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LAND SUITABILITY EVALUATION FOR UPLAND RED RICE IN THE KARST TOPOGRAPHY OF PACAREJO SEMANU GUNUNGKIDUL

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ABSTRACT

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Pacarejo, a village in Kapanewon Semanu, is located a karst area. Karst conditions cause the ability of land for agriculture to be very limited. However, this is an opportunity to develop dry land into productive agricultural land by planting potential crops that are suitable for land conditions and having a good economic value. The purpose of the study was to determine the level of land suitability in Pacarejo Village for upland red rice. This study used a survey method. Land system maps were produced from overlays of land use maps, land type maps, and slope maps so that 37 land systems were obtained. The determination of sampling points used the purposive sampling method based on the selected land system, namely 11 sample points by excluding settlements and land with steep slopes. The data analysis method used matching between land characteristics and suitability criteria for crops according to the Technical Guidelines for Evaluating Suitability for Agricultural Commodities. The results showed that the suitability class for upland red rice was S3 (Marginal Suitable) covering an area of 1.636,63 ha (57,87%) with limiting factors of oxygen availability (oa), root conditions (rc), and nutrient retention (nr). Land suitability in several land systems can potentially be improved to S2 class by improving the limiting factors of rapid soil drainage and low soil base saturation.

Keywords: upland red rice, karst, soil mapping unit, land suitability, Pacarejo

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INTODUCTION

Pacarejo, located in Kapanewon Semanu, Gunungkidul, is a hilly karst landscape characterized by considerable spatial variation in soil solum depth, limited surface water availability, and high susceptibility to erosion (Fatmayanto & Suharko, 2025; Montgomery et al., 2017). Soils developed within this karst formation are generally shallow, averaging less than 50 cm in depth, a condition linked to the geomorphological processes of bedrock dissolution and irregular topography, which collectively constrain the accumulation of weathered soil material. The landscape's hilly relief not only restricts the limits of land suitable but also compounds vulnerability to erosive processes, particularly during periods of intense rainfall. Furthermore, karst regions are distinguished by chronic water scarcity, as the highly permeable and fissured carbonate bedrock facilitates rapid subsurface percolation, severely lowering surface water retention (Elsheikh et al., 2013). The convergence of these edaphic and hydrological constraints shallow solum, erosion susceptibility, and water deficit has collectively restricted optimal agricultural productivity, underscoring the urgent need for systematic land resource assessment.

Dryland ecosystems occupy more than half of the total land area in Pacarejo, however, crop productivity within this agroecological zone has exhibited a marked decline in recent years. Upland rice production, for instance, declined from 5,974 tons per hectare in 2023 to 4,414 tons per hectare in 2024 (BPP Semanu, 2025), signaling underlying constraints in land management and resource allocation that warrant further investigation. Although the average productivity of dryland food crops remains comparatively lower than that of irrigated paddy fields, the considerably larger spatial extent of dryland presents a substantial and largely unrealized opportunity for strengthening regional food security. Despite agronomic and infrastructural limitations, the prevailing agroecological conditions offer considerable potential for developing drought-adapted commodities, including upland rice, brown (red) rice, porang (*Amorphophallus muelleri*), and ginger (Subowo, 2009).

Among these commodities, red upland rice has emerged as a premium crop of substantial economic value, increasingly incorporated into contemporary dietary programs due to its significantly higher dietary fiber content relative to conventional white rice (Suliartini et al., 2019). Its comparatively low glycemic and sugar content further renders it suitable for individuals managing diabetes mellitus. Nutritionally, this variety contains 73.16–79.58% carbohydrates, 1.00–2.07% fat, 7.72–9.10% protein, and significant concentrations of anthocyanins, which function as potent natural antioxidants (Pangerang, 2022). A further agronomic advantage lies in its minimal water requirement throughout the growth cycle, enabling successful cultivation within dry, water-limited karst landscapes (Ilmam et al., 2025). Unlike conventional lowland rice, upland rice exhibits pronounced tolerance to drought stress and does not depend on continuously flooded soil conditions, making it agronomically well matched to the hydrological limitations of karst environments. The relationship between land suitability and productivity has been previously documented by Partoyo et al. (2015), who found that land classified as S3 (marginally suitable) yielded 6.4 tons of unhulled dry grain (GKP) per hectare, whereas S2 (moderately suitable) land achieved 8.4 tons GKP per hectare demonstrating a clear positive correlation between suitability class and attainable yield.

Despite this evident land use potential, comprehensive information concerning the biophysical characteristics of Pacarejo Village remains conspicuously limited, particularly with respect to land suitability for red rice cultivation. The optimal utilization of land resources, commensurate with their inherent carrying capacity, can only be achieved through the availability of accurate, site-specific suitability information. Agricultural development potential is fundamentally determined by the degree of congruence between the physical properties of the biophysical environment and the ecological requirements of the target crops (Sirappa et al., 2016).

To address this existing knowledge gap, the present study was conducted to directly assess field level land characteristics within Pacarejo. The resulting biophysical data were subsequently employed to evaluate land suitability classes through a systematic matching procedure against established criteria for red rice cultivation. This suitability assessment is considered essential, as it not only addresses a prevailing void in the local scientific literature but also establishes a foundational, evidence-based framework for determining optimal and sustainable land-use strategies tailored to the specific biophysical characteristics of the study area.

MATERIALS AND METHODS

Research location and design

This research was conducted from March to July 2025 in Pacarejo Village, Semanu, Gunungkidul (8° 01′ 38.1″ S, 110° 36′ 43.9″ E). Soil analyses were performed at the Land Resources Laboratory (Faculty of Agriculture, Universitas Pembangunan Nasional "Veteran" Yogyakarta), BPSIP Yogyakarta Laboratory, and Laboratory of Soil Chemistry and Fertility (Faculty of Agriculture, Universitas Sebelas Maret). A purposive sampling method was employed, based on overlay results from land use, soil type, and slope maps. Eleven sample points were subsequently identified, representing three land-use types (moorland, rice fields, and industrial plantation forests), three slope classes (fat, sloping, and slightly steep), and two soil types: Inceptisol and Alfisol (Figure 1)

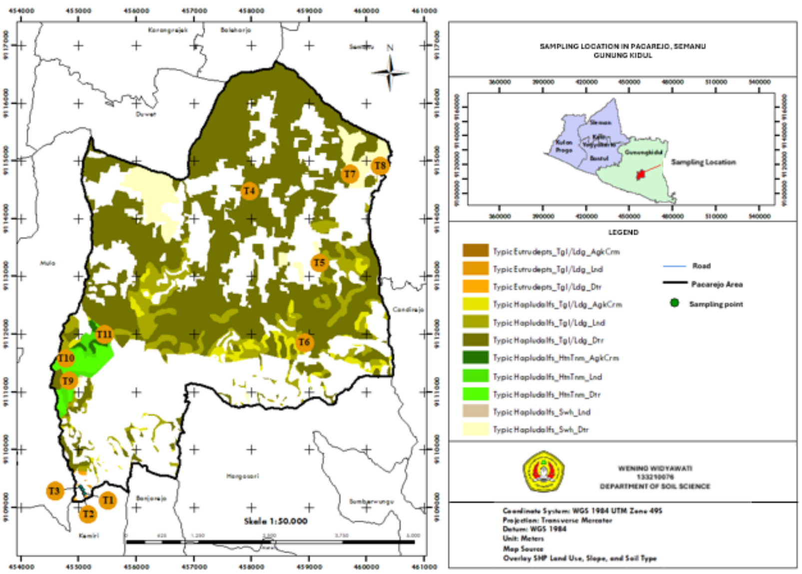

Figure 1. Map of the research area sampling points

Sampling procedures

Field sampling was conducted using soil drills, measuring meters, GPS, and clinometers. The research comprised two main stages: (1) field sampling and (2) data collection. During the sampling stage, climate data (temperature and humidity) were recorded. The field parameters measured included soil depth, drainage, slope, erosion hazard, surface rock, rock outcrops, coarse materials, and flood or inundation hazards.

Data analysis

Laboratory analyses were performed using equipment such as distillation flasks, Erlenmeyer flasks, heating mantles, burettes, retort stands, clamps, pH meters, and EC meters. The materials used included soil samples and chemical reagents, namely distilled water, 1 N NH_4OAc, 1 N $K_2Cr_2O_7$, concentrated H_2SO_4, 85% H_3PO_4, and 0.5 N $FeSO_4$. The laboratory parameters analyzed comprised cation exchange capacity (CEC), texture, pH H_2O, base saturation (BS), C-organic, salinity, and alkalinity. Analytical methods were as follows: CEC and BS were determined using the 1 N NH_4OAc saturation method; texture via the pipette method; pH H_2O using the potentiometric method; C-organic using the Walkley and Black method; salinity measured with an EC meter; and alkalinity determined by the exchangeable sodium percentage (ESP) value.

Land suitability classification was performed using a matching procedure that compared crop suitability criteria (Table 1) with actual land characteristics (Table 2), following the Technical Guidelines for Land Suitability Evaluation for Agricultural Commodities (Djaenudin et al., 2011). This system categorizes land into four specific classes: S1, S2, S3, and N (Not suitable). The final suitability class is determined by the lowest class among the evaluated factors, which serves as the primary limiting factor. Suitability classes were assessed under both actual conditions (actual land suitability) and potential conditions (potential land suitability), with the latter derived by simulating improvements or management interventions for each identified limiting factor.

Table 1. Criteria for land suitability for upland red rice

Land Characteristics	Land Suitability Class			
	S1	S2	S3	N
Temperature (tc)				
Temperature average (°C)	24-29	22-24 29-32	18-22 32-35	<18 >35
Water availability (wa)				
Moisture (%)	33-90	30-33	<30 >90	
Oxygen availability (oa)				
Drainage	Slow, very slow	Slightly slow, slightly fast	Medium, good	Fast
Root conditions (rc)				
Texture	Smooth, slightly smooth, medium	-	Slightly rough	Rough
Coarse material (%)	<3	3-15	15-35	>35
Soil depth (cm)	>50	40-50	25-40	<25
Peat				
Thickness (cm)	<60	60-140	140-200	>200
Thickness (cm), if mineral material is present	<140	140-200	200-400	>400
Maturity	Sapric	Sapric, hemic	Hemic, fibric	Fibric
Nutrient retention (nr)				
CEC (cmol(+)/kg)	>16	≤16		
Base saturation (%)	>35	20-35	<20	
pH H_2O	5,5-8,2	5,0-5,5 8,2-8,5	<5,0 >8,5	
C-organic (%)	>1,5	0,8-1,5	<0,8	
Toxicity (xc)				
Salinity (dS/m)	<2	2-4	4-6	>6
Xodisiness (xn)				
Alkalinity/ESP (%)	<20	20-30	30-40	>40
Sulfide hazard (xs)				
Sulfide depth (cm)	>100	75-100	40-75	<40
Flood hazard (fh)				
Flood	F31, F32	F41, F42, F43, F33	F21, F22, F3, F24, F34, F44	F11, F14, F15, F25, F35, F45
Land preparation (lp)				
Rocks on the surface (%)	<5	5-15	15-40	>40
Rock outcrops (%)	<5	5-15	15-25	>25

S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N = not suitable

Table 2. Land characteristics and actual land suitability assessment

Land Characteristics	Land Systems										
	SP 1	SP 2	SP 3	SP 4	SP 5	SP 6	SP 7	SP 8	SP 9	SP 10	SP 11
Temperature (tc)											
Temperature average (°C)	26,36	26,36	26,36	26,36	26,36	26,36	26,36	26,36	26,36	26,36	26,36
Water availability (wa)											
Rainfall at the time of growth (mm)	1,798	1,798	1,798	1,798	1,798	1,798	1,798	1,798	1,798	1,798	1,798
Moisture (%)	81,86	81,86	81,86	81,86	81,86	81,86	81,86	81,86	81,86	81,86	81,86
Oxygen availability (oa)											
Drainage	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Root conditions (rc)											
Texture	Smooth	Medium	Slightly smooth	Smooth	Smooth	Medium	Medium	Slightly smooth	Smooth	Smooth	Slightly smooth
Coarse material (%)	10,5	9,4	10,6	15	10	14,2	15	11,5	13,6	12,9	12,2
Soil depth (cm)	35	55	60	70	60	45	80	60	35	50	25
Nutrient retention (nr)											
CEC (cmol(+)/kg)	62,08	58,13	70,67	56,97	71,59	57,01	74,12	61,56	86,89	69,98	84,49
Base saturation (%)	12,26	12,56	13,22	36,71	14,72	14,47	29,58	30,10	17,67	13,19	4,38
pH H_2O	6,10	6,13	5,75	5,92	5,96	6,34	6,36	6,61	6,42	6,21	6,94
C-organic (%)	3,62	4,42	3,64	3,73	2,83	3,36	4,09	1,75	4,77	2,81	2,63
Toxicity (xc)											
Salinity (dS/m)	0,066	0,062	0,056	0,072	0,136	0,052	0,088	0,078	0,052	0,056	0,062
Xodisiness (xn)											
Alkalinity/ESP (%)	0,086	0,187	0,118	0,250	0,140	0,167	0,0136	0,349	0,066	0,396	0,125
Erosion hazard (eh)											
Slope (%)	4	13	16	3	10	19	4	11	3	15	18
Erosion hazard	Very low	Very low	Very low	Very low	Very low	Very low	Very low	Very low	Very low	Very low	Very low
Flood hazard (fh)											
Flood	F0	F0	F0	F0	F0	F0	F0	F0	F0	F0	F0
Land preparation (lp)											
Rocks on the surface (%)	5	3	3	0	0	5	0	4	4	5	5
Rock outcrops (%)	0	0	0	0	0	0	0	0	0	0	4

SP: Sampling Point.

RESULTS AND DISCUSSION

Land characteristics

Land characteristics including drainage, coarse material, soil depth, erosion and flood hazards, surface rocks, and rock outcrops were assessed at each sampling point, along with key chemical properties such as cation exchange capacity (CEC), base saturation, pH, C-organic, salinity, and alkalinity (Ritung *et al*., 2011). The complete results of these observations are presented in Table 2. Temperature and humidity data, obtained from the Yogyakarta Meteorology, Climatology, and Geophysics Agency (BMKG) for the 2020-2024 period, showed no spatial variation across sites, attributable to the relatively uniform elevation throughout the village. The dominant soil textures were classified as clay, loam, and clay loam according to the criteria of Djaenudin *et al.* (2011). Coarse materials were present in minor amounts at all sampling points, soil depth varied, drainage was uniformly good, and both surface rock content and rock outcrops occurred only in small quantities.

Field observations of surface, rill, and gully erosion indicated a very low erosion hazard, largely supported by the widespread implementation of terraces on steeper slopes a practice that effectively reduces erosion rates and prevents slope gradient from becoming a limiting factor. Furthermore, no flooding risk was identified across any of the land systems, as the well-drained soils facilitate rapid rainwater infiltration, thereby minimizing surface inundation potential. The specific characteristics of each land system within Pacarejo Village are comprehensively detailed in the table 2.

Land suitability

Based on the results of matching between the characteristics of the land and the land suitability criteria in each land system, the actual land suitability class and potential land suitability class were obtained. Current suitability is land suitability that has not considered improvement efforts and the level of management that can be carried out to overcome existing obstacles or limiting factors. Potential land suitability is land suitability that will be achieved after land improvement efforts are carried out (Khoriyah et al., 2023).

The actual land suitability class for upland red rice (Attachment 1) was included in the S3 (Marginal Suitable) class. The actual suitability class map for upland red rice crops was presented in Figure 2. This study presents subclasses of land suitability, namely S3oa, S3oanr, and S3oarcnr, thereby providing a more detailed understanding of the limitations of each type of land. The limiting factors for upland red rice plants are the availability of oxygen in the form of drainage that is too fast, the condition of the roots in the form of shallow soil depth, and nutrient retention in the form of low base saturation. These limiting factors affect plant growth, such as the shallow soil depth causing plants to not optimally absorb nutrients. Low base saturation affects plant growth because the supply of nutrients for plants will be limited so that plants will grow dwarf, their leaves will turn yellow, and yields will decrease.

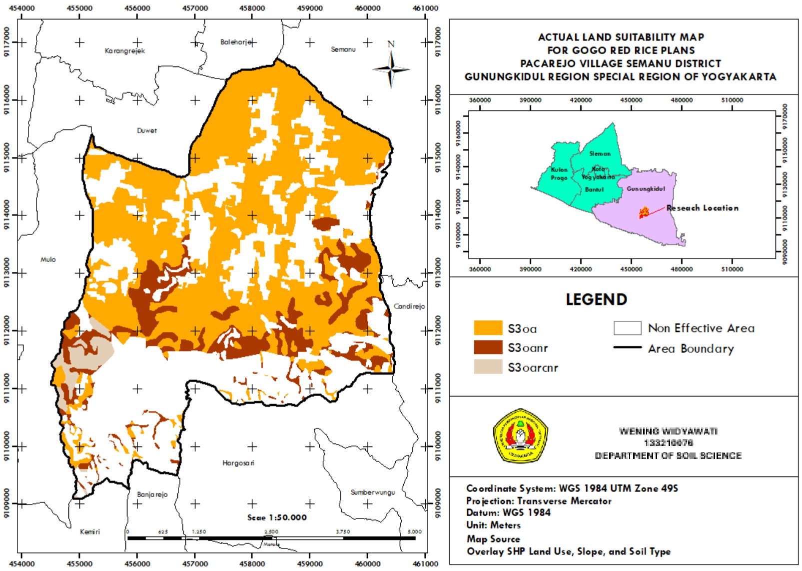

Figure 2. Actual land suitability map for upland red rice

The potential of each land type can be improved by addressing the limiting factors. Improvement of drainage limiting factors by making irrigation channels to increase water needs (Hardjowigeno & Widiatmaka, 2011). The limiting factor of low base saturation can be improved through fertilizer application. The application of fertilizers plays a role in enriching the content of organic matter and micro and macro nutrients. Organic fertilizers contain various macronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) as well as other micronutrients (Santari et al., 2021). In addition to organic fertilizers, inorganic fertilizers such as KCl fertilizers can also contribute to increasing soil alkaline saturation through the addition of K^+ alkaline cations (Safitri et al, 2025). In the soil depth factor, it generally cannot be repaired except for soft and thin layers of soil by dismantling or digging the soil in land cultivation. However, this advice is not recommended to be implemented at the location because it is inefficient and not easy to do and requires large operational costs (Hardjowigeno & Widiatmaka, 2011).

CONCLUSION

This study concludes that the actual land suitability class for upland red rice is S3 (Marginally Suitable). Through targeted improvements, the land system can potentially be upgraded to S2 (Sufficiently Suitable). The principal limiting factors identified include excessively rapid soil drainage, low base saturation, and shallow soil depth. Excessively rapid drainage can be alleviated through the construction of irrigation canals, while low base saturation can be addressed via fertilization. However, shallow soil depth represents a constraint that is inherently difficult to fix.

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