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Can Organic Farming development be driven by Remote Sensing technology? †

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Abstract: Organic Farming (OF) is a form of production that uses a diverse set of methods and techniques focused on product quality, conservation of natural resources and biodiversity, and then seeking to ensure the sustainability of ecosystems and the health of farmers and consumers. The role of OF in rural development has been characterized by a great dynamic in the diversity of goods produced, good adaptation to the condition of smallholdings, family agriculture and local production. It has ensured a good compromise between the achievement of food security and nature conservation goals. The modernization of agriculture is increasingly dependent on the application of Precision Agriculture (PA) technologies, and Remote Sensing (RS) techniques become an essential tool for their effective application. PA technologies can deal with some crop production issues linked to OF, related to water and soil management, plant protection, and mechanization. These problems have limited the expansion of OF, due to the greater demands in technical knowledge and the accessibility to specific equipment, and farmer's reticence for investments. This work addresses this critical issue for OF, analyzing the potential of RS-based PA techniques to face these problems. Different technologies are explored, based on the information provided by multispectral and thermal sensors on board satellite platforms and drones, as well as handheld devices. Data provided with the required frequency and spatial resolution allows a continuous monitoring of the crop growing and can be very helpful in several processes of OF vegetal production. Here are some examples, to assess: i) plant water stress to determine irrigation timing; ii) crop development vigor, to plan fertilization, irrigation needs, cultivation operations, or harvesting; iii) signs of biotic and abiotic diseases, to assess pesticide treatments or micronutrient application and iv) weeds, to determine quantity and typology and stablish timing and control processes. Successful examples reported in the bibliography and a specific study case focused on the Lis Valley, Portugal will be presented. This study will contribute to a better understanding on how the OF development could be driven by RS technology.

Keywords: organic farming; rural development; irrigation; remote sensing; Operational Groups; Lis Valley Irrigation District

1. Introduction

The area occupied by OF continues to expand worldwide, representing 72,3 million hectares in 2019, with a share of 1,5% of total agricultural land [1]. OF products are increasingly sought by consumers particularly because, when compared to conventional products, organic food seems to be healthier [2], being more highly valued in the market.

This happens because OF is more respectful to the environment, avoiding the use of synthetic chemical fertilizers and pesticides and, consequently, conserving natural resources and biodiversity. OF also has the potential to trigger rural development, even in places where agriculture is mainly characterized by family farming, responding to the concerns and demands of modern society regarding food security and safety, and the social and environmental role of agricultural systems, which has been witnessed worldwide, for example in Iran [3], Syria [4], and Europe [5]. OF can also meet the mitigation measures imposed upon agriculture by climate change emergencies, through practices such as tillage, composting, soil carbon sequestration, and energy offsets [6,7]. Other examples of circular economy with environmental benefits include the nutrients recycling of agricultural wastes and by-products, as well as the use of local and renewable energy sources [8,9].

In the last decades, PA has been providing valuable tools for an efficient crop management, being the key to optimize the use of available resources to increase the profitability and sustainability of agricultural operations, reduce negative environmental impact and improve the quality of the work environment and social aspects of farming [10]. Moreover, it also aims to improve site-specific agricultural decision-making (e.g. the accurate quantity of agricultural inputs, such as irrigation, fertilization and herbicides, in a specific field area), through collection and analysis of data, formulation of specific management recommendations and implementation of management practices to correct the factors that limit crop growth, productivity and quality [11]. RS techniques, generally defined as the process of acquiring information about an object or area without being in physical contact with it [12], are an important source of information with manifold applications in agriculture, including crop discrimination, crop growth monitoring and stress detection, crop inventory, soil moisture estimations, computation of crop evapotranspiration, site-specific nutrient management, crop acreage estimation and yield prediction [13]. The advantage of timely and reliable information, free or with reduced costs, can be highly beneficial to the producers, managers and policy planners, for taking tactical decisions regarding to agriculture management.

This study analyses how OF development can be driven by RS tools in Lis Valley, Portugal. This paper is included in an ambitious research project, aiming to survey and systematize the potential of RS at district scale, complementing other study related to OF in LVID [14].

2. Lis Valley case study

2.1. Study Area

The study area is located in the Irrigation District of Vale do Lis (LVID), which is a public irrigation district, located in the Coastal Centre of Portugal (coordinates 39°51'22.1" N 8°50'56.1" W), belonging to the Administrative District of Leiria and managed by Water Users' Association. The total area is about 2000 ha, mainly with modern alluvial soils of high agricultural quality, although some have poor drainage conditions, and the main crops cultivated include maize, fodder, horticulture, orchards and rice [15].

A particular feature of this study area is a high heterogeneity regarding the field parcels size and their spatial distribution. The structure of the on-farm parcels property is characterized by a majority of small parcels, with an average of 0.20 ha [14], being an effective constraint to the field irrigation modernization and agriculture development and sustainability. This problem is being mitigated through an informal reparcelling of the fields carried out by farmers, through renting the properties.

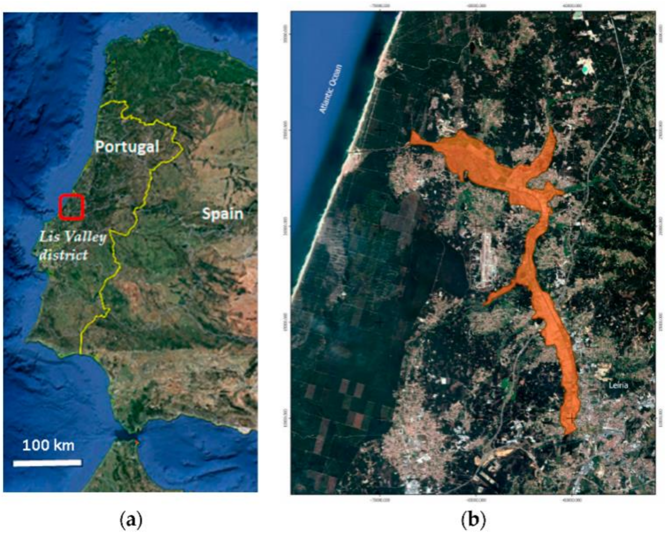

Figure 1. (a) Lis Valley Irrigation District location in Portugal (red circle) and (**b**) in the center region of Portugal (orange line contour) (source: 1a. SpiderwebGIS: https://spiderearth.appspot.com, 1b: Google Earth: https://earth.google.pt).

2.2. The potential of OF in LVID

The expectation of organic farming profitability in small-scale family farming was the theme of a field study on Lis Valley Irrigation District [14] to assess the constraints to its expansion in order to outline the procedures for the acquisition of technical knowledge, the adaptation of technologies, the support for the conversion of production models, and the specialized training of farmers for action. Results revealed that the: (i) farmer's land structure, (ii) their mature age, (iii) low education level, and (iv) markets, are the main constrains for OF development. Furthermore, other uncertainties were identified, namely: (i) the certification process, (ii) the knowledge of new technologies, especially of crop protection, and (iii) the marketing problems to guaranteeing profitability. This study concluded that OF has significant potential for development in the Lis Valley.

2.3. Application of RS tools and techniques to OF in LVID

In Portugal, within the scope of the Common Agricultural Policy Strategic Plan (2023-2027), a strategy for digitalization of the agricultural sector is being discussed, based on the need to renew the Portuguese agricultural entrepreneur fabric and the attraction that digital awakens in young people. RS technologies, such as Unmanned Aerial Vehicles (UAV's), satellite images and sensors trigger interest in younger farmers (however, there are also cases of Portuguese farms that successfully use RS tools in and are run by older farmers). The new CAP intends to give priority to small and medium-sized farms and encourage young farmers to enter the agricultural activity [16].

Although there are few studies published about the applicability of RS to OF [2,17], and mainly directed towards certification, numerous researches studied the application of RS in sustainable agriculture and good practices. For e.g., the prediction of biomass and nitrogen fixation of legume-grass mixtures, a technique used in OF, using sensor fusion [18]; application of RS in conservation tillage, for crop residue recognition [19]; sustainable water management using RS and hydrologic modeling [20]; and use of Unmanned Aerial Vehicles (UAV's) to access water stress for sustainable agriculture [21].

Data provided by RS, with high frequency and spatial resolution, allows a continuous monitoring of the crop growing and can be very helpful in several processes of OF vegetal production, such as:

i) Plant water stress to determine irrigation timing, allowing saving water.

The calculation of crop water requirements could be favored by satellite RS data, processed by informatics platforms. It complements the agrometeorological data observed on ground and provides a more detailed spatial information. Note that the great strength of the reflectance-based models from the point of view of crop irrigation management is the capability to estimate the potential crop transpiration, based on the temporal evolution of the RS-based K_{cb} and the actual ET_o values [22]. This information, integrated with the mapping of irrigated areas, and the evaluation of crop development through vegetation indexes (e.g., NDVI), allows to calculate the crop water consumption, and the water used at on-farm and off-farm levels [23].

ii) Crop development vigor, to plan fertilization, irrigation needs, cultivation operations, or harvesting and signs of biotic and abiotic diseases, to assess pesticide treatments or micronutrient application.
At satellite images scale, differences in vegetative vigor will be translated into different colored areas in the NDVI chart, showing heterogeneity in the plot. However, it should be noted that satellite images do not tell us what is happening concretely in the crop: we do not know if the heterogeneity is due to lack of water or insufficient drainage in certain places, if there is the presence of pests, diseases or rodents, if the soil has a different texture or if there are nutrients that are not being absorbed. They should be complemented with the monitoring of the crop in the field. Often they can no longer be used in the same year, but can serve as a warning or term of comparison for subsequent years

iii) Weeds, to determine quantity and typology and stablish timing and control processes.
At local scale, the presence of weeds often manifests itself early in the crop, through areas with higher NDVI values, because they compete for water, nutrients, and light, expressing greater vegetative vigor. At district scale, riparian vegetation management is also important, since herbicides are used by WUA's in riparian areas, which can contaminate adjacent plots through drift effect. The management of riparian vegetation on the drainage system is very important in many irrigation districts, becoming a costly and complex process. This vegetation decreases the ditches flow capacity and obstructs gates and hydrants. The management operation represents an added difficulty for workers, because it is often located in areas of difficult access. The RS monitoring of this vegetation is a very useful task, since it provides information on its development and density, which is required to adjust the management plans.

As an example, to illustrate the use of the SpiderwebGIS tool, Figure 2 shows the temporal evolution of the NDVI, for the period 2019 - 2020, in a selected point of a chosen experimental parcel. An NDVI subset from a Sentinel-2 image, corresponding to 9th September 2020, is also shown in Figure 2. The field chosen is cultivated with maize, in spring/summer and with forage crops, in autumn/winter. This type of information will allow to determine indicators related with crop and water management, namely, the spacial crop development and irrigation uniformity, the relationship of NDVI with crop productivity and soil fertility, and the identification of subareas with specific problems, such as drainage, or crop protection.

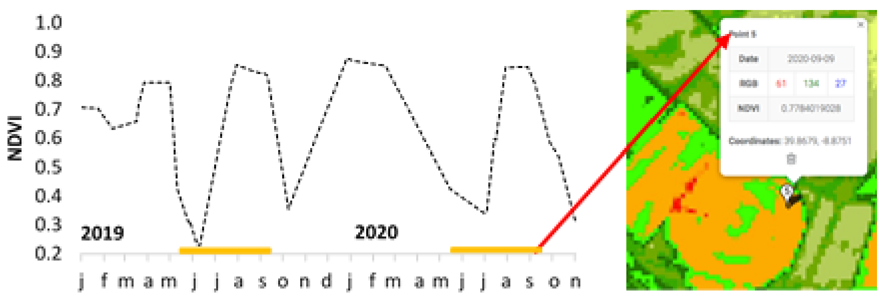

Figure 2. Example of NDVI evolution of an Experimental Parcel, between 2019 and 2020, based on satellite remote sensing (note: orange bar represents the maize crop season). At right, details of the NDVI chart obtained with Sentinel-2, image of 9th September 2020 (source: SpiderwebGIS: https://spiderearth.appspot.com).

Final considerations

This study demonstrates the potential of RS for monitoring plant growth and crop productivity, detect weed infestations and water stress. RS can be an ally of the OF that gives primacy to preventive rather than curative means, relying on continuous monitoring. Due to its operationally and constant progress, RS operative applications are being offered to different water managements, as it introduces the advantages of monitoring large areas at plot spatial scale. The enrichment of RS applications over large and diverse irrigation surface areas offers both public and private water managers a complementary tool to obtain information. In the latest years, cost of RS application together with programs of data analyses have decreased and have become more common in agricultural sectors.

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