Exploring Soil Moisture Index to Analyze Cavendish Banana (*Musa Acuminata*) Yield and Stress Pattern in Cabadbaran City, Agusan del Norte, Philippines

John Rell S. Cagalawan[1], Liane Lee Cubio[1], Arturo G. Cauba Jr.[1,2]

[1]Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga State University, Butuan City 8600, Philippines - {johnrell.cagalawan; lianelee.cubio; agcauba}@carsu.edu.ph

[2]Caraga Center for Geo-Informatics, Caraga State University, Butuan City 8600, Philippines

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Abstract

Cavendish bananas are essential to the agricultural economy of Barangay Soriano, Cabadbaran City, but their growth and yield are highly sensitive to soil moisture conditions. This study explored the use of remote sensing and GIS technologies to assess soil moisture levels, stress patterns, and their effects on banana yield through the Soil Moisture Index (SMI). The main objective was to create SMI maps, analyze stress patterns, and determine the correlation between SMI and banana yield. This was achieved using satellite imagery from Landsat 8 OLI and TIRS, combined with field validation using gravimetric soil moisture measurements. The study provided a detailed understanding of moisture conditions across the plantation and their impact on crop performance. Results revealed that an SMI range of 0.46 to 0.82 or 46% to 82% supports optimal growth, while extreme dryness or wetness significantly reduces yield. Areas with balanced soil moisture showed the highest productivity, contributing to the overall health and sustainability of the plantation. Also, SMI and Cavendish banana yield has a significant positive correlation with an R^2 that is equal to 0.7976 or 79.76%. Furthermore, the study demonstrated that remote sensing and GIS are effective tools for monitoring soil moisture and managing Cavendish banana plantations. By applying these methods, farmers can optimize resource management, reduce stress-related crop losses, and enhance agricultural productivity.

1. Introduction

An important export crop, Cavendish bananas *(Musa acuminata)* are essential to tropical agricultural economies, especially in the Philippines (Imtiaz et al., 2024). Farmers and communities rely on the productivity and health of Cavendish bananas as a significant source of agricultural revenue. However, this type of banana is extremely susceptible to changes in soil moisture, which can hinder growth and lower yields. The sustainability of banana cultivation is threatened by crops that are stressed by either too much or too little soil moisture (Ravi and Vaganan, 2016), which can result in disease, stunted development, and decreased fruit yield.

The Soil Moisture Index (SMI) has become a widely used metric for evaluating soil conditions and identifying areas of moisture-related stress in crops (F. Imtiaz et al., 2024). By quantifying the moisture levels in the soil, the SMI helps detect extremes such as drought or excessive water, both of which have adverse effects on crop health and yield (Martínez-Fernández et al., 2016). Researchers and farmers can utilize the SMI to gain insights into soil conditions and identify potential risks before they impact crop production. For Cavendish bananas, understanding soil moisture dynamics is particularly important (Stevens et al., 2020), as this crop requires stable moisture levels to thrive, making precise moisture monitoring invaluable.

Recent advances in Remote Sensing and Geographic Information System (GIS) technology have transformed how researchers assess crop health (Zhang and Cao, 2019). Spectral indices such as the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and Soil Moisture Index (SMI) have been widely applied to staple crops. For example, NDVI has been used to evaluate drought impacts in wheat and maize (Martínez-Fernández et al., 2016), while LST combined with vegetation indices has been employed to monitor water stress in rice paddies (Ahmad, 2021). Similarly, SMI has been applied in maize production systems to detect periods of excessive or deficient soil moisture (Mishra et al., 2024). These applications demonstrate the effectiveness of spectral indices in identifying crop stress across different agricultural contexts.

Despite these advances, several research gaps remain. First, most applications of NDVI, LST, and SMI have been concentrated on staple crops such as rice, maize, and wheat, while high-value crops like Cavendish banana remain underexplored despite their economic importance. Second, many studies operate at broad regional scales, overlooking within-plantation variability that directly affects management practices and yield outcomes. Third, although indices are effective for detecting stress, fewer studies have explicitly integrated remote sensing–derived soil moisture indices with actual yield data to quantify the relationship between moisture conditions and crop productivity. In the Philippines, in particular, there is limited evidence connecting SMI-derived stress patterns with Cavendish banana yield. Addressing this gap requires localized, crop-specific approaches that combine soil moisture monitoring with empirical yield correlations.
The monitoring of Cavendish banana in the Philippines through Remote Sensing and GIS has an influence on mitigating the problems related to stress or health issues and yield loss. In this way, the agricultural system that enables maintaining the stability of distribution and production of all agricultural goods, such as the Cavendish banana, will become more resilient and adaptable to various challenges. Remote sensing and GIS offer real-time data on crop health and environmental conditions, allowing for timely interventions to prevent yield loss.

This study aims to assess the potential of remote sensing and GIS to analyze yield and stress pattern of Cavendish banana through Soil Moisture Index as an indicator of drought and water excess of the soil, that can be obtained from Landsat 8 OLI and TIRS. Also, it aims to correlate the relationship of SMI to the yield of Cavendish banana and how stress pattern affects the yield.

2. Study Area

The study was conducted in a Cavendish banana plantation located in Barangay Soriano, Cabadbaran City, Agusan del Norte, Philippines. The plantation covers an area of approximately 236 hectares (2,360,000 square meters) and lies within a Type II climate zone, characterized by the absence of a dry season and a pronounced maximum rainfall from November to January. The soil in the area is predominantly sandy loam, which is well-suited for banana cultivation due to its good drainage and nutrient retention properties. Topographically, the area has a minimum elevation of 5.04 meters and a maximum of 30.68 meters above sea level. Historical observations and local reports indicate that the plantation has experienced both severe dry conditions and excessive wetness, which have adversely affected banana yield. These extremes in soil moisture underscore the importance of monitoring and managing soil water content to ensure optimal crop performance. Figure 1 shows the map of the study area.

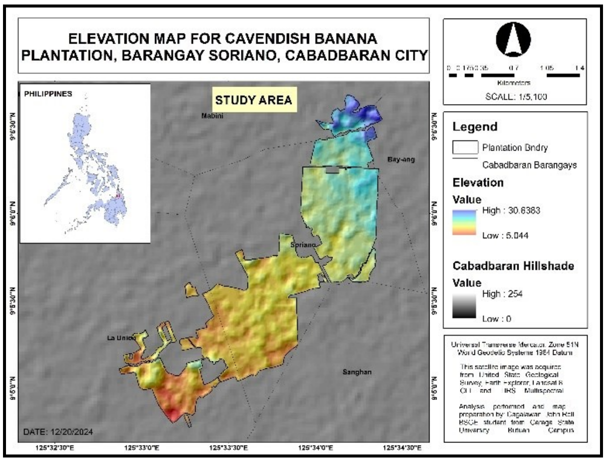

Figure 1. Map of the Study Area

This study used remote sensing and GIS approach to analyze soil moisture conditions and their effects on Cavendish banana yield in Barangay Soriano, Cabadbaran City, Agusan del Norte, Philippines. Landsat 8 OLI and TIRS image data was used to derive the Soil Moisture Index (SMI) by combining NDVI and Land Surface Temperature (LST). The SMI was then classified into stress categories to identify moisture-related issues in the plantation. Lastly, a quadratic regression was applied to examine the relationship between soil moisture and Cavendish banana yield.

3. Methodology

3.1 Methodological Flowchart

Shown in figure 2 is the methodological flowchart of the study. This study aimed to analyze and estimate the yield and stress pattern of the Cavendish banana in Barangay Soriano, Cabadbaran City using the Soil Moisture Index (SMI) obtained from remote sensing data. Remote sensing and GIS approaches were employed to achieve this objective. First, a Landsat 8 OLI and TIRS image covering the study area were acquired for various time periods throughout the banana growing cycle. Pre-processing steps were applied to the imagery to ensure radiometric, atmospheric, and geometric correction. Second, relevant spectral indices sensitive to soil moisture, such as the Normalized Difference Vegetation Index (NDVI) or Land Surface Temperature (LST), were calculated from the processed imagery. These spectral indices were then used to generate the SMI using established formula. Third, field surveys were conducted to validate the soil moisture data, ensuring the reliability and credibility of the remotely sensed estimates. Fourth, statistical analyses, specifically regression analysis, were performed to explore the relationship between the derived SMI and ground-based data on yield and plant stress. Through this process, the potential of using SMI as a predictor for banana yield and stress patterns was assessed. The findings of this study provide valuable insights for precision agriculture, particularly in Cavendish banana production. By applying remote sensing and GIS technologies, farmers and agricultural corporates can gain a better understanding of soil moisture conditions within their fields, enabling them to implement targeted irrigation strategies and optimize resource management for improved yield and stress resilience.

3.2 Data Sources and Preprocessing

Landsat 8 OLI and TIRS imagery with a 30 × 30-meter spatial resolution and a 16-day temporal resolution was used in this study due to its wide availability, sufficient spectral bands, and free accessibility. The satellite images were acquired from the United States Geological Survey (USGS) Earth Explorer platform. In addition, essential reference data such as the plantation boundary shapefile, banana yield in metric tons, and total plantation area were obtained from the Philippine Statistics Authority (PSA) and the Department of Agriculture (DA).

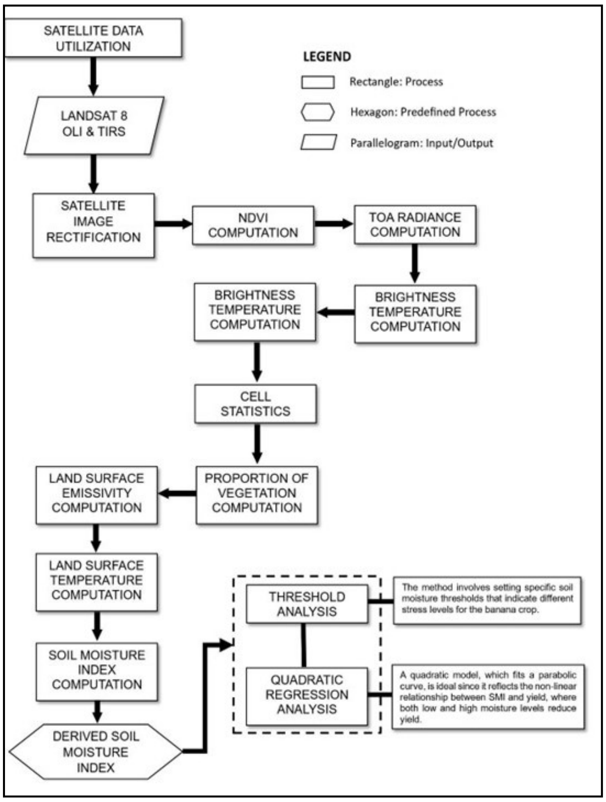

Figure 2. Methodological Flowchart

To ensure the accuracy and reliability of the satellite imagery, the data underwent a series of preprocessing steps. These included radiometric calibration to correct sensor-related distortions, atmospheric correction to reduce the effects of haze and aerosols, and geometric correction to align the imagery with real-world coordinates. All these corrections were performed using ENVI Classic 5.3, a widely recognized remote sensing software. These preprocessing steps ensured that the imagery was suitable for further analysis such as NDVI and Land Surface Temperature (LST) computation, which are essential for deriving the Soil Moisture Index (SMI).

3.3 Soil Moisture Index (SMI) Computation

To compute the Soil Moisture Index (SMI), the study first derived two key components: the Normalized Difference Vegetation Index (NDVI) and the Land Surface Temperature (LST). NDVI was calculated using Band 5 (NIR) and Band 4 (Red) from Landsat 8 imagery, using the equation.

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \tag{1}$$

This index helped indicate vegetation density and health, which is important for understanding how much water plants may be using or needing.

After NDVI, the Land Surface Temperature (LST) was calculated to estimate the heat condition of the land surface. This started with converting the thermal band (Band 10) into Brightness Temperature (BT) using the formula.

$$BT = \frac{K2}{ln\left(\left(\frac{K1}{L\lambda}\right) + 1\right)} - 272.15 \tag{2}$$

where $K1$ = calibration constant from the satellite data
$K2$ = calibration constant from the satellite data
$L\lambda$ = top-of-atmosphere radiance.

$$LST = \frac{K2}{\left(1 + \left(\lambda \times \frac{BT}{p}\right) \times ln(\varepsilon)\right)} \tag{3}$$

where λ = wavelength of emitted radiance
ρ = constant
ε = land surface emissivity

Finally, the Soil Moisture Index (SMI) was calculated using this normalized equation.

$$SMI = \frac{(LST - LSTmin)}{(LSTmax - LSTmin)} \tag{4}$$

This gave values between 0 and 1, where lower values indicate drier conditions and higher values indicate wetter soil. This index helped identify areas in the banana plantation experiencing drought or excess moisture (Arif and Susena, 2024). Gravimetric soil moisture measurements collected in the field were used to validate the remotely sensed SMI estimates, thereby ensuring the reliability of the derived index.

3.4 Threshold-Based Stress Classification

Once the SMI raster was generated, a threshold-based classification was applied. The SMI values were divided into 11 categories, ranging from "Extremely Dry" to "Extremely Wet." Each category was analyzed based on its spatial extent using GIS, allowing the researchers to map and quantify the areas affected by different levels of soil moisture stress. The Soil Moisture Index values (SMI) and stress pattern in crops, particularly Cavendish banana is related because soil moisture plays an important role in Cavendish banana health (Panigrahi et al., 2021). When the SMI is too low, it indicates that the soil is dry, leading to water stress in Cavendish banana which can result in wilting, slower growth, or even reduced yields. On the other hand, if the SMI is too high, it suggests excess soil moisture, which can cause waterlogging and reduce oxygen availability to the roots (Mishra et al., 2024), leading to crop stress. In contrast, Cavendish banana can be considered not stress when the SMI values fall within the optimal range (Ravi and Vaganan, 2016).

For Cavendish bananas, Moderately Dry and Slightly Dry can still be considered suitable based on their development (Vu et al., 2017), but proper management of soil moisture is still required in these categories. Moreover, the ideal condition for Cavendish bananas is within the Normal to Moderately Wet range to ensure consistent development (Thompson et al., 2019).

The SMI values are divided into equal intervals to ensure consistency and accuracy in determining soil moisture conditions. Furthermore, for Cavendish banana, this categorization is highly relevant. Cavendish bananas are sensitive to both drought and excessive witness, which can stress plants, reduce yields, and increase susceptibility to disease such as Panama disease. Table 1 shows the SMI categories and their corresponding descriptions.

SMI Category	SMI Value Interval	Description
Extremely Dry	≤ 0.09	Severely dry, plants cannot survive
Very Dry	0.09 to 0.10	Critically low, early stress starts
Dry	0.10 to 0.20	Low moisture, reduced crop growth
Moderately Dry	0.20 to 0.30	Mild stress, limited water availability
Slightly Dry	0.30 to 0.40	Slight water deficit, manageable
Normal	0.40 to 0.50	Ideal moisture, healthy growth
Slightly Wet	0.50 to 0.60	Moisture slightly above normal
Moderately Wet	0.60 to 0.70	Approaching saturation, mostly stable
Wet	0.70 to 0.80	Excess water, limited infiltration
Very Wet	0.80 to 0.90	Nearly saturated, anaerobic stress begins
Extremely Wet	≥ 0.90	Fully saturated, flood-prone soils

Table 1. SMI Categories and Descriptions

3.5 Yield Integration and Estimation

To assess how moisture levels influence Cavendish banana yield, the SMI categories were linked with actual yield data. Yield values, expressed in metric tons and associated with the total number of bearing trees and plantation area, were integrated with the SMI stress map. For each moisture class, the area was calculated and converted into a percentage of the total plantation. These percentages were then used to estimate the proportion of yield each moisture class contributed to, based on the assumption that yield is affected by stress severity. Yield data were obtained directly from plantation records and expressed in metric tons per defined plantation area. These values were then spatially integrated with SMI categories to establish the relationship between soil moisture stress levels and yield distribution.

3.6 Regression Analysis

To analyze the relationship between SMI and banana yield, a quadratic regression analysis was performed. This method was chosen because the effect of soil moisture on banana yield is not linear both too little and too much moisture can negatively affect crop growth. The regression model took the form:

$$Y = aX^2 + bX + c \qquad (5)$$

where Y = banana yield
X = SMI value

The fitted curve allowed the researchers to identify the optimal soil moisture range for Cavendish banana production. The R^2 value was also computed to determine how well the SMI values explained the yield variation across the plantation.

4. Results

This section presents the analysis of Soil Moisture Index (SMI) and its relationship with Cavendish banana yield and stress patterns in Barangay Soriano. The SMI was used to classify moisture conditions and identify areas experiencing drought or excessive wetness. These conditions were then linked to banana yield using spatial analysis and regression modeling. The results help highlight which soil moisture levels support optimal crop growth and where improvements in water management may be needed.

4.1 Derived Soil Moisture Index (SMI) and Distribution Analysis

Figure 3 shows the Soil Moisture Index (SMI) where the color blue in the map corresponds to a high SMI value with a range of 0.92 to 1 or 92% to 100%. For Cavendish bananas, this high SMI can lead to the development of diseases like Fusarium wilt (Panama disease) and bacterial wilt (Ismaila et al., 2023). These diseases attack the roots and vascular systems of the Cavendish banana, causing yellowing and wilting of the leaves. The presence of high SMI areas highlights the need to carefully monitor these zones as prolonged wetness can make the crop more vulnerable to infections. Based on the map, the optimal SMI falls within 0.46 to 0.82 or 46% to 82%, respectively, which indicates normal to moderately wet conditions favorable for growth but must still be managed to avoid disease outbreaks.

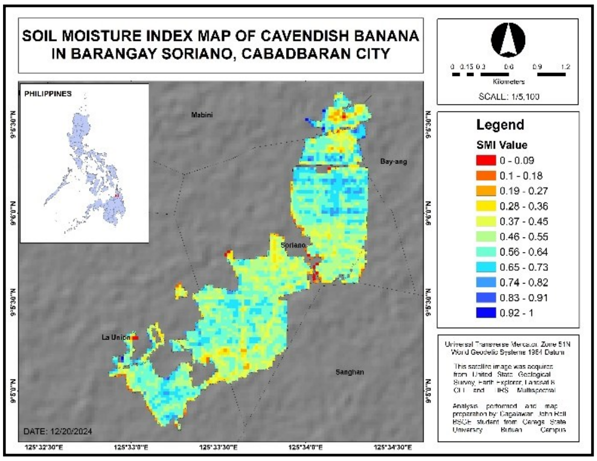

Figure 3. SMI Map of the Cavendish banana plantation

On the other hand, low SMI values, represented by color red, indicate low SMI with a range from 0 to 0.09 or 0% to 9% which can cause Cavendish bananas to experience drought stress. In these areas, the Cavendish bananas become susceptible to diseases like Black Sigatoka, which damages leaves and reduces fruit quality, and nematode infestations that weaken the roots (Fullerton and Casonato, 2019). These problems can lead to poor crop growth, reduced yield, and even plant death if dryness persists. The map emphasizes the critical need to monitor these dry areas as they can lead to significant losses in banana production if not properly addressed. Managing soil moisture to avoid extremes is essential to minimize these risks and maintain healthy Cavendish banana plantation.

4.2 Stress Pattern Analysis for Cavendish banana

Figure 4 shows the Stress Pattern Map in Barangay Soriano, Cabadbaran City, highlighting areas prone to stress. The categories range from Extremely Dry to Extremely Wet, indicating varying moisture levels across the region.

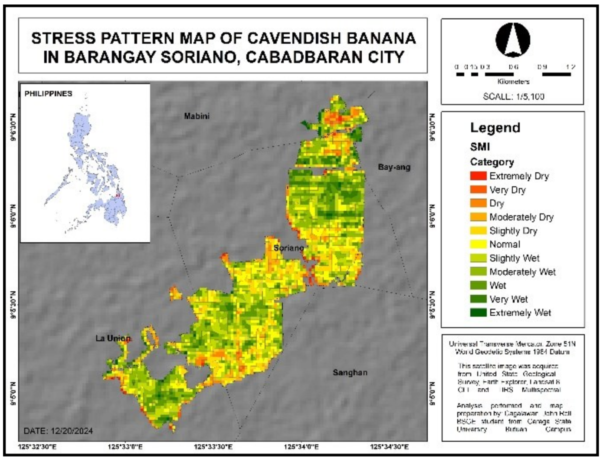

Figure 4. Stress Pattern Map of the Cavendish banana plantation

The map shows that most areas are within the Normal to Moderately Wet, suggesting a very favorable conditions for Cavendish banana cultivation, likewise areas within Moderately Dry, Slightly Dry, and Wet are only favorable condition for Cavendish banana. Furthermore, certain sections face Dry or Very Wet stress, are favorable but must be observed at often times to ensure the crop development, though Very Dry, Extremely Dry, and Extremely Wet stress, which may negatively affect crop growth and not favorable for Cavendish banana. The map is useful for identifying stress zones, allowing for specific actions like irrigation, particularly in Extremely Dry and Very Dry areas to improve soil moisture.

4.3 Cavendish Banana Yield Map Analysis

Figure 5 shows the variations in yield across the plantation. Areas with high yield (>2,000 metric tons) are predominantly located in the central and southern parts of the plantation, as represented by green. Moderate-yield areas (1,000-2,000 metric tons) are scatters throughout the plantation, particularly surrounding high-yield regions. Low-yield areas (<1,000 metric tons), shown in red, are minimal but are mostly situated at the edges of the plantation, which may indicate less favorable conditions or stress factors.

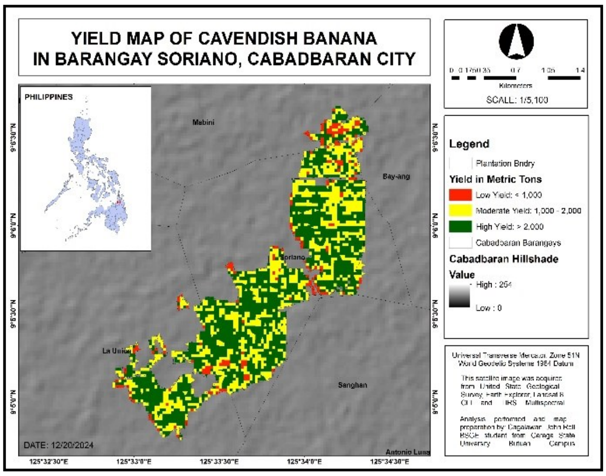

Figure 5. Cavendish Banana Yield Map

The results suggest that certain areas within the plantation are more conducive to higher yields, potentially due to optimal soil moisture level or management practices. These findings provide an important understanding about improving yields in underperforming area.

4.4 Soil Moisture Index and Cavendish Banana Yield Correlation

Figure 6 shows the relationship of Soil Moisture Index (SMI) and Cavendish banana yield, with an R^2 value of 0.7976 indicates that the model explains 79.76% of the variation in Cavendish banana yield based on SMI. Moreover, in quadratic regression analysis, the p-value of 0.001 indicates that this correlation is statistically significant at the $p < 0.01$ level and signifies SMI value has an impact on yield prediction. The results show that Cavendish banana yield increases as the SMI reaching its peak before gradually declining. This suggests that the optimal soil moisture levels are crucial for maximizing yield. Dryness or wetness beyond this range significantly reduces banana production. The data signifies the importance of maintaining proper soil moisture levels for sustainable Cavendish banana farming.

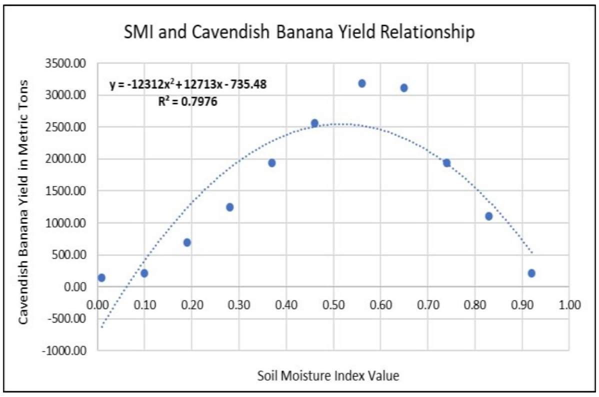

Figure 6. Soil Moisture Index (SMI) VS. Cavendish Banana Yield

4.5 SMI and Cavendish Banana Yield Quadratic Equation

Based on the relationship of Soil Moisture Index (SMI) and Cavendish banana yield their non-linear correlation signifies that Cavendish bananas are not good for both extremes such as Extremely Dry and Extremely Wet. The equation $y = -12312x^2 + 12713x - 735.48$ represents the relationship between the SMI and the yield of Cavendish banana yield in metric tons. This quadratic equation signifies a parabolic relationship, where the banana yield is influenced by changes in soil moisture levels. The negative coefficient of x^2 (-12312) indicates that the parabola opens downward, suggesting that there is an optimal soil moisture level at which the yield is maximize.

In addition, the positive linear coefficient which is 12713 implies that as the SMI increases from zero, the yield initially rises until it reaches the optimal point. Beyond this point, as indicated by the downward slope, excessive soil moisture begins to negatively impact the yield. The equation also highlights that optimal SMI value, which maximizes the yield, can be calculated from the vertex of the parabola using $x = -b/2a$. Substituting the coefficients, the maximum yield is achieved at an SMI of approximately 0.52. This emphasizes that maintaining soil moisture levels around this value is crucial for optimizing Cavendish banana production.

5. Conclusion

The study focused on analyzing the relationship between Soil Moisture Index (SMI) values derived from remote sensing and GIS techniques and their influence on Cavendish banana yield and stress patterns in Barangay Soriano, Cabadbaran City. Several statistical and spatial analyses were employed to investigate these relationships and to assess the applicability of SMI for agricultural monitoring.

The spatial analysis of SMI values, calculated from NDVI and LST, revealed significant variability across the plantation, with certain areas identified as prone to drought or water saturation. In the quadratic regression analysis, the correlation coefficient results revealed significant positive correlations between SMI and Cavendish banana yield, expressed by the equation $y = 12312x^2 + 12713x - 735.48$ ($R^2 = 0.7976$, $p < 0.01$), which showed that the optimal SMI category for maximizing yield is between Normal to Moderately Wet with corresponding SMI values of 46% to 82%. Outside this range, yields decreased due to either water stress or over-saturation. Additionally, the stress patterns aligned with extreme SMI values, confirming that moisture imbalances significantly

impact crop health and productivity. These results highlight the importance of monitoring soil moisture conditions for improving crop management practices. The study demonstrated that SMI is an effective and scalable tool for managing moisture-sensitive crops like Cavendish bananas.
These findings underscore the potential of integrating Remote Sensing and GIS in precision agriculture. The study contributes valuable insights into the practical application of SMI for monitoring soil moisture dynamics and optimizing Cavendish banana yield, paving the way for data-driven and sustainable agricultural practices.

6. Recommendations

Based on the findings of this study, several recommendations are proposed to enhance the management of Cavendish banana plantations and promote high productivity and sustainability. First, conducting a multi-seasonal analysis is recommended to better understand the temporal variability of soil moisture and yield patterns. This approach will help establish consistent trends and correlations across different growing seasons, leading to more reliable insights. As this study focused on a single cropping season, the results should be regarded as an initial demonstration of the feasibility of using SMI for Cavendish banana monitoring. Future research should extend the analysis across multiple seasons to capture temporal variability and establish more robust trends. Second, integrating other stress indicators, such as nutrient levels, pest infestations, and disease outbreaks, into the analysis will allow for a more comprehensive understanding of the various factors influencing banana yield. Third, the use of advanced technologies such as drones (UAVs) or higher-resolution satellite imagery, such as Sentinel-2, is encouraged for real-time monitoring and more detailed spatial analysis. Future studies should also incorporate other relevant factors such as topography, irrigation practices, and soil property variability, which may influence both moisture distribution and yield outcomes. Finally, applying a community-level, participatory approach is suggested, wherein local farmers are actively involved in interpreting SMI maps and implementing recommended practices. This inclusive strategy will help ensure that technological interventions are well understood, locally adapted, and sustainable in the long term.

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