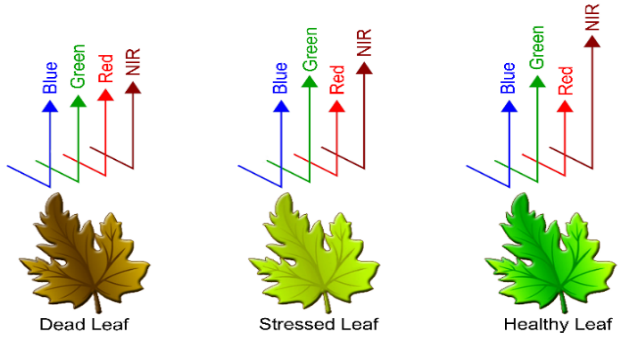

Figure 9. Indexes of vegetation with a percentage of radiation emissions.

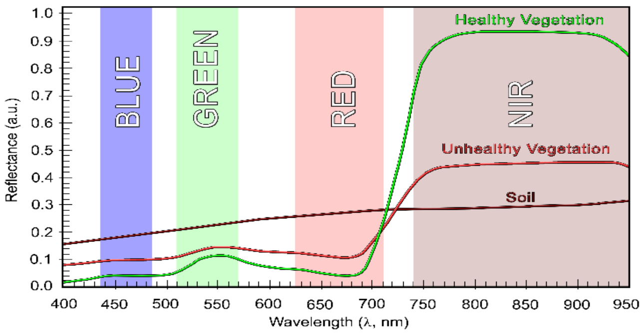

Figure 10. Typical reflectance spectrum of vegetation.

The NDVI index is traditionally used to monitor the growth and health of plants. In particular, it can be used to optimize fertilization and irrigation techniques. In this work, we plan to use the NDVI index "in reverse", namely, to check the "death" of the vegetation induced by spraying the herbicide.

Specifically, the NDVI index is calculated as:

$$NDVI = \frac{NIR - RED}{NIR + RED} . \qquad (1)$$

In (1), RED and NIR stand for spectral reflectance measurements acquired in the red and near-infrared regions, respectively. In our specific case, use of the sensor, we considered the 610 nm, 645 nm, 680 nm spectral channels for the RED and the 760 nm, 810 nm, 860 nm, and 900 nm spectral channels for the NIR. Index values are typically between -1 and +1.

The idea behind the NDVI index stems from the fact that healthy plants significantly reflect near-infrared light and that chlorophyll in plants absorbs red light during photosynthesis. An NDVI score ranges from +1 to -1, with +1 denoting healthy plants and -1 denoting dead or severely stressed plants. Values close to 1: vigorous vegetation. Values close to 0: correspond to bare ground. Negative values: usually associated with marshy areas or the presence of snow. Depending on the vegetative state, Figure 11 shows typical values of the NDVI index.

Therefore, the NDVI index is strongly indicated to control the effectiveness of the herbicide. It is also good at identifying where the herbicide needs to be sprayed.

4. EXPERIMENTAL RESULTS

To verify the effectiveness of the proposed system, some preliminary tests were carried out (without the use of the rover). Figure 12(a) shows the image of a weed before and after the action of the herbicide; in this case acetic acid was used as an herbicide. Figure 12(b) refers to 5 days after spraying the herbicide. In this experiment it was preferred to use a natural product, acetic acid, as an herbicide. This product was chosen, even knowing that it is not recommended in the presence of archaeological finds, to avoid the use of glyphosate. It is our opinion that it is best to avoid the use of glyphosate unless it is absolutely essential.

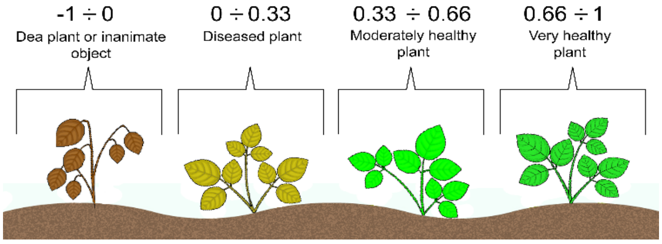

Figure 11. Conceptual diagram showing typical values of the NDVI index. A number between -1 and 0 suggests dead plants. A value between 0 and 0.33 indicates unhealthy or stressed plant material, 0.33 to 0.66 is moderately healthy, and 0.66 to 1 is very healthy.

Figure 12. Acetic acid used as an herbicide. (a) Image captured before spraying the herbicide. (b) Image captured 5 days after treatment. In the period between the two acquisitions, there was no meteorological precipitation.

Figure 13 and Figure 14 show the spectra obtained by the AS7265x sensor relating to the situations illustrated in Figs 6(a) and 6(b). The sensor AS7265x was placed circa 50 cm from the weeds under artificial (4200 K Xenon Lamp) light conditions to overcome the problem of sunlight variability.

The two spectra, but above all the two NDVI indices obtained, show that it is possible to identify the areas with the presence of "live" vegetation ($NDVI > 0.33$) and the effectiveness of weeding ($NDVI < 0.33$).

Another test was carried out to verify a failed weed control operation. Figure 15(a) shows the image of a weed before and after the action of the herbicide; in this case, also, the test was

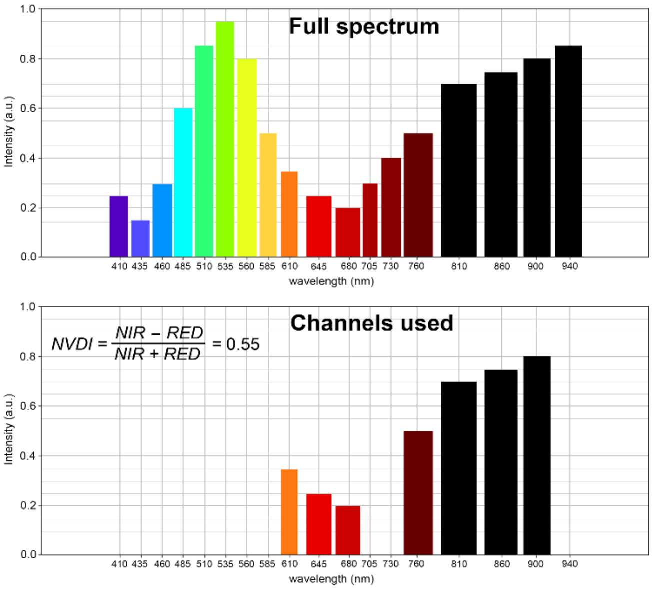

Figure 13. Spectrum obtained with the AS7265x sensor on the vegetation shown in Figure 12(a); that is, **before** administering the herbicide agent. With this spectrum an index *NDVI* = 0.55 was obtained.

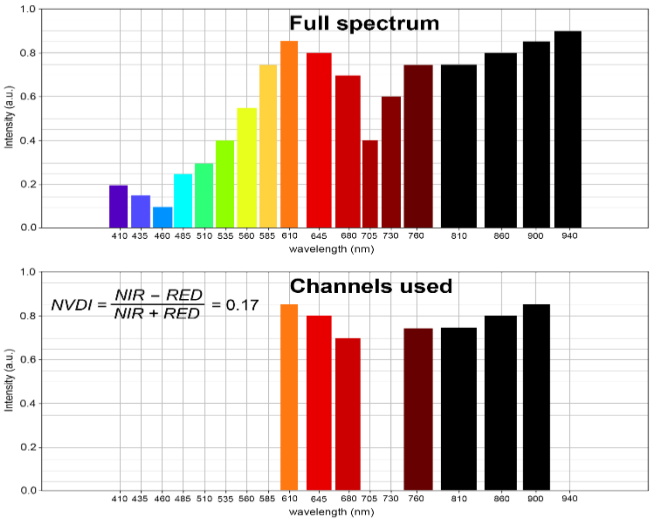

Figure 14. Spectrum obtained with the AS7265x sensor on the vegetation shown in Figure 12(b); that is, **after** administering the herbicide agent. With this spectrum an index *NDVI* = 0.17 was obtained.

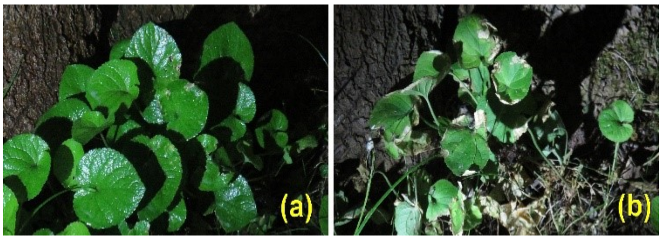

Figure 15. Acetic acid used as an herbicide. (a) Image captured before spraying the herbicide. (b) Image captured 5 days after treatment. On the second day after the treatment, moderate rainfall occurred which partially compromised the weeding operation.

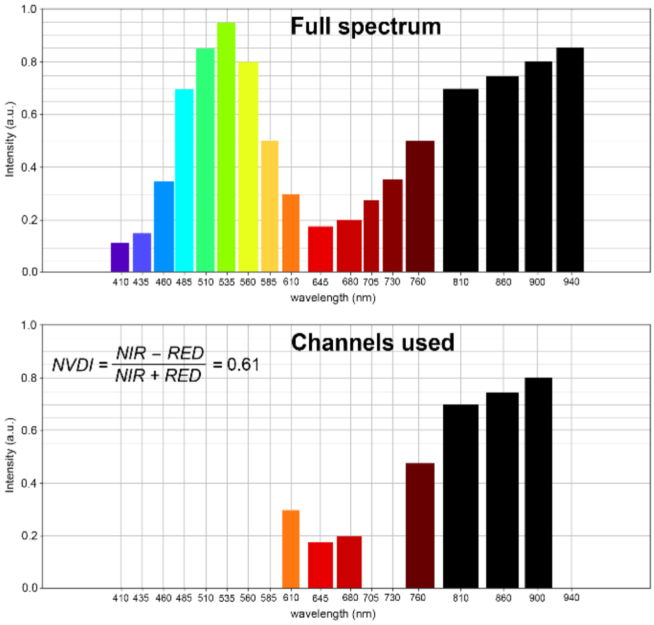

Figure 16. Spectrum obtained with the AS7265x sensor on the vegetation shown in Figure 15(a); that is, **before** administering the herbicide agent. With this spectrum an index *NDVI* = 0.61 was obtained.

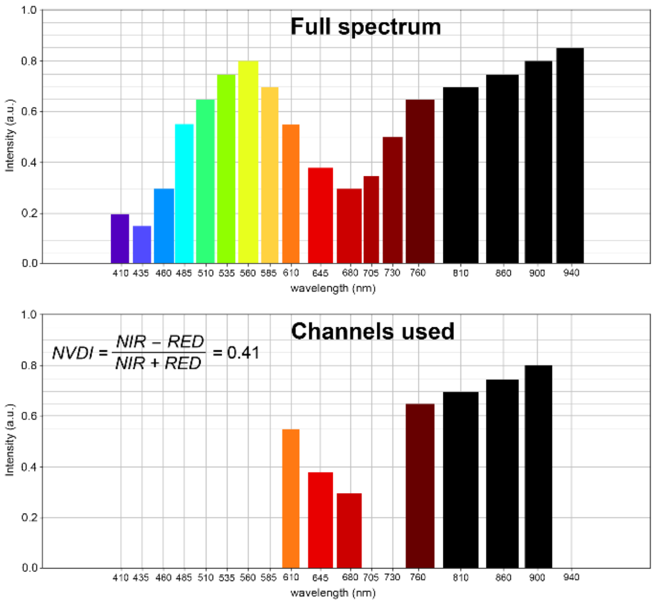

Figure 17. Spectrum obtained with the AS7265x sensor on the vegetation shown in Figure 15(b); that is, **after** dispensing the herbicide agent. With this spectrum an index *NDVI* = 0.41 was obtained.

carried out with artificial light and using acetic acid as an herbicide. Image 15(b) is for 5 days after spraying the herbicide. In the range between the acquisition before and after the spraying of the herbicide, atmospheric precipitation occurred which partially compromised the weeding action.

Figure 16 and Figure 17 show the spectra obtained with the AS7265x sensor relating to the situations illustrated in Figure 15(a) and Figure 15(b). The same experimental situation as the previous one was used.

As seen in the previous case, the weed vegetation is correctly identified, before weeding there is an NVDI index of 0.61; well above the threshold value of 0.33. Instead, contrary to what was previously observed, the effectiveness of the weeding action was not successful. In fact, we have an NVDI index of 0.41. The action of washing away due to atmospheric precipitation partially affected the treatment. In this specific case, subsequent action is necessary.

5. CONCLUSION

In this work, we presented the project of a system for the elimination of vegetation in a secondary archaeological site.

Weeding of secondary archaeological areas, useful/indispensable for conservation and restoration, must necessarily be economical, respectful of the site and ecologically minimally invasive. Furthermore, it is essential that weeds are constantly kept under control. To respond to all these needs, the only possibility is chemical weeding carried out only where and when it is necessary. To allow constant and economically sustainable monitoring, it was decided to use an agricultural rover capable of delivering small quantities of herbicide. A multispectral sensor will be placed on the rover. The sensor will be placed in a position to identify areas with the presence of vegetation. Furthermore, the rover will be equipped with a georeferencing system. The treated areas must be identifiable and recoverable to check over time. In this way, it will be possible to periodically check the site and to establish if and when further weeding is necessary. The multispectral sensor solution was chosen, instead of a "normal" video system, to limit the computing power and the amount of memory needed for the monitoring system. In fact, wanting to limit the quantity of herbicide used as much as possible, it is essential to divide the site into a very dense grid. The storage of many images would require demanding processing and storage systems both in terms of processing capacity and the amount of memory required. In contrast, storing data from a multispectral sensor allows us to reduce the data to be processed and stored by a factor of $10^5 \div 10^6$. In the present work, we focused on the feasibility of the system and the use of the multispectral sensor to verify the effectiveness of weeding. In this context, we have given importance to the use of the NVDI index, the parameter normally used to control the vigor of vegetation. We used it in an unconventional way. We use the NDVI index both to identify areas with the presence of vegetation and to verify the "death" of weeds. The results obtained are more than promising. The research will continue using the preliminary results of the present study to create a prototype to be mounted on an agricultural rover. A further study will concern the possibility of using the system with natural rather than artificial sunlight.

In this project we focused on the feasibility of the system. Obviously, subsequent studies will have to identify the limits of detection of weeds and, above all, the limit of detection of the effectiveness of the weed control intervention. The other words will be necessary measurement campaigns to identify the CER (Crossover Error Rate) which describes the point at which the FAR (False Acceptance Rate - percentage of false recognitions - intervention incorrectly recognized as effective) and the FRR (False Rejection Rate - intervention recognized mistakenly not effective) [65], [66], [67].

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