USE OF RADAR SAR IMAGES TO ASSESS SOIL MOISTURE IN CANE CROPS: PRACTICAL IMPLICATIONS IN AGRICULTURAL OPERATION

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Abstract.

Sugar cane cultivation in the geographical region of the Cauca River Valley is a key industry for the local economy. However, this crop faces constant challenges related to the management of agricultural machinery for soil cultivation in conditions of high soil moisture. In this context, the synthetic aperture radar (SAR Radar) of the Sentinel 1 satellite emerges as a promising technology. The purpose of this work is to explore the use of the Sentinel 1 satellite SAR radar sensor in sugarcane cultivation to estimate soil volumetric moisture. It was evaluated how this technology can improve accuracy in measuring soil moisture. Using maps of apparent electrical conductivity obtained with the Topsoil Mapper ® sensor, field sampling was designed using the conditioned Latin hypercube technique and samples of gravimetric humidity were taken at two depths, from 0 to 20 cm and from 20 to 40cm depth. Seven samples were made from August 03 when the cane crop was harvested and thus until October 2023. These were programmed to take the sample on the day and time at which the Sentinel 1 satellite passes, the images were downloaded in the VV and VH polarizations, which are available for Colombia. Radar images and analysis made on the Google Collaboratory platform. Through analysis in a Pearson matrix, a correlation index 0.6 for field-measured gravimetric humidity was found with VV polarization in samples 0 to 20 cm and up to one month of age of sugarcane cultivation. Once the correlation was identified, it was decided to develop a machine learning model to select a model that would allow estimating volumetric humidity from images of the Sentinel 1 radar SAR sensor. The best model was found to be Random Forest with a R^2 of 0.87. The Sentinel 1 SAR sensor can be useful for estimating soil moisture if the soil is bare, insofar as cane cultivation begins to cover the soil, the data obtained are not consistent with moisture content but probably with changes in plant architecture related to crop growth. The practical application of this estimation of humidity lies in the possibility of making decisions about the entry of the farming machinery prior to the planting of the crop, the machinery used for this agricultural work is over 310 horsepower and its transport requires costly logistics, so having a geographic tool that helps in making this decision is of high impact on the costs of the mechanized agricultural operation in the geographical valley of the Cauca River.

Keywords.

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Radar SAR, soil moisture, sugarcane, Colombia, agricultural operation

Introduction

The cultivation of sugarcane in the Geographic Valley of the Cauca River plays a fundamental role in the local economy, generating employment and contributing significantly to the production of sugar and its derivatives. However, it faces constant challenges, especially in managing natural resources such as soil moisture and optimizing irrigation. In response to today's demands for significant change in areas such as society, the economy, the environment, and government policies, greater innovation and courage are required from businesses. Synthetic aperture radar (SAR) is emerging as a promising technology that could revolutionize the way these challenges are met. SAR, a remote sensing tool that uses microwaves, provides a detailed view of the Earth's surface and could improve the measurement of soil moisture in sugarcane (Saccharum officinarum) cultivation. This report aims to comprehensively explore the application of SAR radar in this context, evaluating how this technology can improve accuracy in soil moisture measurement and provide a detailed understanding of the relationship between field data and those obtained through SAR radar. It seeks not only to identify the capabilities of the SAR, but also to align them with the specific needs and challenges of sugarcane agriculture in the region to optimize its use and obtain more accurate and effective results.

Global climate change has driven humanity to be more efficient in the use of natural resources (Cordero, 2012), In response to this need, the European Space Agency launched into space in 2014 a constellation of two polar-orbiting satellites equipped with radar images, capable of capturing data both day and night for terrestrial and ocean services .These satellites, Sentinel 1A and 1B, orbit the Earth with a 180-degree offset, capturing images over the entire planet every six days (España, 2018). Therefore, it has been decided to carry out research focusing on soil moisture using SAR radar imagery, given the existence of multiple studies that have used satellite imagery in the agricultural field. (Ernesto, 2013) emphasizes the importance of accurately parameterizing investment models to improve the ability of SAR data in the reliable estimation of soil moisture, which has significant implications for water resource monitoring, precision agriculture, and the management of soil moisture-related risks such as drought and flooding. In addition, (García et al., 2016), they mention the reach of TerraSAR-X in crops such as soybeans, which prompts reflection on the potential of Sentinel 1 in the soils of Valle del Cauca, Colombia, considering the geographical conditions of the region (Caballero et al., 2018). According to Annual report of Cenicaña (2024), in Valle del Cauca there are altitudes of between 980 and 1200 meters above sea level where sugar cane is grown on 241,000 hectares.

In the study conducted by Arango (2020), a soil moisture analysis was carried out using both field data and SAR radar, concluding that there were no significant differences between the methods. These results raise a question about how it was possible to correlate field data with radar data, especially considering the age of the crop, given that biomass can influence measurements due to sugarcane density. Also, as mentioned by Ado (1998), the backscatter of the signal emitted by synthetic aperture radar presents positive correlations if it interacts with the soil, which highlights the importance of considering the presence of vegetation in soil moisture studies. Based on these considerations, we proceed with the research work focused on sugarcane (Saccharum officinarum) crops.

Methodology

To determine the research methodology, the data sheet for Sentinel-1, a component of the European Space Agency's (ESA) constellation of C-band SAR satellites, was examined. This constellation, composed of two polar-orbiting satellites, Sentinel-1A and Sentinel-1B, operates at a center frequency of 5.405 GHz, which corresponds to a wavelength of approximately 5.547 centimeters (Podest, 2016), as shown in Table 1.

Table 1. Radar wavelengths and frequencies (España, 2018).

Band	Wavelength (cm)	Frequency (GHz)
Ka	0.75 - 1.2	40 - 25
K	1.2 - 1.67	25 -18
Ku	1.7 - 2.5	17.6 - 12
X	2.5 - 4	12 - 7.5
C	**4 - 8**	**7.5- 3.75**
S	8 - 15	3.75 - 2
L	15 - 30	2 - 1
P	60 - 120	05 - 0.25

The penetration capacity of the decks varies according to the working frequency on the radar and is influenced by the corresponding wavelength. The main applications of radar according to the different bands are summarized in the following table (España, 2018).

Table 2. Application of the different radar bands (España, 2018).

	Ka	**Ku**	**X**	**C**	**S**	**L**	**P**
General Purpose, Most Used			■	■		■	
Vegetation cover penetration						■	■
Capture subsoil						■	■
Capture subsoil						■	■
Agriculture Monitoring			■	■	■	■	
Ocean & Ice Monitoring			■	■	■	■	
Subsidence studies			■	■	■	■	
Snow Monitoring		■	■				
Snow Monitoring	■		■				

Dispersion at a specific wavelength can vary due to various conditions, such as the physical size of the dispersers, their electrical properties, and their moisture content. In addition, the wavelength of SAR pulses and their polarization also influence signal backscatter (España, 2018). Surface scattering phenomena occur when radiation strikes a surface, and depend on its roughness or texture, as well as its dielectric constant. In general, rougher surfaces tend to produce greater backscatter and appear brighter on radar images. Conversely, smooth surfaces reflect little to no energy back to the radar sensor, resulting in darker areas in the image. Vegetation, with moderate roughness compared to the scale of radar wavelengths, tends to be depicted in shades of gray or light gray in radar imagery (Podest, 2014).

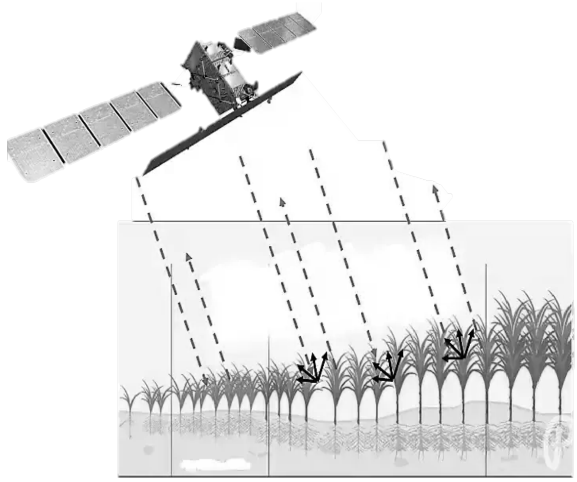

Figure 1. Dispersion Mechanism Source: Own authorship

Once the satellite's passage dates were obtained, a schedule was developed to carry out the soil sampling. The sampling points were selected using an algorithm known as a Latin hypercube, which allowed the random selection of the points (Puerres Tipas et al., 2021).

For the calculation of gravimetric moisture content, the method was used (Radulovich, 2009), which consists of introducing a ring with known dimensions at a depth of 10 and 20 cm and extracting the soil sample (Palacio et al., 2018). Each sample was marked with the identification of the site and then weighed while being removed from the batch (Palacio et al., 2018). Once weighed, the samples were transported to the soil laboratory in Cenicaña, where they were arranged in trays and placed in an oven at a temperature of 105 degrees for 24 hours to dry them completely (Radulovich, 2009). After this process, they were weighed again to obtain the dry weight of each sample. Then the percentage of moisture that our soil sample has is calculated, the resulting data were loaded into a database for further analysis in Python (Colab et al., 2021), below is the equation that is used to calculate the percentage of soil moisture. 150 data points were taken for this research.

$$\%W = \frac{\mathrm{Psh} - Pss}{Pss} \; x\,100$$

Where:

% W: Gravimetric moisture content (%)

WSW: Wet Soil Weight (g)

DSW: Dry Soil Weight (g)

Results and discussion

Main In the processing of the images, machine learning techniques were used to analyze the data collected in the field (Cajahuanca & Elvis, 2022) and compared to the data from Radar SAR (The data collected in the field were filtered, selecting only those corresponding to uncovered soils. A correlation analysis was made between the humidity data and the radar image data in the VV polarization, this analysis showed a coefficient of 66. Indicating a significant correlation between the moisture data in discovered soils and the SAR Radar data. Figure 2.

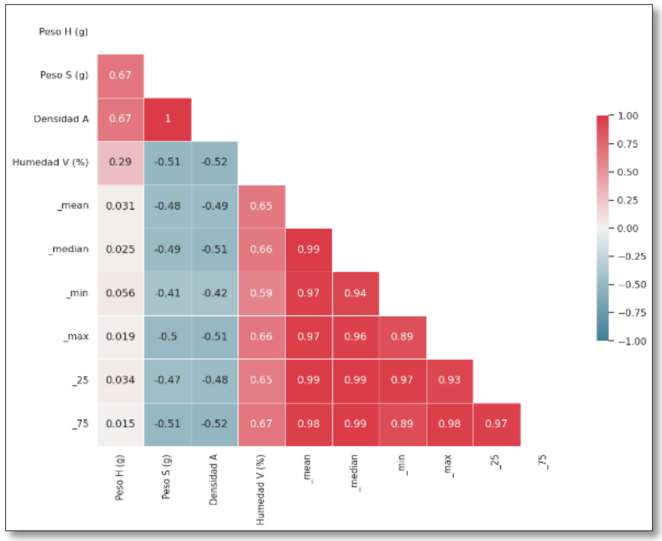

Figure 2. Correlation matrix on bare soils

A comprehensive analysis of SAR radar response in relation to gravimetric moisture content was carried out by training a Random Forest algorithm, as detailed in the study by (Mullissa et al., 2021). This strategy proved to be effective in enabling the modelling and understanding of the complex relationships between SAR radar variables and volumetric density. Figure 3 illustrates the performance of the model against SAR radar data, highlighting the importance of the mean of the radar image data. It is crucial to note that the model uses the average satellite image data in a 10-meter radius around the sampling point, adjusting the buffer size based on the pixel sizes of the radar image.

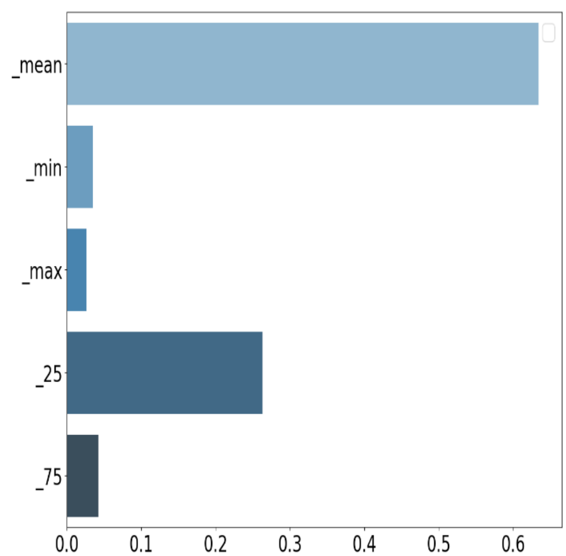

Figure 3. Diagram of the Most Significant Variables

After an exhaustive training process, a coefficient of determination (R^2) of 87.10% was obtained. This value of R^2 indicates that the Random Forest Model (RFM) managed to explain approximately 87.10% of the variability observed in the data. In other words, the model can successfully capture and predict a large portion of the variation in gravimetric density from the significant variables.

Conclusions

When analyzing SAR radar and soil moisture data, a significant correlation between the two datasets is evident. By evaluating ten machine learning models, it is found that the RDF model provides the best results in predicting soil moisture. This suggests that the use of SAR technology in combination with the machine learning RDF model is highly effective in estimating soil moisture in sugarcane cultivation in the Cauca River Valley.

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