Dynamics of the Indices NDVI and GNDVI in a Rice Growing in Its Reproduction Phase from Multi-spectral Aerial Images Taken by Drones

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Abstract. In this study, the dynamics of two vegetation indices, the normalized differential vegetative index (NDVI) and the variant of the NDVI that uses the green band (GNDVI) in a rice growing of the variety fedearroz 2000 in reproduction phase, are analyzed. These indices were calculated through the geoprocessing of multi-spectral aerial images taken by a drone or UAVs, with the aim of identifying which zones of the crops are under stress, healthy or dense. The rice growing had an area of approximately 4,1 hectares and its location corresponds to the farm El Faro in the footpath Campo Hermoso within the municipal district of San José de Cúcuta – Norte de Santander. For this research, two flights were carried out, one at the beginning of the reproduction phase dated September 4th 2016 and the second one at the end corresponding to October 8th 2016; these flights were performed with a Iris+ 3DR drone, a canon S100 camera was implemented as a catch images sensor converted into NDVI by using a NGB filter (Near infrared, Green and Blue). As a result, 4 mosaics are shown, one NDVI and one GNDVI on September 4th 2016 and one NDVI and one GNDVI on October 8th 2016, each one of them were classified according to the characteristics observed in field in zones under stress or with low development, healthy and dense zones. Finally, a NDVI dynamic analysis was completed.

Keywords: Precision farming · Drones · Geoprocessing
Multi-spectral images

J. C. Corrales et al. (Eds.): AACC 2018, AISC 893, pp. 106–119, 2019.
https://doi.org/10.1007/978-3-030-04447-3_7

1 Introduction

Rice plays a very important role as a staple food, and the agricultural systems where it is produced are essential for food security, poverty decrease, and the population's lifestyle improvement. Rice became an important agricultural product and an income-generating crop throughout the 20th century. It has evolved from a pioneer crop, mainly rainfed on the agricultural boundary during the first half of that century to become a highly technical and productive crop, where the irrigation system has dominated in recent decades [1]. However, despite the advances, rice, and agriculture in general face phenomena such as variability and climate change that can affect their performance and increase production costs; this generates instability and socioeconomic problems.

In the last decade, climatic variations related to the phenomenon of El Niño and La Niña have brought serious challenges for Colombian agriculture, demonstrating the low capabilities that many farmers have to effectively manage risk and adapt to climatic fluctuations and catastrophes. Anthropogenic climate change is likely to exacerbate this situation. Scientists present improvements in climatic variability, higher temperatures, and erratic precipitation. Probably by the middle of this century, both the average annual temperature and precipitation have increased, which would have significant impacts on agriculture; this has a wide impact on the national economy, rural poverty rates, and food security [2].

Nearby in Norte de Santander, in 2011, climatic variability has impacted rice cultivation; relative humidity averages exceeded 80%, rains were more intense from February to May and November to December. The phytosanitary evaluation of about 90 farms inside and outside the irrigation district of the Zulia River, showed a high incidence of diseases such as helmintosporiosis, sarocladium, and brown spots; these diseases are associated with the stress of the plant. Helmintosporiosis is related to inadequate nutrition plans, nutritional imbalance, nutrient deficiency, toxicity and application of fertilizers out of season [3].

In response to the phenomena of variability and climate change and to cut the negative impacts generated by traditional agriculture to the environment, precision agriculture (PA) is taken as a possible solution to this situation. According to Díaz [4], precision agriculture is the differentiated management of crops using different technological tools (GPS, plant-climate-soil sensors and multispectral images from both satellites and UAS/RPAS). This differentiated management of crop we will be able to detect the variability that has a certain agricultural exploitation, as well as to do an integral management of already stated exploitation.

The current study pretends to give contributions to precision farming through the use of versatile and economic technologies such as drones and unmanned aerial vehicles (UAVs). These are unmanned flight systems, with the capacity of being controlled from land or flying in automatic mode from a geo-referenced flight plan by GPS. They have the capacity of flying at low height and maintaining a real time communication with the station in land [5].

In Norte de Santander, there is a great amount of small crops, with complex fields that cannot be studied from satellite images because their spatial, temporal and spectral resolution does not allow it. Berni et al. [6] enunciate that the current satellites have some limitations for the management of crops, such as the lack of images with optimal spatial and spectral resolutions and unfavorable times of visit to detect the stress in the crops; besides, the study mentions that the manned aerial platforms have high operating costs. The remote detection sensors set in unmanned aerial vehicles can fill this gap, providing low cost focuses to accomplish the critical requirements of spatial, spectral and temporal resolutions. Diaz [4] indicates that the multispectral images of drones capture data from the near infrared and invisible spectra, and depart from them, images of the crop which differentiate the healthy and sick plants can be created. Moreover, it is possible to obtain weekly, daily and even real time information through the drones, which allows to create a temporal series to observe changes and to make appropriate decisions about the crop.

There are studies about drones and multispectral aerial images which have been successfully carried out in agriculture. In the city of Rugao, district of Jiangsu, China, Zhou et al. [7] acquired multispectral and digital images in critical stages of the growth of different rice varieties, they calculated several vegetation indexes, among them are the normalized differential vegetative index (NDVI), and they correlated them with the grain yield and the leave area index (LAI), the results showed that the best stage to predict the performance is the beginning of the panicle (belonging to the reproduction phase), the index with the best results was the $NDVI_{[800.720]}$ which showed a lineal relation with the grain yield and the value of R^2 de 0.75. In Kampung Setia Jaya, Yan, Kedah, Teoh et al. [8] obtained multispectral aerial images, they geo-processed them and conducted a correlation between the performance of the rice and the values of the red bands (R), green ones (G), NRI and NDVI, the correlation showed a $R^2 = 0.748$ between the NDVI and the performance of the crop, this permitted to establish a regression model to estimate the performance of rice from NDVI values. In the Klein-Altendorf campus, 40 kms south of Cologne, Germany, Bendig et al. [9] executed a study of barley to evaluate if the digital models of the crop surface (CSM) obtained from RGB images taken from UAVs can predict the biomass; the comparison between the height of the plant in field (PHref) and the CSM produced a R^2 of 0.92; also, they obtained a high correlation between the CSM and the fresh biomass ($R^2 = 0.81$) and the dry biomass ($R^2 = 0.82$).

The articles deals with dynamic analysis of two vegetative indexes; the normalized differential vegetative index (NDVI) and the NDVI variant that uses the green band (GNDVI) in a rice crop of the variety Fedearroz 2000 in reproduction phase. These indexes were calculated thanks to the geoprocessing of multispectral aerial images taken from drones or UAVs aiming at identifying which zones of the crop are under stress, healthy or dense and analyzing their variability in time and space.

Different from other studies in which satellites to analyze indexes of vegetation or drones with multispectral and hyperspectral camera of high value were employed, this project used two low cost equipment, Canon S100 camera converted to a NDVI through a NGB filter and the Iris+ dron of the 3DR brand. The filter partially blocks the red band (600–675 nm) and allows the entry of a portion of red and near infrared light (676–773 nm), the camera also captures the information from the green bands (441–565 nm) and from the blue ones (384–537 nm). With this capacity for the capture of spectral information, it is possible to estimate several indexes of vegetation, among these are the NDVI and the GNDVI.

2 Methodology

Two flights were developed for this study, one at the beginning of the reproduction phase dated (September 4th 2016) and the second one to at the end (October 8th 2016). This phase goes from the initiation of the panicle to the flowering, it means, it starts when vegetative phase ends. It is characterized by the appearance of the reproductive organs of the plant. The length of it is continuous in all varieties and on average it lasts 35 days [10].

The flights were carried out with the Iris+ 3DR drone, a canon S100 camera was implemented as a catch images sensor converted into NDVI by using a NGB filter (Near infrared – Green and blue). This special filter blocks red light and, in return, it permits the passage of the near infrared above 700 nm. Additionally, it allows the passage of green waves (G) and blue waves (B), thus it has two variants of the visible and one of the near infrared, which enables the basic analysis of the phytosanitary state of the crops: the darker and more intense green color is, the denser and healthier vegetation is [11].

The methodology adopted comprises the following five activities:

2.1 Definition of the Growing and Study Zone

A rice crop of approximately 4.1 hectares was selected which is located in the farm El Faro in the footpath of Campo Hermoso of the district of San José de Cúcuta – Norte de Santander, its geographical location is –72.583857, 8.029046 decimal degrees, in the WGS_1984 geographical coordinate system.

The following images shows the geographical location of the rice growing under study (Fig. 1):

Fig. 1. Location of the growing (Source: Author. Satellite image obtained from Google Earth)

2.2 Design of the Flight Path

The flight path of the Iris+ 3DR drone was designed; in doing so, the Tower app was used. Parameters such as height, flight time and distance covered were taken into account. Due to the growing area, (approximately 5 hectares) and the autonomy of the Iris+ 3DR flight (16–22 min), it was necessary to divide the flight into two parts to avoid possible complications.

The flight height is according to the scale that is pretended to be obtained in the photographs and the focal distance of the camera 5.8 mm. To obtain this resolution of approximately 1.5 cm/pix, a flight height of 50 m was established. At this height, the camera generates a squared image of 47.6 m side; to generate a longitudinal overlap of 60%, it was necessary that the distance between the two expositions or photos were of 19.04 m. The interval of picture taking was obtained thanks to the following formula:

$$I = \frac{\mathrm{B}}{\mathrm{V}} \tag{1}$$

Where

I = Interval of time among images
B = Distance between two consecutive images
V = speed of the plane.

$$\mathrm{I} = 3.7\ \mathrm{s} \tag{2}$$

Characteristics of the flight sections are displayed into the next tables and images (Tables 1 and 2):

Table 1. Section 1 of the flight

Section 1	
Flying altitude	50 m
Distance	1.4 km
Flight time	4:59 min

Table 2. Section 2 of the flight

Section 2	
Flying altitude	50 m
Distance	1.9 km
Flight time	6:46 min

2.3 Execution of the Flight and Acquisition of Spatial Data

Flights were executed in automatic mode by a pilot and an observer who supported the mission. For the multi-spectral image capture, a canon S100 camera was implemented as a sensor converted into NDVI.

2.4 Calibration of the NGB Images

For the radiometric calibration, a white piece of foam was used as panel of reference, which was put on the floor during each flight, this served for the correction of the near infrared, green and blue bands of the images obtained by the canon S100 camera.

The following formula was employed for the calibration:

$$\frac{Bx}{P} * SBx \tag{3}$$

Where,

Bx, is the reflectance of each band in the image.
P, is the reflectance of the white piece of foam in the Bx band.
SBx, is the average reflectance of the white piece of foam of the x band measured with a spectroradiometer.

The spectral signature of the white piece of foam was taken using an Apogeo ps-100 spectroradiometer which has a range from 400 nm to 1000 nm, the values of the reflectance in the different wavelength ranges were obtained this way.

2.5 Geoprocessing of Images from the Near Infrared (NGB)

Agisoft Photoscan and Arcgis software was used for geoprocessing of images.

To elaborate orthophoto mosaics, the following steps were established:

Elaboration of NGB Orthophoto Mosaics

- NGB images were aligned using their coordinates into the Agisoft Photoscan software.
- 4 control points were assigned over the NGB images in order to diminish the error in the georeferencing, which permitted to obtain even mosaics. The four points were taken from a Google Earth satellite image. In the following image, the distribution of the control points in the aligned images is detailed (Fig. 2):

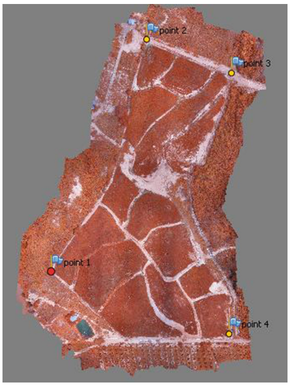

Fig. 2. Control points

- The dense cloud of points, the mesh and the texture were created, steps necessary for the working pace of the Agisoft Photoscan in generating the mosaic.
- The NGB orthophoto mosaic was exported as a .tiff file.

Calculation of the Vegetation Indices

In Arcgis software a mesh over the growing was digitalized to generate a 261-point sampling within a distance of 10 m each one; then, a 5-m buffer was created around each point with the aim of analyzing not only a pixel but representative zones.

The normalized differential vegetative index NDVI and its variant of the GNDVI were calculated through the raster calculator of Arcgis software. Afterwards, the zones with values less than 0.2 were excluded, due to the fact that they represent mere soil, rocks and water. Using the buffer and the NDVI and GNDVI mosaics, the tables with the statistics of the 261 buffer for the zone analysis were created through the zone statistics tool.

NDVI Classification

A classification of the orthophoto mosaics was completed according to the different spectral responses. This was based on the comparison of what was observed in field versus the values generated by the NDVI mosaics.

3 Results and Discussions

Two NGB orthophoto mosaics were obtained, one was dated September 4th 2016 and the other one was dated October 8th 2016, with an average height of 50 m, each mosaic geoprocessed with more than 300 images and with a resolution of approximately 1.5 cm/pixel. The characteristics of the mosaics are listed below (Tables 3 and 4):

Table 3. Characteristics of the NGB orthophoto mosaic (September 4th 2016)

Characteristic	Value
Number of images	352
Flying altitude	49.14 m
Ground resolution:	0.0151347 m/pix

Table 4. Characteristics of the NGB orthophoto mosaic (October 8th 2016)

Characteristic	Value
Number of images	339
Flying altitude	52.16 m
Ground resolution:	0.0134423 m/pix

From this NGB orthophoto mosaics, the following four mosaics were generated:

- By the date of the beginning of the reproduction phase September 4th 2016, 1 NDVI mosaic and 1 GNDVI were obtained.
- By the date of the end of the reproduction phase October 8th 2016, 1 NDVI mosaic and 1 GNDVI were obtained.

The pixels containing NDVI values less than 0.2 were eliminated, it is why in NDVI mosaics it is observed blank or without data spaces, these were furrows of land disposed to watering system, as observed in the following image (Fig. 3):

Fig. 3. Aerial photograph of the growing

3.1 NDVI Classification

Mosaics were classified by ranks of values of NDVI in order to visualize different zones of spectral response as follows (Table 5):

Table 5. NDVI classification of the orthophoto mosaics

Id	NDVI	Color	Characteristic
1	0.2 to 0.3	Orange	Vegetation under stress or few developed
2	0.3 to 0.6	Light green	Healthy vegetation
3	0.6 to 1	Dark green	Dense vegetation

This classification was based on the comparison of what was observed in field versus the values of the NDVI mosaics, also what was consigned in [11, 12].

The zones under stress, the healthy and dense zones already defined are associated to the spectral response of the rice plant, because the NDVI values are established depending on the energy absorbed or reflected by plants in several parts of the electromagnetic spectrum. The spectral response of the healthy vegetation shows a clear contrast between the spectrum of the visible one, specially the red band (for this study the blue band was employed), and the Near Infrared (NIR) [4].

The previous statements are supported by many authors; for instance Araque and Jimenez [13] state: the region of the visible spectrum in the vegetation is characterized by low reflectance and transmittance, due to the strong absorption by leaf pigments. For example, chlorophyll pigments absorb the violet-blue and red light because of photosynthesis. The green light is reflected for the photosynthesis, reason why many plants emerge green.

Sanger [14] enounces that when the leaf is sick, the chlorophyll degrades faster than carotenes. This effect causes a rise on the reflectance of the red wavelength, owing to the reduction of the absorption of the chlorophyll. Carotenes and Xanthophylls are now dominant in leaves, and the leaves appear being yellow because of carotenes and xanthophylls absorb blue light and reflect green and red light.

Abdullah and Umer [15] propose that damages by diseases and plagues can be measurable according to variants in the content of the plants chlorophyll, which can be analyzed in terms of their changes in their spectral images patterns taken by satellites. These techniques use multi-spectral images to detect areas under stress.

3.2 Dynamic Analysis NDVI–GNDVI

The NDVI mosaics of the beginning (September 4th 2016) and end dates (October 8th 2016) of the reproduction phase are shown below (Fig. 4):

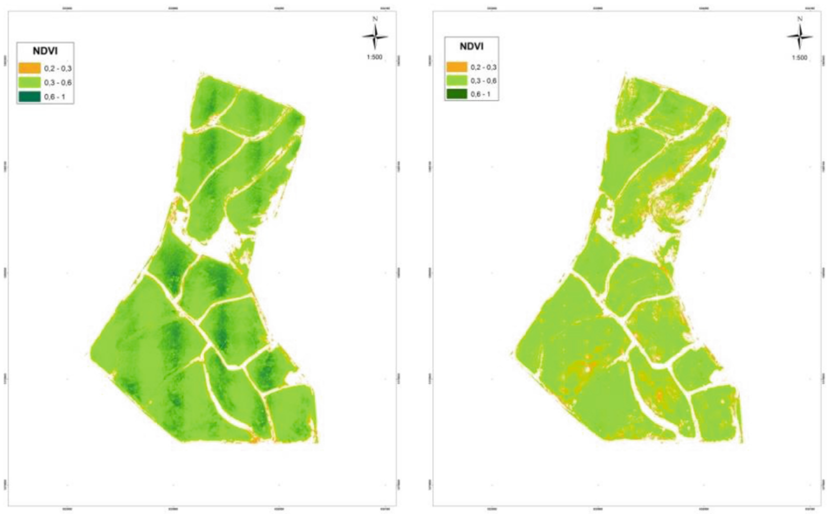

Fig. 4. September 4th 2016 NDVI (left) and October 8th 2016 NDVI (right)

The NDVI mosaic sampling dated September 4th 2016 established that the minimum value was 0.29, the maximum one was 0.54 and the average was 0.40, whereas the sampling dated October 8th 2016 yielded a minimum value of 0.42, a maximum of 0.61 and an average of 0.52. An increase in the NDVI value was observed over a period of roughly 35 days (period belonging to the reproductive phase of cultivation), the underdeveloped or stressed areas (which were minimal) became healthy zones and an important area of healthy zones managed to be dense. This NDVI growth is due to the fact that the cultivation was in the reproductive phase, which includes the initiation period of the panicle until the flowering, the panicle primordium develops and the size of the plant and dry matter increase rapidly, the height of the plant shows a progressive growth up to the flowering (98 days of development), while the leaf area increases until reaching its maximum value at 91 days. The phase is characterized by the elongation of the stem, emergence of the decayed leaves, stuffing and filling of the spikelets, it lasts until maturation and it is marked by an increase in the weight of the panicle accompanied by a decrease in the weight of the straw [16].

The increase in the NDVI value and therefore in the rice crop growth coincides with the study conducted by Zhou et al. [7], in which its correlation between the performance of the rice and the $\Sigma NDVI_{[800.720]}$ had a $R^2 = 0.75$; this study established that the best period for the calculation of the rice performance is the starting or beginning stage of the panicle, due to the production of yellow leaves raises the difficulty of calculation of the LAI and the prediction of the performance in the last growth stages.

For the analysis of the results of the date September 4th 2016, the NDVI and GNDVI mosaics are shown as follows (Fig. 5):

Fig. 5. September 4th 2016 NDVI (left) and September 4th 2016 GNDVI (right)

The GNDVI is calculated similarly to the NDVI, but the green band is used instead of the red band. It is related to the radiation proportion absorbed photosynthetically and is linearly correlated with the leaf area index (LAI) and the base. Therefore, GNDVI is more sensitive to chlorophyll concentration than NDVI and varies from 0 to 1.0 [17].

In the NDVI mosaic dated September 4th 2016 (left image), the crop presented healthy vegetation (light green) in most of its extension, followed by zones with stressed vegetation in minor proportion and dense zones were absent. At this time the cultivation was finishing the vegetative phase and began the reproductive phase of its development. The vegetative phase of delay, maximum tillering, internode elongation and panicle initiation occur almost simultaneously, the size of the seedling and the increase of the dry matter increase at a lower speed and the number of culms decreases. Its duration depends on the variety and climatic conditions, especially the duration of the day and the temperature [16].

In the following image the development of the rice plant in this phase is shown (Fig. 6):

Fig. 6. Rice plant at the beginning of the reproduction phase (September 4th 2016)

For the analysis of the results on October 8th 2016, the following NDVI and GNDVI mosaics are shown (Fig. 7):

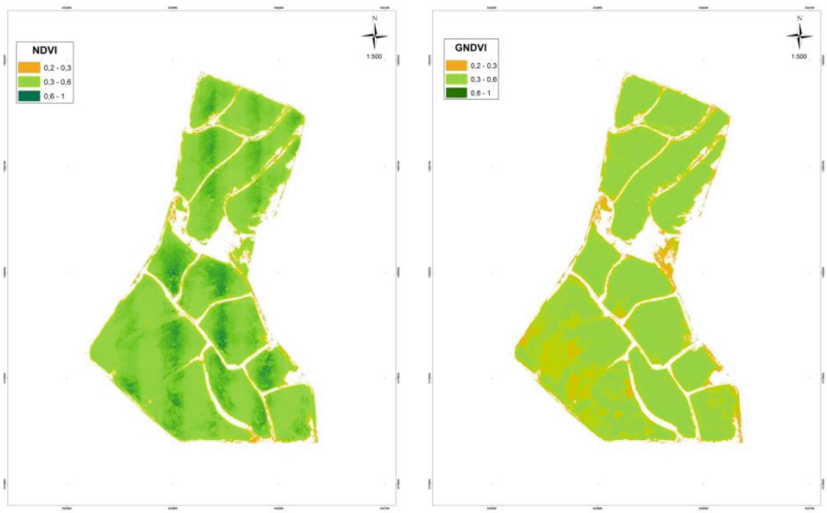

Fig. 7. October 8th 2016 NDVI (left) and October 8th 2016 GNDVI (right)

During this time the growing showed NDVI values usually above 0.4 with a large number of healthy and dense areas (left image). Few peripheral zones emerged with vegetation under stress, this vegetation belongs to weeds, according to what was observed in field, as shown in the following image (Fig. 8):

Fig. 8. Weeds in the periphery of the growing

In this date, the growing was in the flowering stage, which occurs from the emerging of the panicle of the flag leaf sheath, until when the anthesis is completed throughout the panicle. It has a lapse from 7 to 10 days [10].

In the comparison between NDVI mosaics versus GNDVI mosaics, a difference of the average values of the zones was noticed which is comprised from 0.02 to 0.16 on the first date (September 4th 2016) and from 0.10 to 0.22 on the second date (October 8th 2016); generally, in both cases, the zones where NDVI increased, GNDVI did it as well and viceversa. Furthermore, as GNDVI values were from 0.02 to 0.2 below NDVI, some parts of the GNDVI mosaic showed zone with a lower classification according to NDVI parts, it means, where NDVI mosaics registered healthy zones, GNDVI evidenced zones under stress. Finally, it is important to mention that this project and classification were emphasized on NDVI index, which is the most cited index for these kinds of analysis.

4 Conclusions

Through the Iris+ 3DR drone with a canon S100 camera converted to NDVI, it is possible to collect information from the visible spectrum bands and NIR with a good real-time spatial and spectral resolution of agricultural crops (in this case of rice), from there to generate orthophoto mosaics of vegetation indices (NDVI - GNDVI), this allows to analyze different areas of spectral response and to make precise decisions in order to combat the spread of diseases and plagues, to intervene zones with nutritional deficiencies, to decrease chemical products dependency, costs and negative impacts towards the environment.

The NDVI varied in the rank from –1 to 1, the zones belonging to mere soil, rocks and water generated values lower than 0.2, the vegetation under stress was in the rank from 0.2 to 0.3, healthy plants showed values from 0.3 to 0.6 and finally the dense vegetation showed values above 0.6. This demonstrates that healthy plants generate a high contrast between the blue and the near infrared bands, used for the calculation of the NDVI, while in the underdeveloped or under stress is minimal. Therefore, it can be deduced that healthy plants pigments such as chlorophyll and carotenoids of the photosynthetically active region (visible spectrum) have a high absorption of energy and reflect a minimal part, whilst in the infrared the reflected energy is high.

For the rice producers, the spatio-temporal statistics of the vegetation indexes obtained through multispectral cameras installed in drones become a fundamental tool to undertake sustainable agriculture when acquiring detailed information and, in early stages of the rice crop, problems, diseases or deficiencies can be detected so that an adequate management of all processes can be made such as: applying fertilizers just on necessary zones, diminishing the application of chemical products (herbicides, pesticides, insecticides and fungicides) and estimating the performance of the rice grain in order to undertake actions that increase the production and decrease the costs.

The classification of the healthy and sick zones and the analysis of the vegetation indexes allow the grower to conduct a correct management of the water, doing the watering in zones that are really damaged, this appears to be relevant in dry seasons and attenuates the impact by reduction of the hydrological resource.

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