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Modified land-unit-based actual-to-potential agroecological suitability assessment for *Anthurium andraeanum* in Bali's highland floriculture landscape, Indonesia

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ABSTRACT

Highland floriculture in Bali is increasingly relevant for supporting tourism-associated ornamental flower supply, rural livelihoods, and green economy-oriented agricultural diversification. However, commodity-specific agroecological evidence for high-value ornamental crops remains limited, particularly for *Anthurium andraeanum*, because explicit suitability criteria for this species are not available in the Indonesian land evaluation guideline. This study developed and applied a modified land-unit-based actual-to-potential agroecological suitability assessment for anthurium in Baturiti District, Bali, Indonesia. The assessment was conducted using 16 homogeneous land units covering 9,204.14 ha, derived from field surveys, laboratory soil analysis, climate records, and spatial interpretation. The modified assessment combined the standard land-matching structure, Indonesian agricultural land evaluation criteria, published agronomic knowledge of anthurium, and explicit improvement rules for manageable land limitations. The evaluated land characteristics included temperature, rainfall, drainage, texture, effective soil depth, nutrient retention and availability, salinity, slope, erosion hazard, surface rock, and rock outcrop. Actual suitability was dominated by S3, covering 5,734.55 ha or 62.30%, followed by N with 1,866.68 ha or 20.28%, and S2 with 1,602.91 ha or 17.42%. After feasible improvement measures were considered, potential S2 increased to 8,847.75 ha or 96.13%, while 356.39 ha or 3.87% remained S3 due to persistent texture limitation. The main limiting factors were slope, drainage, soil depth, rainfall, temperature, and texture. The results were translated into priority development, conservation-controlled, drainage-improvement, and restricted management zones, providing a reproducible land-unit-based basis for targeted anthurium development in Bali's highland floriculture landscape.

Keywords: *Anthurium andraeanum*, actual-to-potential suitability, land-unit-based assessment, limiting factors, highland floriculture, Bali.

INTRODUCTION

Floriculture has become an increasingly important component of agricultural transformation in many tropical and subtropical regions. Unlike conventional food crops, ornamental flowers are closely linked to aesthetic consumption, cultural practices, tourism services, urban landscapes, and high-value agricultural diversification. Recent studies show that floriculture can support rural income, strengthen agricultural diversification, and create new market-oriented opportunities when it is developed under suitable agroecological and infrastructural conditions (Islam et al., 2026). In several Asian regions, the expansion of flower cultivation has also been associated with a shift from traditional crop production toward high-value horticultural systems, particularly where market demand, climate suitability, and farmer adaptation capacity are strong (Kandegama et al., 2022; Lakhiar et al., 2025; Monder et al., 2024; Yeshiwas et al., 2026).

In Bali, the development of floriculture has a specific strategic relevance because the island's tourism economy creates continuous demand for ornamental flowers. Hotels, villas, restaurants, ceremonial activities, landscape decoration, and hospitality services require stable supplies of fresh flowers throughout the year (Darma et al., 2021; Peterson and McCarthy, 2003). This condition places highland agricultural areas in an important position, not only as production zones, but also as ecological and economic support systems for the tourism sector. Baturiti District, located in the highland area of Tabanan Regency, is one of Bali's horticultural landscapes with strong potential for floriculture development. However, the expansion of flower commodities in highland landscapes cannot be based solely on market preference. It must also consider land capability, soil properties, climate conditions, slope stability, drainage, erosion risk, and the specific growing requirements of each commodity.

Among ornamental crops, anthurium (*Anthurium andraeanum*) is a particularly attractive commodity because of its high commercial value, distinctive spathe morphology, and strong market appeal as both a cut flower and potted ornamental plant. Anthurium is widely recognized as an important ornamental crop in the global flower market. Its ornamental value is mainly determined by the spathe and spadix, while commercial quality is influenced by flower development, vase life, water relations, pigment characteristics, and postharvest performance (Evelyn et al., 2020; Wan et al., 2024). Previous studies have emphasized that *A. andraeanum* has high commercial importance in the world flower trade, but its production is often constrained by biological and physiological factors, including long vegetative growth and flower bud development problems (Liu et al., 2024; Wan et al., 2024).

Most scientific studies on anthurium have focused on plant physiology, flower development, spathe color, genetic regulation, postharvest quality, and vase life. For example, recent research has examined the role of auxin and carbohydrate signals in flower bud development (Wan et al., 2024), the genetic and pigment-related mechanisms controlling spathe color (Li et al., 2023), and the influence of light conditions on vase life and water status in cut anthurium flowers (Evelyn et al., 2020). These studies are important for improving production quality and postharvest performance, but they do not directly address where anthurium should be cultivated from a land resource perspective. This creates an important research gap because successful floriculture development requires not only superior planting material and postharvest handling, but also a spatially explicit understanding of land suitability.

At the same time, recent geospatial studies on floriculture have generally focused on crop identification, remote sensing classification, land use transformation, and socio-economic changes. Studies using Sentinel, PlanetScope, PRISMA, machine learning, and land use models have shown that floriculture mapping is useful for agricultural planning, resource allocation, and sustainable management (Kar et al., 2026; Patra et al., 2026). Other studies have demonstrated that floriculture expansion can change agricultural land use systems and improve farmer income, but may also require environmental safeguards related to water management, soil health, chemical input, and ecological balance (Islam et al., 2026).

Despite these advances, there is still limited research that specifically evaluates the agroecological land suitability of *Anthurium andraeanum*, especially in tropical highland landscapes that function as flower-supply zones for tourism regions. This gap is particularly important in Indonesia, where national land evaluation guidelines do not provide a specific crop requirement table for anthurium. As a result, the assessment of anthurium suitability requires a modified and scientifically transparent approach that combines the standard land evaluation matching framework, available horticultural knowledge of anthurium, field-based land characteristics, and expert-based adjustment of crop requirements. Such an approach is necessary to avoid inappropriate land allocation, reduce production risk, prevent land degradation, and support more sustainable floriculture planning.

Land suitability evaluation provides a systematic basis for matching crop requirements with land characteristics (Baghkhanipour et al., 2026; Mistri et al., 2026; Paul et al., 2026). In practical agricultural planning, this approach allows researchers and land managers to identify actual suitability, limiting factors, potential suitability after improvement, and site-specific land management options. For highland floriculture, this is especially relevant because slope, erosion hazard, drainage, soil depth, nutrient availability, soil reaction, and climate conditions may vary substantially within a relatively small area. A previous floriculture suitability assessment in Baturiti showed that the area consists of diverse land uses, including dryland farming, paddy fields, mixed gardens, and secondary dryland forest, with actual suitability classes generally constrained by rainfall, slope, erosion hazard, drainage, soil depth, nitrogen, organic carbon, texture, surface rock, and rock outcrop (Diara et al., 2022; Ni Made Trigunasih, 2022; Prabhaswara et al., 2025; Sardiana and Kusmiyarti, 2021; Sari et al., 2022).

Therefore, a focused assessment for anthurium is needed to move beyond general land suitability studies toward commodity-specific floriculture planning. The scientific gap addressed by this study is the absence of a transparent, land-unit-based, and commodity-adapted agroecological suitability assessment for *Anthurium andraeanum* in Bali's highland floriculture landscape. The main hypothesis is that homogeneous land units can reveal spatial differences in anthurium suitability and distinguish between manageable limiting factors, such as drainage, nutrient status, and conservation-related slope constraints, and persistent limitations, such as rainfall, temperature, and inherent soil texture. We further expect that actual suitability will improve under feasible land management scenarios, but not all land units will reach high suitability because some agroclimatic and soil physical constraints cannot be fully corrected at the land-unit scale.

Based on this gap and hypothesis, this study aimed to: (1) characterize the agroecological conditions of the study area based on homogeneous land units, (2) determine actual and potential land suitability classes for anthurium using a modified agroecological land-matching approach, (3) identify the dominant limiting factors affecting anthurium development, and (4) formulate site-specific land management directions to support more targeted and conservation-oriented floriculture planning in Bali's tourism-supporting highland agricultural landscape. The expected scientific contribution is a reproducible commodity-specific suitability matrix and management-zoning approach that links land characteristics, actual-to-potential suitability transition, limiting-factor diagnosis, and practical land management directions for anthurium development.

MATERIALS AND METHODS

Study area

The study was conducted in Baturiti District, Tabanan Regency, Bali Province, Indonesia (Figure 1a). Baturiti District is located in the central highland zone of Bali and represents one of the important horticultural landscapes in the province. Geographically, the district lies approximately between 08°14′30″–08°30′07″ S and 114°54′52″–115°02′57″ E. It covers about 99.17 km² and consists of 12 villages: Angseri, Antapan, Apuan, Bangli, Batunya, Baturiti, Candikuning, Luwus, Mekarsari, Perean, Perean Kangin, and Perean Tengah.

The land suitability assessment covered 9,204.14 ha of homogeneous land units. The study area is characterized by undulating to hilly topography, with slope classes ranging from 0–8% to 25–40%. Land use consists mainly of dryland farming, paddy fields, mixed gardens, secondary dryland forest, perennial plantation, settlement, and upland cultivation. The dominant soil types are Greyish Brown Andosols, Grey Regosols, and Yellowish Brown Latosols, derived from the soil type map of the Bali Provincial Geoportal at a scale of 1:250,000 (Suyarto et al., 2023; Ustriyana et al., 2025.)

Rainfall and temperature data were obtained from the Bali Climatology Station of the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) for the 2016–2025 period. The highland climate, sloping terrain, and variation in soil and land-use conditions make Baturiti relevant for evaluating *Anthurium andraeanum*, particularly because the crop is sensitive to moisture availability, temperature, drainage, soil aeration, rooting media, and nutrient availability.

Research design

This study applied a modified land-unit-based actual-to-potential agroecological suitability assessment for *Anthurium andraeanum*. The evaluation followed the general land evaluation framework of FAO and the Indonesian agricultural land evaluation guideline, but the crop suitability matrix was modified because *A. andraeanum* is not specifically listed in the national guideline (FAO, 1976; Ritung et al., 2011; Fresco et al., 1990; Rossiter, 1996).

The analysis focused on biophysical and agroecological land characteristics and excluded agro-economic feasibility variables, including market price, production cost, farmer preference, supply-chain capacity, and institutional readiness. The evaluation unit was the homogeneous land unit (HLU), defined as a spatial unit with a relatively uniform combination of land use, slope class, and soil type.

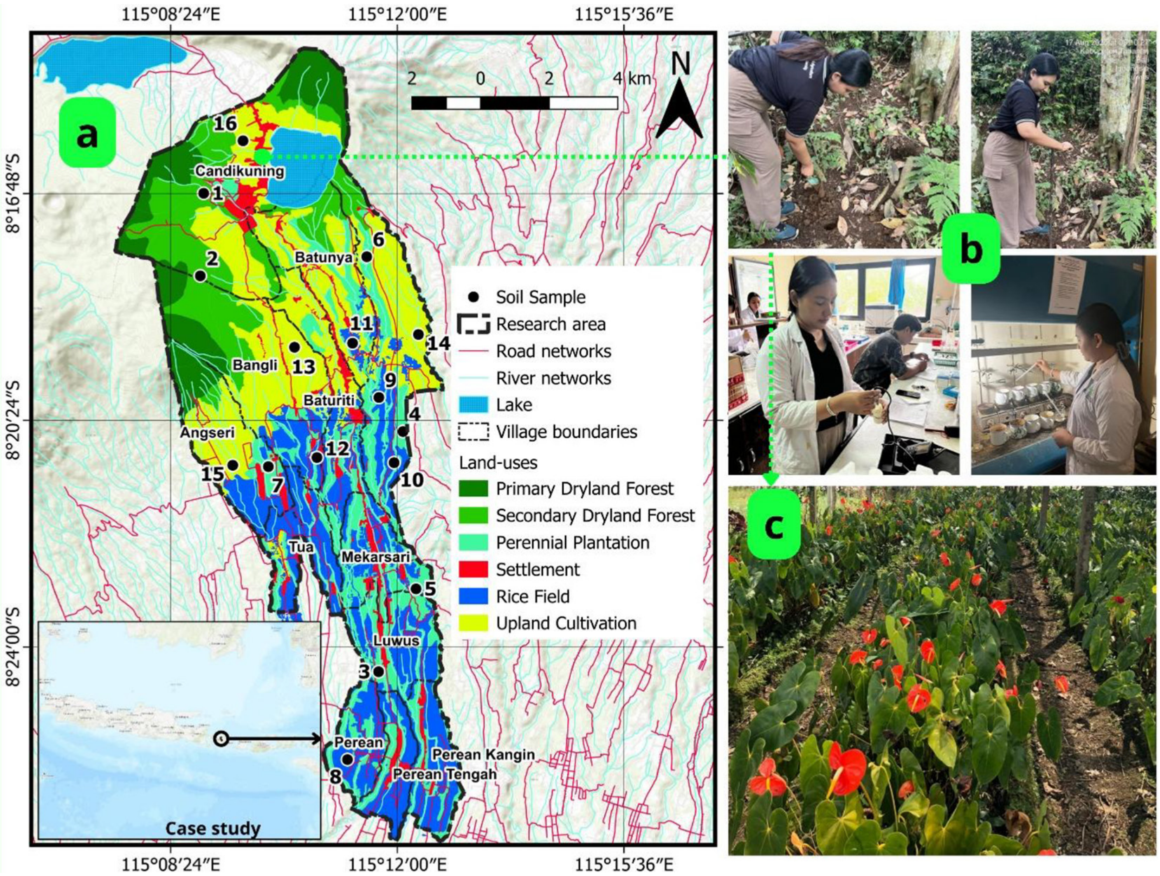

Figure 1. Study area and field documentation in Baturiti District, Bali, Indonesia: (a) research location and soil sampling points; (b) field observation, soil sampling using a soil auger, and laboratory analysis; (c) existing *Anthurium andraeanum* cultivation in the highland floriculture area

Two suitability conditions were evaluated. Actual suitability (S_a) represents suitability under observed field, laboratory, spatial, and climatic conditions. Potential suitability (S_p) represents suitability after feasible land improvement measures were considered. The suitability classes used in this study were S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, and N = not suitable

Materials, data sources, and instruments

The study used primary and secondary data sources, as summarized in Table 1. Primary data were obtained from field observation, GPS-based sampling, soil drilling, and laboratory soil analysis. Secondary data included administrative boundaries, land use, soil type, DEM, rainfall, temperature, erosion hazard, and flooding or inundation information. All spatial analyses were performed using QGIS LTR 3.44. All spatial layers were projected to WGS 1984 UTM Zone 50S before overlay and area calculation.

Homogeneous land unit delineation

Homogeneous land units were delineated by overlaying land use, slope class, and soil type maps in QGIS LTR 3.44 (Apriadi et al., 2025; Sari et al., 2022; Trigunasih et al., 2017; Vandani et al., 2025). Slope was derived from DEMNAS with a spatial resolution of 8.1 m. The DEM was processed into percentage slope and reclassified into four slope classes: 0–8%, 8–15%, 15–25%, and 25–40%.

The HLU delineation was conducted through slope derivation, slope reclassification, vector conversion where required, and polygon overlay between land use, soil type, and slope class. The resulting polygons were dissolved based on unique combinations of land use, soil type, and slope class. This process produced 16 HLUs, which were used as the basis for field verification, soil sampling, laboratory analysis, suitability matching, limiting-factor diagnosis, and area-based calculation. The resulting HLUs are presented in Table 2.

Table 1. Materials, data sources, and instruments used in the study.

Data/material/instrument	Source/specification	Scale/resolution/period	Function
Administrative boundary	Geospatial Information Agency of Indonesia	Official administrative vector data	Study area delineation
Land use map	Geospatial Information Agency of Indonesia	Official land-use layer	HLU delineation and land-use interpretation
Soil type map	Bali Provincial Geoportal	1:250,000	Soil type interpretation and HLU delineation
DEM	DEMNAS, Geospatial Information Agency of Indonesia	8.1 m	Slope derivation
Rainfall data	Bali Climatology Station, BMKG	2016–2025	Water availability assessment
Temperature data	Bali Climatology Station, BMKG	2016–2025	Temperature suitability assessment
Erosion hazard information	Previous land-resource and erosion studies	Based on (Trigunasih and Saifulloh, 2023)	Erosion hazard classification
Flooding/inundation information	Previous land-resource studies and field verification	Based on (Suyarto et al., 2023b)	Flooding hazard classification
GPS receiver	Garmin Montana 680s	Field positioning	Sampling point recording
Soil auger and sampling tools	Field equipment	0–30 cm sampling depth	Soil sampling and soil depth observation
Laboratory soil analysis	Soil Fertility and Soil Chemistry Laboratory, Faculty of Agriculture, and Analytical Laboratory, Udayana University	Standard soil analytical methods	Soil physical and chemical characterization
GIS software	QGIS LTR 3.44	Vector and raster analysis	Overlay, reclassification, mapping, and area calculation

Table 2. Homogeneous land units used for anthurium land suitability evaluation

HLU	Village	Land Use	Slope Class	Soil Type	Area (ha)
I	Candikuning	Secondary dryland forest	25–40%	Greyish Brown Andosol	897.32
II	Candikuning	Secondary dryland forest	25–40%	Grey Regosol	661.25
III	Perean Tengah	Mixed garden	0–8%	Yellowish Brown Latosol	971.88
IV	Antapan	Mixed garden	15–25%	Greyish Brown Andosol	243.31
V	Luwus	Mixed garden	15–25%	Yellowish Brown Latosol	358.58
VI	Antapan	Mixed garden	8–15%	Greyish Brown Andosol	280.58
VII	Baturiti	Mixed garden	8–15%	Yellowish Brown Latosol	255.31
VIII	Perean Tengah	Paddy field	0–8%	Yellowish Brown Latosol	1,652.35
IX	Antapan	Paddy field	15–25%	Greyish Brown Andosol	169.81
X	Luwus	Paddy field	15–25%	Yellowish Brown Latosol	305.26
XI	Batunya	Paddy field	8–15%	Greyish Brown Andosol	103.12
XII	Apuan	Paddy field	8–15%	Yellowish Brown Latosol	337.07
XIII	Bangli	Dryland farming	15–25%	Yellowish Brown Latosol	2,208.66
XIV	Antapan	Dryland farming	25–40%	Greyish Brown Andosol	308.11
XV	Angseri	Dryland farming	8–15%	Yellowish Brown Latosol	95.14
XVI	Candikuning	Dryland farming	8–15%	Grey Regosol	356.39

Field survey and soil sampling

Field surveys were conducted to verify HLU boundaries, observe land characteristics, and collect representative soil samples. Sampling followed a purposive sampling approach, in which each sampling point was selected to represent the dominant land condition within each HLU (Kartini et al., 2023; Trigunasih et al., 2023; Trigunasih and Saifulloh, 2022). One representative soil sampling point was established for each HLU, resulting in 16 soil samples.

Sampling points were georeferenced using a Garmin Montana 680s GPS receiver. Soil samples were collected from the 0–30 cm topsoil layer, which represents the main rooting zone relevant for field cultivation of *A. andraeanum*. At each sampling point, soil drilling was conducted using a soil auger to observe soil depth and rooting conditions. The field observation and soil sampling activities are documented in Figure 1b, while existing anthurium cultivation observed in the highland floriculture area is shown in Figure 1c.

Field observations included drainage class, slope gradient, coarse fragments, effective soil depth, surface rock, rock outcrop, existing land use, erosion indicators, and flooding or inundation evidence (Trigunasih et al., 2023). Drainage was classified qualitatively using field indicators such as soil wetness, mottling, water stagnation, and land-use condition. Surface rock and rock outcrop were visually estimated as percentage cover within the observation area.

Laboratory soil analysis

Soil samples were air-dried, gently disaggregated, and passed through a 2 mm sieve before laboratory analysis. Laboratory analyses were conducted at the Soil Fertility and Soil Chemistry Laboratory, Faculty of Agriculture, Udayana University, and the Analytical Laboratory, Udayana University. The parameters used in the suitability assessment and their analytical methods are presented in Table 3. The laboratory results were used to evaluate rooting media, nutrient retention, nutrient availability, soil reaction, and salinity. Erosion hazard and flooding or inundation hazard were not derived from laboratory analysis. These variables were obtained from previous land-resource studies by (Suyarto et al., 2023b; Trigunasih and Saifulloh, 2023) and were checked during field verification.

Erosion hazard and flooding or inundation hazard were included as land suitability parameters because they affect land management risk and field cultivation feasibility. In this study, both parameters were obtained from previous land-resource and environmental studies in the Baturiti highland landscape and surrounding areas (Suyarto et al., 2023b; Trigunasih and Saifulloh, 2023). These data were used as categorical hazard classes and verified during the field survey through observation of slope condition, visible erosion indicators, drainage condition, water stagnation, and local land-use characteristics.

The erosion hazard class was used in the matching matrix as one of the erosion-related limiting factors, while flooding height and flooding duration were used to evaluate flooding hazard. Their suitability thresholds are presented together with other land characteristics in Table 4.

Modified agroecological suitability criteria for *Anthurium andraeanum*

Specific land suitability criteria for *Anthurium andraeanum* are not explicitly available in the Indonesian agricultural land evaluation guideline. Therefore, this study developed a modified agroecological suitability matrix by integrating the FAO land evaluation framework, the Indonesian land evaluation guideline, published agronomic information on anthurium, and expert-informed adjustment for tropical highland floriculture conditions (FAO, 1976; Ritung et al., 2011; Fresco et al., 1990; Rossiter, 1996).

Table 3. Soil parameters and laboratory analytical methods used in the suitability assessment

Parameter	Unit	Analytical method
Organic carbon	%	Walkley and Black method
Total nitrogen	%	Kjeldahl method
Soil texture	Texture class	Pipette method
Soil pH H_2O	pH unit	Potentiometric method, soil:water ratio 1:2.5
Available P	ppm, converted to mg 100 g^{-1}	Bray-1 extraction for pH < 7 and Olsen extraction for pH > 7
Available K	ppm, converted to mg 100 g^{-1}	Bray-1 extraction for pH < 7 and Olsen extraction for pH > 7
Salinity	dS m^{-1}	Potentiometric method, soil:water ratio 1:2.5
Cation exchange capacity	cmol(+) kg^{-1}	NH_4OAc 1 N pH 7 extraction
Base saturation	%	Calculated from exchangeable base cations relative to CEC
Total P	mg 100 g^{-1}	25% HCl extraction
Total K	mg 100 g^{-1}	25% HCl extraction

The criteria for taro or *Colocasia esculenta* in the Indonesian guideline were not directly adopted as anthurium criteria. They were used only as a comparative structural reference because both crops belong to Araceae and share broad sensitivities related to moisture, aeration, rooting media, and drainage. The final criteria were adjusted to the growth behavior of anthurium, which requires a moist but well-aerated rooting environment, good drainage, suitable soil reaction, low salinity, adequate nutrient availability, and protection from severe erosion or prolonged waterlogging.

The main modifications were applied to temperature, rainfall, drainage, texture, and slope interpretation. General soil chemical thresholds, including CEC, base saturation, organic carbon, nutrient availability, salinity, flooding, surface rock, and rock outcrop, followed the structure of the Indonesian land evaluation guideline with adjustment to the study context. Each land characteristic was classified into S1, S2, S3, or N using the numerical thresholds presented in Table 4. Peat-related criteria were not included because the evaluated HLUs were mineral soils.

Land suitability matching analysis

Land suitability was determined using the matching method. Each observed land characteristic in every HLU was compared with the modified suitability criteria presented in Table 4. The final suitability class was determined using the limiting factor approach, in which the lowest-rated land characteristic controls the final class of the land unit. The final suitability class for land unit *i* was calculated using Equation 1:

$$S_i = \min(Q_{i1}, Q_{i2}, \dots, Q_{in}) \quad (1)$$

where: S_i is the final suitability class of land unit i, Q_{ij} is the suitability class of land characteristic j in land unit i, and n is the total number of evaluated land characteristics.

The limiting factors were identified using Equation 2:

$$LF_i = \{ Q_{ij} \mid Q_{ij} = S_i \} \quad (2)$$

where: LF_i is the set of limiting factors in land unit i, Q_{ij} is the suitability class of land characteristic j, and S_i is the final suitability class of land unit i.

Table 4. Modified agroecological suitability criteria for *Anthurium andraeanum*

Land characteristic	Unit/class	S1	S2	S3	N
Mean temperature	°C	16–25	>25–30	14–16 or >30–32	<14 or >32
Annual rainfall	mm year^{-1}	1.500–2.000	1.200–1.500 or >2.000–3.000	1.000–1.200 or >3.000–3.500	<1.000 or >3.500
Drainage	Class	Good to moderate	Moderately slow	Somewhat rapid or poorly drained	Very rapid or very poorly drained
Texture	Class	Fine to moderately fine	Medium	Moderately coarse	Coarse or very coarse
Coarse fragments	%	<15	15–35	35–55	>55
Effective soil depth	cm	>75	50–75	25–50	<25
CEC	cmol(+) kg^{-1}	>16	5–16	<5	-
Base saturation	%	≥35	20–35	<20	-
Soil pH H_2O	pH unit	5.5–7.5	5.0–5.5 or >7.5–8.0	<5.0 or >8.0–8.5	>8.5
Organic carbon	%	>1.2	0.8–1.2	<0.8	-
Total nitrogen	%	≥0.21	0.10–0.20	<0.10	-
P_2O_5	mg 100 g^{-1}	≥21	10–20	<10	-
K_2O	mg 100 g^{-1}	≥21	10–20	<10	-
Salinity	dS m^{-1}	<2	2–3	3–4	>4
Slope	%	0–8	>8–15	>15–25	>25
Erosion hazard	Class	Very light to light	Moderate	Heavy	Very heavy
Flooding height	cm	None	<25	25–50	>50
Flooding duration	day	None	<7	7–14	>14
Surface rock	%	<3	3–15	15–40	>40
Rock outcrop	%	<2	2–10	10–25	>25

Actual and potential land suitability

Actual suitability was determined from observed field, laboratory, climatic, and spatial data without assuming improvement. Potential suitability was estimated by adjusting only land characteristics that can reasonably be improved through feasible land management. The adjustment did not assume that all constraints could be eliminated. Rainfall, temperature, inherent soil texture, and severe terrain conditions were treated as residual or persistent limitations. The adjusted suitability score was calculated using Equation 3:

$$Score(Q'_{ij}) = \min\,[4, Score(Q_{ij}) + \Delta_j \quad (3)$$

where: Q'_{ij} is the adjusted suitability class of land characteristic j in land unit i, Q_{ij} is the actual suitability class, and Δj is the class adjustment assigned to each manageable limitation.

The ordinal scores were S1 = 4, S2 = 3, S3 = 2, and N = 1. The potential suitability class was calculated using Equation 4:

$$S_{pi} = \min(Q'_{i1}, Q'_{i2}, \dots, Q'_{in}) \quad (4)$$

where: S_{pi} is the potential suitability class of land unit i, Q'_{ij} is the adjusted suitability class after feasible improvement, and n is the total number of evaluated land characteristics.

The improvement rules used to transform actual into potential suitability are presented in Table 5. This rule-based transformation was used to avoid overestimating potential suitability. For example, slope was not interpreted as physically removed after improvement. Instead, slope-related limitation was reclassified only under a conservation-controlled cultivation scenario.

Suitability improvement index

The magnitude of change from actual to potential suitability was quantified using an ordinal improvement index, as shown in Equation 5:

$$I_i = Score(S_{pi}) - Score(S_{ai}) \quad (5)$$

Table 5. Improvement rules for transforming actual into potential suitability

Limiting factor	Modifiability	Improvement measure	Adjustment rule
Rainfall	Non-modifiable	No direct field-scale intervention	Class retained
Temperature	Non-modifiable	No direct open-field intervention	Class retained
Drainage	Manageable	Raised beds, micro-drainage channels, drainage outlets, porous growing media	Can improve by one to two classes depending on severity
Texture	Persistent	No field-scale correction under direct planting	Class retained
Effective soil depth	Partly manageable	Raised beds, limited tillage, rooting-zone improvement	Can improve by one class where restriction is manageable
CEC and base saturation	Manageable	Organic matter addition, liming, and fertility improvement	Can improve by one class
Soil pH	Manageable	Liming or organic amendment	Can improve by one class
Organic carbon	Manageable	Compost, manure, mulch, and residue return	Can improve by one class
Total nitrogen	Manageable	Organic matter addition and balanced fertilization	Can improve by one to two classes
Available P and K	Manageable	Balanced fertilization and nutrient management	Can improve by one to two classes
Salinity	Partly manageable	Leaching and drainage improvement if salinity source is controllable	Can improve by one class when not severe
Slope	Terrain persistent, management risk manageable	Terracing, contour planting, cover crops, runoff control	Cannot become S1; may improve to conservation-controlled S2
Erosion hazard	Manageable	Mulching, cover crops, contour farming, terrace maintenance	Can improve by one class
Surface rock	Partly manageable	Selective stone removal where feasible	Can improve by one class if not severe
Rock outcrop	Mostly persistent	Avoidance or restricted cultivation	Class retained if severe
Flooding	Partly manageable	Raised beds, drainage channels, water control	Can improve if flooding is shallow and temporary

where: I_i is the improvement index of land unit i, S_{pi} is the potential suitability class, S_{ai} is the actual suitability class, and *Score* is the ordinal score assigned to each class, namely S1 = 4, S2 = 3, S3 = 2, and N = 1.

This index indicates the magnitude of suitability class improvement, but it does not represent a continuous biophysical variable.

Area-based suitability calculation

The total area of each suitability class was calculated by summing the area of all HLUs assigned to the same class. The percentage of each suitability class was calculated using Equation 6:

$$P_c = \left(\frac{\sum A_{ic}}{A_t}\right) \times 100 \quad (6)$$

where: P_c is the percentage of suitability class c, A_{ic} is the area of land unit i belonging to class c, and A_t is the total evaluated area.

This calculation was applied separately to actual and potential suitability classes. All area calculations were performed in QGIS LTR 3.44 using projected spatial data in WGS 1984 UTM Zone 50S.

RESULTS

Agroecological characteristics of the homogeneous land units

The study area was divided into 16 homogeneous land units (HLUs) that represented different combinations of land use, slope class, soil type, and area. These HLUs were used as the spatial basis for evaluating the agroecological suitability of *Anthurium andraeanum* in Baturiti District. The total evaluated area was 9,204.14 ha, consisting of secondary dryland forest, mixed gardens, paddy fields, and dryland farming areas. The spatial distribution of the HLUs and soil sampling points is presented in Figure 2, while field

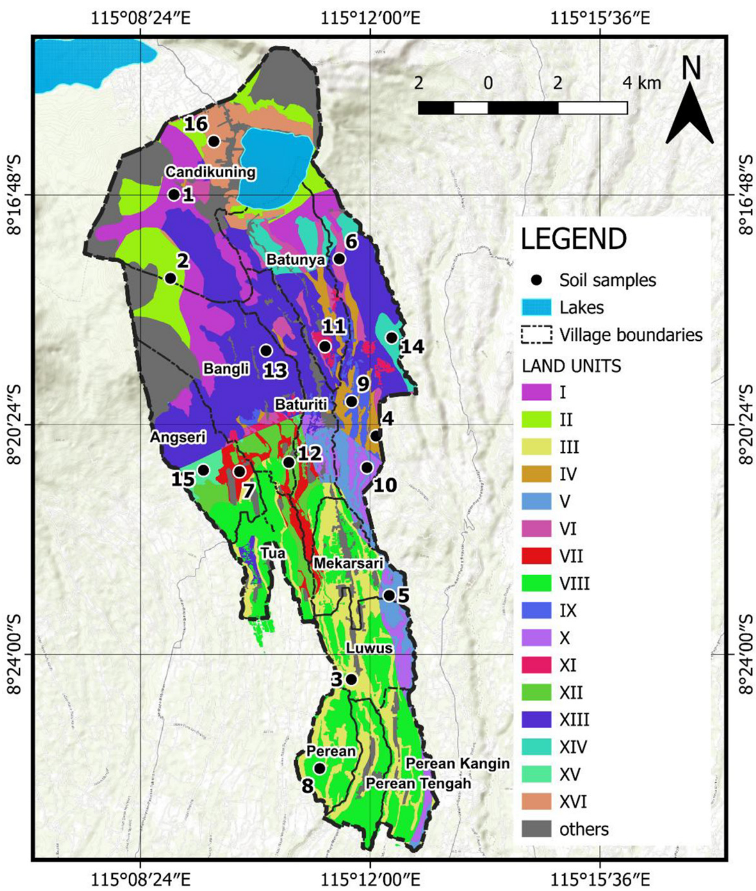

Figure 2. Spatial distribution of homogeneous land units used for agroecological land suitability evaluation of Anthurium andraeanum in Baturiti District, Bali, Indonesia

observation, soil sampling, and existing anthurium cultivation are documented in Figure 1b and Figure 1c. These materials were used to support the traceability of the land-unit delineation, field verification, and suitability interpretation.

The largest land unit was HLU 13, which covered 2,208.66 ha of dryland farming on Yellowish Brown Latosol with a slope class of 15–25%. The second largest unit was HLU 08, covering 1,652.35 ha of paddy field on Yellowish Brown Latosol with a slope class of 0–8%. In contrast, HLU 15 and HLU 11 were the smallest units, with areas of 95.14 ha and 103.12 ha, respectively.

The land units showed clear variation in slope conditions, ranging from 0–8% to 25–40%. Several units, particularly HLU 01, HLU 02, and HLU 14, were located on slopes of 25–40%, indicating stronger topographic constraints for intensive cultivation. These slope conditions are important because anthurium development requires careful land preparation, stable rooting conditions, and protection from erosion. Meanwhile, several paddy-field units, including HLU 08, HLU 09, HLU 10, HLU 11, and HLU 12, were more closely associated with drainage constraints. This variation confirms that anthurium development in Baturiti cannot be generalized across the entire district and should be interpreted at the land-unit level. Thus, the HLU approach provides a more detailed spatial basis than administrative-level interpretation because each unit reflects a specific combination of land use, soil type, slope class, and field-observed land characteristics.

Actual and potential land suitability for *Anthurium andraeanum*

The actual land suitability assessment showed that no land unit was classified as S1 for anthurium under existing conditions. The actual suitability classes consisted of S2, S3, and N. The dominant actual class was S3, covering 5,734.55 ha or 62.30% of the evaluated area. The N class covered 1,866.68 ha or 20.28%, while S2 occupied 1,602.91 ha or 17.42% (Table 6; Figure 3a).

After feasible improvement measures were considered, the suitability pattern changed substantially. The potential suitability was dominated by S2, which increased to 8,847.75 ha or 96.13% of the evaluated area. The remaining 356.39 ha or 3.87% remained in S3, represented by HLU 16. This unit did not improve to S2 because soil texture remained a persistent limitation. No land was classified as S1 under either actual or potential conditions, indicating that the study area is better interpreted as a moderately suitable highland floriculture zone, not as an optimum or limitation-free production area (Table 6; Figure 3b). Therefore, the large increase in potential S2 should be interpreted as a scenario-based suitability improvement under feasible land management, not as evidence that all areas can be developed without technical and conservation requirements.

The class-transition analysis showed that 1,866.68 ha of land classified as N under actual conditions shifted to S2 under potential conditions. In addition, 5,378.16 ha of actual S3 land shifted to S2 after improvement. The area that remained in S3 was 356.39 ha, while all land already classified as S2 under actual conditions remained in S2 after improvement (Table 7; Figure 4). This transition indicates that most actual constraints were potentially manageable, but not all inherent land limitations could be corrected through ordinary land management. Using the ordinal suitability improvement index, 20.28% of the evaluated area improved by two class levels from N to S2, 58.43% improved by one class level from S3 to S2, and 21.29% showed no class improvement. The area-weighted mean improvement index was 0.99 class units, indicating a moderate overall response to feasible improvement measures. However, this value is an ordinal indicator and should not be interpreted as a continuous biophysical measurement.

Table 6. Area distribution of actual and potential land suitability classes for *Anthurium andraeanum*

Suitability class	Actual area (ha)	Actual area (%)	Potential area (ha)	Potential area (%)
S1	0.00	0.00	0.00	0.00
S2	1,602.91	17.42	8,847.75	96.13
S3	5,734.55	62.30	356.39	3.87
N	1,866.68	20.28	0.00	0.00
Total	9,204.14	100.00	9,204.14	100.00

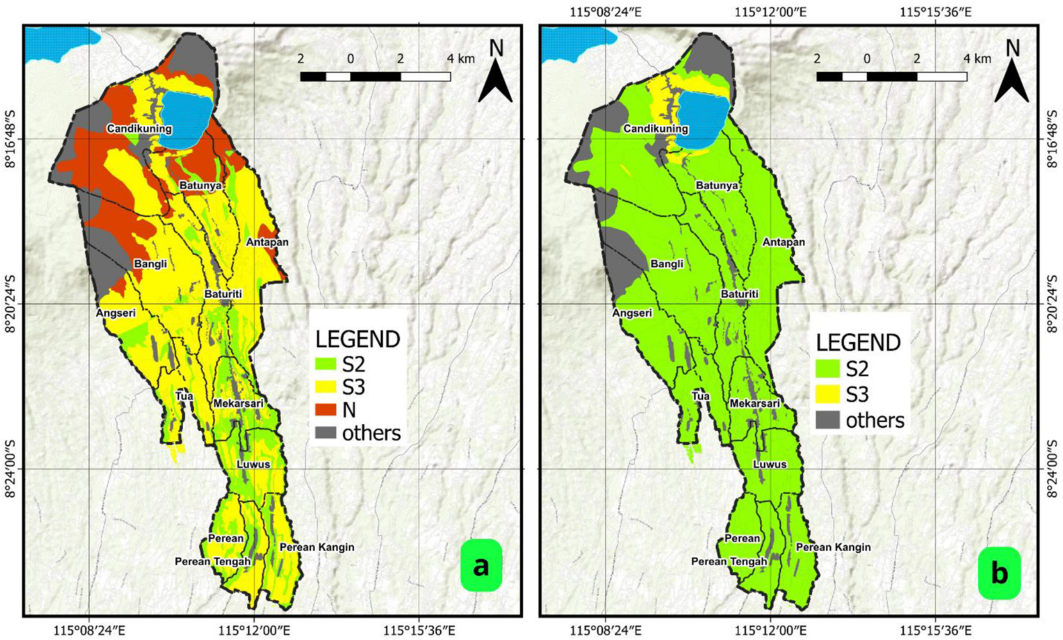

Figure 3. Spatial distribution of actual and potential land suitability classes for *Anthurium andraeanum* in Baturiti District: (a) actual suitability and (b) potential suitability after feasible land improvement measures

Table 7. Transition from actual to potential suitability classes for *Anthurium andraeanum*

Actual class	Potential class	Area (ha)	Area (%)	Improvement index
N	S2	1,866.68	20.28	+2
S2	S2	1,602.91	17.42	0
S3	S2	5,378.16	58.43	+1
S3	S3	356.39	3.87	0
Total		9,204.14	100.00	

Dominant limiting factors affecting *Anthurium suitability*

The suitability-rating heatmap showed that the dominant actual limiting factors varied among land units. The main actual limitations were slope, drainage, rainfall, temperature, soil depth, texture, and total nitrogen. Among these, slope and drainage were the most visible constraints across the evaluated land units Figure 5). To avoid interpreting the heatmap only visually, the limiting factors were also quantified based on the number and area of HLUs rated below S1 for each parameter. Under actual conditions, slope affected 11 HLUs covering 5,783.33 ha or 62.83% of the evaluated area, while rainfall occurred as an S2 residual limitation in 12 HLUs covering 5,864.94 ha or 63.72%. Drainage limitation affected five HLUs covering 2,567.61 ha or 27.90%, soil depth limitation affected four HLUs covering 1,602.91 ha or 17.42%, temperature limitation affected three HLUs covering 2,982.81 ha or 32.41%, texture limitation affected two HLUs covering 664.50 ha or 7.22%, and total nitrogen limitation occurred in one HLU covering 169.81 ha or 1.84%.

Slope was the most severe limitation in several units. HLU 01, HLU 02, and HLU 14 were classified as N under actual conditions due to slope limitation. Other land units, including HLU 04, HLU 05, HLU 09, HLU 10, and HLU 13, were classified as S3 partly due to slope-related constraints. These units require soil and water conservation measures if they are considered for anthurium cultivation.

Drainage limitation was mainly observed in paddy-field units. HLU 08, HLU 09, HLU 10, HLU 11, and HLU 12 showed actual drainage limitation. This result indicates that paddy-field units cannot be directly assumed suitable for anthurium without water-control improvement. Anthurium requires a rooting environment that remains moist but sufficiently aerated, so excessive

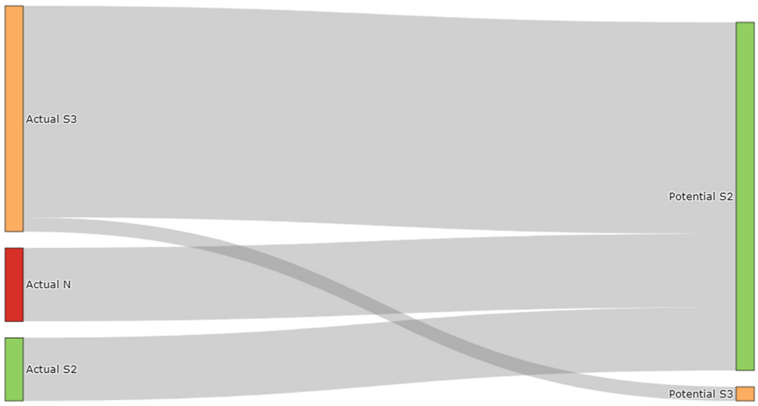

Figure 4. Transition from actual to potential land suitability classes for *Anthurium andraeanum*. Flow width represents land area in hectares

wetness or poor drainage may reduce the suitability of these land units.

Soil depth limitation occurred in several units, particularly HLU 03, HLU 06, HLU 07, and HLU 15, but these constraints were not severe enough to reduce the final class below S2. Total nitrogen appeared as a limiting factor only in HLU 09, suggesting that nutrient limitation was more localized than slope or drainage constraints. Texture limitation was most clearly observed in HLU 16, where it remained at S3 under both actual and potential conditions.

Under potential conditions, most manageable limitations improved. Drainage, soil depth, and total nitrogen were no longer shown as severe constraints after improvement. However, rainfall remained as an S2 residual limitation in many units, while temperature remained as an S2 limitation in selected units. Texture remained the main persistent constraint in HLU 16, explaining why this land unit stayed in S3 even after potential improvement. Under potential conditions, remaining below-S1 limitations were dominated by rainfall, slope, temperature, and texture. Rainfall remained below S1 in 5,864.94 ha or 63.72% of the area, slope remained below S1 in 1,866.68 ha or 20.28%, temperature remained below S1 in 2,982.81 ha or 32.41%, and texture remained below S1 in 664.50 ha or 7.22%. This confirms that the potential suitability map still contains residual constraints and should not be interpreted as an unlimited development map.

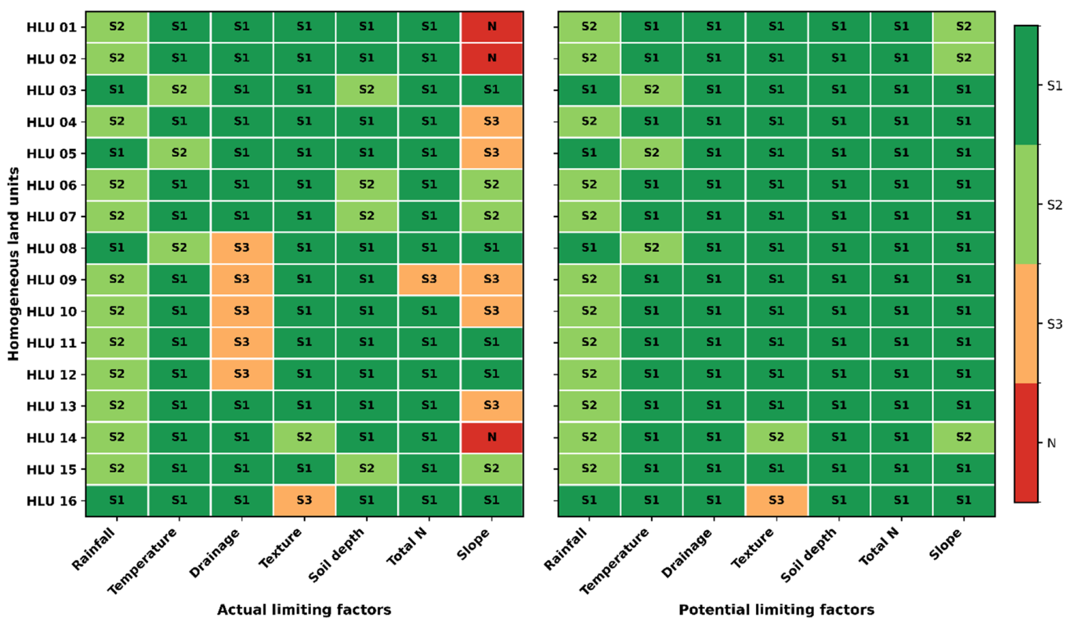

Figure 5. Suitability-rating heatmap of actual and potential limiting factors for *Anthurium andraeanum* across homogeneous land units. The color scale represents suitability ratings from N to S1

Site-specific land management directions

The suitability results were translated into four site-specific management zones: priority development, conservation-controlled development, drainage improvement, and restricted or cautious development. These zones were developed based on actual class, potential class, dominant limiting factors, and the expected response to feasible improvement measures (Table 8; Figure 6). To reduce subjectivity, each zone was assigned using rule-based criteria derived from the suitability transition matrix, dominant limiting factors, and the modifiability of each constraint. Priority development was assigned to HLUs already classified as S2 under actual conditions. Conservation-controlled development was assigned to HLUs where slope was the main limitation but potential suitability reached S2 only under conservation measures. Drainage improvement was assigned to paddy-field HLUs where drainage was the dominant manageable limitation. Restricted or cautious development was assigned to HLU 16 because it remained S3 after improvement due to persistent texture limitation.

The largest zone was the conservation-controlled development zone, covering 4,677.23 ha or 50.82% of the evaluated area. This zone consisted of HLU 01, HLU 02, HLU 04, HLU 05, HLU 13, and HLU 14. The main limitation in this zone was slope. Therefore, anthurium cultivation in these land units should only be considered under strict soil and water conservation practices. This zone should not be interpreted as a recommendation for unrestricted land conversion, particularly where the existing land use is secondary dryland forest.

The drainage improvement zone covered 2,567.61 ha or 27.90% of the study area. This zone included HLU 08, HLU 09, HLU 10, HLU 11, and HLU 12, which were mainly associated with paddy-field conditions. These land units require raised beds, micro-drainage channels, porous planting media, and careful irrigation management before being used for anthurium cultivation.

The priority development zone covered 1,602.91 ha or 17.42%, consisting of HLU 03, HLU 06, HLU 07, and HLU 15. These land units were classified as S2 under actual conditions and remained S2 under potential conditions. Therefore, they represent the most appropriate initial target areas for anthurium development, provided that moderate improvement measures are applied.

The restricted or cautious development zone covered 356.39 ha or 3.87%, represented by HLU 16. This unit remained in S3 because of persistent soil texture limitation. Direct field cultivation is therefore less recommended in this unit. If anthurium is still developed in this zone, controlled systems such as pot culture, shade house cultivation, greenhouse production, or modified growing media would be more appropriate than direct soil-based cultivation.

DISCUSSION

Land-unit-based suitability as a more precise basis for anthurium development

The results demonstrate that the suitability of Baturiti District for *Anthurium andraeanum* is spatially heterogeneous and strongly controlled by land-unit characteristics. Under actual conditions, the evaluated area was dominated by S3, while a smaller but important proportion was classified as N. After feasible improvement measures were considered, most of the area shifted to potential S2, although no land unit reached S1. This pattern indicates that Baturiti has moderate agroecological potential for anthurium development, but not under uniform or unrestricted

Table 8. Site-specific management zones for *Anthurium andraeanum* development based on suitability response and limiting factors

Management zone	HLU	Area (ha)	Area (%)	Development priority	Main interpretation
Priority development	3, 6, 7, 15	1,602.91	17.42	High	Suitable for initial anthurium development with moderate land improvement
Conservation-controlled development	1, 2, 4, 5, 13, 14	4,677.23	50.82	Medium, conditional	Development requires strict soil and water conservation due to slope constraints
Drainage improvement	8, 9, 10, 11, 12	2,567.61	27.90	Medium, conditional	Development requires drainage improvement and raised-bed cultivation
Restricted or cautious development	16	356.39	3.87	Low to conditional	Direct field cultivation is less recommended due to persistent texture limitation
Total		9,204.14	100.00		

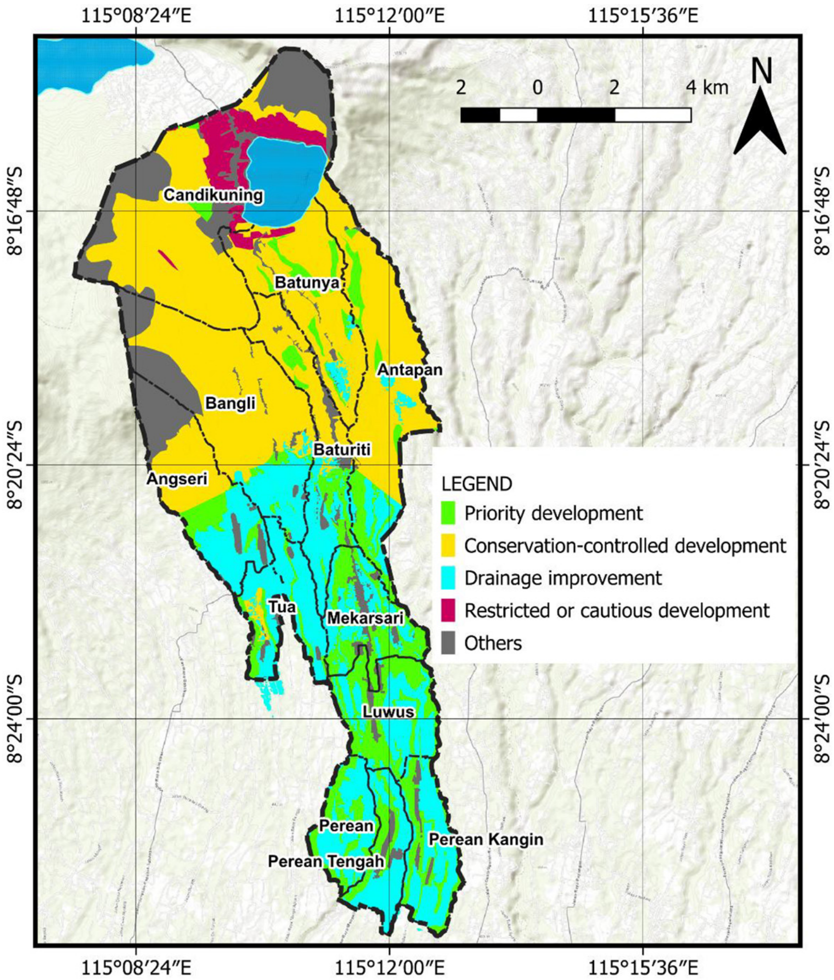

Figure 6. Site-specific land management priority zones for sustainable *Anthurium andraeanum* development in Baturiti District

land-use expansion. The absence of S1 under both actual and potential conditions is an important result because it shows that the study area should be interpreted as a managed suitability landscape rather than an optimum production zone.

This finding is consistent with the basic concept of land suitability evaluation, where land capability for a specific commodity depends on the interaction between crop requirements and site-specific land characteristics rather than administrative boundaries alone (Trigunasih and Wiguna, 2020). Similar land evaluation studies in Bali have also shown that slope, erosion risk, drainage, soil fertility, and soil physical properties often become decisive constraints for agricultural land-use planning (Kartini et al., 2023; Susila et al., 2024; Suyarto et al., 2023a; Ustriyana et al., n.d.; Adnyana et al., 2025). However, the present study differs from previous land suitability studies because it focuses specifically on anthurium, a high-value ornamental crop, rather than food crops, estate crops, or general floriculture commodities. This crop-specific focus is important because the same land limitation may have different practical meanings depending on the commodity being evaluated.

The land-unit-based approach is particularly important for anthurium because its production is closely associated with both plant growth performance and ornamental quality. Previous studies have emphasized that *Anthurium andraeanum* is an important ornamental species in the global cut flower and potted plant market, with commercial value strongly linked to spathe quality, flower longevity, color, and postharvest performance (Li et al., 2023; Zhang et al., 2023). Therefore, land suitability for anthurium should not only be interpreted as the ability of land to support plant survival, but also as the ability to provide stable growing conditions required for consistent ornamental production. This interpretation strengthens the novelty of the study because the modified matching framework links land-unit characteristics, actual-to-potential suitability response, limiting-factor diagnosis, and management zoning specifically for anthurium development.

Slope as a major physical constraint and its implication for conservation-based floriculture

Slope was one of the most important actual limiting factors in this study. The land units classified as N under actual conditions were mainly associated with steep slopes, especially those in the 25–40% slope class. This result is consistent with previous studies in Bali showing that sloping agricultural land is highly sensitive to soil degradation, erosion, and conservation-related constraints (Adnyana et al., 2024; Soniari et al., 2024; Trigunasih and Saifulloh, 2023). In highland agricultural landscapes, slope affects not only the ease of cultivation but also runoff generation, soil loss potential, accessibility, and the long-term stability of the rooting environment.

The shift of several slope-limited land units from actual N or S3 to potential S2 suggests that some topographic constraints can be reduced through appropriate conservation measures. However, this improvement should be interpreted carefully. Terracing, contour planting, mulching, cover crops, vegetative barriers, and runoff control can reduce erosion hazard and improve land management, but they do not eliminate slope as an inherent landscape condition (Trigunasih et al., 2026). Therefore, land units categorized as conservation-controlled development should not be treated as freely available expansion areas for anthurium. This is why the potential S2 class in slope-limited HLUs was interpreted as conditional suitability, not as unrestricted suitability.

This interpretation is important because floriculture development in highland Bali is often linked to market opportunity, tourism demand, and farmer income. However, if development is directed to steep land without conservation measures, floriculture expansion may increase soil erosion and land degradation. The present study therefore supports a conservation-based floriculture strategy, where anthurium cultivation is possible only when soil and water conservation practices are integrated into land management. This position is more realistic than simply classifying steep land as suitable after improvement.

Drainage limitation and the need for controlled rooting conditions

Drainage limitation was mainly observed in paddy-field land units. This result has an important implication for anthurium cultivation because paddy fields may provide adequate water availability, but they do not automatically provide suitable rooting conditions for ornamental crops that require well-aerated media. Anthurium requires sufficient moisture, but excessive water saturation can reduce root aeration and may increase the risk of root-related stress. Previous studies on anthurium have shown that flower longevity and quality are closely related to plant water relations and physiological stability (Khan, 2024; Sadiq et al., 2025; Shaw et al., 2025). Although these studies focused mainly on postharvest and physiological aspects, they support the interpretation that water status is a critical factor for anthurium performance.

In this study, drainage-limited land units improved to potential S2 after drainage improvement was considered. This indicates that these areas may be used for anthurium cultivation, but only with appropriate water-control systems. Raised beds, micro-drainage channels, porous planting media, and irrigation regulation are required to create a moist but aerated rooting environment. Direct field cultivation without drainage modification should be avoided, especially in land units previously managed as paddy fields.

This finding also distinguishes anthurium from several other agricultural commodities. For crops that tolerate wetter soil conditions, paddy-field conversion may be less problematic. For anthurium, however, the quality and stability of the rooting environment are directly linked to plant vigor and ornamental performance. Therefore, drainage improvement is not a minor technical intervention, but a central requirement for converting drainage-limited land into suitable anthurium production areas. The field observation of existing anthurium cultivation in Baturiti, shown in Figure 1c, provides contextual evidence that anthurium can be cultivated in the highland landscape; however, this observation was not used as quantitative validation of yield or flower quality. Therefore, the suitability results should be interpreted as agroecological zoning rather than production-performance prediction.

Persistent agroclimatic and soil-texture constraints

The potential suitability results showed that rainfall and temperature remained as residual S2 constraints in several land units. These factors are difficult to modify under open-field conditions and explain why no land unit reached S1 even after improvement. This finding is consistent with the logic of land suitability evaluation, where agroclimatic variables often act as relatively permanent constraints compared with soil fertility or drainage, which can be improved through management (AbdelRahman et al., 2025; Sidabutar et al., 2023; Trigunasih and Wiguna, 2020).

The persistence of texture limitation in HLU 16 is another important finding. Unlike nitrogen status, organic matter, drainage, or soil depth, soil texture is an inherent soil property that cannot be easily modified at the land-unit scale. The fact that HLU 16 remained in S3 under both actual and potential conditions indicates that this land unit should not be prioritized for direct soil-based anthurium cultivation. This interpretation is consistent with land resource evaluation principles, where persistent limitations should be treated differently from manageable limitations.

However, S3 classification does not necessarily mean that anthurium cultivation is impossible. Rather, it indicates that conventional field cultivation is less favorable. In texture-limited land units, controlled cultivation systems such as pot culture, shade-house production, greenhouse cultivation, and modified growing media may be more appropriate. This is particularly relevant for anthurium because commercial production often allows partial separation between plant growth and native soil conditions through the use of containerized or media-based systems. Therefore, HLU 16 should be interpreted as a conditional production area, not as a priority land-based expansion zone. This distinction reduces the risk of overestimating potential suitability because inherent limitations such as texture, rainfall, and temperature were retained in the potential assessment rather than assumed to be fully correctable.

Comparison with previous land suitability studies and the contribution of this study

Previous land suitability studies in Baturiti and other parts of Bali have primarily focused on food crops, conservation crops, plantation commodities, soil fertility, soil degradation, erosion risk, and conservation planning. These studies have consistently shown that slope, drainage, erosion hazard, soil depth, nutrient status, and soil physical properties are important determinants of agricultural land suitability in Bali's volcanic and highland landscapes (Rusadi et al., 2023; Sari et al., 2022; Sidabutar et al., 2023; Trigunasih and Wiguna, 2020; Vandani et al., 2025). However, specific agroecological land suitability assessment for floriculture commodities, particularly high-value ornamental crops such as *Anthurium andraeanum*, remains rarely addressed. To the authors' knowledge, no previous study has specifically evaluated actual and potential land suitability for anthurium in Bali's highland floriculture landscape using a land-unit-based agroecological matching approach.

The present findings show both similarities and differences compared with previous land suitability studies in Bali. The similarity lies in the recurring role of slope, drainage, and soil-related limitations as major determinants of agricultural suitability in highland and sloping landscapes. In this study, slope strongly influenced the classification of several land units into N or S3 under actual conditions, whereas drainage limitation was particularly evident in paddy-field units. This pattern supports previous findings that topographic and soil-water constraints are critical factors in agricultural land-use planning in Bali's highland environments.

The main difference lies in the crop-specific interpretation of these constraints. For anthurium, drainage and rooting-media conditions have a more specific meaning because the crop requires a moist but well-aerated rooting environment. Therefore, paddy-field land units cannot be directly interpreted as suitable for anthurium without drainage improvement, even when water availability is generally adequate. Similarly, slope is not only a physical constraint for cultivation, but also a conservation issue because highland floriculture development may increase erosion risk when implemented without appropriate soil and water conservation measures. This interpretation makes the assessment more specific than general land suitability mapping because the same land limitation may have different implications depending on the target commodity.

This study contributes by translating homogeneous land-unit characteristics into anthurium-specific suitability classes, actual-to-potential transitions, dominant limiting factors, and management zones. The rule-based matching approach was used as a foundational agroecological assessment because official suitability criteria and calibrated field-performance datasets for *Anthurium andraeanum* are not yet available in the study area. Under these conditions, the priority is to establish a transparent and reproducible suitability matrix that can be traced from measured land characteristics to explicit threshold values and documented improvement rules. Therefore, the contribution of this study is not the development of a new modelling algorithm, but the adaptation of an established land evaluation structure into an anthurium-specific actual-to-potential framework. This framework provides an initial scientific basis for floriculture planning by separating manageable and persistent limiting factors and translating them into HLU-based management directions. Future studies may further refine this baseline using fuzzy logic, AHP, or machine-learning-based suitability modelling when sufficient yield, growth, flower-quality, and management-response data for anthurium become available (G.S. et al., 2025; Khan, 2024; Kılıc et al., 2022; Saha and Mondal, 2022; Sathiyamurthi et al., 2024; Shaw et al., 2025).

Implications, uncertainty, and cautious use of the suitability zones

The results have practical implications for floriculture planning in Bali's highland agricultural landscape. The priority development zone should be used as the first target for anthurium cultivation because it already meets moderate suitability under actual conditions. The conservation-controlled zone can support anthurium only when soil and water conservation practices are implemented, especially in slope-limited HLUs. The drainage-improvement zone requires raised beds, micro-drainage, porous media, and irrigation control before cultivation. The restricted or cautious zone should not be prioritized for direct soil-based planting because persistent texture limitation remained after improvement.

These management zones should be interpreted as agroecological guidance, not as a final investment or land-conversion decision. The classification was based on biophysical land characteristics, while market access, production cost, farmer preference, planting material availability, postharvest handling, and institutional support were not included. Therefore, the results provide a land-resource basis for directing anthurium development, but they should be complemented by agro-economic and production-performance studies before large-scale implementation.

Several sources of uncertainty should also be considered. First, the suitability criteria were modified because specific national criteria for *Anthurium andraeanum* are not available. Second, the potential suitability map is scenario-based because it assumes feasible improvement of manageable constraints, not actual implementation in the field. Third, field observation confirmed the presence of anthurium cultivation in the study area, but independent quantitative validation using yield, flower quality, or farmer production records was not available. Fourth, the HLU-based approach captures dominant land-unit conditions, but small within-unit variations may still occur. These uncertainties do not invalidate the results, but they define the appropriate scope of interpretation.

Overall, the main scientific contribution of this study is the development and application of a modified, transparent, and land-unit-based actual-to-potential suitability framework for anthurium. The framework strengthens floriculture planning by connecting measured land characteristics, explicit suitability thresholds, limiting-factor diagnosis, improvement scenarios, and management zoning. This makes the assessment more reproducible and more specific to anthurium than general land suitability mapping for food crops, plantation crops, or broad horticultural commodities.

CONCLUSIONS

The hypothesis that a spatially explicit, land-unit-based agroecological assessment can distinguish actual and potential suitability for *Anthurium andraeanum* in a heterogeneous highland landscape is supported by the results. Actual suitability was dominated by S3, covering 5,734.55 ha or 62.30%, followed by N with 1,866.68 ha or 20.28%, and S2 with 1,602.91 ha or 17.42%. After feasible improvement scenarios were considered, potential suitability shifted strongly toward S2, covering 8,847.75 ha or 96.13%, while 356.39 ha or 3.87% remained S3. No land unit reached S1, indicating that Baturiti should be interpreted as a moderately suitable and management-dependent floriculture landscape, not as an optimum or limitation-free production zone.

The main new finding is that anthurium suitability in Baturiti is controlled by a clear distinction between manageable and persistent limitations. Slope and drainage constraints can be reduced through conservation measures, raised beds, micro-drainage, porous growing media, and improved rooting-zone management. In contrast, rainfall, temperature, and soil texture remained as residual or inherent constraints that limit the attainment of highly suitable conditions. This distinction explains why many land units improved from actual S3 or N to potential S2, but none reached S1.

The scientific novelty of this work lies in establishing a commodity-specific actual-to-potential agroecological suitability framework for *A. andraeanum*, linking measured land characteristics, explicit suitability thresholds, limiting-factor diagnosis, and land-unit-based management zoning. This fills a gap in land evaluation studies that have more commonly focused on food crops, plantation crops, soil fertility, erosion, and general agricultural suitability, while high-value floriculture commodities in tropical highland landscapes remain less represented.

Because the available Indonesian land evaluation guideline and previous land suitability studies do not provide explicit suitability criteria for *A. andraeanum*, several threshold interpretations in this study required literature-based and expert-informed adjustment. Therefore, the suitability classes should be understood as an agroecological planning baseline rather than a direct prediction of yield, flower quality, or farm profitability. The actual-to-potential transition also depends on assumed management responses, particularly for drainage improvement, conservation measures, and nutrient correction. For this reason, the results are most applicable to Baturiti District and should not be directly transferred to other regions without recalibration using local climate, soil, management, and anthurium performance data.

Future research should validate the proposed suitability zones using field performance indicators, including plant growth, flower quality, productivity, disease incidence, farmer adoption, production cost, and market access. Further studies may also compare this rule-based baseline with weighted, fuzzy, or data-driven suitability models when sufficient anthurium performance datasets become available..

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REFERENCES

1. AbdelRahman, M.A.E., Yossif, T.M.H., Metwaly, M.M., (2025). Enhancing land suitability assessment through integration of AHP and GIS-based for efficient agricultural planning in arid regions. *Sci. Rep. 15*, 31370.
2. Adnyana, I.W.S., As-syakur, A.R., Suyarto, R., Sunarta, I.N., Nuarsa, I.W., Diara, I.W., Saifulloh, M., Wiyanti, (2024). *Geospatial Technology for Climate Change: Influence of ENSO and IOD on Soil Erosion,* in: Technological Approaches for Climate Smart Agriculture. Springer, pp. 249–275.
3. Apriadi, P.A., Trigunasih, N.M., Mega, I.M., (2025). Soil quality analysis and land management direction on dry land areas in Tejakula and Buleleng Districts, Indonesia. *Agro Bali Agric. J. 8*, 446–458.
4. Baghkhanipour, M.S., Sayahnia, R., Mobarghaee Dinan, N., Danehkar, A., (2026). Integrated assessment of ecological land capability and land suitability for irrigated agriculture in Alborz Province *Iran. Sci. Rep.*
5. Darma, I.D.P., Sutomo, S., Hanum, S.F., Iryadi, R., Rahayu, A., (2021). Flowers and value of conservation in the culture of Hindu community in Bali. *Biosaintifika J. Biol. Biol. Educ. 13*, 34–40.
6. Diara, I.W., Suyarto, R., Saifulloh, M., (2022). Spatial distribution of landslide susceptibility in new road construction Mengwitani-Singaraja, Bali-Indonesia: Based on geospatial data. *Int. J. Geomate 23*. https://doi.org/10.21660/2022.96.3320
7. Evelyn, S., Farrell, A.D., Elibox, W., Abreu, K. De, Umaharan, P., (2020). The impact of light on vase life in (Anthurium andraeanum Hort.) cut flowers. *Postharvest Biol. Technol. 159*. https://doi.org/10.1016/j.postharvbio.2019.110984
8. Food and Agriculture Organization of the United Nations. (1976). *A framework for land evaluation* (FAO Soils Bulletin No. 32). Food and Agriculture Organization of the United Nations.

9. Fresco, L., Huizing, H., van Keulen, H., Luning, H.A., Schipper, R., (1990). Land evaluation and farming systems analysis for land use planning: FAO guidelines: working document.
10. G.S., L., Devidas, A.R., Pushpalatha, R., Gangadharan, B., K.M., H., (2025). Enhancing coconut yield potential: A climate-smart land suitability analysis using machine learning. *Smart Agric. Technol. 12*. https://doi.org/10.1016/j.atech.2025.101087
11. Islam, A., Mandal, B.K., Sarkar, B., Rahman, A., Mohinuddin, S., Sengupta, S., (2026). Land use dynamics and agricultural transformation to floriculture in a coastal region of India using information entropy and Markov chain model. *Model. Earth Syst. Environ. 12*. https://doi.org/10.1007/s40808-025-02661-z
12. Kandegama, W.M.W.W., Rathnayake, R.M.P.J., Baig, M.B., Behnassi, M., (2022). I*mpacts of climate change on horticultural crop production in Sri Lanka and the potential of climate-smart agriculture in enhancing food security and resilience,* In: Food Security and Climate-Smart Food Systems: Building Resilience for the Global South. Springer, pp. 67–97.
13. Kar, S., Bera, D., Dutta, D., Kundu, A., (2026). Identification of floriculture using multi-temporal Sentinel datasets and machine learning techniques. *Appl. Geomatics 18*. https://doi.org/10.1007/s12518-025-00653-3
14. Kartini, N.L., Saifulloh, M., Trigunasih, N.M., Narka, I.W., (2023). Assessment of soil degradation based on soil properties and spatial analysis in dryland farming. *J. Ecol. Eng. 24*. https://doi.org/10.12911/22998993/161080
15. Khan, S., (2024). Site Suitability analysis for fruit crop production using satellite remote sensing and GIS based multi-criteria evaluation approach. *Yashwan t Singh Parmar Univ. Hortic. For.*
16. Kılıc, O.M., Ersayın, K., Gunal, H., Khalofah, A., Alsubeie, M.S., (2022). Combination of fuzzy-AHP and GIS techniques in land suitability assessment for wheat (*Triticum aestivum*) cultivation. *Saudi J. Biol. Sci. 29*. https://doi.org/10.1016/j.sjbs.2021.12.050
17. Lakhiar, I.A., Yan, H., Syed, T.N., Zhang, C., Shaikh, S.A., Rakibuzzaman, M., Vistro, R.B., (2025). Soilless agricultural systems: Opportunities, challenges, and applications for enhancing horticultural resilience to climate change and urbanization. *Horticulturae 11*, 568.
18. Li, J., Tan, Q., Yi, M., Yu, Z., Xia, Q., Zheng, L., Chen, J., Zhou, X., Zhang, X.Q., Guo, H.R., (2023). Identification of key genes responsible for green and white colored spathes in *Anthurium andraeanum* (Hort.). *Front. Plant Sci. 14*, 1–14. https://doi.org/10.3389/fpls.2023.1208226
19. Liu, Y., Cai, T., Su, Q., Yi, M., Xia, Q., Yuan, Y., Zeng, R., Xie, L., Guo, H., Zhang, Z., (2024). The origin, germplasm resources, and breeding of Anthurium andraeanum: an overview. Ornam. *Plant Res. 5.*
20. Mistri, P., Das, S., Jaman, M.H., Roy, S., Chatterjee, J., Sengupta, S., (2026). Understanding the complexities of mustard intercropping: Inferences based on land suitability and farmers' choices in a paddy-dominated cropping system of eastern India. *J. Clean. Prod. 538*, 147235.
21. Monder, M.J., Pacholczak, A., Zajączkowska, M., (2024). Directions in ornamental herbaceous plant selection in the central European temperate zone in the time of climate change: benefits and threats. *Agriculture 14*, 2328.
22. Ni Made Trigunasih, M.S., (2022). Spatial distribution of landslide potential and soil fertility: A case study in Baturiti District, Tabanan, Bali, Indonesia. *J. Hunan Univ. Nat. Sci. 49*.
23. Patra, S., Dutta, D., Kar, S., Bera, D., (2026). Optimizing floriculture mapping with deep learning using high-resolution multispectral and hyperspectral imagery. *Remote Sens. Appl. Soc. Environ. 42*, 101968. https://doi.org/10.1016/j.rsase.2026.101968
24. Paul, R., Saishree, R., Ghadei, M., Prusty, B.A.K., (2026). Soil health and agricultural land suitability assessment of highlands of the Eastern Ghats using geospatial index. *Agric. Syst. 233*, 104622.
25. Peterson, C.A., McCarthy, C., (2003). Hotel development of cultural tourism elements. *Tour. Rev. 58*, 38–42.
26. Prabhaswara, I.G.N.M., Kartini, N.L., Kesumadewi, A.A.I., (2025). Residu pestisida pada tanah dan kotoran cacing di lahan pertanian sayur kecamatan Baturiti, Kabupaten Tabanan: Pesticide Residues in soil and worm feces on vegetable farms in Baturiti District, Tabanan Regency. *J. BETA (Biosistem dan Tek. Pertanian) 13*, 310–316.
27. Ritung, S., Nugroho, K., Mulyani, A., Suryani, E. (2011). *Petunjuk teknis evaluasi lahan untuk komoditas pertanian* (Edisi revisi). Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Penelitian dan Pengembangan Pertanian, Kementerian Pertanian.
28. Rossiter, D.G., (1996). A theoretical framework for land evaluation. *Geoderma 72*, 165–190.
29. Rusadi, N.W.P., Pitana, I.G., Sunarta, I.N., Arida, I.N.S., (2023). Development of Subak Lestari as a sustainable tourism attraction in Denpasar city. *Int. J. Green Tour. Res. Appl. 5*, 114–128. https://doi.org/10.31940/ijogtra.v5i2.114-128
30. Sadiq, F.K., Yaqub, M.T., Maniyunda, L.M., Alalwany, A.A.M., Abubakar, F., Anyebe, O., (2025). Soil classification and land suitability evaluation for tomato cultivation using analytic hierarchy process under different land uses. *Heliyon 11*.
31. Saha, S., Mondal, P., (2022). Estimation of the effectiveness of multi-criteria decision analysis and

machine learning approaches for agricultural land capability in Gangarampur Subdivision, Eastern India. *Artif. Intell. Geosci. 3*. https://doi.org/10.1016/j.aiig.2022.12.003

32. Sardiana, I.K., Kusmiyarti, T.B., (2021). Sustainability performance of organic farming at vegetable fields in Tabanan, Bali, Indonesia. *Sains Tanah 18*. https://doi.org/10.20961/STJSSA.V18I1.45482
33. Sari, D., Trigunasih, N., Mega, I., (2022). Suitability evaluation of several food crops on rice fields based on geographic information system in Baturiti Sub-District. *Agroekoteknologi Trop. 11*, 265–275.
34. Sathiyamurthi, S., Sivasakthi, M., Saravanan, S., Gobi, R., Praveen kumar, S., Karuppannan, S., (2024). Assessment of crop suitability analysis using AHP-TOPSIS and geospatial techniques: A case study of Krishnagiri District, India. *Environ. Sustain. Indic. 24*. https://doi.org/10.1016/j.indic.2024.100466
35. Shaw, S.K., Sravani, N., Sharma, A., Anand, J., (2025). Assessment of probable zones of agricultural land suitability based on MCDM, probabilistic, and data-driven approach in Krishna District, India. *Environ. Monit. Assess. 197*, 339.
36. Sidabutar, F., Trigunasih, N.M., Sumarniasih, M.S., (2023). Evaluation of land suitability for development of conservation crops and plantations in the Unda Watershed, Bali Province, Indonesia. *Agro Bali 6*, 852–859. https://doi.org/10.37637/ab.v6i3.1277
37. Soniari, N.N., Trigunasih, N.M., Sumarniasih, M.S., Saifulloh, M., (2024). Exploring soil erodibility: integrating field surveys, laboratory analysis, and geospatial techniques in sloping agricultural terrains. *J. Degrad. Min. Lands Manag. 12*.
38. Susila, K.D., Ginting, D.C.B., Adnyana, I., Saifulloh, M., Arthagama, I., (2024). Enhancing soil quality for sustainable agricultural practices in Subak rice fields. *J. Degrad. Min. Lands Manag. 12*.
39. Suyarto, R., Diara, I.W., Susila, K.D., Saifulloh, M., Wiyanti, W., Kusmiyarti, T.B., Sunarta, I.N., (2023a). Landslide inventory mapping derived from multispectral imagery by support vector machine (SVM) algorithm, in: *IOP Conference Series: Earth and Environmental Science.* https://doi.org/10.1088/1755-1315/1190/1/012012
40. Suyarto, R., Wiyanti, Saifulloh, M., Fatahillah, A.W., Diara, I.W., Susila, K.D., Kusmiyarti, T.B., (2023b). Hydrological approach for flood overflow estimation in Buleleng Watershed, Bali. *Int. J. Saf. Secur. Eng. 13*. https://doi.org/10.18280/ijsse.130512
41. Trigunasih, N.M., Lanya, I., Hutauruk, J., Arthagama, I.D.M., (2017). Spatial Numeric Classification Model Suitability with Landuse Change in Sustainable Food Agriculture Zone in Kediri Sub-district, Tabanan Regency, Indonesia, in: *IOP Conference Series: Earth and Environmental Science.* https://doi.org/10.1088/1755-1315/98/1/012046
42. Trigunasih, N.M., Narka, I.W., Saifulloh, M., (2023). Measurement of soil chemical properties for mapping soil fertility status. *Int. J. Des. Nat. Ecodynamics 18*. https://doi.org/10.18280/ijdne.180611
43. Trigunasih, N.M., Saifulloh, M., (2023). Investigation of soil erosion in agro-tourism area: guideline for environmental conservation planning. *Geogr. Tech. 18*. https://doi.org/10.21163/GT_2023.181.02
44. Trigunasih, N.M., Saifulloh, M., (2022). Correlation between soil nitrogen content and NDVI derived from Sentinel-2A satellite imagery. *J. Lahan Suboptimal J. Suboptimal Lands 11*. https://doi.org/10.36706/jlso.11.2.2022.574
45. Trigunasih, N.M., Saifulloh, M., Sunarta, I.N., (2026). Geospatial identification of soil erosion hotspots exacerbating the catastrophic flash flood in Bali, Indonesia 21, 105–126. https://doi.org/10.21163/GT
46. Trigunasih, N.M., Wiguna, P.P.K., (2020). Land suitability for rice field and conservation planning in Ho Watershed, Tabanan Regency, Bali Province, Indonesia. *Geogr. Tech. 15*. https://doi.org/10.21163/GT_2020.151.11
47. Ustriyana, I.N.G., Saifulloh, M., Diara, I.W., Suyarto, R., n.d. Mapping agrotourism potential using geospatial data and random forest: A case study from Bali. *Ecol. Eng. Environ. Technol. 26.*
48. Vandani, Y., Trigunasih, N.M., Sumarniasih, M.S., (2025). Evaluating soil fertility and quality status for balanced fertilization-based agricultural land management in Mendoyo Subdistrict. *J. Agrotek Trop. 13.*
49. Wan, X., Zou, L.H., Pan, X., Ge, Y., Jin, L., Cao, Q., Shi, J., Tian, D., (2024). Auxin and carbohydrate control flower bud development in *Anthurium andraeanum* during early stage of sexual reproduction. *BMC Plant Biol. 24*, 1–13. https://doi.org/10.1186/s12870-024-04869-0
50. Wayan Sandi Adnyana, I., Rahman As-syakur, A., Wayan Nuarsa, I., Saifulloh, M., Setiawati, M.D., 2025. *Comparing Soil Erosion Rate Predictions Using USLE Method Based on Conventional and Remote Sensing Data Calculations,* in: Remotely Sensed Rivers in the Age of Anthropocene. Springer, pp. 357–392.
51. Yeshiwas, Y., Tadele, E., Mohammed, A., Hu, X., (2026). Impacts of climate change on horticultural systems with focus on socio-economic implications, production and postharvest challenges, and adaptive pathways. *Discov. Environ. 4*, 55.
52. Zhang, L., Chen, Y., Leng, Q., Lin, X., Lu, J., Xu, Y., Li, H., Xu, S., Huang, S., López Hernán, A., Wang, Y., Yin, J., Niu, J., (2023). A High-Resolution Linkage Map Construction and QTL Analysis for Morphological Traits in Anthurium (*Anthurium andraeanum* Linden). *Plants 12*. https://doi.org/10.3390/plants12244185