Application of remote sensing for mapping organic cereal crops

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Abstract. Today checks on organically managed fields are done by taking soil samples and carrying out laboratory analyzes to verify the presence of chemical fertilizers or other prohibited substances.
A monitoring system based on the proposed procedure could allow targeted investigations to be carried out where the algorithm reports an anomaly or a doubtful situation, instead of carrying out blanket verification samples or randomly chosen sample fields. This would lead to significant savings for producers on the costs relating to laboratory analyzes of soil samples and further quality certification of the product.
The study area was the Basilicata region in southern Italy. It is a predominantly cereal-growing region that is beginning to open up to sustainable management and the use of precision machinery and monitoring systems. The objective of the present work is the evaluation of the possibility of identify biological cereal crops by using multitemporal analysis of vegetation indices from Sentinel 2 satellite images. The developed algorithm has proven to be based on valid principles. It was validated by using 40 organic cereals crops fields reaching a satisfactory overall accuracy.

Keywords: organic cereals, remote sensing, sustainability.

1 Introduction

The use of high-resolution data from remote and proximal sensing still encounters great difficulties in use outside research areas mainly due to costs. Free medium resolution satellite images such as Landsat-8 and Sentinel-2 are ideal for offering a "low cost" product with extensive automation possibilities and which allows high-definition temporal control of the entire national territory [1]. Medium resolution satellite images are widely used to monitor soil and plants [2]. The integration of the crop management information with the information layer of vegetation indices deriving from Sentinel-2 images had the objective of monitoring the health status of the vegetation and in particular of evaluating the possibility of identifying biological cereal crops. The vegetation indices derived from Sentinel-2 images [3] were used because of their spatial (10/20 m) and temporal (5 days) resolution which is optimal for the analysis. Certainly, the high temporal definition of these satellite images has introduced a new crop monitoring system [4] capable of supporting the planning of field investigations aimed at the areas in which the satellite analysis has highlighted risks [5]. A DSS platform was specifically created to support the management and integration of the various information layers. It will make possible to remotely consult numerous data acquired in the field by comparing and integrating them with the information obtained from satellite data.

2 Material and Methods

The study area was the Basilicata region in southern Italy. It is a predominantly cereal-growing region that is beginning to open up to sustainable management and the use of precision machinery and monitoring systems.

The study year was 2019. All remote sensing images acquired from February to May, by the Sentinel-2 satellites, compatibly with the cloud cover, were involved in the analysis. The Sentinel-2 mission consists of 2 twin satellites with the same orbit but positioned antipodal to each other, with a revisit time of 10 days at the equator with one satellite and 5 days with two. The sensors mounted on the Sentinel-2 satellites cover 13 spectral bands, from 443 to 2190 nm, with spatial resolutions varying from 10 to 60 meters per pixel and a swath of 290 km. The satellite images are made available to users free of charge by accessing ESA's "Sentinel Scientific Data Hub" portal, selecting the area of interest, the acquisition period and the cloud cover. The data provided by the European Space Agency (ESA) are orthorectified and georeferenced in the UTM/WGS84 system and report the reflectance measurement at the top of the atmosphere; a further processing step was performed to obtain the data referring to the bottom of the atmosphere, the algorithm is currently integrated in the ESA opensource SNAP program.

In the pre-processing step, both clouds and water (streams, wet areas, ponds and ditches) were masked. Semi-automatic algorithms (SPC- QGIS) were used to calculate these masks. Finally, the images were reprojected into the Lat/Long WGS84 geographic reference system.

Starting from the satellite images of February, April, May, August and October 2019, a map of land use was elaborated and the fields with cereal crops were extracted. The map was preliminary validated by using the orthophotos of the Basilicata region geoportal (RSDI). A data set of 100 points was generated, so that the sampling points were homogeneously, but randomly distributed over the entire area attributed to the cereal class. The belonging of each point to the attributed class was verified by comparison with the validation data [6]. The total accuracy associated with classification was approximately 87%. Subsequently, in order to evaluate the possibility of identifying organically managed fields, the biomass index [7], namely the Normalized Difference Vegetation Index (NDVI) and the chlorophyll/nitrogen content index MTCI (Meris Terrestrial Chlorophyll Index) of plants were computed [8]. Two vegetation indices, one related to chlorophyll content and the other to crop biomass, were selected to take into account the dilution effect of nitrogen during crop development. This element is very important in the optics of conventional and organic crop discrimination. The operating procedure is shown in figure 1. The segmentation procedure was performed by applying a K-means algorithm in R-project. K-means by default aims to minimize within-group sum of squared error as measured by Euclidean distances. The number of selected classes was evaluated based on the optimal separation between them.

Organic cereal crops differ from those conventionally managed because they do not allow a series of practices, in particular the use of conventional fertilizers is not permitted. Fertilizations, when permitted, are limited to only some products. Organic cereals should differ from conventional ones due to a lower nitrogen 'uptake' between 17 February and 8 April, when the effect of fertilization is detectable on the vegetation [9]. To monitor the nitrogen 'uptake' of the crop, the map of the differences between the MTCI index of February and April was calculated [10]. Furthermore, cereals grown using organic techniques should have a more gradual development and maturation over time compared to conventional practices [11]. This can be highlighted by studying the evolution of the NDVI index over time. Following the procedure in figure 1, five classes of cereals were identified whose characteristics are shown in table 1 and figure 2. The spatial resolution of the final map was equal to 20 meters.

The validation data were provided by ALSIA, a regional agency that provided information relating to the location of 40 parcels that fall within organic farms.

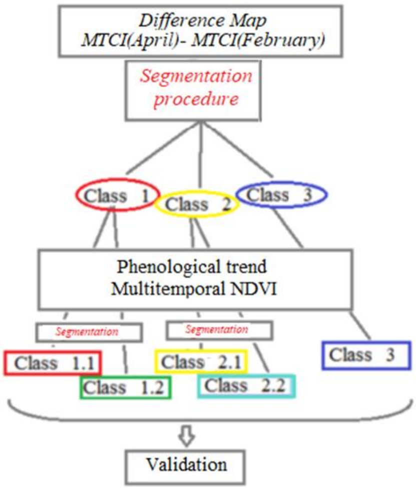

Figure 1. Operational scheme to identify organically managed cereal crops field in Basilicata region.

Table 2. Characterization of the classes obtained from the image segmentation of the differences between the MTCI index of 17 February and 8 April 2019.

	Min	Max	Mean	STD
Class 1	0.10	1.30	0.80	0.340
Class 2	1.30	2.65	1.83	0.374
Class 3	2.65	1.00	3.42	0.856

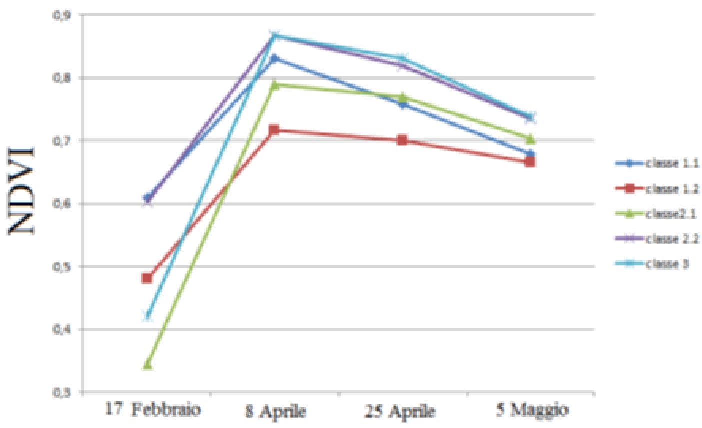

Figure 2. Average values of the NDVI index for each cereal class identified in 2019.

3 Results and Discussion

Vegetation is characterized by a spectral signature that is easily distinguishable from other objects on the surface. The MTCI vegetation index is known in the literature to be correlated with the chlorophyll (nitrogen) content of the vegetation (Bruijn, 2016). Since in conventional practices, in the Mediterranean environment, generally the fertilization is applied in March, by evaluating the difference between the value of the index on 17 February and 8 April ($MTCI_{diff}$), a map of the nitrogen 'uptake' of the crop was obtained [12]. This map was segmented by dividing the 'range' of values into three classes, as shown by the statistics in table 1. The analysis was limited to cereal-growing areas only. Class 1 was characterized by lower $MTCI_{diff}$ values (table 1), in which case the 'uptake' of nitrogen by the crop was low. The multi-temporal analysis of the NDVI maps allows to study the evolution of the vegetation between February and May by distinguishing two cases:

1. the variation in the chlorophyll content of the vegetation was low, however starting from higher biomass values (NDVI). This case falls into the class called class 1.1 (figure 2);

2. the variation in the chlorophyll content of the vegetation was low starting from lower biomass values (NDVI). This case falls into the class called class 1.2 (figure 2). This class highlighted a more gradual trend in the NDVI index between April and May and therefore a more gradual development and maturation process of the crop.

Class 2 is characterized by intermediate $MTCI_{diff}$ values (table 1), in which case the 'uptake' of nitrogen by the crop was higher than in the previous case. The multi-temporal analysis of the NDVI maps allows to study the evolution of the vegetation between February and May by distinguishing two cases:

1. the variation in the chlorophyll content of the vegetation was medium, but the values of the biomass index (NDVI) were higher. This case falls into class 2.1 (figure 2). This class highlighted a more gradual trend in the NDVI index between April and May and therefore a more gradual development and maturation process of the crop;

2. the variation in the chlorophyll content of the vegetation was medium, associated with lower biomass values (NDVI). This case falls into class 2.2 (figure 2).

Class 3 was characterized by high $MTCI_{diff}$ values (table 1), in this case the 'uptake' of nitrogen by the crop was high. As can be seen from figure 2, the average biomass variation (NDVI) between February and April was the highest, with a rather rapid maturation process. Class 3 certainly cannot be associated with organic cereal crops, nor classes 1.1 and 2.2. According to the selected criteria, only classes 1.2 and 2.1 could potentially be compatible with the presence of organically managed cereal crops in the field. Figure 3 shows a series of examples of areas indicated by ALSIA as biologically conductive fields. The figure shows the classification map of cereal areas according to the 5 identified classes. In particular, of the 40 fields indicated by ALSIA, 6 were associated with another crops, this is compatible with the crop alternation set by the biological management of the soil. 7 of the remaining parcels, were associated with non-organic cereal crops. Figure 3a shows a case of cereal fields in which organic management was declared, but not recognized by the classifier. The last figure shows the fields, recognized as organically managed cereals, in this case the farm declared only the use of permitted fertilization. As can be seen from figure 3g, in this case, the confusion with the other classes is higher, but occurs mainly with classes 1.1 and 2.2, associated with low nitrogen 'uptake'.

To produce more accurate results, it would be necessary to reproduce this type of analysis for several years, taking into account climatic trends and evaluating aspects such as crop alternations which could provide a valid tool to support this investigation procedure. Other important elements, which should be included in the procedure in order to improve its accuracy, are the topography and the characterization of the pedo-climatic areas in which the individual fields fall.

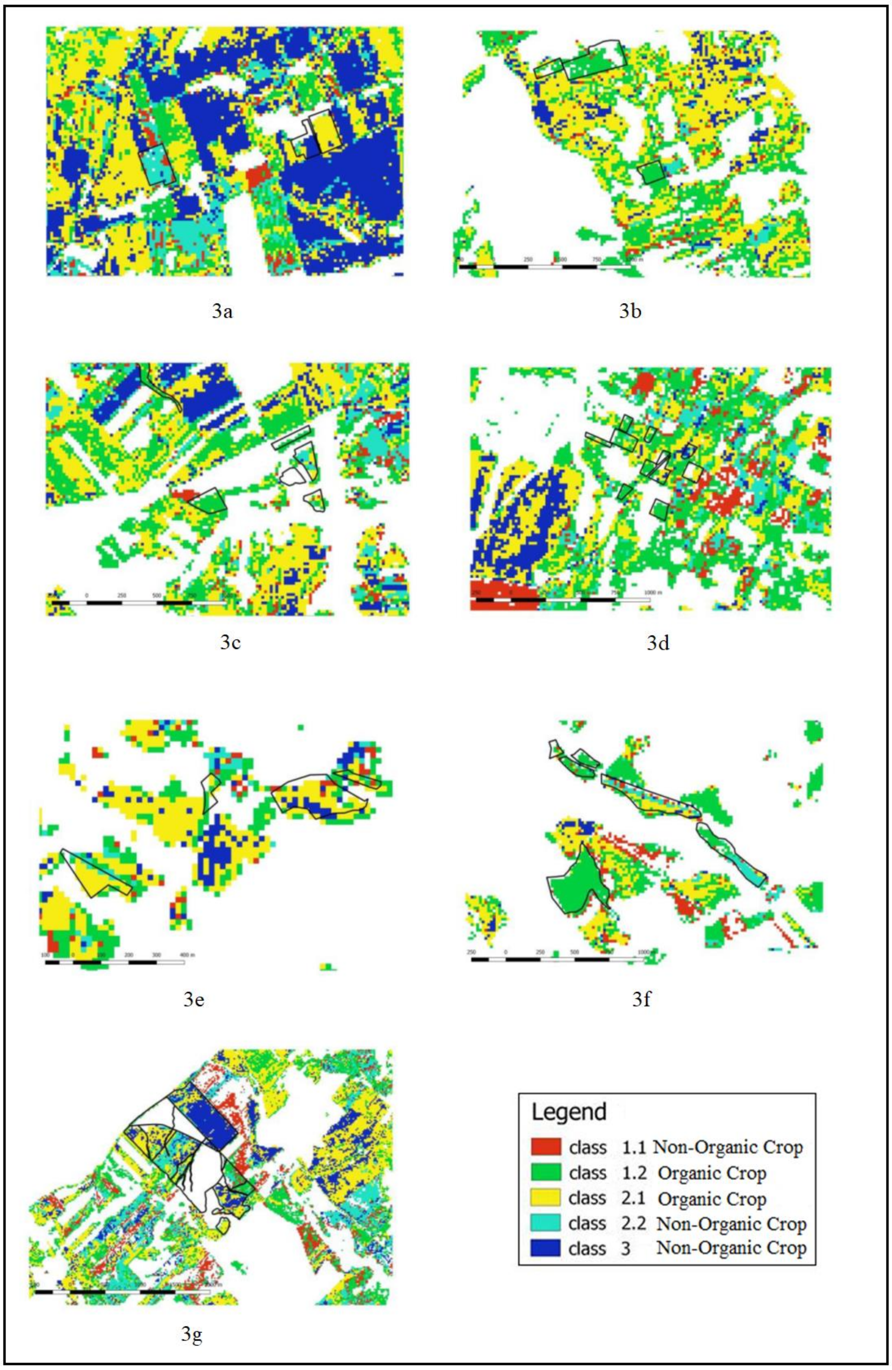

Figure 3. Examples of biologically managed fields. The figures show the classification map of cereal areas according to the 5 identified classes.

4 Conclusion

The developed procedure could be a useful verification tool, for example, for consortia of certified organic cereal crops in order to identify organic cereal crops compared to conventional managed cereals. The algorithm has proven to be based on valid principles, although to improve its accuracy it would be necessary to cross-reference the results obtained from the analysis of Sentinel2 satellite images with further information such as: climatic trends (average temperatures and rainfall), crop alternation, topography, classification of pedo-climatic areas.

Today checks on organically managed fields are done by taking soil samples and carrying out laboratory analyzes to verify the presence of chemical fertilizers or other prohibited substances.

A monitoring tool like the one proposed could allow targeted investigations to be carried out where the algorithm reports an anomaly or a doubtful situation, instead of carrying out blanket verification samples or randomly chosen sample fields. This would lead to significant savings for producers on the costs relating to laboratory analyzes of soil samples and further quality certification of the product.

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