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Correlation Between Soil Nitrogen Content and NDVI Derived from Sentinel-2A Satellite Imagery

Hubungan antara Kandungan Nitrogen Tanah dengan NDVI dari Citra Satelite Sentinel-2A

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ABSTRAK

United Nations Educational, Scientific and Cultural Organization (UNESCO) telah mengakui sistem pengairan pertanian Bali yang disebut subak sebagai bagian dari warisan budaya dunia. Subak merupakan penggerak sektor pertanian dan pariwisata di Bali sehingga harus dilestarikan. Peningkatan jumlah penduduk berdampak terhadap alih fungsi lahan, yakni dari lahan subak menjadi lahan terbangun, seperti di Kota Denpasar. Di sisi lain, bertambahnya jumlah penduduk mengakibatkan kebutuhan pangan meningkat sehingga menyebabkan petani melakukan intensifikasi lahan pertanian, seperti pemberian pupuk kimia yang melebihi dosis, yang dapat menurunkan kesuburan tanah. Salah satunya adalah pupuk urea yang mengandung unsur hara makro Nitrogen (N). Penelitian ini bertujuan menganalisis kandugan N serta korelasinya dengan pertumbuhan padi melalui pendekatan *Normalized Difference Vegetation Index* (NDVI). Analisis N tanah menggunakan metode *Kjeldahl* dan dilakukan di Laboratorium Ilmu Tanah dan Lingkungan, Fakultas Pertanian, Universitas Udayana. NDVI diesktraksi dari data penginderaan jauh, yaitu Citra Sentinel 2A, pada platform *cloud computing* Google Earth Engine (GEE). Analisis NDVI menggunakan Band 8 (NIR) dengan panjang gelombang 0,842 μm dan Band 4 (Red) dengan penjang gelombang 0,665 μm. Hasil penelitian menunjukkan kadar N berkisar antara 0,09% hingga 0,31%. Rerata nilai NDVI berkisar antara 0,47 hingga 0,54. Terdapat korelasi yang kuat (r = 0,75 sampai 0,78) antara kadar N tanah dan NDVI. Kadar N dan NDVI yang tinggi secara spasial terletak di sebagian Subak Kerdung, Mergaya, Padanggalak dan Sembung selama tahun 2019-2021.

Kata kunci: Google Earth Engine (GEE), NDVI, subak, Sentinel-2A

ABSTRACT

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) has recognized the Balinese agricultural irrigation system known as *subak* as part of the world's cultural heritage. *Subak* is the driver of Bali’s agricultural and tourism sectors and, therefore, must be preserved. Population growth triggers the conversions of land functions, from *subak* to built-up lands, such as those transpiring in Denpasar City. On the other hand, with the population continuously increasing, the demand for food becomes inevitably higher. This has caused farmers to intensify their agricultural practices through, for instance, applying chemical fertilizers excessively-potentially decreasing soil fertility. An example is urea fertilizer that contains a macronutrient, i.e., nitrogen (N). This study aimed to analyze the soil N content and its correlation with rice growth using the Normalized Difference Vegetation Index (NDVI). The *Kjeldahl* method was conducted to measure the N levels in the soil laboratory. NDVI was extracted from remote sensing data, namely Sentinel-2A imagery, on a cloud computing platform, Google Earth Engine (GEE), using Band 8 (NIR) with a wavelength of 0.842 m and Band 4 (Red) with 0.665 m. The results showed that the N levels varied from 0.09% to 0.31% and the average NDVI values ranged from 0.47 to 0.54. There is a strong correlation (r = 0.75 to 0.78) between the NDVI values derived from the Sentinel-2A Satellite Imagery and the soil nitrogen content. Spatially, based on the analysis results of the 2019−2021 data, parts of existing *subak* systems, i.e., Subak Kerdung, Mergaya, Padanggalak, and Sembung, have high soil N contents and NDVI values.

Keywords: Google Earth Engine (GEE), NDVI, *subak*, Sentinel-2A

INTRODUCTION

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) has recognized the Balinese agricultural irrigation system known as *subak* as part of the world's cultural heritage (Windia et al., 2018). *Subak* is the driver of Bali's agricultural and tourism sectors (Sunarta et al., 2021), and thus must be preserved. Population growth triggers the conversions of land functions, from *subak* to built-up lands, such as those transpiring in Denpasar City. On the other hand, food needs become higher with the continuous increase of the population. This has caused farmers to intensify their agricultural practices by, among others, applying chemical fertilizers excessively, which can reduce soil fertility. It is essential to study soil fertility as the basis for sustainable agricultural land management (Rafie et al., 2019; Rawal et al., 2018; Sardiana et al., 2017). Several determinant parameters used to evaluate its status are chiefly the nutrients needed for plant growth, including pH, organic matter, P_2O_5, K_2O, N, Ca, Mg, S, B, Fe, Zn, Cu, and Mn (Khadka et al., 2018, 2019; Oli et al., 2020). One of which is the macronutrient N (Trigunasih & Wiguna, 2020), which is most needed in the vegetative phase of rice plants (Gholizadeh et al., 2017; Hendrayanti et al., 2020).

Plant growth response in *subak* lands to the soil N content can be analyzed using the Normalized Difference Vegetation Index (NDVI) derived from Sentinel-2A. Sentinel-2 is a satellite image with 13 bands namely, four bands with a resolution of 10 m, six bands with 20 m, and three bands with 60 m and a swath area of 290 km.

This study only uses the Near-Infrared (NIR) and Red (R) bands. NDVI is a spectral transformation representing vegetation density and greenery levels. Remote sensing data have been previously utilized for the NDVI analysis of paddy fields by Amano et al. (2021) using the platform Google Earth Engine (GEE) (Chen et al., 2020). GEE is a cloud computing platform for real-time remote sensing data acquisition, data processing into maps, and data visualization (Amani et al., 2020; Tamiminia et al., 2020), making it more practical for remote sensing data analysis. In addition, a previous study measured the growth response of rice plants to nutrients by direct observation upon applying N fertilizer (Setiawati & Suryatmana, 2019). However, this research differs in the method used and the temporal analysis, i.e., the correlation between plant growth and the N content is measured in three rice planting seasons in the *subak* land at Denpasar City, namely 2019, 2020, and 2021. This study aimed to analyze the soil

N content and its correlation with rice growth using the Normalized Difference Vegetation Index (NDVI).

MATERIALS AND METHODS

This research was conducted in Denpasar City, Bali Province, Indonesia (Figure 1). It focuses on paddy fields with the *subak* traditional irrigation system. The city geographically spans from 08°35'31" to 08°44'49" S and from 115°10'23" to 115°16'27" E (Figure 1). The study area covers several *subak* lands in the four districts of the city, i.e., North Denpasar (e.g., Subak Lungatad, Sembung, Pakel I, Pakel II, among others), East Denpasar (Subak Buaji, Temaga, and Padanggalak), West Denpasar (Subak Mergaya, Tegal Buah, and Semila), and South Denpasar (Subak Kerdung, Renon, and Intaran Barat).

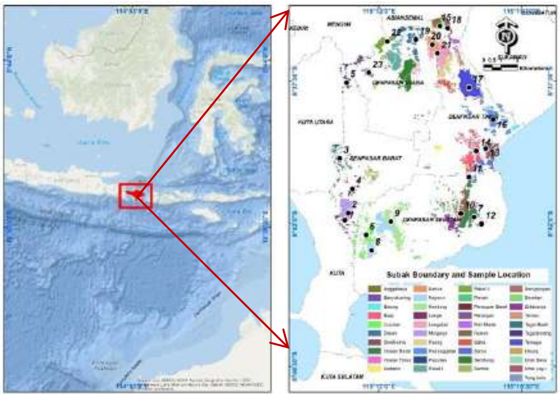

Figure 1. Research location in Bali Province (left), and *subak*-irrigated rice fields as the research focus and the soil sampling sites for N analysis (right)

Tools and Materials

The laboratory equipment used to analyze the soil N content included test tubes, Erlenmeyer flasks, *Kjeldahl* flasks, and distillation apparatus. The tools used were a cloud computing application, Google Earth Engine (GEE), to derive the NDVI values and ArcGIS 10.6 software to extract pixel values.

The materials and chemicals used in the N analysis included rock powder, ion-free water, 1% boric acid, 10% NaOH, H_2SO_4. The NDVI analysis used Sentinel-2A image data acquired in August 2019, 2020, and 2021.

Methods

Soil N Analysis

The N content was analyzed in the soil laboratory with the *Kjeldahl* method (Bremner, 1960). In the distillation step, 10 ml of the sample extract was pipetted into a boiling flask. Then, the rock powder that was firstly boiled was added to the flask, and then the ionized water was poured until half of the flask volume. A container for the liberated NH_3 was prepared—i.e., an Erlenmeyer flask containing 10 ml of 1% boric acid plus two drops of Conway indicator and connected to a distillation apparatus. Afterward, the boiling flask containing the sample was added with 10 ml of 40% NaOH, closed immediately, and then distilled until the reservoir volume reached 50–75 ml. The distillate was titrated with standard acid (H_2SO_4 0.050 N). The titration volume (ml) for the sample (Vc) and blank (Vb) was recorded. N levels (%) were calculated using equation 1.

N (%) .... **(1)**

= (Vc - Vb) x N x bst N x 50 ml 10 ml-1 x 100 mg sample-1 x fk

= (Vc - Vb) x N x 14 x 50/10 x 100/250 x fk

= (Vc - Vb) x N x 28 x fk

where:

Vc, b	=	tritation volume for the sample and blank analysis (ml)
N	=	normality of standard H_2SO_4 solution (0.050)
14	=	equivalent weight of nitrogen
100	=	conversion factor to %
fk	=	moisture correction factor = 100/(100% moisture content)

NDVI Analysis

The Sentinel-2A images used were cloud-free, with a clarity level of 90%, and obtained by filtering the best images acquired in August 2019, 2020, and 2021.

$$NDVI = \frac{Nir - Red}{Nir + Red} \quad \text{.............. (2)}$$

The NDVI values range between -1.0 and +1.0. Values greater than 0.1 usually indicate an increase in the degree of vegetation greenery and intensity. Values between 0 and 0.1 were generally characteristic of rock and bare land, while less than 0 may indicate clouds of ice, clouds of water vapor, and snow. Surface vegetation ranges from 0.1 for savanna (grasslands) to 0.8 for tropical rainforests (Ghebrezgabher et al., 2020; Huang et al., 2021).

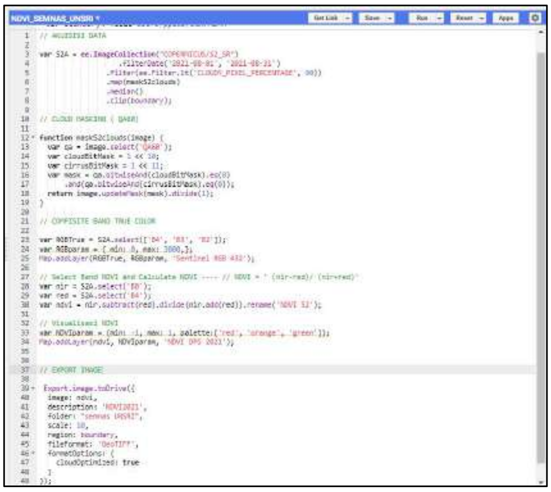

Figure 2. Screen capture of the script Code Editor on GEE Dashboard for NDVI analysis

Correlation

Regression analysis was performed to statistically determine the correlation between two variables: soil nitrogen contents, as derived from the laboratory analysis, and NDVI. Correlation analysis only used linear regression because, in this study, only two variables were used, namely NDVI and soil nitrogen content. Relevant linear regression is used to determine the relationship between two variables in scientific research (Wicki & Parlow, 2017). Table 1 showed the correlation strength and its corresponding range of coefficient (r). The coefficient of correlation was calculated using equation 3.

$$r = \frac{n\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{\{n\Sigma x^2 - (\Sigma x)^2\}\{n\Sigma y^2 - (\Sigma y)^2\}}} \quad \text{...(3)}$$

Table 1. Strength of correlation between variables

Correlation Strength	Range of r
Very Weak	0.00–0.19
Weak	0.20–0.39
Moderate	0.40–0.59
Strong	0.60–0.79
Very Strong	0.80–1.00

Source: (Singh, 2018, p. 57)

RESULTS

Based on the analysis results, the soil in *subak*-irrigated rice fields in Denpasar City contained 0.09% to 0.31% N, with an average of 0.19%. The highest N level was found in sample 9, located in Subak Kerdung, South Denpasar. In contrast, sample 13 in Subak Dlod Sema, East Denpasar, had the lowest N. The difference in the soil N content was presented in Figure 3 and was spatially depicted in Figure 5a, where the blue polygon indicates the highest N, while the red one marks the lowest N.

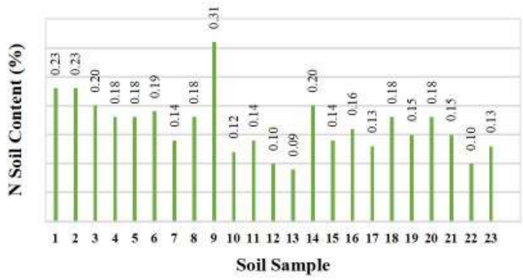

Figure 3. Graph of the soil nitrogen contents in *subak*-irrigated rice fields in Denpasar City

In addition to the soil N content, the analysis results also showed varying NDVI. The NDVI values were in the range of -0.31 to 0.91 (averagely 0.47) in 2019, -0.19 to 0.92 (0.54) in 2020, and -0.11 to 0.92 (0.53) in 2021. The average NDVI value in 2019–2021 was relatively the same, i.e., between 0.47 and 0.54. The histogram of the NDVI values for these three years is presented in Figure 4.

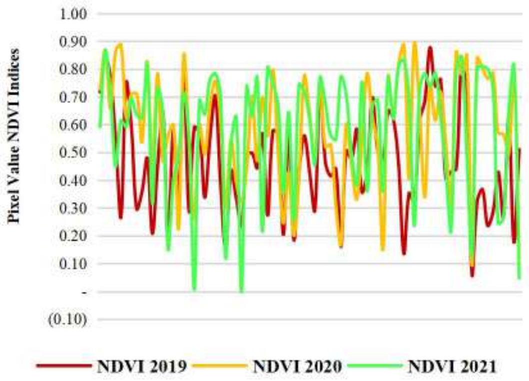

Figure 4. Histogram of differences in the NDVI pixel values of *subak*-irrigated rice fields in Denpasar City

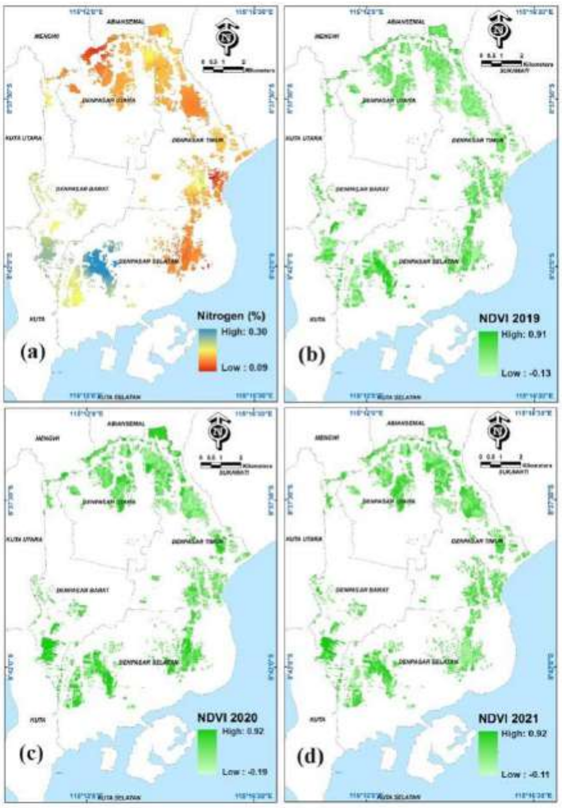

Figure 5. Spatial distribution of N content (a), 2019 NDVI (b), 2020 NDVI (c), NDVI 2021(d)

The NDVI values were showed in green gradations, with the greenest indicating the highest pixel value of *subak* land. Visually, based on the 2019 data displayed in Figure 5b, the high NDVI values were located in Subak Kerdung (South Denpasar), Semila and Tegallantang (West Denpasar), Padanggalak (East Denpasar), and Sembung (North Denpasar). The 2020 NDVI, presented in Figure 5c, was the highest in several *subak* lands such as Subak Kerdung and Renon (South Denpasar), Mergaya and Semila (West Denpasar), Padanggalak (East Denpasar), and Sembung (North Denpasar). As shown in Figure 5d, the highest NDVI in 2021 was in Subak Kerdung and Kepaon (South Denpasar), Mergaya (West Denpasar), Temaga (East Denpasar), and Sembung (North Denpasar).

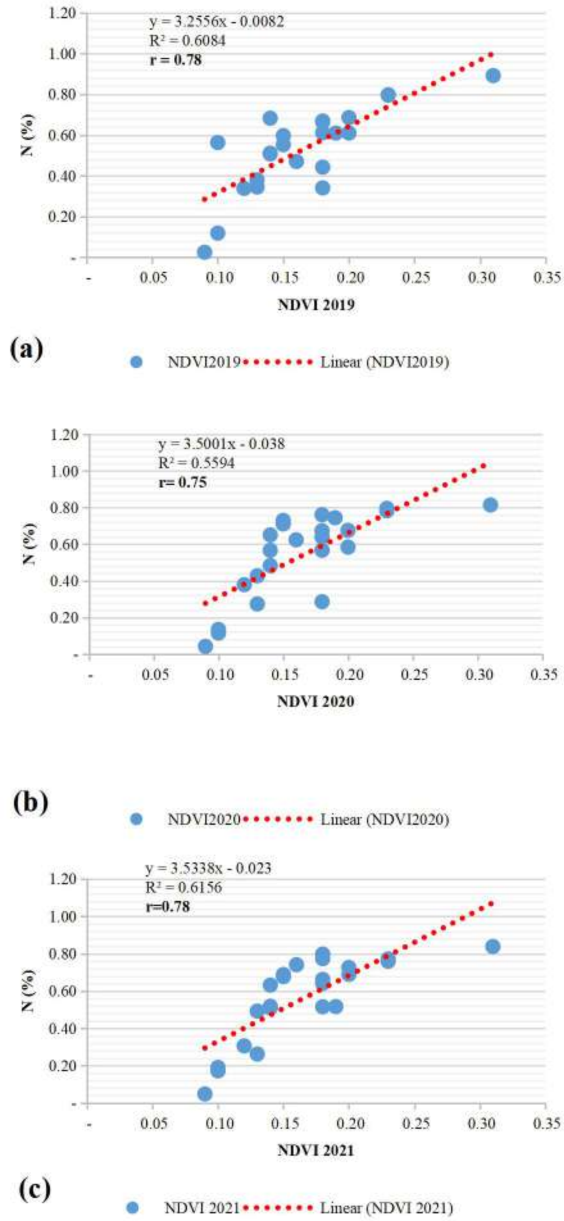

Figure 6. Correlation analysis results between soil N contents (%) and NDVI in 2019 (a), 2020 (b), 2021 (c)

The correlation between the soil N content (%) and NDVI was expressed in r and illustrated in Figure 6. The r in 2019 was 0.78, indicating a strong relationship between the two variables. This result was similar to the r in 2021, i.e., 0.78 (strong relationship). However, the correlation between the N content (%) and NDVI in 2020 was strong, as evident from r = 0.75. In other words, the highest coefficient of correlation between soil N content and NDVI was in 2021 (Figure 6c), while the lowest was in 2020 (Figure 6b).

DISCUSSION

The soil N content of the *subak* lands in North Denpasar was lower than that of South Denpasar because of at least two factors: altitude and slope. South Denpasar was 0−10 meters above sea level (masl) with 0−8% slopes, while North Denpasar lies > 50 masl on 15−25% slopes. Furthermore, when it rains, N was easily leached (Chen et al., 2021; Song et al., 2021) and then transported through the irrigation channels in the *subak* system before being sedimented in lowland rice fields with relatively flat slopes. Other factors that make the soil N content vary spatially and temporally were the presence of N-fixing microbes due to the use of biofertilizers (Bustomi et al., 2021; Sukmasari et al., 2021) and the volatile nature of N (Patti et al., 2018), which has implications to how plants in *subak* lands grow in response to this macronutrient.

The growth response of rice plants to the soil N content was reflected by the vegetation greenness level (NDVI), and this study has found a moderate to strong correlation between the N content and NDVI. Spatially, NDVI showed a different distribution pattern each year due to the uneven planting pattern and, thus, different growth phases. The highest NDVI value was in the vegetative stage (Liyantono et al., 2020; Rokhmatuloh et al., 2020), while the low NDVI (-0.13 to -0.19) in the *subak* lands was attributed to the phase of harvesting and dry fallow during which the response to the spectral reflectance value was generally low. Soil deficient in nutrients impedes the growth of rice plants, resulting in pale green to could occur because of the low chlorophyll production in plants (Tando, 2019). This study, however, has a weakness in that it only uses one vegetation index to scrutinize the growth response of *subak*-irrigated rice plants to soil N content. Therefore, for future research, it was necessary to compare it with other vegetation indices, such as the Soil Adjusted Vegetation Index (SAVI) and Enhanced Vegetation Index (EVI), and the water index like the Normalized Difference Water Index (NDWI). This comparison could represent the specific greenery level of rice plants with a few to no effects from other land covers.

CONCLUSION

The *subak*-irrigated rice fields in Denpasar City contain 0.09% to 0.31% soil N, with an average of 0.19%. The research has successfully derived NDVI using Sentinel-2A images acquired in 2019, 2020, and 2021. The NDVI values average 0.47 to 0.54. Furthermore, there was a moderate (R^2 = 0.56) to strong (R^2 = 0.62) correlation between soil N content and NDVI. Spatially, based on the 2019−2021 data, parts of Subak Kerdung, Mergaya, Padanggalak, and Sembung have high N levels and NDVI values.

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