STOCKHOLM JUNIOR WATER PRIZE 2020

REMOTE SENSING APPLIED TO PRECISION AGRICULTURE

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Abstract

The world's population is growing, and more food must be produced. The introduction of new technologies and sustainable management practices can help improve agriculture. Among these new technologies, remote sensing makes it possible to monitor crops, soil and water more closely and to check the variability of fields.

This research project has put precision agriculture into practice and has shown that it can bring together and merge very diverse fields, such as aerospace technologies, engineering, physics, biology... and make known the breadth and interest of this field of study.

By means of remote sensing, with the use of a drone equipped with a multispectral camera, flights have been made over the horticultural exploitation of the *Torre d'en Malla* farmhouse in Gallecs (Catalonia - Spain) and data have been obtained from the tomato plants. These data have been processed with the QGIS program and digital maps have been created. These maps have provided information about the Normalized Difference Vegetation Index (NDVI) of each row of tomato plants. This index is based on the reflectance of the vegetation in the red and near-infrared bands. All the information obtained has been analysed and interpreted in order to make more efficient decisions that allow for more efficient soil and water management.

Keywords: *precision agriculture, remote sensing, NDVI, crop, water, tomato plant*

I. Introduction

According to the United Nations (UN), the world's population is expected to grow from 7.7 billion today to 8.5 billion in 2030 and 9.7 billion in 2050. The world population is growing and more food must be produced. FAO estimates that by 2050 global demand for agricultural products will increase by 70%. Consequently, agricultural production will have to grow faster than population, but with the same tillage as today.

According to FAO, agriculture is an engine of growth, but it faces natural resource scarcity, increased salinization, water pollution, climate change, etc. Agriculture is responsible for 70% of all freshwater withdrawals in the world and therefore more efficient water management is needed to achieve high productivity.

Another of the chronic problems of agriculture is the aging of its population and the lack of generational relay, due to the emigration of young people to the cities. All this can lead to the abandonment of farms.

According to the Research Group in Agriculture and Precision Agriculture of the University of Lleida, traditional agriculture always does the same agricultural work, that is, the farmer sows, irrigates, fertilizes, etc. with the same intensity all areas of his field. However, the harvest is not the same in all areas, but there are differences in production or quality between some areas and others. The resources used or the work done may be inefficient and consequently, part of the harvest may be lost, more water may be consumed than necessary or more fertilizers may be used with an environmental impact.

The introduction of new technologies and sustainable management practices can help improve agriculture. Among these new technologies, remote sensing makes it possible to monitor crops, soil, and water more closely and to check the variability of fields. Sensors can capture data from the farm, which are then processed into information for more efficient decision-making.

In fact, since the 1990s, many countries have started to use remote sensing and precision farming techniques, but their potential is not yet sufficiently exploited. According to FAO, one of the challenges is to make these technologies accessible to everybody and to adopt the latest techniques. These new agricultural practices can contribute to improving intensive production and food quality, as well as reducing environmental impacts through efficient land and water use.

This research project implements the challenge of the FAO to make new technologies known and accessible to farmers in the closest agricultural environment, in this case the Gallecs Natural Park (Catalonia - Spain). Three high school technology students, with no previous knowledge of precision agriculture or remote sensing, design a drone, add a multispectral camera to it and obtain data from the crops that they later analyse and interpret to obtain information. This information can be implemented to manage land and water more efficiently.

II. Objectives

On the one hand, one of the objectives is to implement the challenge of FAO and make these new technologies, such as remote sensing, and new practices in precision agriculture known to the closest agricultural environment, as well as to the educational and social environment.

On the other hand, our purpose is to bring agriculture closer to young people. One of the great problems of agriculture in many countries is the ageing of their rural population and the lack of generational change. The aim is to show that agriculture can embrace and merge very diverse fields, such as aerospace technologies, engineering, physics, biology, photography, cartography, information technology, the environment, etc. In short, agriculture is also technology.

This study presents the results of high school technology students, with no previous knowledge of agriculture or remote sensing, that they have been able to assemble a drone, attach a multispectral camera to it, collect and analyse the data obtained with a specialized program and interpret the information to improve agricultural production and reduce water consumption.

The hypothesis is that a drone with a multispectral camera can provide information to optimize agricultural production, reduce water consumption and detect plant diseases, drought or other problems. The fieldwork is reduced to a small agricultural plot, but could be extrapolated to large farms.

III. Materials and methods

1. Assembly of the drone and incorporation of the multispectral camera

A drone or UAV is a small remote-controlled aircraft that usually has a camera to view images or video from the drone's perspective and in real time. The drone is a remote sensing platform very suitable for projects with a small territorial range and high spatial resolution, since it can easily and cheaply fly over agricultural areas.

After searching for the different types of complete drones or by pieces that are on the market, we have chosen the DJI F550 + NAZA-M V2 parts set. At first, there was a sudden choice between the quadricòpter (four engines) or hexacòpter (six engines) model. However, since a multispectral camera and a portable battery have to be added, the hexacopter model has been chosen, since it offered a higher thrust-to-weight ratio, as well as greater aerodynamic efficiency.

This model of *Flame Wheel 550 (F550)* is a multirotor drone designed for all kinds of uses. The NAZA controller system allows to execute any flight movement and take aerial photography. A receiver, a battery and a multispectral camera must be added to this set.

During the first fortnight of March 2019, the drone was assembled with the various pieces and on 17th March, the first test was made.

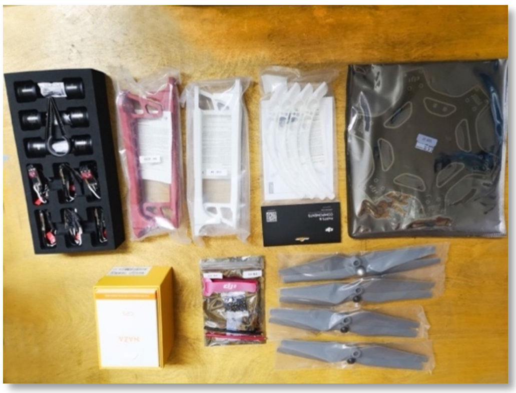


Figure 1: drone parts kit DJI F550

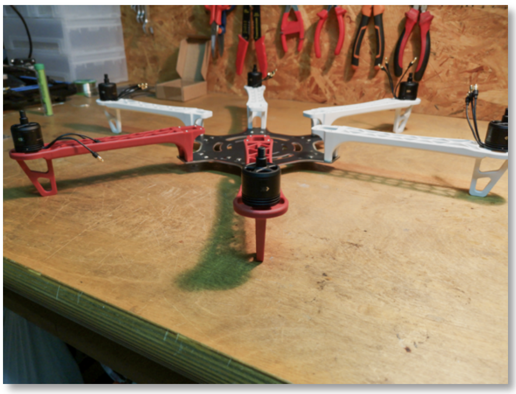


Figure 2: assembling the frame, arms and motors of the drone

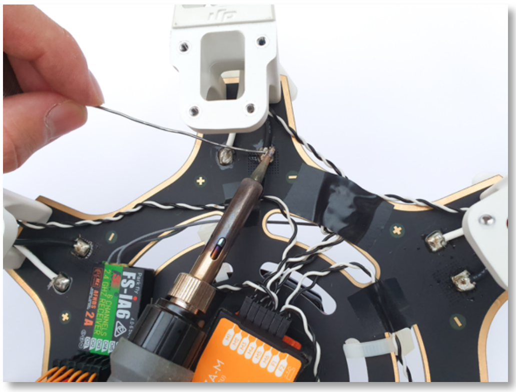


Figure 3: welding process

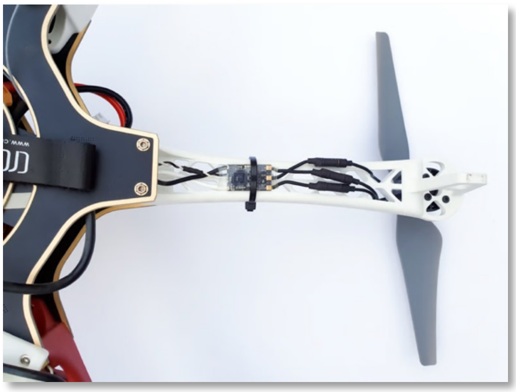


Figure 4: electronic speed control of drone

A multispectral camera is required for this drone and a support piece is needed. After discarding different options, we have decided to design and print the workpiece. Its 3D printing allows to eliminate an economic expense and to achieve the necessary lightness.

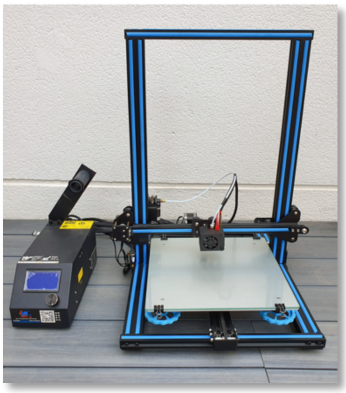


Figure 5: 3D printer


Figure 6: printing camera support

On 22nd April 2019, the drone was tested with a built-in camera. Before the flight, we have calibrated the camera and verified the correct functioning of the sensors. Afterwards, the camera, incorporated in the drone, was recalibrated to verify the operation of the gyroscope. Once this process was completed, the engine shall be started. Everyone holds their breath waiting for the drone to take off, despite the weight of the camera. A success! The drone took off, the structure was stable and its control was easy. This success was enough to continue working on the project.


Figure 7: drone

2. First flights and choice of agricultural exploitation

On 31st March 2019, we filled in the applications for activities to the Consortium of Gallecs Park and requested to fly our drone over the fields. On 1st April 2019, this request is informed favourably.

The Gallecs Park has about 535 hectares of cultivated fields and a large part of these fields are extensive rainfed crops where cereals (wheat, spelt, rye, barley...), legumes (chickpeas, beans, lentils...) and fodder for animals are grown. The rest are irrigated vegetable crops. It is also a leisure area for the surrounding villages, as well as a green lung for the Barcelona metropolitan area and its highly urbanized surroundings.

The first flights were done in the Experimental Area of the Research Group on Ecology of Agricultural Systems of the University of Barcelona. However, the monitoring of this experimental area was too complicated and there was not enough knowledge to control all the variables that were being considered. In addition, during some periods no vegetation was seen.

Gallecs also has cereal fields, which remain empty during the months of August and September after the harvest, and the leguminous fields are already sown since March, whereas the horticultural areas have plants all year. For this reason and after making several flights over some Gallecs plots, during the months of June and July 2019, we decided to do the project on a horticultural farm. This type of exploitation allows to follow the growth of plants in all stages.

There are few orchards but after talking to the tenant farm of the *Torre d'en Malla* farmhouse, a decision was made. This horticultural exploitation with different vegetables was chosen. The research project focuses on the observation of two areas of tomato plants called "block 1" and "block 2". These tomato plants were planted on different dates and this variability would allow comparisons between the different rows of tomato plants.

Figure 9: situation map of Gallecs
Source: Cartographic Institute of Catalonia

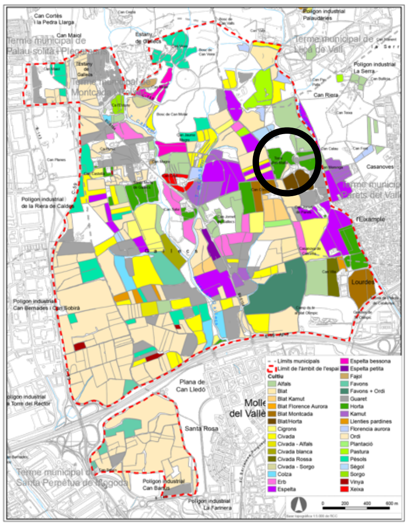


Figure 10: Gallecs crops map
Source: Consorci del Parc Natural de Gallecs

Figure 11: orthophoto of Gallecs
Source: Cartographic Institute of Catalonia

Figure 12: *Torre d'en Malla* farmhouse

3. Drone flights and image capture

We carried out six flights over this horticultural plot with the drone equipped with the multispectral camera.

Figure 13: agricultural exploitation of the *Torre d'en Malla* farmhouse

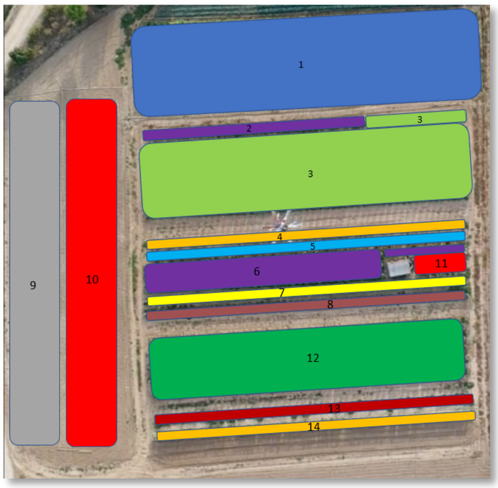


Figure 14: numbering of the crops

Figure 15: rotation of the drone on the z-axis

Figure 16: rotation of the drone upwards

Table 1. Flights

Flight date	Num. flight
30/07/2019	Flight num. 1
27/08/2019	Flight num. 2
09/09/2019	Flight num. 3
22/09/2019	Flight num. 4
05/1072019	Flight num. 5
19/10/2019	Flight num. 6

We obtained five images from each flight, each from a different spectral side: RGB, green, red, red margin and near-infrared. However, in order to calculate the NDVI indexes, only the data from the red and near-infrared spectral regions were needed

4. Analysis of the images with QGIS program

Figure 17: flight of drone over the study area

Figure 18: connection card to computer

In this phase, we processed the images and data obtained with the QGIS program (Quantum Geographic Information System). QGIS is a data visualization, edition, and analysis program that corresponds to a geographic information system. The fact that this program is free of charge was decisive for our choice.

The application of this program allowed to obtain the data about the tomato plants vigour (blocks 1 and 2). In order to obtain a graphic representation of the plant's state of vigour, it was necessary to follow a series of phases.

First, it must be clear that to calculate the Normalized Difference Vegetation Index (NDVI) of the plants, we needed at least two types of image: an image in the red spectral band (RED) and another image in the near infrared spectral band (NIR). The values of these two spectral bands help us to calculate the NDVI index, and, therefore, to know vigour state of the plants.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Also, we needed a coordinate system and the choice of a projection to geolocate the images. We selected the UTM coordinate system where Catalonia (Spain) is located (Figure 19).

The images obtained by the multispectral camera were raster images, formed by a matrix of pixels. Each pixel contains a value that represents information. In order to make the NDVI calculations, it was necessary to georeference the raster images.

To georeference the images, 7 characteristic points of the raster image had to be selected, such as the well house, the intersection of two roads, the vertices of the plot, etc. This georeferencing allowed the coordinates of these points to be precisely determined, and later, to serve as a reference to compare all the images (Figure 20).

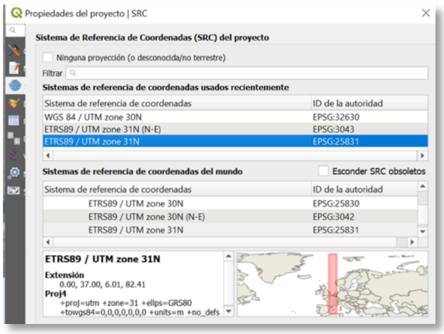


Figure 19: choice of the coordinate reference system

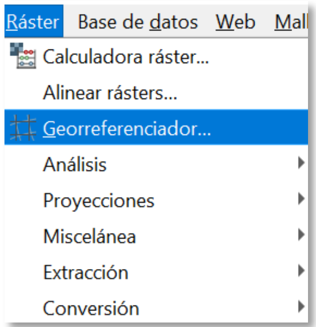


Figure 20: georeferencer of QGIS program

Subsequently, the NDVI index was calculated:

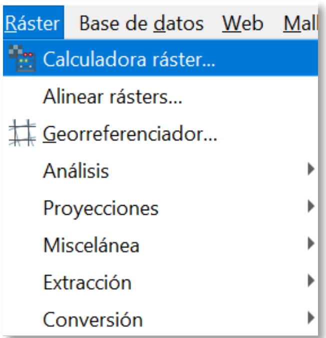


Figure 21: raster calculator

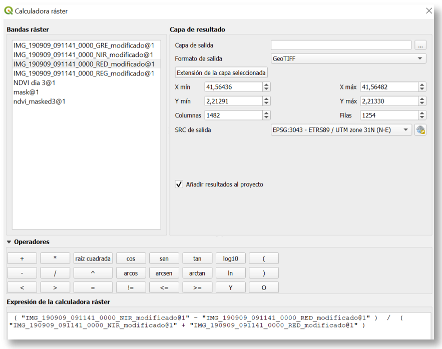


Figure 22: calculation of the NDVI index

This NDVI calculation shows vegetation vigour throughout the image. However, this NDVI was not definitive, since it was only interested in knowing the tomato plants vigour of blocks 1 and 2. Consequently, an interval of this NDVI was established for the images of subsequent flights. The values of this interval were from 0.28 to 1, since a large part of the values with an index NDVI<0.28 did not form part of this plot and were found around the horticultural farm. In contrast, on-farm values always had an NDVI>0.28. Then, to represent the NDVI index, the colour option "Pseudocolour monoband" was chosen within the "Symbology" section (Figure 23).

Figure 23: thumbnail of the colours used

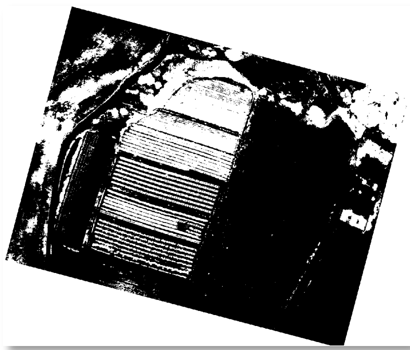


Figure 24: representation of vegetation and soil without vegetation

In order to obtain a simple graphic representation of the NDVI indices, we applied a mask that converted indices greater than 0.28 to value 1 and the indices less than 0.28 to value 0. Value 0 represented soil without vegetation and was black, while value 1 represented vegetation and was white (Figure 24). This image of the NDVI indices was rotated, since it was georeferenced.

Then, the "Raster Calculator" was applied again to define higher rates to 0.28 as value 1. Subsequently, the first NDVI was multiplied by the mask number 1.

The object of study was the rows of tomato plants in blocks 1 and 2. Therefore, a new layer was created and each row of tomato plants had a different colour according to the NDVI indices. Example:

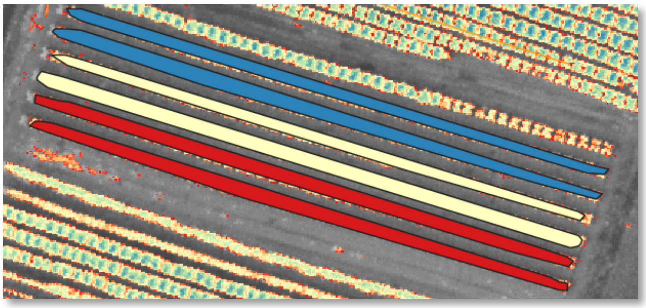


Figure 25: rows of different colour according to the NDVI

Finally, we calculated the zone statistics to calculate the real NDVI and performed the NDVI count per pixel, based on the polygons selected with the masks. When reference was made to the real NDVI or NDVI_OV (only vegetation), it meant that the shadow effects of sun have been eliminated, and therefore, the average obtained from the NDVI of the pixels were usually only vegetation. To obtain the NDVI_OV index the formula was applied. Next, the calculations for each polygon were made and, finally the average of the NDVI_OV indices were calculated:

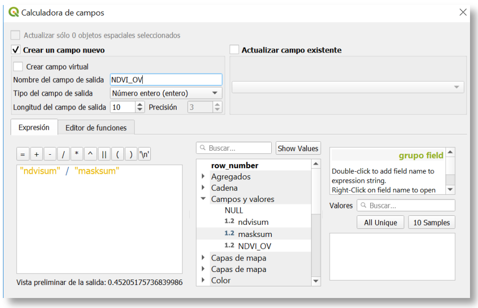
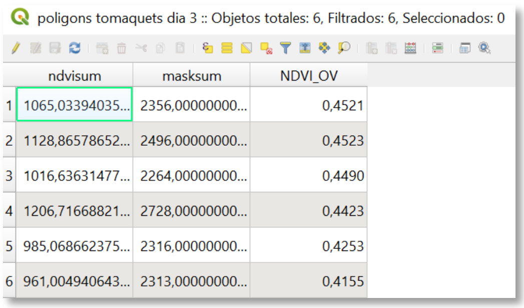


Figure 26: field calculator



poligons tomaquets dia 3 :: Objetos totales: 6, Filtrados: 6, Seleccionados: 0

	ndvisum	masksum	NDVI_OV
1	1065,03394035...	2356,00000000...	0,4521
2	1128,86578652...	2496,00000000...	0,4523
3	1016,63631477...	2264,00000000...	0,4490
4	1206,71668821...	2728,00000000...	0,4423
5	985,068662375...	2316,00000000...	0,4253
6	961,004940643...	2313,00000000...	0,4155

Figure 27: NDVI_OV calculation

IV. Results

1. Introduction

In order to analyse the tomato plant area, we divided it into two blocks: block 1 and block 2. Block 1 was formed by the tomato plants that were in the North, at the top of the image, while block 2 was in the South, at the bottom of the image.

Table 2. Tomato blocks

Block	Num. location map	Num. rows tomato plants	Planting data (2019)
1	3	6 and portion	row 1 and 2: 8th June row 3 and 4: 15th June row 5, 6 and portion: 28th June
2	12	5	22nd April

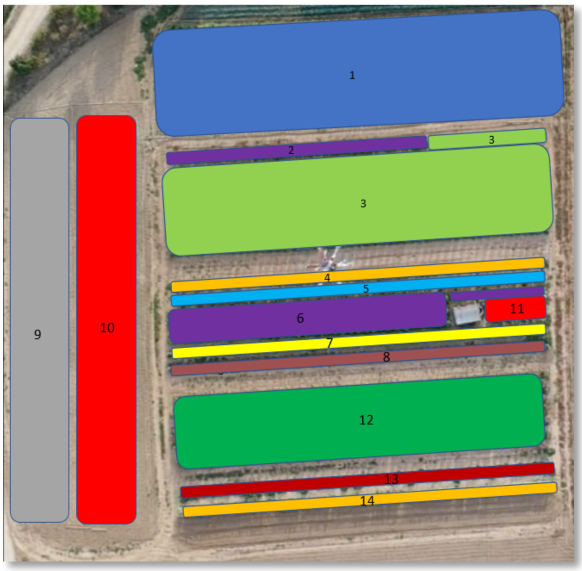


Figure 28: numbering of the type of crops on the horticultural exploitation

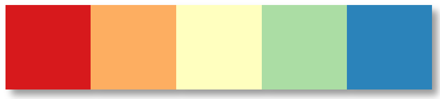


Figure 29: levels of the NDVI index represented by colours

To understand the analysis, it was important to know that each colour of the resulting image was referenced to a level in the NDVI range. Our interval was composed of five levels, each of them represented by a colour: red, orange, yellow, green and blue (Figure 29). Each level corresponded to a range of values of the NDVI and this index varied according to the phenological development of the plants. In our case, the lowest level of the NDVI index corresponded to the colour red, followed by orange, yellow, green, and finally the blue colour that corresponded to the maximum level of the NDVI index.

Finally, we considered that, from each flight, we would carry out an analysis for block 1 and another for block 2. Each of these blocks had been planted on a different date, and therefore the two blocks could not be compared to each other.

2. Interpretation of the information from the 6 flights

2.1. Block 1

This block was composed of 6 rows of tomato plants. The first pair of rows were planted on 8th June and the other two pairs of rows, two weeks apart.

1) The northern pair of rows were planted last, on 28th June. Consequently, they were the youngest and their phenological development was less advanced than the rest of the rows. They were represented in red (Figure 30).

2) The central pair of rows were planted on 15th June, and their phenological development was less advanced, and therefore, they were less vigorous and appeared in yellow (Figure 30).

3) The southern pair of rows were the oldest tomato plants as they were planted first on 8th June. Their phenological development was more advanced than the other rows, and therefore the plants were more vigorous. Since these plants did not have any pests or diseases, they appeared in blue (Figure 30).

In the flight of 30th July (Figure 30), the older rows had more advanced phenological development than the younger rows. This showed that the older tomato plants were in full growth and were very healthy, while the younger tomato plants did not show this vigour, they appeared to be sick or perhaps did not have enough irrigation.

In the second flight, on 27th August (Figure 31), the northern rows or the youngest rows were at the peak of their phenological development and were represented in blue and yellow.

In the third flight, 9th September (Figure 32), the two southern rows were in the phase of senescence, while the youngest rows, those of the North, were in full phenological development.

In the fourth flight, 22nd September (Figure 33), the rows of tomato plants, in the blue and yellow zones, had the highest values of the limits of the interval. This meant that the vigour of the plants increased, although the representation colour did not change.

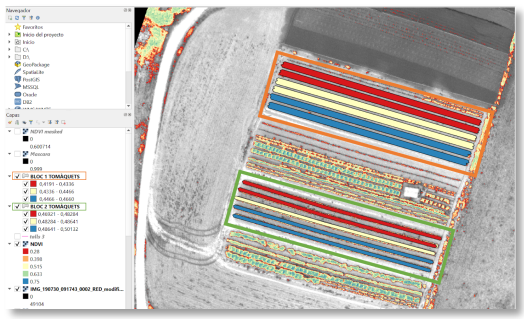


Figure 30: NDVI representation of QGIS program 30/07/2019

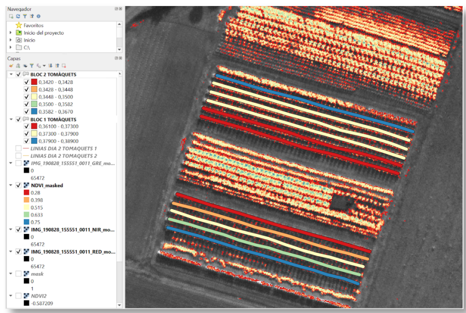


Figure 31: NDVI representation of QGIS program 27/08/2019

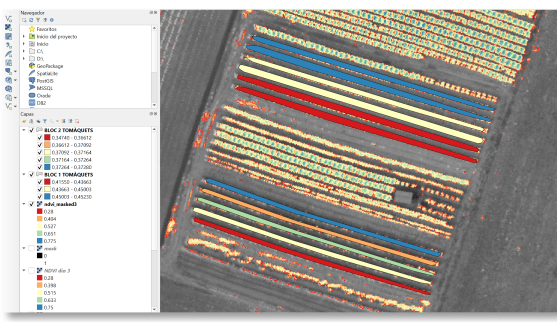


Figure 32: NDVI representation of the QGIS program 09/09/2019

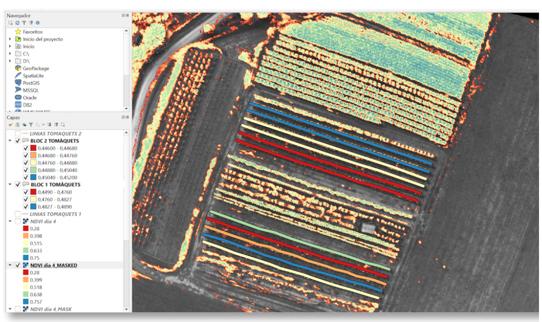


Figure 33: NDVI representation of the QGIS program 22/09/2019

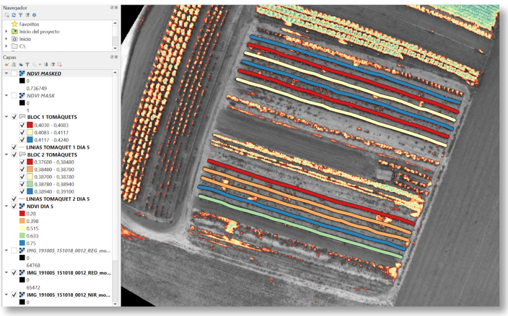


Figure 34: NDVI representation of the QGIS program 05/10/2019

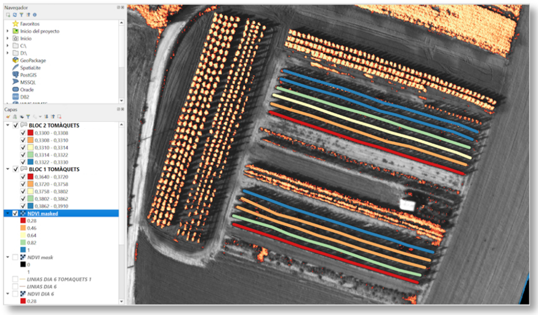


Figure 35: NDVI representation of the QGIS program 19/10/2019

2.2. Block 2

The five rows of tomato plants in block 2 were planted on 22nd April 2019, and therefore, all the rows would have to be represented by the same colour. However, the tomato plants in the South were more vigorous than those in the North, despite being the same age (Figure 30). This difference in vigour indicated that something was wrong. However, we did nothing and hoped that the plants would recover their vigour, without any intervention from the farmer.

A possible hypothesis of this anomaly could be the action of the inclination of Earth's axis. This inclination causes the sun's rays to arrive more directly in the southern zone, and therefore these plants received more light and had more vigour than the plants in the northern zone. In contrast, the plants of the northern zone could have a lower NDVI.

In the second flight (Figure 31), this block 2 showed all the levels of the NDVI index, from the lowest level, corresponding to the colour red, to the highest level, corresponding to the colour blue. The first two northern rows had not evolved as expected, and therefore a decision would have to be made to return to normal. The second row had improved, as the tomato plants had recovered their vigour and were healthy, but the first row showed signs of serious problems and possibly they were sick, maybe they lacked water or suffered a pest.

We reported this anomaly to the farmer and proposed that he had to increase the water supply in this area with a new irrigation system, in order to verify if this abnormal growth was a consequence of the lack of water. However, this was caused by any kind of plant disease or pest.

In the third flight (Figure 32), the farmer informed us that fungi had spread in block 2, but it had already been extinguished. This information confirmed the data obtained. There was an anomalous evolution in this area. Our study was on the right track.

Likewise, the farmer had increased irrigation in the northern zone of this block 2, as had been advised. It could be verified if the introduction of this change had had a positive effect on the plants. As it can be seen in the image (Figure 32), a change occurred, since two of the three rows of tomato plants had improved their development due to the increased irrigation. The second row, starting from the north, had an extra irrigation channel incorporated, but did not experience an improvement. A possible hypothesis was that this row was more affected by the fungi than the other two rows.

On the other hand, it could be seen that the two southern rows had a faster phenological cycle. This fact could be a consequence of the effects of the fungicide that had been applied locally to eliminate the pest, and therefore the plants continued to grow.

In the fourth flight (Figure 33), we could no longer notice the colours of the layers, since they began to be misleading, due to the state of senescence in all the rows.

2.3. Data analysis and interpretation

In short, we had reached the end of our analysis and interpretation of the data. We had detected the growth problems of the plants and the tomato plants were finishing their phenological process and were entering the senescence phase.

In the last two flights, 5 and 19 October (Figures 34 and 35 respectively), the biological process of the tomato plants had finished. In this situation, we could only demonstrate numerically, through their NDVI value, that the two blocks were finishing the senescence phase, by means of the range of each colour

During these three months of monitoring the plantations, in addition to seeing the growth of the tomato plants, we had been able to detect anomalies in the vigour or health of the plants and we had been able to notify the farmer to implement corrective measures. As for example, the data obtained between flight num. 2 (27/08/2019) and flight num. 3 (09/09/2019) allowed to increase the irrigation of three rows of tomato plants in block 2, and luckily two of the three rows evolved correctly.

2.4. Graphic study of the evolution of tomato plants

Once the processing of the data from the two blocks of tomato plants was completed with the QGIS application (Quantum Geographic Information System), we calculated the real value of the NDVI index for each of the rows. Later, we entered these values in a graphics application to show the evolution of tomato plants.

The graph shows a decrease in NDVI indices during the second flight. This decrease means that the vegetation had lost vigour, possibly due to lack of irrigation, disease or pest. The loss of vigour was probably due to lack of irrigation, since the data were recorded in the middle of summer when temperatures were high and rains were non-existent.

The farmer had increased irrigation and this was observed in the data of the next two weeks until reaching their maximum during flight number 4, on 22nd

September. From here, the plants entered into the senescence stage until their death.

In these graphs you can see the evolution of the health status of each of the rows of tomato plants, depending on the dates of the data collection.

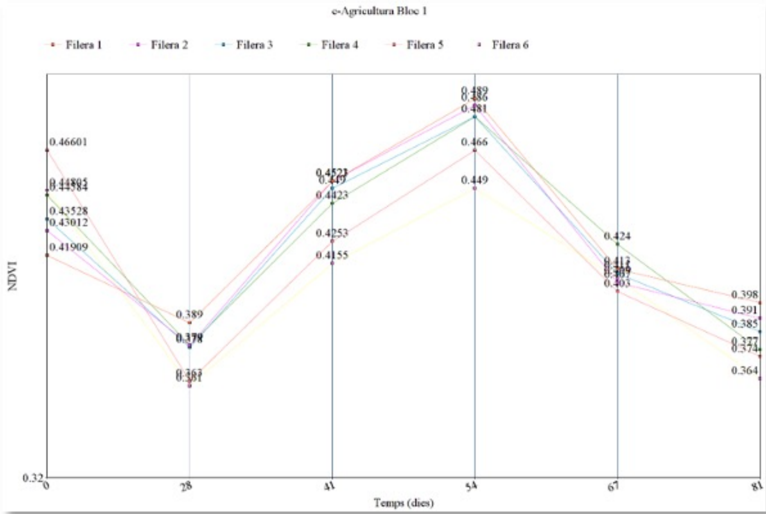


Figure 36: real NDVI of each row of tomato plants in block 1

In the case of block 2, a similar evolution of the NDVI indices was registered. However, the decrease in the NDVI indices during the second flight was more evident. In this case, not only was there a lack of irrigation, but the farmer confirmed the detection of fungi. The farmer had applied measures to avoid the pest. Subsequently, there was a recovery of the vegetation vigour, but the levels reached were lower than those of block 1.

During flight number 4, tomato plants reached their maximum point of vigour and then entered the stage of senescence and death.

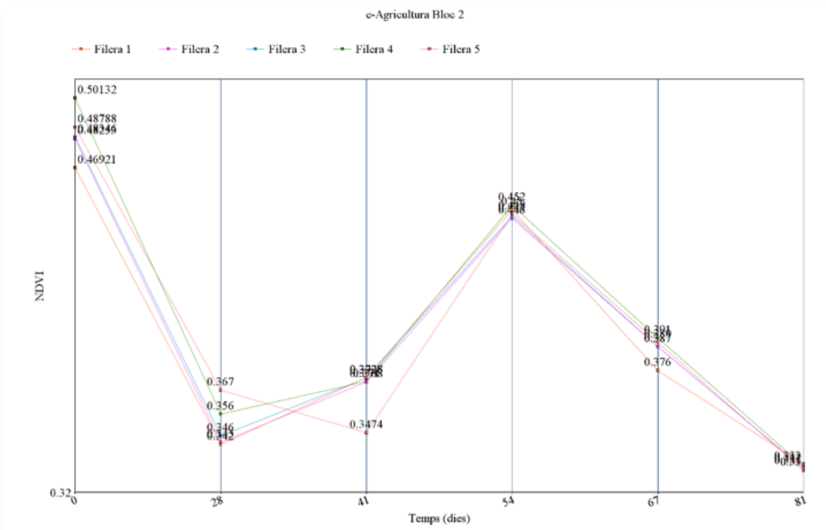


Figure 37: real NDVI of each row of tomato plants in block 2

V. Conclusions

The hypothesis formulated in the research project advocates the use of a drone with a multispectral camera to obtain information and thus optimize agricultural production, reduce water consumption, and detect plant diseases, drought or other problems. The fieldwork has been limited to the horticultural exploitation of the *Torre d'en Malla* farmhouse in Gallecs, but it could be extrapolated to large agricultural exploitations.

In this study, areas of abnormal growth were detected in some rows of tomato plants. It was assumed that the cause of this lack of vegetation vigour was a lack of irrigation, a disease or a pest. It was proposed to the farmer the implementation of some measures, such as increasing irrigation. The farmer has confirmed the appearance of fungi in one of the tomato plants blocks and he proceeded to make it disappear. Later, the tomato plants have continued to grow to a maximum point and then the state of senescence began.

Finally, it must be said that in this research project, precision agriculture has been put into practice. Through remote sensing, with the use of a drone equipped with a multispectral camera, data have been obtained from the horticultural farm. The data obtained have been processed with the QGIS program and the NDVI indexes of the tomato rows have been obtained, using the reflectance of the vegetation in the red and near infrared bands. Healthy plants have absorbed radiations from the red region to photosynthesize and have reflected radiations from the near infrared region. In contrast, diseased plants, lacking water or attacked by a pest, have reflected more red radiation and less near infrared radiation.

In short, the hypothesis is correct, it can be said that the use of the drone with the multispectral camera provides the information needed to optimize production, reduce water consumption and detect plant diseases, drought or pests.

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