Lecture Notes in Mechanical Engineering

Francisco Cavas-Martínez
Manuel D. Marín Granados
Ramón Mirálbes Buil
Oscar D. de-Cózar-Macías *Editors*

Advances in Design Engineering III

Proceedings of the XXXI INGEGRAF International Conference 29–30 June, 1 July 2022, Málaga, Spain

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Preface and Acknowledgements

The INGEGRAF 2022 Conference originates as the 31st International Conference on GRAPHICS ENGINEERING "Graphic Expression: reunion, reflection, representation".

INGEGRAF 2022 has been organized by the Department of Graphic Expression, Design and Projects and Graphic Design and Engineering Research Group of the University of Málaga. Cutting-edge topics in Product Design and Manufacturing, Innovative Design and Computer Aided Design were especially encouraged.

The list of topics (and subtopics) covered in the present edition are the following:

- Product design & development: Integrated Product and Process Design, Interactive Design, Innovative Design Methods, Knowledge-based Engineering, Industrial Design, Human factors and Ergonomics, Image Processing and Analysis, Green Engineering and Ecodesign, Product Lifecycle Management, Systems Engineering and Design, User-centered Design (UCD), Robust Design, Reliability and Maintenance, Circular Economy.
- Manufacturing and industrial process design: Product Manufacturing, Additive Manufacturing, Experimental Methods in Product Development, Advanced Manufacturing, Configurable Manufacturing Systems, Smart Production Systems and Advanced Manufacturing Technologies, Flexible Assemblies, Remanufacturing, Industry 4.0, Rapid Prototyping.
- Applied Graphic Engineering: Nautical, Aeronautical and Aerospace Modelling and Design, Biomechanics, 3D Modelling for Biological Structures, Computer Aided Design for Pathologies Diagnosis, Biological Systems Visualization and Simulation, Medical Modelling and Design.
- Computer Aided Design: Virtual Simulation, Virtual and Augmented Reality, Reverse Engineering, Virtual Prototyping and 3D Modelling, Geometric Modelling and Analysis, Surveying, Mapping and GIS Techniques, BIM new technologies, BIM and Architecture, Simulation and Virtual Approach.
- Teaching and representation techniques: Teaching Product Design and Drawing History, Teaching Engineering Drawing, Representation Techniques, Education,

Learning and Knowledge, Innovative Teaching Experiences, Graphic Design, Interactive 3D Support, New Approaches in the Teaching/Learning Process.
- Miscellany: Geometric Product Specification and Tolerancing, Geometrical and Functional Characterization of Products, Sustainability, Innovation and Creativity Methods, Collaborative Engineering, Industrial and Intellectual Property Management, Research Methods and Design.

Some cross-cutting themes applied to the previous themes, such as: Geometric Product Specification and Tolerancing, Sustainability, Innovation and Creativity Methods, Collaborative Engineering and Artificial Intelligence.

We would like to thank our main organizer/institutions and the rest of the sponsoring/collaborating companies and institutions for their support and grants.

We would also like to express our gratitude to the members of the different committees for their support, collaboration and good work. Thanks to all reviewers for their selfless effort in reviewing contributions, which positively influenced the quality of the final papers presented at the Conference.

Last, but not least, thanks to all the participants of INGEGRAF2022.

Málaga, Spain
September 2022

Dr. Francisco Cavas-Martínez
Dr. Manuel D. Marín Granados
Dr. Ramón Mirálbes Buil
Dr. Oscar D. de-Cózar-Macías

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Protected Horticultural Crops Characterization Through Object-Based Image Analysis and Satellite Imagery Time Series in Almería (Spain)

Rafael Jiménez-Lao, Manuel A. Aguilar, and Fernando J. Aguilar

Abstract Agricultural greenhouse is crop system that has showed its efficiency in enhance food production. The importance of agriculture in the sustainable management of natural resources requires the development of operational methodologies for mapping and monitoring farmland. This study aims to analyze the potential of time series of Sentinel-2 images for monitoring Plastic Covered Greenhouse (PCG) crops in Almería (Spain). For this, a set of 22 Sentinel-2 images taken during 2021 were used. Throughout the year 2021, monthly field visits were made on 32 PCG to know the characteristics of these greenhouses, the crops they contained (i.e., to mato, pepper, cucumber, melon and watermelon) and their evolution over time. By combining both the satellite and the field data, the crops, which are growing into each PCG, can be characterized. Two different spectral indices, NDVI (related to vegetative growth) and Brightness (related to the whitewashing of PCG), derived from the Sentinel-2 images shown their usefulness for differentiating crops growing under plastic sheet. This work could be the first step for discriminating crops through indices derived from Sentinel-2 images for the development of future management strategies for PCG areas.

Keywords Sentinel-2 · Horticultural crops · Time series · Object-based analysis · Greenhouse mapping

1 Introduction

During the last decades, food security has become a crucial global concern driven by projections of population increase and aggravated by the approaching pressure of climate change on agriculture [1–3]. Agricultural greenhouse is crop system that has showed its efficiency in enhance food production. These agricultural systems constitute a possible alternative to guarantee food supply [4].

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In 2018, the global surface area of plastic agricultural structures was estimated as ~3,400,000 ha, where 15% of this area was greenhouses and their area is growing. This increase as well as its importance raises the need to map and classify agricultural plastic structures and the type of crops that could be planted [5].

The province of Almería, located in eastern Andalusia, in the semi-arid of Southeast Spain, has a huge plastic covered greenhouses (PCG) area and an even larger crop-growing surface, thanks to the programing of two growing cycles per year. These make Almeria the province with the highest concentration of protected crop surface (greenhouses) not only in Spain but in the world [6]. This wide concentration of PCG demand transformative solutions for social, economic and environmental challenges and processes. In that sense, remote sensing offers coverage of long areas with precision and is a very efficient and contracted instrument to improve management across scales [7].

Agriculture is of increasing importance in the administration of sustainable natural resources and requires the improvement of functional methodologies for mapping and monitoring agricultural areas [8]. The data obtained by remote sensing offer a significant increase to provide regular and precise images of land use and land cover, specifically of the agricultural sector. It takes significant relevance considering its applicability in a new era of land cover analysis, which has been allowed by free and open access data (e.g., Sentinel-2 (2A and 2B), Landsat 8 or even Landsat 9 images), analysis-ready data, high-performance computing, and rapidly developing data processing and analysis aptitude [9, 10]. For instance, a joining of data from Sentinel-2a, Landsat 8 and Sentinel-2b provides a global median average revisit interval of less than 3 days [11].

In the last ten years, a rising quantity of scientific literature has been published on PCG mapping from remote sensing, that has mainly focused on Landsat imagery and Sentinel-2. A few indices especially adapted to plastic sheet detection, such as the Index Greenhouse Vegetable Land Extraction (Vi), Plastic Greenhouse Index (PGHI), Moment Distance Index (MDI), Normalized Difference Builtup Index (NDBI) and Greenhouse Detection Index (GDI) have been recently proposed [12].

The crop classification via remote sensing from medium resolution satellite imagery (e.g., Landsat or Sentinel-2) was commonly conducted by using pixel-based approaches until more than ten years. As a result of spaceborne sensors was allowing the application of the object-based image analysis (OBIA) model to extract crop types from satellite image time series. Peña-Barragán et al. [13] developed a methodology for outdoor crop identification and mapping using OBIA and decision tree algorithms. This methodology was also applied to a Landsat time series to map sugarcane over large areas [14]. Adapting this research line to PCG horticultural crops (indoor crops), Aguilar et al. [15, 16] went one step further by addressing the identification from using a single WorldView-2 satellite image and Sentinel-2 and Landsat 8 Operational Land Imager (OLI) time series.

Satellite based vegetation index data, such as the normalized difference vegetation index (NDVI), is useful for estimating outdoor crop types because it is relatively easy to get and globally scalable. NDVI is a common vegetation index that has been use since the 1970s. Singla et al. [17], identified outdoor types of sugarcane crops efficiently using a temporal profile of NDVI at any given scale.

Remote sensing techniques are commonly used in agriculture and agronomy because, agricultural production follows strong seasonal patterns related to the biological lifecycle of crops. The grown crops depend on the physical landscape (e.g., soil type), as well as climatic driving variables and agricultural management practices, among others factors [18, 19].

This work is dealing with the optimized use of Sentinel-2 satellite image data for acquisition of consistent and near in time information associated to the greenhouse crops in spatial and temporal domain. The goal of the proposed study is to discriminate different inside greenhouse crops based on the multi temporal Sentinel-2 remotely sensed data temporal profile of NDVI, Brightness and the agricultural management of PCG.

2 Study Area and Datasets

The research has been carried out in Almería, the most eastern of the eight provinces that make up Andalusia. Over 32,554 hectares of this province are currently dedicated to greenhouse crops production. Considering the area cultivated by product in the 20/21 season, production was 52,350 hectares of which was 12,575 ha of watermelon, 12,310 ha of pepper, 8423 ha of tomato, 8061 ha of zucchini, 5280 ha of cucumber, 3205 ha of melon, 2277 ha o aubergine, and 219 ha of green bean. About 60.8% of greenhouses cultivated area in Almería in 2020/21 season had two crops grown per year [20].

The study area comprised a rectangle area of about 40 km^2 centered on the WGS84 geographic coordinates of 36.7856°N and 2.6681°W.

2.1 Data Set Pre-processing

The European Space Agency (ESA) provides free, open access products, for example Sentinel 2 images level 2A (S2), that could be freely downloaded from Copernicus Scientific Data Hub tool, used for this study. The Sentinel-2 mission offer a combination of systematic global coverage of land surfaces, a high revisit of 5 days at the equator under the same viewing conditions, a large field of view for multi-spectral observations from 13 bands in the visible, near infrared and short- wave infrared part of the electromagnetic spectrum [21].

A time serie of 22 cloud-free Sentinel-2 satellite images (both Sentinel-2B and 2A) were acquired in different dates (Table 1) during the 2021. In this study, the six 20 m ground sample distance (GSD) bands (Red Edge1, 2 and 3, SWIR 1 and 2 and NIR8a) and four 10 m GSD bands (Blue, Green Red and NIR8) were used. These images were clipped coincide to the study area.

Table 1 Characteristics of the Sentinel-2A images acquired

Orbit	Granule	Date of acquisition	Sensor
R094	30SFW	January 3, 2021	2B
R051	30SFW	January 15, 2021	2A
R094	30SFW	February 7, 2021	2A
R094	30SFW	February 22, 2021	2B
R051	30SFW	March 14, 2021	2B
R051	30SFW	March 24, 2021	2B
R094	30SFW	April 18, 2021	2A
R051	30SFW	May 5, 2021	2A
R051	30SFW	May 25, 2021	2A
R051	30SFW	June 9, 2021	2B
R051	30SFW	June 29, 2021	2B
R051	30SFW	July 4, 2021	2A
R051	30SFW	July 19, 2021	2B
R051	30SFW	August 8, 2021	2B
R051	30SFW	August 28, 2021	2B
R051	30SFW	September 12, 2021	2A
R051	30SFW	September 17, 2021	2B
R051	30SFW	October 7, 2021	2B
R051	30SFW	November 11, 2021	2A
R094	30SFW	November 29, 2021	2B
R051	30SFW	December 6, 2021	2B
R094	30SFW	December 19, 2021	2B

2.2 Horticultural Crops Under PCG Reference Data

A variety of data as farming practice, crop growth, agricultural management practices and greenhouse information as type, height, material is essential for carrying out this study. During 2021 were acquired field data to obtain rigorous and real information about 32 controlled greenhouses (Fig. 1b). Ground truth data at reg- ular intervals of a month have been collected to extract the information related to the PCG crop growth cycle of controlled greenhouse.

These greenhouses contained different crops and managements that in turn changed during the course of the year. Among the PCG crops present, the most represented were characterized. In this case, four different crops management: Long cycle (September–April cycles) cherry tomato, Long-cycle bell red pepper (Fig. 2), short crop cycles (two cycles per year autumn to winter cycle and spring to summer cycle) watermelon and cucumber and long cycle zucchini was controlled.

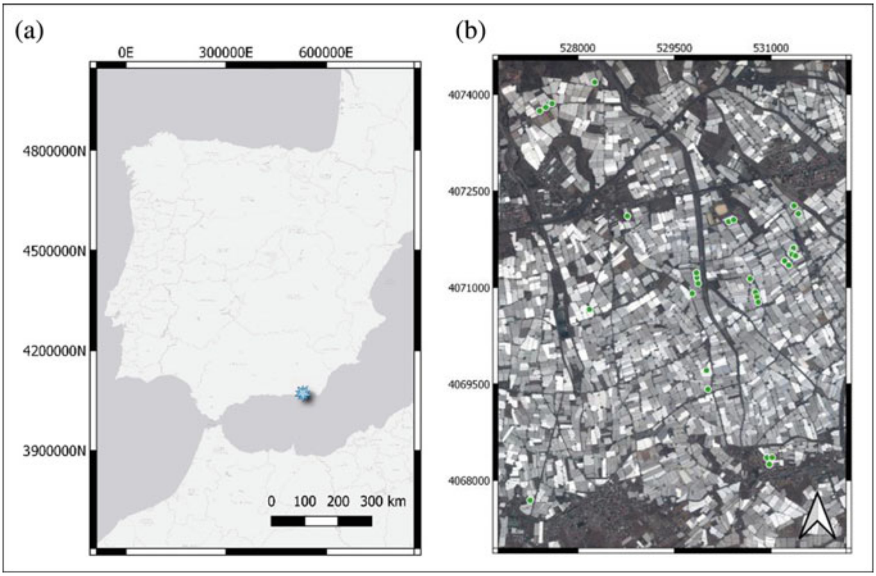

Fig. 1 **a** Location of the study area in Almería (Spain); **b** detailed view of the study area and location of the reference horticultural crops growing under plastic-covered greenhouses (PCG). Coordinate system: ETRS89 UTM Zone 30N

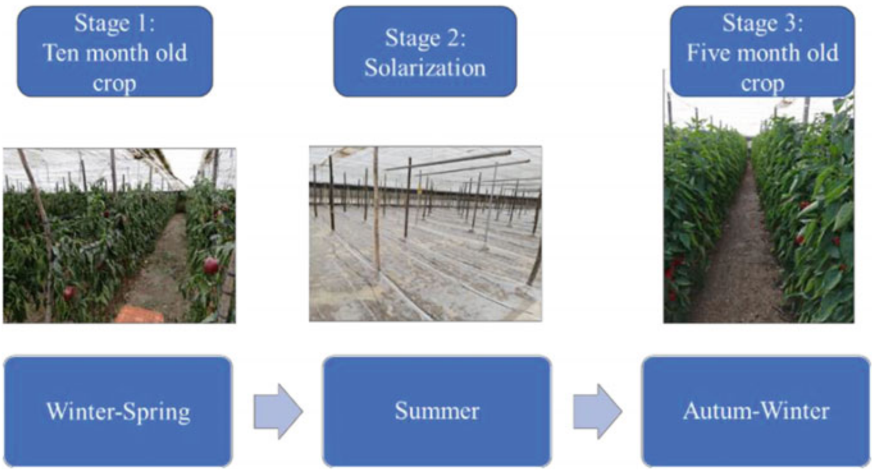

Fig. 2 Grow stage of long-cycle bell red pepper

3 Methodology

As shown in Fig. 3, the methodology proposed in this article mainly includes three steps, process starts with Sentinel-2 data preprocessing. These satellite images (Table 1) after the preprocessing operations are further used to PCG crop characterization. Trimble eCognition Developer v. 10.1 software was employed for the Object-Based Image Analysis (OBIA) and the extraction of NDVI and Brightness. Finally, an assignment of classes of the horticultural crops studied under PCG in winter-spring 2021 and summer-autumn 2022 is made.

The crop characterization was evaluated using 32 polygons over of individual PCG. These polygons were manually digitized on the WV3 pansharpened image generated on July 11. Moreover, each polygon was made, adapting its boundary to the shape of each PCG. To prevent mixed pixels all the PCG polygons were get smaller by 10 m using the buffer tool in QGIS v 3.16 platform (QGIS Development Team 2021). This technique attempts to elude possibly mixed pixels located at the borders of the sampled PCG, which is a very usual point when working on medium resolution satellite imagery as S2.

Trimble eCognition Developer v. 10.1 software was applied for the extraction of the mean surface reflectance values of all the pixels interior of each polygon from S2 products. To do this, the chessboard segmentation algorithm included in eCognition was used to a formerly digitized thematic layer containing the 32 reference polygons. The mean values of the Bottom-of-Atmosphere (BOA) reflectance values for all the pixels within an object for every band were labeled as basic spectral in

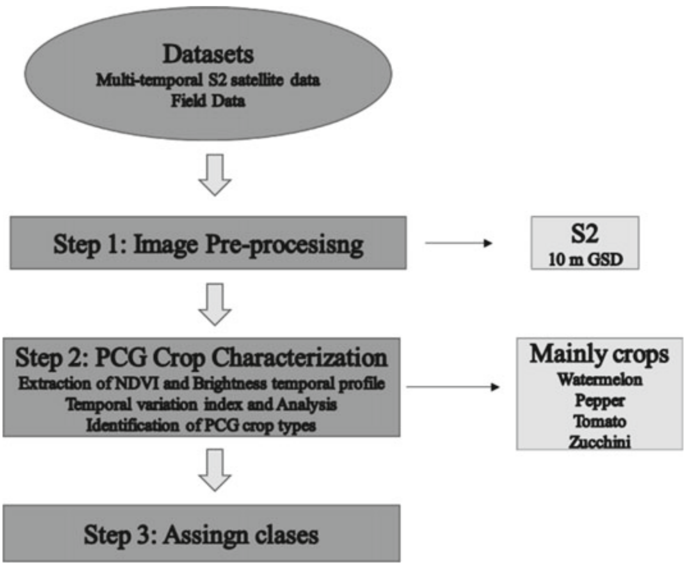

Fig. 3 Flow diagram of the methodology

formation and date. The rest of the features consisted of two spectral and vegetation indices for single images. All the pixels (with an enhanced spatial resolution of about 1.25 m) within the OBIA segments were considered. NDVI and Brightness were also computed for each polygon and date, using the mean values acquired from Blue, Green Red, NIR8, SWIR1 and SWIR2 (Eqs. 1 and 2).

$$\mathrm{NDVI} = \frac{(\mathrm{NIR8} - \mathrm{R})}{(\mathrm{NIR8} + \mathrm{R})} \tag{1}$$

$$\mathrm{Brightness} = \frac{(\mathrm{B} + \mathrm{G} + \mathrm{R} + \mathrm{SWIR1} + \mathrm{SWIR2})}{5} \tag{2}$$

4 Results and Discussion

After conducting a review of the available literature, the NDVI index was revealed as the nucleus of land cover related information. Consequently, temporal, and spatial variations in the numerical values of the NDVI may be successfully used to crop growth monitoring [17, 22] Brightness is another key factor that makes it possible to determine one of the actions on greenhouses that is easiest to detect in remote sensing, whitewashing [23]. These two indices and an exhaustive knowledge of the management tasks carried out in the PCG crops controlled for this study, allow characterizing the crop.

Long-cycle tomato crop is characterized by having higher NDVI values around 0.2 in the winter months when the crop shows greater development and brightness peaks at the end of summer with values between 0.6 and 0.7, when whitewashing is carried out to the planting of the crop, as well as small whitewashes in spring that reach brightness values close to 0.5 (Fig. 4).

Long-cycle bell red pepper is characterized by NDVI values close to 0.30 in the winter months, and by receiving the strongest whitewashes at the end of summer, reaching brightness values above 0.8. Small whitewashes are also carried out in the spring months (Fig. 5).

Another widely distributed crop cycle in the study area is the combination of growing watermelon in spring and cucumber in winter. The watermelon crop under plastic is characterized by starting at the end of winter and presenting high NDVI values exceeding 0.4. In addition, it is a crop in which no whitewashing is carried out (Fig. 6). PCG Cucumber crop is a that undergoes whitewashing and also has high NDVI values, although these have greater variability due to the use of management techniques with greenhouse interior plastics. Although the characterization represented in this study is that of the PCG watermelon crop, it was observed that the PCG melon crop presents very similar spectral characteristics and management.

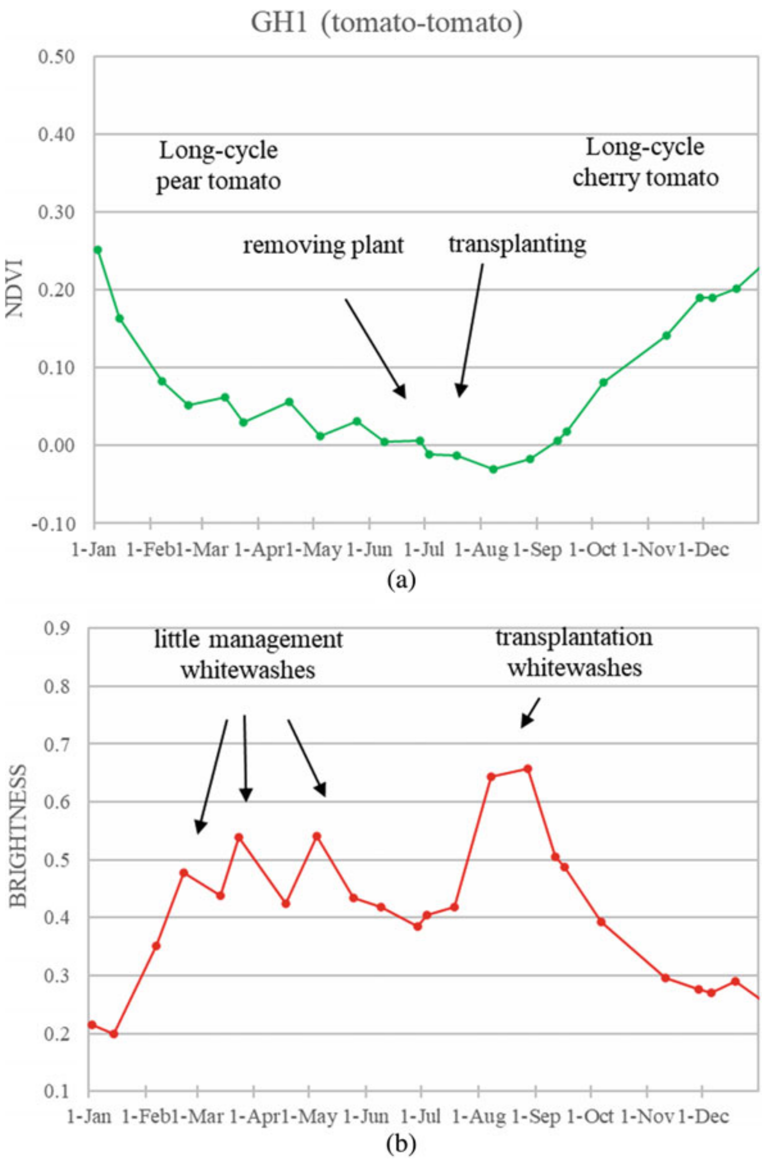

Fig. 4 NDVI temporal profile of **a** mean NDVI and **b** mean brightness for long-cycle tomato

The zucchini crop, although less represented, was characterized in this study, presenting high values and NDVI in the winter months and no Whitewashing through out the year (Fig. 7).

An analysis of the spectral signature was carried out on Sentinel-2 images of the crops in which the highest NDVI values and lowest Brightness values, the