# INTEGRATION OF SCIENCE (NATURAL SCIENCES), REMOTE SENSING, AND NIAS LOCAL WISDOM IN MODELING FOOD CROP PRODUCTIVITY

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**Abstract**

This study aims to develop an integrated model for food crop productivity by combining natural sciences, remote sensing technology, and Nias local wisdom in South Nias Regency, Indonesia. The agricultural sector in this region faces challenges such as low productivity, soil fertility variability, and limited access to modern agricultural monitoring systems. To address these issues, a mixed-methods approach was applied, integrating quantitative geospatial analysis and qualitative ethnographic data. Remote sensing data from Sentinel-2 and Landsat satellites were used to extract vegetation indices (NDVI) for assessing crop health and spatial productivity patterns. Soil parameters and climatic variables from natural sciences were incorporated to explain biophysical factors influencing crop growth. In addition, local wisdom practices such as organic farming, mixed cropping, and traditional planting systems were quantified into a Local Wisdom Index (LWI). The data were analyzed using Geographic Information Systems and machine learning models to generate a predictive productivity map. The results show that the integrated model significantly improves prediction accuracy compared to single-source approaches, with strong spatial consistency between vegetation health, soil fertility, and traditional farming practices. This study demonstrates that combining scientific data, geospatial technology, and indigenous knowledge provides a more holistic and sustainable framework for agricultural productivity modeling in tropical rural regions.

**Keywords:** *Food Crop Productivity; Remote Sensing; Natural Sciences; Local Wisdom; Nias Selatan; NDVI; Precision Agriculture; Machine Learning*

## A. Introduction

South Nias Regency, located in the southern part of Nias Island, North Sumatra, Indonesia, is an archipelagic region characterized by diverse agro-ecological conditions, including coastal lowlands, undulating hills, and limited irrigated agricultural land. The agricultural sector remains the main livelihood for most rural communities, with food crops such as rice, maize, cassava, and local tubers forming the backbone of household food security (Harefa, D. 2024). However, agricultural productivity in this region is still relatively low and highly variable due to soil fertility constraints, climate variability, limited irrigation infrastructure, and traditional farming practices that are not yet fully supported by modern scientific approaches Tafonao et al., 2024). Strengthening agricultural productivity in South Nias therefore requires an integrated framework that combines natural sciences, geospatial technologies, and indigenous knowledge systems to enhance sustainable food crop production.

Remote sensing technology has become a critical tool in modern agricultural monitoring and crop productivity modeling. Satellite platforms such as Landsat, Sentinel-2, and MODIS provide high-resolution spatial and temporal data that allow researchers to assess vegetation health, land use dynamics, soil moisture, and crop growth patterns over large and inaccessible areas (Wolanin et al., 2020). Vegetation indices such as NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) are widely used to estimate crop condition and predict yield variability. Recent studies demonstrate that machine learning models combined with multisource satellite data significantly improve crop yield estimation accuracy compared to traditional field-based approaches, particularly in regions with limited agricultural monitoring infrastructure Mateo-Sanchis et al. (2020). This makes remote sensing especially relevant for geographically fragmented areas like South Nias, where field data collection is often constrained.

From a natural sciences perspective, agricultural productivity is strongly influenced by soil properties, nutrient availability, hydrological conditions, and plant physiological responses. Soil science and agronomy provide the foundation for understanding how physical, chemical, and biological soil characteristics affect plant growth and yield formation (Harefa, D, 2025). In South Nias, studies indicate that soil fertility is closely linked to organic matter content, traditional composting practices, and cropping patterns adapted to local environmental conditions. Integrated soil management approaches, including organic amendments and crop rotation, have been shown to improve soil quality and productivity sustainability. When combined with scientific soil analysis and ecological modeling, these approaches can significantly enhance agricultural output while maintaining ecosystem balance (Ibrahim, 2019).

Local wisdom (kearifan lokal) in South Nias plays a fundamental role in shaping agricultural systems that are adaptive to environmental conditions and climate variability. Traditional farming knowledge includes communal land management, organic fertilization practices, crop rotation systems, and culturally embedded agricultural calendars that guide planting and harvesting activities (Harefa, D. 2025). These indigenous practices have been proven to contribute positively to soil fertility improvement, biodiversity conservation, and long-term sustainability of agricultural land. However, despite its importance, local knowledge is often underrepresented in formal agricultural modeling and scientific decision-support systems (Widodo & Purnomo, 2017). Integrating local wisdom into modern agricultural science can bridge the gap between empirical knowledge and technological innovation, ensuring that agricultural development is both culturally relevant and environmentally sustainable.

Despite advances in remote sensing and agricultural modeling, most existing studies treat scientific data, geospatial technology, and local wisdom as separate components rather than integrated systems. In South Nias, agricultural research has largely focused on

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partial aspects such as technology adoption, soil fertility improvement, or productivity analysis without combining these elements into a unified predictive model (Zega, 2025). This fragmentation limits the ability to develop accurate, context-sensitive agricultural decision-support systems that reflect real-world farming conditions. Recent global studies emphasize the importance of integrating multisource data—including satellite imagery, weather variables, and field observations—using machine learning and geospatial analytics to improve crop yield prediction accuracy (Michler et al., 2020).

Therefore, integrating natural sciences, remote sensing technology, and Nias local wisdom offers a novel and interdisciplinary approach to modeling food crop productivity in South Nias Regency. This integrative framework enables the combination of biophysical crop parameters, satellite-derived environmental indicators, and socio-cultural farming practices into a unified analytical system (Wolanin et al., 2020). Such a model is expected to improve the accuracy of productivity forecasting, support precision agriculture, and provide actionable insights for policymakers and farmers. Moreover, it contributes to the development of sustainable agricultural systems that are both technologically advanced and culturally grounded, ensuring long-term food security and environmental resilience in the region (Harefa, D 2025).

## B. Research Methodology

### 1. Research Design

This study employs a mixed-methods approach combining quantitative and qualitative designs to develop a comprehensive model of food crop productivity in South Nias Regency. The quantitative component focuses on geospatial analysis and crop productivity modeling using remote sensing and natural science variables, while the qualitative component integrates local wisdom practices of Nias farming communities. This integrated approach is widely recommended in agricultural system studies to capture both biophysical and socio-cultural dimensions of productivity (Wolanin et al., 2020; Gyamfi et al., 2024).

### 2. Study Area

The research is conducted in South Nias Regency, North Sumatra, Indonesia, a tropical archipelagic region characterized by heterogeneous topography, including coastal lowlands and hilly inland agricultural zones. The area is selected due to its dependence on food crop agriculture and the presence of strong indigenous farming systems rooted in Nias local wisdom. The variability in soil conditions, rainfall patterns, and land use makes it an ideal location for integrating remote sensing-based agricultural modeling with field-based agronomic and socio-cultural data (Tafonao et al., 2024; Harefa, 2024).

### 3. Data Collection

Data collection involves three main components:

a. Remote sensing data obtained from satellite imagery (e.g., Landsat 8 and Sentinel-2) to extract vegetation indices such as NDVI and EVI for assessing crop health and productivity patterns.

b. Natural science data, including soil properties (pH, organic carbon, nitrogen content), rainfall, temperature, and land

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slope, collected through field sampling and secondary meteorological datasets.

c. Local wisdom data, gathered through structured interviews, participatory observation, and focus group discussions with local farmers to document traditional agricultural practices such as crop rotation, organic fertilization, and culturally guided planting calendars.

The integration of multisource datasets is essential in precision agriculture and has been proven to improve predictive accuracy in crop modeling systems (Mateo-Sanchis et al., 2020).

**4. Data Analysis**

Quantitative data are analyzed using Geographic Information Systems (GIS) and machine learning algorithms such as Random Forest and Multiple Linear Regression to develop a crop productivity prediction model. Satellite-derived vegetation indices are used as independent variables, while crop yield data serve as dependent variables. Soil and climate parameters are included as biophysical predictors.

Qualitative data from local wisdom are analyzed using thematic analysis, identifying key indigenous agricultural practices and converting them into measurable socio-agronomic indicators (e.g., "local ecological management index"). These indicators are then integrated into the predictive model to improve contextual accuracy. This hybrid modeling approach reflects current developments in smart agriculture and Earth observation analytics, where data-driven methods are combined with human ecological knowledge systems (Alreshidi, 2019; Wolanin et al., 2020).

5. Model Development and Validation

The final model integrates three components:

a. **Natural science variables** (soil, climate, topography)
b. **Remote sensing variables** (NDVI, land surface reflectance)
c. **Local wisdom index** (indigenous farming practices)

Model validation is conducted using cross-validation techniques and comparison with actual agricultural yield data obtained from local agricultural offices. Model accuracy is assessed using statistical indicators such as $R^2$, RMSE (Root Mean Square Error), and MAE (Mean Absolute Error).

This integrated validation approach ensures robustness and reliability of the predictive model in heterogeneous agricultural environments such as South Nias (Gyamfi et al., 2024).

## C. Results and Discussion

**Data Analysis of Research Results**

**1. Remote Sensing–Based Vegetation Analysis**

The analysis of satellite imagery using NDVI (Normalized Difference Vegetation Index) from Sentinel-2 and Landsat data revealed significant spatial variability in vegetation health across South Nias Regency. Areas located in lowland agricultural zones showed higher NDVI values (0.65–0.82), indicating healthy and dense vegetation, while upland and coastal dryland areas exhibited moderate to low NDVI values (0.30–0.55). This spatial variation reflects differences in soil moisture availability, land management practices, and crop types cultivated by farmers.

These findings are consistent with previous studies demonstrating that NDVI is a reliable indicator for monitoring crop health and estimating productivity across large agricultural landscapes. NDVI-based models are widely used in agricultural remote sensing because they correlate strongly with chlorophyll activity and biomass accumulation, enabling large-scale crop monitoring with high accuracy (Wolanin et al., 2020). In addition, recent advances in machine learning integration with NDVI have improved the precision of crop condition classification, enabling differentiation between healthy, stressed, and low-yielding crops with high accuracy exceeding 90% in experimental models (Judith et al., 2025). This reinforces the reliability of satellite-based monitoring for agricultural decision-making in South Nias.

**2. Soil and Natural Science Variables in Productivity Modeling**

Soil analysis results from field sampling indicated variation in key fertility parameters such as soil organic carbon (1.2%–3.5%), nitrogen content (0.08%–0.25%), and pH levels ranging from acidic (5.2) to moderately neutral (6.8). These variations significantly influenced crop productivity patterns across different villages in South Nias.

Areas with higher organic matter content and balanced nitrogen levels showed higher crop yield estimates, confirming the strong relationship between soil fertility and agricultural productivity. Agronomic studies emphasize that soil physical and chemical properties remain fundamental drivers of crop yield formation, especially in tropical agroecosystems where nutrient depletion is common due to intensive rainfall and erosion processes (Harefa, D. 2026).

The integration of soil science with geospatial data allows more accurate modeling of crop productivity, as biophysical parameters directly influence vegetation indices derived from satellite imagery. Machine learning–based models that incorporate soil variables alongside remote sensing data have been shown to significantly improve predictive accuracy compared to single-source models (Mateo-Sanchis et al., 2020).

**3. Integration of Local Wisdom into Productivity Modeling**

The qualitative analysis of Nias local wisdom revealed that traditional agricultural practices play a significant role in maintaining soil fertility and stabilizing crop productivity. Farmers in South Nias commonly apply organic composting, mixed cropping systems, rotational planting, and culturally guided agricultural calendars based on ancestral knowledge.

These practices contribute to improved soil structure, increased organic matter, and reduced dependency on synthetic fertilizers. Research in South Nias has shown that local wisdom is strongly linked to sustainable soil management and agricultural resilience, particularly in rural communities with limited access to modern inputs (Harefa, 2024).

To incorporate local knowledge into the quantitative model, a "Local Wisdom Index (LWI)" was developed based on indicators such as organic farming intensity, traditional land management adherence, and community-based farming practices Widodo & Purnomo, 2017).. This index was normalized and integrated into the regression and machine learning models as a socio-cultural predictor variable.

Studies confirm that integrating indigenous knowledge into agricultural modeling enhances contextual accuracy and improves system sustainability, especially in smallholder farming systems (Harefa, 2024)

**4. Integrated Productivity Model Performance**

The final integrated model combined three main components:
(1) remote sensing variables (NDVI, EVI),
(2) natural science variables (soil fertility and climate factors), and
(3) local wisdom index (LWI).

Using a Random Forest regression algorithm, the integrated model achieved a coefficient of determination ($R^2$) of 0.87, indicating strong predictive capability (Wolanin et al., 2020). The Root Mean Square Error (RMSE) was significantly lower compared to models that used only NDVI or soil data independently. This demonstrates that multi-source integration substantially improves crop productivity prediction accuracy (Harefa, D. 2025).

Recent global research supports this finding, showing that combining satellite data, environmental variables, and machine learning significantly enhances crop yield estimation performance, especially in heterogeneous agricultural landscapes (Mateo-Sanchis et al., 2020).

The improvement in model accuracy highlights the importance of integrating socio-ecological factors, not only biophysical parameters, in agricultural productivity modeling systems.

**5. Spatial Distribution of Crop Productivity**

The spatial output of the model revealed that high productivity zones are concentrated in central inland areas of South Nias, where soil fertility is relatively higher and traditional farming systems are still actively practiced. Low productivity zones were identified in coastal drylands and degraded upland areas, where soil erosion and limited water availability reduce agricultural potential.

These spatial patterns align with remote sensing–based environmental change studies in Nias, which indicate declining vegetation density in areas affected by land degradation and climate variability (Tampubolon et al., 2017).

The integration of spatial analysis and local knowledge provides a more realistic representation of agricultural conditions compared to conventional yield estimation methods.

**Analysis of Research Results**

**1. Spatial Pattern of Vegetation and Crop Condition**

The analysis of remote sensing data using NDVI derived from Sentinel-2 imagery reveals a clear spatial heterogeneity of vegetation health across South Nias Regency. High NDVI values (0.65–0.82) are predominantly found in inland agricultural zones, indicating dense and healthy vegetation associated with relatively fertile soils and active farming practices. Conversely, coastal and upland marginal areas exhibit lower NDVI values (0.30–0.55), suggesting stressed vegetation conditions due to soil degradation, limited water availability, and less intensive agricultural management.

These results confirm that vegetation indices derived from satellite imagery are reliable indicators of crop condition and biomass distribution. NDVI has been widely validated as a proxy for vegetation vigor and is strongly correlated with chlorophyll content and photosynthetic activity, making it suitable for large-scale agricultural monitoring. The integration of remote sensing enables continuous observation of crop dynamics in regions where field-based monitoring is limited due to geographic constraints such as those in Nias Selatan (Harefa, D. 2025).

Recent studies also highlight that combining NDVI with machine learning algorithms improves spatial prediction accuracy of crop productivity, especially in heterogeneous landscapes Abdul Mutolib., et al. (2025). This supports the reliability of remote sensing as a core component in agricultural modeling systems.

**2. Influence of Soil and Natural Science Variables**

Soil analysis results indicate that agricultural productivity in South Nias is strongly influenced by variations in soil fertility parameters. Soil organic carbon ranges between 1.2% and 3.5%, nitrogen content varies from 0.08% to 0.25%, and soil pH fluctuates from acidic (5.2) to near neutral (6.8). These variations significantly affect crop growth performance and yield potential.

Areas with higher organic matter and balanced nutrient content show higher predicted productivity levels, confirming the central role of soil fertility in determining agricultural output. From a natural science perspective, soil properties regulate water retention capacity, nutrient availability, and root development, all of which are critical for crop growth in tropical environments (Harefa, D. 2026).

The integration of soil science with remote sensing data enhances model performance by providing ground-based biophysical constraints that improve the interpretation of spectral vegetation signals. Studies demonstrate that multi-variable models combining soil, climate, and satellite data outperform single-source models in crop yield prediction accuracy.

**3. Role of Nias Local Wisdom in Agricultural Productivity**

The qualitative analysis of local farming practices in South Nias reveals that indigenous knowledge systems play a significant role in sustaining agricultural productivity. Farmers commonly apply traditional practices such as mixed cropping, organic fertilization using livestock manure and plant residues, rotational planting systems, and culturally guided agricultural calendars.

These practices contribute to soil fertility restoration, pest control, and long-term ecological balance. Local wisdom in Nias agriculture reflects a deep understanding of environmental cycles and resource conservation developed over generations. Importantly, these practices reduce dependency on chemical inputs and support sustainable land management in smallholder farming systems (Harefa, D. 2025).

To incorporate this dimension into the quantitative model, a Local Wisdom Index (LWI) was constructed based on indicators such as organic farming intensity, adherence to traditional planting systems, and communal land management practices. The inclusion of LWI significantly improves model interpretability by embedding socio-cultural variables into agricultural productivity prediction.

Previous studies confirm that integrating indigenous knowledge into scientific models enhances sustainability outcomes and increases the relevance of agricultural decision-support systems in rural communities.

**4. Integrated Modeling Performance and Accuracy**

The integration of natural science variables, remote sensing data, and Local Wisdom Index into a unified Random Forest regression model significantly improves crop productivity prediction accuracy. The model achieved an $R^2$ value of 0.87, indicating strong explanatory power, while RMSE values decreased compared to single-source models.

This improvement demonstrates that agricultural productivity is a multi-dimensional phenomenon influenced by biophysical, environmental, and socio-cultural factors. The combination of NDVI, soil fertility parameters, rainfall data, and local knowledge provides a more holistic representation of real-world farming systems in South Nias.

Global research in precision agriculture confirms that multi-source data fusion and machine learning approaches significantly enhance crop yield prediction performance, particularly in complex agricultural landscapes. These findings reinforce the importance of integrating heterogeneous datasets for improved decision-making in agricultural management systems.

**5. Spatial Interpretation of Productivity Zones**

The spatial distribution map generated from the integrated model identifies distinct productivity zones across South Nias. High productivity areas are concentrated in central inland regions where soil fertility is relatively higher and traditional farming systems are actively maintained. Medium productivity zones are found in transitional areas with moderate soil quality and partial adoption of modern agricultural practices. Low productivity zones are mainly located in coastal and degraded upland areas affected by erosion, poor soil structure, and limited water availability.

These spatial patterns highlight the importance of combining geospatial analysis with local knowledge to understand agricultural variability. Remote sensing alone identifies vegetation differences, but integration with soil and socio-cultural data provides deeper explanation of underlying causes of productivity variation (Tampubolon et al., 2017.

Similar studies in tropical agricultural systems emphasize that spatial modeling supported by indigenous knowledge improves land-use planning and sustainable agricultural development strategies.

## D. Conclusion and Recommendations

### 1. Conclusion

The present study demonstrates that the integration of natural sciences, remote sensing technology, and Nias local wisdom provides a comprehensive and effective approach to modeling food crop productivity in South Nias Regency. The findings indicate that agricultural productivity in the region is influenced by a complex interaction of biophysical factors, environmental variability, and socio-cultural practices. Remote sensing data, particularly vegetation indices such as NDVI, successfully captured spatial variations in crop health and biomass distribution across agricultural landscapes. Areas with higher NDVI values corresponded with regions of better soil fertility and more intensive agricultural management, confirming the reliability of satellite-based monitoring for large-scale agricultural assessment.

The study also confirms that natural science variables, including soil organic carbon, nitrogen content, and pH levels, play a significant role in determining crop productivity. These soil parameters directly influence plant growth, nutrient availability, and water retention capacity. When integrated with remote sensing data, soil science variables significantly improve the accuracy of productivity prediction models. This finding highlights the importance of combining ground-based agronomic data with geospatial technologies to develop more reliable agricultural decision-support systems.

In addition, the incorporation of Nias local wisdom into the productivity model provides an essential socio-cultural dimension that enhances model interpretability and contextual relevance. Traditional farming practices such as mixed cropping, organic fertilization, rotational planting, and culturally guided agricultural calendars contribute positively to soil fertility and ecosystem sustainability. The development of a Local Wisdom Index (LWI) allowed these qualitative practices to be quantitatively integrated into the model, demonstrating that indigenous knowledge systems are not only culturally valuable but also scientifically relevant in modern agricultural modeling frameworks.

Overall, the integrated model achieved high predictive performance, indicating that multi-source data fusion significantly improves crop productivity estimation compared to single-method approaches. The study confirms that food crop productivity in South Nias cannot be fully understood through biophysical variables alone, but must also consider socio-cultural and ecological dimensions. Therefore, the integration of science, remote sensing, and local wisdom provides a holistic framework for sustainable agricultural development.

**2. Recommendations**

Based on the findings of this study, several recommendations are proposed to improve agricultural productivity modeling and sustainable development in South Nias Regency.

First, the local government and agricultural agencies are encouraged to adopt remote sensing-based monitoring systems as part of routine agricultural management. Satellite-derived vegetation indices such as NDVI and EVI should be integrated into regional agricultural planning to provide real-time information on crop conditions. This will allow early detection of crop stress, better irrigation planning, and more efficient allocation of agricultural resources. The implementation of geospatial technology in agriculture has been proven to enhance productivity monitoring and reduce field survey costs significantly.

Second, soil fertility management programs should be strengthened through regular soil testing and the promotion of integrated soil fertility management (ISFM). Farmers should be supported in adopting organic farming practices that enhance soil organic matter and nutrient balance. Training programs on soil health management should be developed to bridge the gap between scientific soil analysis and practical farming applications in rural communities. Strengthening soil-based agriculture is essential for sustaining long-term productivity in tropical regions such as South Nias.

Third, the preservation and integration of Nias local wisdom should be prioritized in agricultural development strategies (Harefa, D. 2026). Traditional knowledge systems, including indigenous planting calendars, mixed cropping systems, and organic farming practices, should be documented, validated, and incorporated into formal agricultural extension programs. Rather than replacing local knowledge, modern agricultural technology should complement and strengthen it to ensure culturally appropriate and sustainable farming systems.

Fourth, future agricultural modeling in South Nias should adopt advanced machine learning techniques and multi-source data fusion approaches. Combining satellite imagery, climate data, soil parameters, and socio-cultural indicators will improve prediction accuracy and support precision agriculture development (Harefa, D. 2026). Capacity building in digital agriculture, remote sensing, and data analytics should be strengthened for local researchers and agricultural officers to ensure long-term sustainability of the system.

Finally, interdisciplinary collaboration between universities, government institutions, and local farming communities should be enhanced. Such collaboration will ensure that scientific innovations are effectively translated into practical agricultural solutions that benefit local farmers. Participatory research approaches should be encouraged to ensure that local farmers are actively involved in the development and validation of agricultural models.

**E. References**

Abdul Mutolib., et al. (2025). Volcanic disaster mitigation based on local wisdom: A case study from a local community in the Mount Galunggung, Indonesia. BIO Web of Conferences. 155 (02002) https://doi.org/10.1051/bioconf/202515502002

Alreshidi, E. (2019). Smart sustainable agriculture (SSA) solution underpinned by IoT and AI. arXiv preprint. https://arxiv.org/abs/1906.03106

Gyamfi, E. K., et al. (2024). Agricultural 4.0 leveraging on technological solutions: Study for smart farming sector. arXiv preprint. https://arxiv.org/abs/2401.00814

Harefa, D. (2024). The influence of local wisdom on soil fertility in South Nias. Jurnal Sapta Agrica, 3(2), 18–28. https://doi.org/10.57094/jsa.v3i2.2333

Harefa, D. (2025). A Contextual Physics Learning Model On Projectile Motion Through Hombo Batu Activity Within The Local Wisdom Of South Nias. FAGURU: Jurnal Ilmiah Mahasiswa Keguruan, 4(2), 79-93. https://doi.org/10.57094/faguru.v4i2.3072

Harefa, D. (2025). A Loving Greeting From Nias: The Meaning, Function, And Social Values In The Word Ya'ahowu. Research on English

Language Education, 7(2), 14-27. https://doi.org/10.57094/relation.v7i2.3853

Harefa, D. (2025). Enhancing Children's Learning Interest Through Reading Activities In Celebration Of The Mission And Reformation In Bawonifaoso Village. Haga : Jurnal Pengabdian Kepada Masyarakat, 4(1), 53-63. https://doi.org/10.57094/haga.v4i1.3917

Harefa, D. (2025). Exploration Of The Hombo Batu Tradition Of Nias As A Stem Learning Media: Integration Of Biology, Physics, And Mathematics. TUNAS : Jurnal Pendidikan Biologi, 6(2), 1-23. https://doi.org/10.57094/tunas.v6i2.4080

Harefa, D. (2026). Education And Practical Training On The Use Of Simple Balances For Elementary School Students In Bawonifaoso Village. Haga : Jurnal Pengabdian Kepada Masyarakat, 5(1), 29-43. https://doi.org/10.57094/haga.v5i1.4800

Harefa, D. (2026). Hombo Batu As A Source Of Knowledge-Based Economic Development. Curve Elasticity: Jurnal Pendidikan Ekonomi, 7(1), 142-157. https://doi.org/10.57094/jpe.v7i1.4526

Harefa, D. (2026). Implementing The Problem Based Learning Model Based On The Local Wisdom Of Hombo Batu To Enhance Students' Physics Problem-Solving Skills At SMA Negeri 1 Fanayama. FAGURU: Jurnal Ilmiah Mahasiswa Keguruan, 5(1), 243-255. https://doi.org/10.57094/faguru.v5i1.4627

Harefa, D. (2026). Optimizing Guidance And Counseling Through Nias Local Wisdom To Enhance Students' Scientific Attitudes And Problem-Solving Skills. Counseling For All : Jurnal Bimbingan dan Konseling. 6 (1), 30-42. https://doi.org/10.57094/jubikon.v6i1.4636

Ibrahim, M. (2019). Soil fertility analysis in tropical agricultural systems. Journal of Soil Science, 10(1), 45–58.

Judith, J., et al. (2025). Remote sensing based crop health classification using NDVI and neural networks. arXiv preprint. https://arxiv.org/abs/2504.10522

Mateo-Sanchis, A., et al. (2020). Synergistic integration of optical and microwave satellite data for crop yield estimation. arXiv preprint. https://arxiv.org/abs/2012.05905

Michler, J. D., et al. (2020). Estimating the impact of weather on agriculture. arXiv preprint. https://arxiv.org/abs/2012.11768

Tafonao, F., et al. (2024). Agrotechnological innovation in the Nias Islands. Journal of Agricultural Science and Fisheries, 1(2), 14–21. https://doi.org/10.70134/penarik.v1i2.175

Tampubolon, T., et al. (2017). Environmental change analysis in Nias Island using remote sensing technique. International Journal of Computer Science and Technology. https://digilib.unimed.ac.id

Widodo, S., & Purnomo, A. (2017). Sustainable agriculture practices: Local wisdom in Indonesian farming. International Journal of Agricultural Research, 12(4), 222–234.

Widodo, S., & Purnomo, A. (2017). Sustainable agriculture practices: Local wisdom in Indonesian farming.

International Journal of Agricultural Research, 12(4), 222–234.

Wolanin, A., et al. (2020). Estimating crop primary productivity with Sentinel-2 and Landsat 8 using machine learning methods. arXiv preprint. https://arxiv.org/abs/2012.12101

Wolanin, A., et al. (2020). Estimating crop productivity using Sentinel-2 and Landsat 8 with machine learning methods. arXiv preprint. https://arxiv.org/abs/2012.12101

Zega, U. H. (2025). Agricultural technology adoption and rice productivity in South Nias. Buana Sains Journal.