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ESTIMATION OF POTASSIUM CONTENT IN SALAK PLANTS USING GREEN NORMALIZED DIFFERENCE VEGETATION INDEX METHOD IN WONOKERTO VILLAGE, TURI, SLEMAN, YOGYAKARTA

ESTIMASI KANDUNGAN KALIUM PADA TANAMAN SALAK MENGGUNAKAN METODE GREEN NORMALIZED DIFFERENCE VEGETATION INDEX DI KALURAHAN WONOKERTO, TURI, SLEMAN, YOGYAKARTA

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ABSTRACT

Salak (*Salacca zalacca*) is a major horticultural crop in Sleman Regency, Yogyakarta, yet recent years have seen a decline in its productivity, potentially due to potassium (K) deficiency. This study aims to estimate potassium content in Salak plant tissues using the Green Normalized Difference Vegetation Index (GNDVI) derived from Sentinel-2 satellite imagery and to evaluate the accuracy of this approach against laboratory-based measurements. The research was conducted in Wonokerto Village, Turi District, Sleman Regency, employing a quantitative descriptive method. A total of 30 sampling points were selected, comprising 20 prediction points and 10 reference points. GNDVI values were extracted through Sentinel-2 image processing using ArcGIS software, while potassium content in leaf tissue was determined via the wet digestion method using HNO_3 and $HClO_4$. Leaf samples were collected from the central part of the midrib, serving as a physiological indicator of plant nutrient status. Statistical analyses included Pearson's correlation, linear regression, paired sample t-test, and Root Mean Square Error (RMSE) assessment. The findings revealed a correlation coefficient (r) of 0.604, indicating a strong positive relationship between GNDVI and potassium content. The regression analysis showed no significant difference between predicted and observed values, while the RMSE value of 0.19445 suggested a low prediction error. These results demonstrate that GNDVI has strong potential as a non-destructive, efficient, and cost-effective tool for estimating potassium levels in Salak plant tissues. The resulting prediction map can be applied to support more precise potassium fertilization strategies in Salak cultivation within the study area.

Keywords: GNDVI, Potassium estimation, Precision agriculture, Salak Plants, Sentinel-2 imagery

ABSTRAK

Salak (*Salacca zalacca*) merupakan komoditas hortikultura unggulan di Kabupaten Sleman, Yogyakarta. Namun, dalam beberapa tahun terakhir mengalami penurunan produktivitas yang diduga disebabkan oleh defisiensi kalium (K). Penelitian ini bertujuan untuk mengestimasi kandungan kalium pada jaringan tanaman salak menggunakan indeks vegetasi *Green Normalized Difference Vegetation Index* (GNDVI) yang diperoleh dari citra satelit Sentinel-2 serta mengevaluasi akurasi pendekatan ini dibandingkan dengan hasil analisis laboratorium. Penelitian dilakukan di Desa Wonokerto, Kecamatan Turi, Kabupaten Sleman dengan menggunakan metode deskriptif kuantitatif. Sebanyak 30 titik sampel dianalisis, terdiri atas 20 titik prediksi dan 10 titik referensi. Nilai GNDVI diperoleh melalui pengolahan citra Sentinel-2 menggunakan perangkat lunak ArcGIS, sedangkan kandungan kalium dalam jaringan daun ditentukan dengan metode destruksi basah menggunakan HNO_3 dan $HClO_4$. Sampel daun diambil dari bagian tengah tulang daun sebagai indikator fisiologis status hara tanaman. Analisis statistik yang digunakan meliputi uji korelasi Pearson, regresi linier, uji t sampel berpasangan, dan perhitungan *Root Mean Square Error* (RMSE). Hasil penelitian menunjukkan nilai koefisien korelasi (r) sebesar 0,604 yang termasuk dalam kategori hubungan yang kuat antara nilai GNDVI dan kandungan kalium. Analisis regresi menunjukkan tidak terdapat perbedaan yang signifikan antara nilai hasil prediksi dan hasil pengamatan, sementara nilai RMSE sebesar 0,19445 mengindikasikan tingkat kesalahan prediksi yang rendah. Hasil ini menunjukkan bahwa GNDVI berpotensi sebagai metode estimasi kandungan kalium jaringan tanaman yang bersifat non-destruktif, efisien, dan ekonomis. Peta prediksi yang dihasilkan dapat dimanfaatkan untuk mendukung strategi pemupukan kalium yang lebih tepat pada budidaya salak di wilayah penelitian.

Kata kunci:* *Citra Sentinel-2, Estimasi kalium, GNDVI, Pertanian presisi, Tanaman Salak

INTRODUCTION

Salak (*Salacca zalacca*) is one of the leading horticultural commodities that plays a significant role in supporting the agricultural sector and regional exports in Sleman Regency, Special Region of Yogyakarta. Wonokerto Sub-district, Kapanewon Turi, serves as one of the main centers for Salak cultivation. According to data from Badan Pusat Statistik Kabupaten Sleman (2024), Salak production in 2021 reached 73,005 tons but declined to approximately 30,000 tons in 2024, accompanied by a reduction in cultivated land by around 150 hectares. This decline in productivity is allegedly due to suboptimal yield performance, which has prompted farmers to shift land use toward other commodities.

The productivity of Salak plants is influenced by the availability of essential macronutrients, one of which is potassium. Potassium plays a crucial role in various physiological processes in plants, including protein synthesis, the translocation of photosynthetic products, and enhancing resistance to both biotic and abiotic stressors. Potassium deficiency may lead to chlorosis and necrosis in leaf tissues, ultimately reducing both the quality and quantity of crop yields. Interviews with local agricultural extension officers revealed that fertilizer application by farmers is still based largely on experience, without adequate consideration of soil conditions and crop nutrient requirements. This practice contributes to inefficient fertilization, especially as potassium availability in intensively cultivated Salak plantations in Sleman tends to be low, while potassium fertilizers remain costly.

Conventional laboratory-based analysis of plant tissue nutrient content is often time-consuming and expensive, particularly for large-scale monitoring. In line with technological advancements, remote sensing and geographic information systems (GIS) have emerged as alternative tools for assessing plant nutrient status in a more efficient and non-destructive manner. One promising approach is the use of the Green Normalized Difference Vegetation Index (GNDVI), which is sensitive to chlorophyll content and can serve as an indirect indicator of potassium status in plants. GNDVI was specifically developed to estimate plant chlorophyll levels and is known to exhibit slower saturation compared to NDVI.

Therefore, this study aims to estimate potassium content in salak plants using the GNDVI approach in Wonokerto Sub-district, Kapanewon Turi, Sleman Regency, Special Region of Yogyakarta. The results of this study are expected to provide insights into the potassium status of salak plants in the study area, serving as a valuable reference for farmers, local communities, and relevant stakeholders in improving fertilizer management practices.

MATERIALS AND METHODS

This research was conducted from March to May 2025 in the salak (*Salacca zalacca*) plantation area of Wonokerto Sub-district, Kapanewon Turi, Sleman Regency, Special Region of Yogyakarta. The study area covered 8.59 hectares. Laboratory analysis of potassium content in plant tissues was carried out at the Chemistry Laboratory, Sebelas Maret University.

The tools used in this study included a mobile phone, GPS device, knife, plastic bags, markers, soil auger, icebox, laptop, ArcGIS 10.8 software, SPSS Statistics 26, soil sieve, oven, grinding machine, 0.5 mm filter paper, digital balance, digestion tubes, microwave digestion system, laboratory dispensette, tube shaker, test tubes, and an Atomic Absorption Spectrophotometer (AAS). The materials used consisted of a 1:25,000 scale Rupa Bumi Indonesia shapefile, Sentinel-2B satellite imagery, leaf samples, soil samples, concentrated nitric acid (HNO_3, 65%) p.a., concentrated perchloric acid ($HClO_4$, 60%) p.a., potassium standard solution, and distilled water.

The study employed a descriptive quantitative method, combining spatial data analysis with field survey data. Sampling locations for leaf and soil were determined using a random sampling technique. A total of 30 sampling points were established, comprising 20 prediction points and 10 reference points. The prediction points were used to build the regression model, while the reference points were used to test for differences between predicted and observed values.

Leaf samples were collected from four midribs representing the four cardinal directions, specifically using the 25th leaflet from each midrib. Soil samples were taken at a depth of 0–30 cm using a soil auger. The research began with a preliminary field survey and the development of a GNDVI (Green Normalized Difference Vegetation Index) map, which was used to guide sampling point selection. Subsequently, samples were collected for laboratory analysis of potassium content in plant tissues and exchangeable potassium (K-dd) in soil.

Laboratory data were analyzed using correlation analysis, linear regression, and paired sample t-tests to assess relationships with vegetation index values, using SPSS Statistics 26 software. The accuracy of the regression model was evaluated using Root Mean Square Error (RMSE). The final output of this study was a prediction map of Salak tissue potassium content, generated by applying the regression formula results to the Raster Calculator tool in ArcGIS.

Green Normalized Difference Vegetation Index Analysis

The Green Normalized Difference Vegetation Index (GNDVI) was used as the basis for determining sampling points. This required Sentinel-2B satellite imagery acquired on 7 April 2025. The Sentinel-2B image was processed using the GNDVI method. According to Gitelson et al. (1996), the GNDVI formula is presented in Equation 1.

$$\text{GNDVI} = \frac{(\lambda\text{NIR} - \lambda\text{Green})}{(\lambda\text{NIR} + \lambda\text{Green})} \quad (1)$$

Description:

GNDVI = *Green Normalized Difference Vegetation Index*

NIR = Near infrared channel reflectance value (*band* 8)

Green = Green edge channel reflectance value (*band* 3)

The GNDVI formula was applied using the Raster Calculator tool in the ArcGIS software. The resulting GNDVI vegetation index output was then clipped to the boundaries of Wonokerto Village using the Extract by Mask tool. Further processing included overlaying the index map with the research area to generate a sampling point distribution map. The GNDVI values were classified into three categories through a reclassification process (Figure 1).

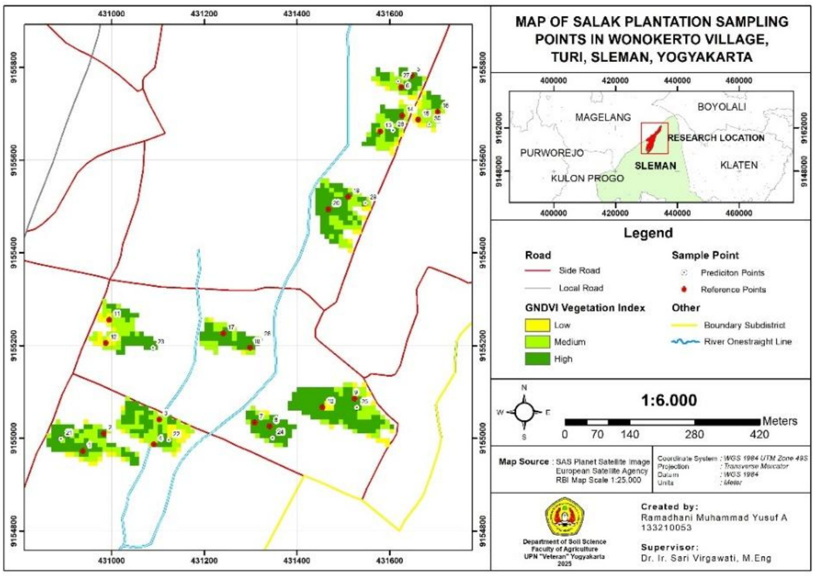

Figure 1. Map of Sampling Points in the Research Area, Wonokerto Sub-district

Based on Figure 1, GNDVI values in the study area ranged from 0.189 to 0.437. The classification scheme for GNDVI values is shown in Table 1. The study area was predominantly classified as Class 5 (High Greenness). A small portion of Class 2 to Class 3 (yellow tones) appeared along the plantation edges. These peripheral zones consisted of field areas, unused land, and nearby settlements. Salak plants located in the central part of the plantation block were generally classified as Class 4 to Class 5 (light to dark green tones).

Table 1. Classification of GNDVI Vegetation Index Values

Class	Range Value	Description
1	-1 – 0	No Greenness
2	0,1 – 0,15	Very Low Greenness
3	0,16 – 0,25	Low Greenness
4	0,26 – 0,35	Moderate Greenness
5	0,36 – 1	High Greenness

Source: Candiago et al. (2015)

RESULTS AND DISCUSSION

General Conditions of the Research Area

Wonokerto Sub-district, Kapanewon Turi is located in the northern part of Sleman Regency, Special Region of Yogyakarta. Geographically, it lies between 110°21'47.7" E – 110°24'36.9" E and 7°37'1.2" S – 7°34'34.6" S. The sub-district covers an area of approximately 1,558 hectares consisting of 13 hamlets with a total population of around 8,904 residents. It is situated at an elevation ranging from 400 to 900 meters above sea level with slopes between 5% and 25%, and lies on the foothills of Mount Merapi.

According to the soil type map published by the Badan Perencanaan Pembangunan Daerah Istimewa Yogyakarta (2022) at a scale of 1:100,000 (2022), the Wonokerto area consists of three dominant soil types: Regosol, Andosol, and Latosol. Based on the Schmidt-Ferguson climate classification, the area falls into the moderate climate category (Type C) with a climatic index (Q) ranging from 60.1% to 100.0%, indicating a relatively balanced number of wet and dry months. The average annual rainfall in this area is approximately 2,259.8 mm.

Salak Farms Characteristics and Management Practices

Each farm exhibited different cultivation management practices and topographical characteristics, both of which can directly or indirectly influence nutrient availability and uptake by plants. The characteristics and management practices of Salak farms in the study area are presented in Table 2.

Table 2. Characteristics and Management of Salak Farms in the Study Area

Farm Plot	Elevation (m)[1]	Slope (%)[1]	Farm Management Type [2]	Fertilizer Type [2]	Fertilizer Frequency [2]	Fertilizer Dosage (kg and L) [2]	Application Method [2]	Irrigation System [2]
1	439 – 442	4	Traditional-Minimalist	Organic goat manure and LOF[*]	once/ month	40 kg and 1 L	Sow and Dribble	Surface Irrigation
2	441 – 445	10	Traditional-Passive	Not fertilized	-	-	-	Surface Irrigation
3	482 – 489	12	Traditional-Passive	Not fertilized	-	-	-	Surface Irrigation
4	450 – 454	10	Traditional-Adaptive	Organic cattle manure, LOF[*] and NPK[**]	twice/ month	60 kg, 1 L, and 0,2 kg	Tugal, Sow, and Poke	Surface Irrigation
5	451 – 456	6	Traditional-Adaptive	Organic cattle manure, LOF[*] and NPK[**]	twice/ month	60 kg, 1 L, and 0,2 kg	Tugal, Sow, and Poke	Surface Irrigation
6	450 – 455	12	Traditional-Minimalist	Organic cattle and goat manure and LOF[*]	twice/ month	20 kg and 1,5 L	Sow and Poke	Surface Irrigation
7	475 – 481	12	Traditional-Adaptive	Organic cattle manure, LOF[*] and NPK[**]	once/ month	60 kg, 1,5 L, and 0,2 kg	Tugal, Sow, and Poke	Surface Irrigation
8	479 – 485	7	Traditional-Minimalist	Organic cattle and goat manure, LOF[*]	once/ month	60 kg and 1,5 L	Sow and Poke	Surface Irrigation
9	452 – 454	6	Traditional-Minimalist	Organic goat manure and LOF[*]	once/ month	40 kg and 1 L	Sow and Poke	Surface Irrigation
10	466 – 474	6	Traditional - Minimalist	Organic goat manure and LOF[*]	once/ month	40 kg and 1 L	Sow and Poke	Surface Irrigation

Source : [1] Badan Informasi Geospasial (2018)
[2] Personal Interviews and Field Surveys
Description : [*] LOF = Liquid Organic Fertilizer
[**] NPK = Nitrogen, Phosphorus, and Potassium Blend Fertilizer

Based on Table 2, the ten farm plots in the study area showed variation in management type, fertilizer type, application frequency and method, as well as fertilization systems. Elevations across the sites ranged from 439 to 482 metres above sea level, with slope gradients between 4% and 12%, indicating that the study area is predominantly flat to gently undulating. Such topographical conditions can affect soil moisture distribution, surface runoff potential, and the accumulation of nutrients like potassium in certain plots. According to Dumasari (2020), farmers' adoption of crop cultivation technologies can be categorized into three types: traditional-passive, traditional-minimalist, and traditional-adaptive. Some farms in the study area implemented traditional-adaptive management, characterized by regular fertilization using a combination of solid organic fertilizer, liquid organic fertilizer, and NPK fertilizer. In contrast, other farms did not apply fertilizers at all or relied solely on organic inputs. Traditional-adaptive farms typically applied fertilizer twice per month using pouring or broadcasting methods.

These differences in management practices influence both the accumulation and availability of nutrients in the soil, as well as nutrient uptake efficiency by plants. Farms that applied a complete fertilizer regime, both in type and intensity, generally exhibited higher potassium availability in both soil and plant tissues compared to farms with no fertilization or those using limited organic inputs. Furthermore, application methods such as pouring may enhance nutrient uptake efficiency by improving root absorption. Therefore, variations in farm management practices play a significant role in determining the nutrient status of Salak soils and plants.

Correlation Analysis between GNDVI and Potassium Content

The Pearson Product Moment correlation test was conducted to determine the strength and direction of the relationship between GNDVI values and potassium content in Salak plant tissues. The correlation between each GNDVI pixel value and the corresponding potassium content in Salak plant tissues within the study area is presented in Table 3.

Table 3. Correlation of GNDVI with Salak Plant Tissue Potassium

Sample Point	GNDVI Index	GNDVI Classification[1)]	K-Tissue (%)	K-Tissue Score [2)]
1	0,416147	Moderate	2,21	Sufficient
2	0,419120	High	2,44	Sufficient
3	0,367476	High	1,73	Sufficient
4	0,408636	High	2,15	Sufficient
5	0,418654	High	2,43	Sufficient
6	0,419596	High	2,47	Sufficient
7	0,407272	Moderate	1,75	Sufficient
8	0,400892	High	1,95	Sufficient
9	0,389397	Moderate	1,80	Sufficient
10	0,401361	Low	1,96	Sufficient
11	0,392857	Moderate	2,02	Sufficient
12	0,338674	High	1,72	Sufficient
13	0,395749	High	2,59	High
14	0,432694	Moderate	1,86	Sufficient
15	0,418389	High	1,94	Sufficient
16	0,355601	High	1,73	Sufficient
17	0,407262	High	2,02	Sufficient
18	0,403371	High	1,97	Sufficient
19	0,411927	Moderate	2,18	Sufficient
20	0,415217	High	2,19	Sufficient
21	0,395342	High	1,85	Sufficient
22	0,405678	High	1,84	Sufficient
23	0,423533	High	2,53	High
24	0,407675	Low	2,12	Sufficient
25	0,400640	Moderate	1,95	Sufficient
26	0,337570	Moderate	1,26	Low
27	0,398040	Moderate	1,94	Sufficient

Sample Point	GNDVI Index	GNDVI Classification[1)]	K-Tissue (%)	K-Tissue Score [2)]
28	0,386517	Moderate	2,03	Sufficient
29	0,396330	Moderate	1,74	Sufficient
30	0,377615	High	2,34	Sufficient
Mean	0,398307		2,02	
Standard deviation	0,02		0,29	
Correlation Coefficient (r)			**0,604**	

Source :[1)] GNDVI Reclassification Result recording 7 April 2025
[2)] Bryson et al. (2014)

Based on Table 3, the Pearson Product Moment correlation coefficient was r = 0.604. According to Jabnabillah and Margina (2022), this value falls into the strong correlation category. This indicates a strong and positive relationship between GNDVI values and potassium content in Salak plant tissues. The positive correlation coefficient implies that an increase in the GNDVI index corresponds to an increase in the potassium content of the Salak plant tissue.

Linear Regression Analysis of GNDVI and Tissue Potassium

A linear regression analysis was conducted to model and examine the effect of the independent variable (GNDVI vegetation index value) on the dependent variable (potassium content in Salak plant tissue). The analysis was performed using sample points 1–20. The results of the regression analysis are presented graphically in Figure 2.

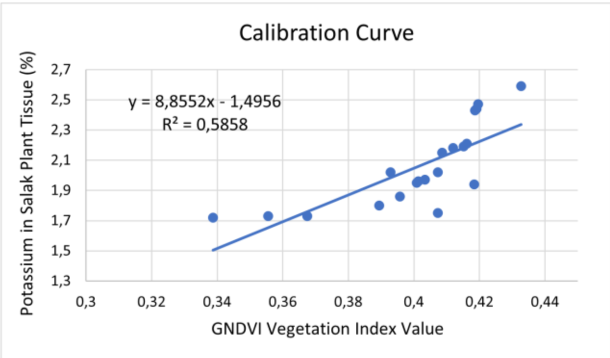

Figure 2. Relationship between GNDVI Vegetation Index and Potassium Content in Salak Plant Tissue.

The regression equation derived from Figure 2 is y = 8.8552x – 1.4956, with a coefficient of determination (R^2) of 0.5858. This indicates that 58.58% of the variation in Salak plant tissue potassium content can be explained by the GNDVI vegetation index. The remaining 41.42% of the variation is attributed to other factors not included in this study, which may be related to environmental and site-specific conditions of the research area.

According to Li et al. (2021), topographic factors such as slope, elevation, and humidity can explain 66–79% of the variation in plant and soil nutrient content, outperforming models based solely on satellite-derived vegetation indices. Variations in slope across different farm blocks may influence the accumulation of potassium and other organic matter. Even when soil type and farm management practices are relatively uniform, topography remains a key factor affecting potassium availability and mobility in both soil and plants. Therefore, spectral indices like GNDVI alone may lack critical information needed for accurate prediction of tissue potassium content in the absence of topographic and environmental variables.

Regression Model Accuracy Level

The accuracy of the regression model y=8.8552x−1.4956 was assessed using the Root Mean Square Error (RMSE), which evaluates the model's predictive performance by measuring the average deviation between the predicted and observed potassium content in Salak plant tissue. The RMSE formula is presented in Equation 2.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(yi - \hat{y}i)^2}{n}} \qquad (2)$$

Description:

y = observed/ actual/ factual value

$\hat{y}$ = predicted value

i = sequence data in the database

n = number of data

Based on the calculations, the RMSE value obtained was ±0.19445. This indicates that the model's prediction of tissue potassium content using GNDVI values has an average error margin of approximately 0.19%. When applied outside the research coverage area, the predicted values may deviate from actual values by this margin. In a related study by Peng et al. (2022) on estimating nitrogen, phosphorus, and potassium content in grape leaves using UAV multispectral imagery, it was reported that models with RMSE values below 0.20 exhibit good accuracy and are considered sufficiently reliable for satellite-based potassium estimation. RMSE reflects the prediction error; values closer to zero indicate better model accuracy. Therefore, the obtained RMSE value suggests that the GNDVI-based regression model developed in this study demonstrates a reasonably high level of accuracy.

Paired-Samples T Test Analysis

The paired-samples T test, a form of comparative hypothesis testing, was used to evaluate the difference between the mean predicted potassium content and the reference (observed) potassium content in Salak plant tissue. The analysis was conducted using sample points 21–30. The results of the test are presented in Table 4.

Table 4. Paired-Samples T Test Results for Predicted and Reference Tissue Potassium Values

Description	N	Mean	Standard deviation	Standard error of mean
K-Tissue Prediction	10	1,978	0,203	0,064
K-Tissue Reference	10	1,960	0,344	0,108
Paired Test	10	0,018	0,079	0,079
T test = 0,227			Sig. (2-tailed) = 0,825	
T table = 2,262			α = 0,05 (5%)	
T test < T table			**Sig. (2-tailed) > α**	

Based on Table 4, the calculated *t*-value is 0,227, and the *Sig.* (2-tailed) value is 0,825. According to Santoso (2014), decision-making in the paired-samples T test can be based on either the *t*-value or the *Sig.* (2-tailed) value. Since the *Sig.* (2-tailed) value is greater than 0.05 (0,825 > 0,05), the null hypothesis (H_0) is accepted, and the alternative hypothesis (H_1) is rejected. This means that there is no statistically significant difference between the predicted and observed (reference) values of tissue potassium. Additionally, since the calculated *t*-value (0,227) is less than the critical *t*-table value (2,262), the conclusion remains the same: H_0 is accepted. Thus, the regression model y=8.8552x−1.4956 is considered statistically valid and can be used for estimating potassium content in Salak plant tissue based on GNDVI values.

Estimation of Salak Plant Tissue Potassium

The estimation map was generated by applying the regression equation y=8.8552x−1.4956 using the Raster Calculator tool in ArcMap 10.3 (ArcGIS). This process converted the GNDVI vegetation index values into predicted potassium content values of Salak plant tissues across the study area. The resulting map of estimated potassium levels in Salak plant tissues is presented in Figure 3.

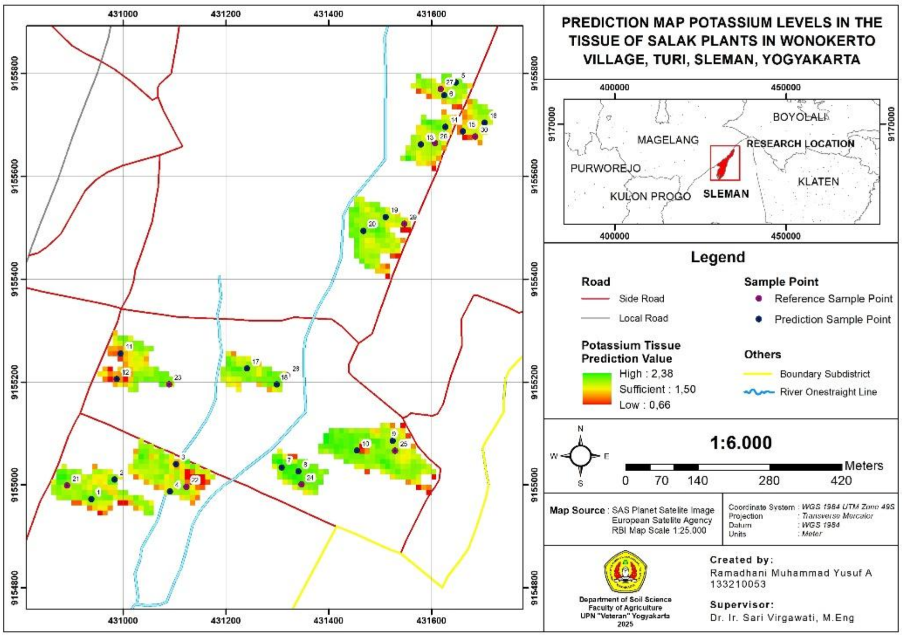

Figure 3. Estimated map of potassium content in Salak plant tissues in the study area

The distribution of predicted potassium content based on Figure 3 ranges from 0.66% to 2.38%. According to the classification proposed by Bryson et al. (2014), potassium levels in Salak plant tissue are categorized into three groups: low (0.70% to 1.50%), sufficient (1.51% to 2.50%), and high (2.51% to 4.00%). The predicted potassium content in this study area is dominated by values in the sufficient category, which is consistent with the laboratory analysis results.

The adequacy of potassium levels in Salak tissues may be influenced by the farm management practices commonly applied in the study area. Based on interviews with farmer group leaders, most Salak farmers only apply organic fertilizers such as manure, and even this is not always done regularly. The application of fertilizers that specifically supply potassium, such as potassium chloride (KCl), potassium sulfate (K_2SO_4), or NPK 12-6-24 is rare. This condition may be related to the declining priority of Salak cultivation among local farmers. Many farmers who own Salak plantations also manage rice fields or dryland plots and tend to shift toward cultivating seasonal horticultural crops that are considered more profitable.

CONCLUSION

Based on the research conducted, the following conclusions can be drawn:

1. There is a strong relationship between the greenness of Salak leaves, as measured through satellite imagery using the GNDVI index, and the potassium content in Salak plant tissues.
2. The linear regression model developed using the GNDVI index demonstrates that this approach is feasible and effective for monitoring potassium levels in Salak plant tissues.
3. The prediction model exhibits a relatively low error rate of approximately ±0.19445 indicating good accuracy and alignment with field conditions.
4. The estimated potassium levels in salak plant tissues, as shown in the prediction map, predominantly fall within the sufficient range, suggesting that the plants are in relatively good nutritional condition.

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