

Land Suitability Assessment and Agricultural Sustainability of Rice Cultivation in the Hilly Region of Jatiroto, Indonesia

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Received : May 23, 2025

Revised : August 2, 2025

Accepted : August 15, 2025

Online : October 2, 2025

Abstract

This study aims to assess land suitability, identify limiting factors, evaluate agricultural sustainability, and develop improvement strategies for rice farming in Jatiroto Sub-district, Wonogiri, Indonesia. Land suitability was analyzed using purposive sampling with matching methods, and sustainability was assessed using the rapid assessment of plantation and farming (RAP-FARM) approach. The results show that inorganic and organic farming systems on slopes of 0–15% fall under land suitability class S3, while semi-organic systems on 0–8% slopes are classified as S2 and on 8–15% as S3. The limiting factor for land suitability was base saturation. Limiting factors in P-available and K-available were found in both inorganic and semi-organic farming systems. The limiting factors for base saturation, organic carbon, soil depth, total nitrogen, available phosphorus, and available potassium were found in the inorganic farming system. Efforts to improve land suitability for rice include adding dolomite, applying P and K fertilizers (semi-organic land), and adding organic matter (inorganic land). The sustainability index of organic farming system (61.30) and semi-organic farming system (55.87) had a moderately sustainable status, while the inorganic farming system (43.43) had a less sustainable status. Attributes that need improvement include landowner-tenant farmer relationships, the intensity of agricultural training and extension services, and market availability. These findings provide that land suitability and agricultural sustainability require specific nutrient inputs and market access, which is important reference for making sustainable agricultural policies.

Keywords: farmer interest, limiting factor, RAP-FARM method, soil nutrients availability

1. INTRODUCTION

The agricultural sector plays a major role in providing food for the community and creating many jobs [1]. One of the food crops that contributes to national food security is rice. Indonesia is one of many countries in the world that focuses on rice production. High consumer demand for rice is the main reason for developing this staple crop. Data showed that milled rice production in 2021 reached 54.4 million tons, equivalent to 31.4 million tons of rice. However, rice production decreased by 0.43% from 2020 to 2021 due to various triggering factors [2].

Land degradation is an agricultural issue that farmers encounter due to critical soil properties [1] [3][4]. Land degradation affects the physical,

chemical, and biological properties of the soil, leading to a decrease in agricultural productivity [5]. Agricultural land productivity can be improved through pre-planting and post-harvest land management activities. However, farmers' lack of knowledge and information regarding soil management and land productivity poses a constrain in the optimal and sustainable utilization of agricultural land. Therefore, appropriate measures need to be taken to address the risk of land degradation through proper agricultural cultivation planning. Land suitability class assessment is one alternative reference for agricultural cultivation planning that considers climate, soil, and environmental factors that influence crop growth [6]. This assessment is based on actual soil conditions in physical, chemical, and biological aspects, as well as general land conditions, which are then adjusted to the minimum growth requirements of crops.

In addition to land degradation, unsustainable agricultural land management can also affect agricultural sustainability. There are three leading indicators in the concept of agricultural sustainability: ecology, economy, and society [6] [7]. First, environmental indicators in the agricultural sector are influenced by physical environmental factors and their activities, such as

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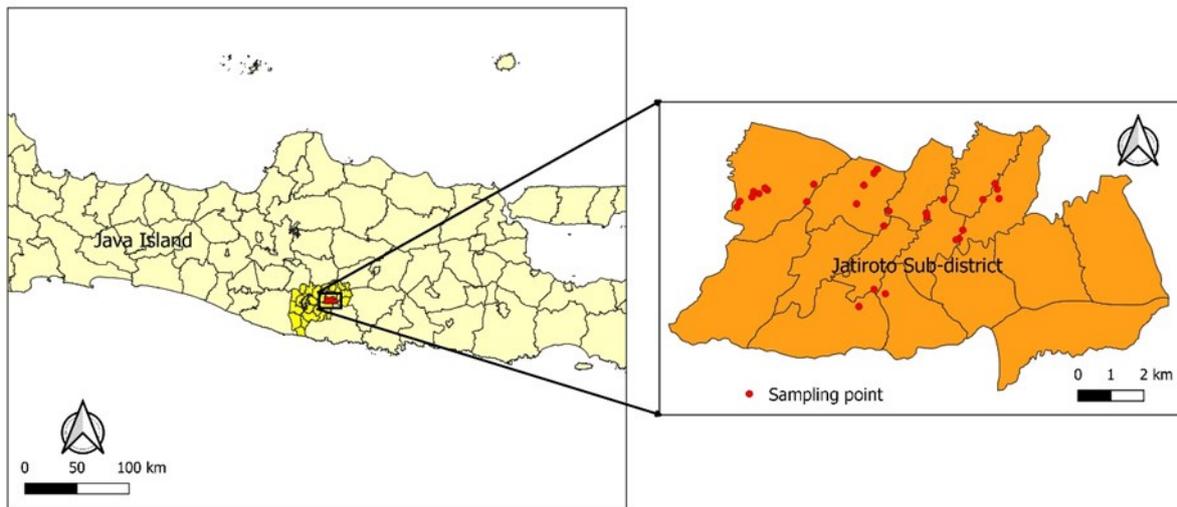


Figure 1. Study site location.

nutrients, pesticides, resources, soil management, greenhouse gas (GHG) emissions, biodiversity, and soil quality [8]. Second, the economic aspects, sustainable agriculture is influenced by market prices, crop yields, public support, and policies [9]. Third, the social aspect of sustainable agriculture can be influenced by 3 internal conditions: education, working conditions, and quality of life, as well as 3 external conditions are multifunctionality, accepted agricultural system, and product quality [10].

Stanny et al. conducted a study on the sustainability of horticultural agriculture in West Bandung used land capability classes to assess the sustainability of horticultural agriculture [11]. This study used Maxar's imagery and rapid appraisal for rice farming (RAP-FARM) to assess sustainability. Meanwhile, in this study, land suitability for rice cultivation was assessed across rice fields managed under different farming practices include organic, semi-organic, and inorganic systems. Additionally, key indicators in the form of strategic formulations were recommended to enhance agricultural sustainability based on specific land and farmer management factors. In this study, we the same approach by modifying research parameters to suit the agricultural conditions in Jatiroto Sub-district, Wonogiri. This study aims to address key challenges in agricultural land use in the Jatiroto Sub-district by integrating land suitability assessment with sustainability evaluation across different rice farming systems. Land suitability evaluation was used to assess land resources as

information that can be used as a basis for land use studies and guidelines [12]. Farm sustainability was carried out as an evaluation of the sustainability of farming practices in land management. We use different type rice cultivation systems in Jatiroto Sub-district, namely inorganic, semi-organic, and organic rice farming systems. Additionally, land management is the focus of this study with three main dimensions, namely ecological, social, and institutional. The objectives of this study are to identify land suitability classes for rice crops, identify limiting factors, develop recommendations for improving land suitability classes for rice crops, and determine the sustainability of agricultural practice in Jatiroto Sub-district.

2. MATERIALS AND METHODS

2.1. Study Area

The research was conducted in Jatiroto Sub-district, Wonogiri Regency, Central Java. The research site was selected using purposive sampling, considering the existence of several rice farming systems in the hilly area of the Jatiroto Sub-district. Geographically, Jatiroto Sub-district is located at $7^{\circ}51' 30.06''-7^{\circ}54'3.208''$ S, $111^{\circ} 3'11.232''-111^{\circ}11'27.708''$ E (Figure 1). Administratively, Jatiroto Sub-district is bordered by Jatisrono Sub-district to the north, Slogohimo, and Kismantoro Sub-district to the east, Tirtomoyo Sub-district and Pacitan District to the south, and Sidoharjo Sub-district to the west. The studied rice fields employ three different farming systems:

Table 1. Land suitability criteria for rice [14][15].

Land use requirements/ Characteristics	Land Suitability Class			
	S1	S2	S3	N
Temperature (tc)				
Average temperature (°C)	24–29	22–24	18–22	< 18
Water availability (wa)				
Humidity (%)	33–90	30–33	< 30; > 90	-
Root capacity (rc)				
Drainage	somewhat inhibited, moderate	Inhibited, well drained	very inhibited, rather fast	fast
Texture	soft, slightly soft	moderate	a bit coarse	coarse
Soil depth (cm)	> 50	40–50	25–40	< 25
Nutrient retention (nr)				
CEC (cmol)	> 16	5–16	< 5	-
Base saturation (%)	> 50	35–50	35	-
pH H ₂ O	5.5–7.0	4.5–5.5; 7.0–8.0	< 4.5; > 8.0	-
C-organic (%)	> 1.2	0.8–1.2	< 0.8	-
Nutrient availability (na)				
N total (%)	moderate	low	very low	-
P ₂ O ₅ (me/100g)	high	moderate	low-very low	-
K ₂ O (me/100g)	moderate	low	very low	-
Sodisity (xn)				
Alkalinity/ESP (%)	< 20	20–30	30–40	> 40
Flood hazard (fh)				
Height (cm)	25	25–50	50–75	> 75
Time (day)	non	< 7	7–14	> 14
Land preparation (lp)				
Rock surface (%)	< 5	5–15	15–40	> 40
Rock outcrop (%)	< 5	5–15	15–40	> 40

organic, semi-organic, and inorganic, with slopes gradients ranging from 0–25%. Organic rice fields are those that used only organic fertilizer. Fields that have received organic fertilizer, even if only as a base fertilizer or a small-scale alternative to chemical fertilizer, are considered semi-organic. In semi-organic system, chemical insecticides are occasionally still used. Rice fields that only used chemical fertilizers are inorganic rice fields. Slope is obtained from digital elevation model (DEM) raster data processed into 5 classes, namely flat (0–8%), gentle (8–15%), rather steep (15–25%), steep (25–45%), and very steep ($\geq 45\%$). This study only used 0–25% slopes because they cover most of the Jatiroto Sub-district. The soil type in the Jatiroto Sub-district is Inceptisols, with moderate rainfall between 2,000–3,000 mm per year.

2.2. Soil Observation and Sampling

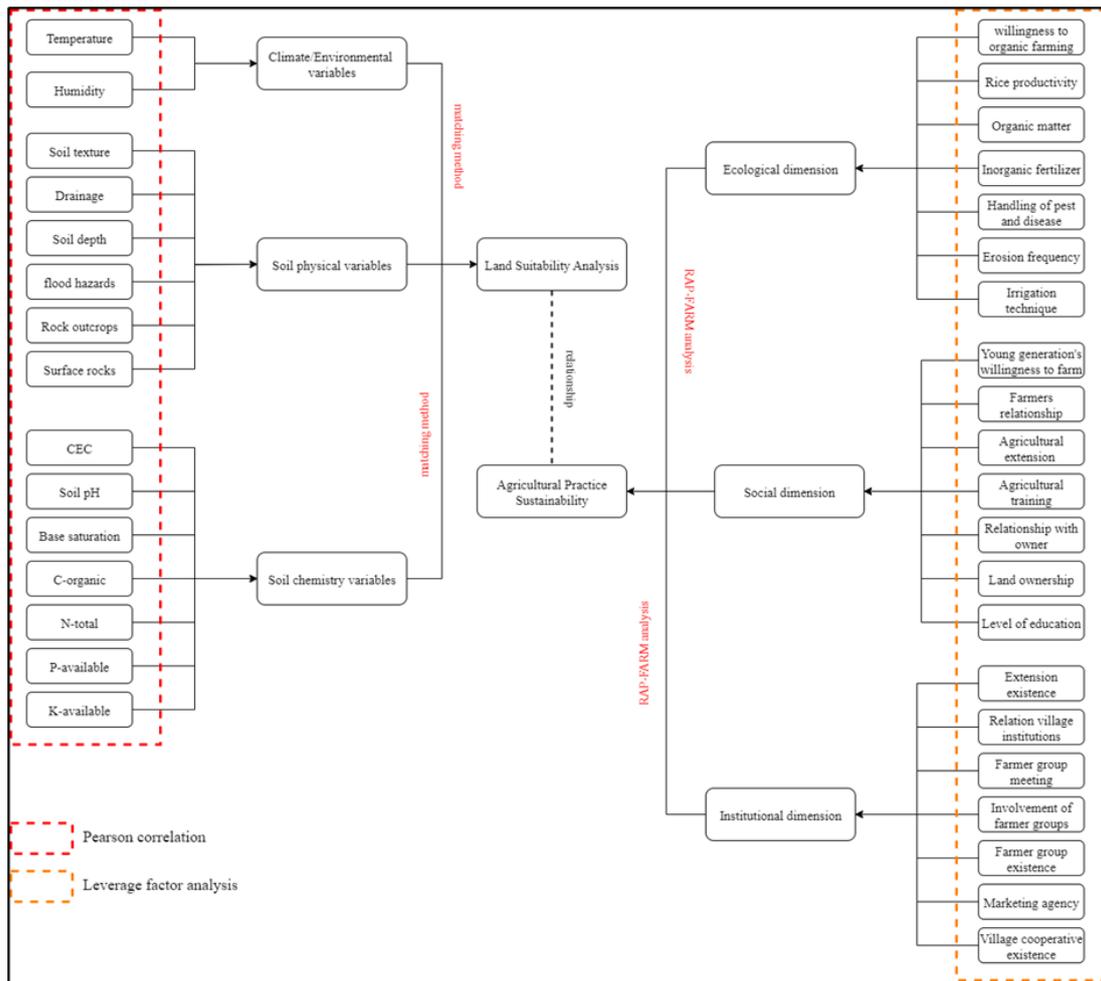
In this study, both primary and secondary data were gathered. Surveys, measurements, and field questionnaires provided the primary data. Average temperature, humidity, and rainfall for the last ten years were determined using secondary sources. The Bengawan Solo River Basin Center provided average rainfall data, while satellite imagery (<https://power.larc.nasa.gov/data-access-viewer/>) provided average temperature and humidity data. In the Jatiroto Sub-district, soil samples were taken from organic, semi-organic, and inorganic rice fields. Purposive sampling was used to sample the soil in Jatiroto Sub-district, Wonogiri Regency, in line with the land unit (LU). Total sample points were obtained 28 composite soil by 7 LU with 4 repetitions. A soil drill and a shovel or hoe were used to collect soil sample to a depth of 20 cm. The soil samples were collected using Eviati and Sulaeman (2009) methods [12]. The soil samples obtained could not be analyzed immediately. Soil samples must be dried by airing them in an open

place away from direct sunlight for 2 to 3 days. Drying was intended to reduce the moisture content of the soil. The following process was sieving to obtain the required sample size of 0.5 mm and 2 mm. Soils corresponding to the size can be subjected to laboratory analysis. Laboratory analysis was carried out on the soil's environmental parameters, including physical and chemical parameters. The parameters analyzed in the laboratory include soil texture, CEC, base saturation, soil pH, C-organic, N-total, P available, and K available. The parameters observed in the field include temperature, humidity, drainage, soil depth, flood hazards, rock outcrops, and surface rocks.

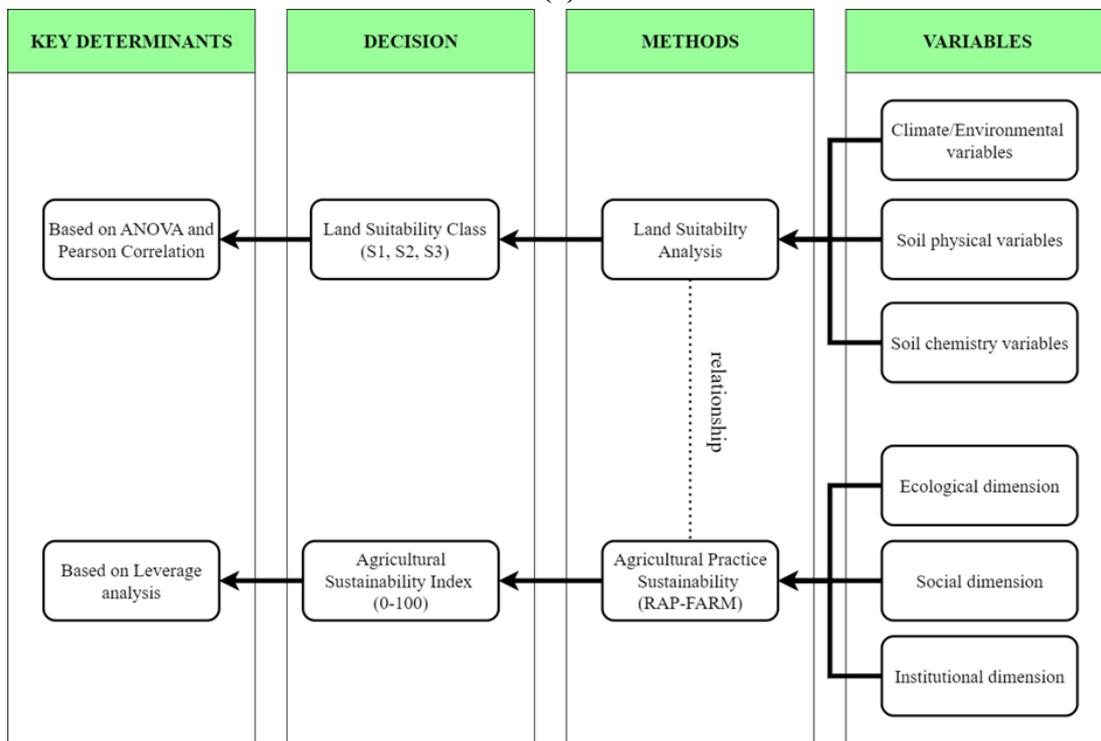
The quality control used to ensure the validity and reliability of the data in this study is the soil moisture content measurement method, which aims to calculate the correction factor so that the analysis results can be expressed on a dry weight basis. In addition to soil samples, the instrument/tool calibration process is carried out periodically using reference materials such as distilled water (aqua distillate) as a zero standard solution to verify the accuracy of the measuring instrument so that it provides consistent results and is in accordance with the established parameters. Respondents were selected using purposive sampling to represent each farming system. The questionnaire consisted of structured questions on socio-economic conditions, farming practices, and sustainability perception. Questionnaire data were collected from people whose main occupation was farming in Jatiroto Sub-district, Wonogiri Regency. Sample questionnaire data were collected from 28 respondents spread throughout Jatiroto Sub-district based on differences in farming systems according to LUs. We use Likert scale to assess agricultural sustainability. Social parameters were carried out to determine the sustainability of farming in the

Table 2. Agricultural practice sustainability index and status [16].

Index Value	Sustainability Status
0-25	Unsustainable
25.01–50	Less Sustainable
50.01–75	Quite Sustainable
75.01–100	Sustainable



(a)



(b)

Figure 2. Framework of (a) conceptual and (b) methodological.

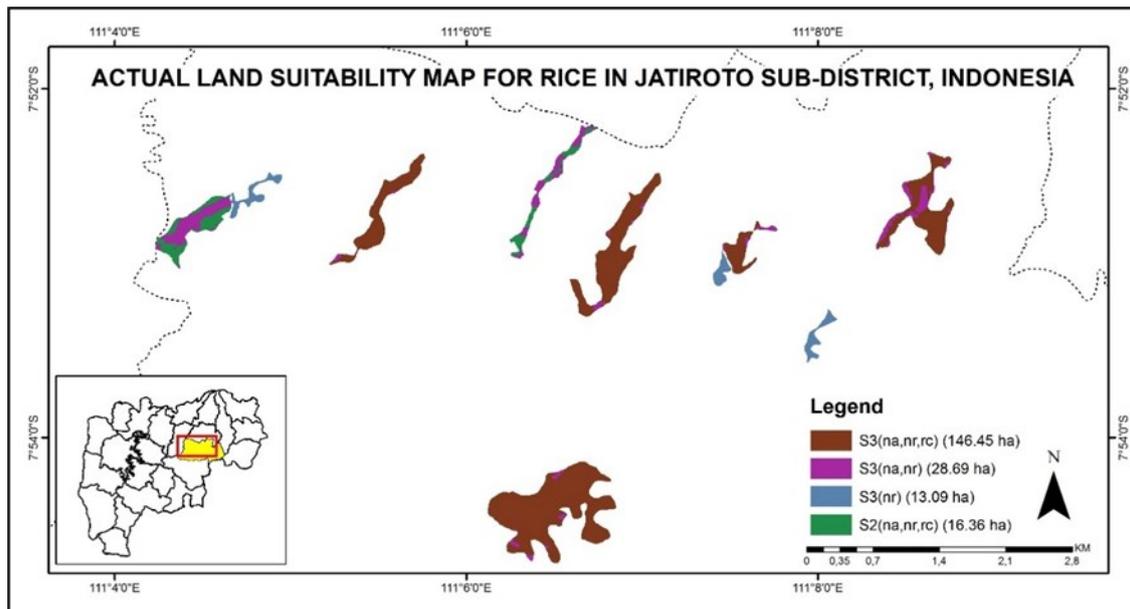


Figure 3. Distribution of land suitability class of study area.

Jatiroto Sub-district.

2.3 Data Analysis

2.3.1. Land Suitability Class

The field observations and laboratory analyses were analyzed using matching method according to Table 1. The matching method matches land characteristic variables in region with crop growth requirements to determine the suitability class of that crop [13]. Limiting factors were determined based on the Leibig minimum law, which can affect the suitability classes. The data obtained can be used to assess the suitability of ricefields in the Jatiroto Sub-district. Recommendations based on limiting factors of land characteristics are provided to improve land suitability classes in various farming systems.

2.3.2. Agricultural Practice Sustainability

Data analysis was conducted using the Microsoft Excel add-in Rapfish (Rapid Appraisal for Fisheries) program. The Fisheries Center at the University of British Columbia created Rapfish in the beginning to assess the sustainability of fisheries [16]. As it develops, Rapfish can be used in various sectors, including agriculture (RAP-FARM). Assessment of the state of sustainability using the multidimensional scaling (MDS) technique. According to previous work [16], the stages of sustainability analysis in rice farming begin with

determining the dimensions to be studied [16]. With the help of 21 attributes, this study investigated the ecological, social, and institutional sustainability of rice production. The researchers selected this dimension because they were interested in learning how farmer involvement affects the long-term viability of rice growing. The results of the ordination analysis of the sustainability state of rice cultivation in each dimension were obtained using the minimum data set (MDS) approach. The number of characteristics sensitive to the sustainability of rice farming in the Jatiroto Sub-district was determined using leverage factor analysis. The calculation error of rice farming sustainability at a level of 5% at the last stage is in the form of a Monte Carlo analysis. The results obtained can then be used to determine sustainability status based on the index values in Table 2. The results of farming sustainability were then linked to land suitability classes with Pearson correlation analysis to determine the relationship between farm sustainability parameters or attributes and farm sustainability status.

2.4. Statistical Analysis

Statistical analysis using SPSS ver 26.0. The analysis of variance (ANOVA) was carried out to determine the impact of rice farming systems on land suitability class parameters. Further experiments were conducted using Duncan's multiple range test (DMRT) to determine the

Table 3. Actual land suitability class for rice in Jatiroto Sub-district.

Land characteristics	LU1	C	LU2	C	LU3	C	LU4	C	LU5	C	LU6	C	LU7	C
Temperature (tc)	24.60	S1	24.90	S1	24.80	S1	25.00	S1	24.90	S1	24.90	S1	24.60	S1
Average temperature (°C)														
Water availability (wa)	83.30	S1	83.30	S1	83.30	S1	83.30	S1	83.30	S1	83.30	S1	83.30	S1
Humidity (%)														
Root capacity (rc)	Well	S2	Moderate	S1	Well	S2	Moderate	S1	Moderate	S1	Well	S2	Moderate	S1
Drainage	Slightly soft	S1	Moderate	S2	Slightly soft	S1	Moderate	S2	Moderate	S2	Slightly soft	S1	Slightly soft	S1
Texture	37	S3	34	S3	41	S2	40	S2	41	S2	41	S2	51	S1
Soil depth (cm)														
Nutrient retention (nr)	21.6	S1	18.60	S1	21.20	S1	16.00	S1	19.80	S1	20.40	S1	16.80	S1
CEC (cmol)	32.69	S3	30.08	S3	24.06	S3	38.00	S2	21.38	S3	22.24	S3	26.00	S3
Base saturation (%)	7.28	S2	7.49	S2	7.36	S2	7.40	S2	7.30	S2	7.25	S2	7.32	S2
pH	0.7	S3	1.15	S2	0.98	S2	1.27	S1	1.41	S1	2.05	S1	1.61	S1
C-organic (%)														
Nutrient availability (na)	0.08	S3	0.11	S2	0.24	S1	0.12	S2	0.30	S1	0.20	S1	0.12	S2
N-total (%)	4.83	S3	6.87	S3	2.90	S3	10.60	S2	10.30	S2	10.14	S2	10.29	S2
P-availability	0.07	S3	0.16	S2	0.07	S3	0.29	S2	0.08	S3	0.10	S2	0.10	S2
K-availability														
Sodicity (xn)	1.28	S1	1.25	S1	1.60	S1	2.06	S1	1.86	S1	1.38	S1	1.74	S1
ESP (%)	< 25	S1	< 25	S1	< 25	S1	< 25	S1	< 25	S1	< 25	S1	< 25	S1
Flood hazard (fh)	< 1	S1	< 1	S1	< 1	S1	< 1	S1	< 1	S1	< 1	S1	< 1	S1
Flood height	< 5%	S1	< 5%	S1	< 5%	S1	< 5%	S1	< 5%	S1	< 5%	S1	< 5%	S1
Flood time	< 5%	S1	< 5%	S1	< 5%	S1	< 5%	S1	< 5%	S1	< 5%	S1	< 5%	S1
Land preparation (lp)														
Rock Surface (%)														
Rock outcrop (%)														
Actual Land Suitability Class	S3 (na,nr,rc)		S3 (na,nr,rc)		S3 (na,nr)		S2(na,nr,rc)		S3 (na,nr)		S3 (nr)		S3 (nr)	

*Temperature (tc); Water availability (wa); Root capacity (rc); Nutrient retention (nr); Nutrient availability (na); Sodicity (xn).

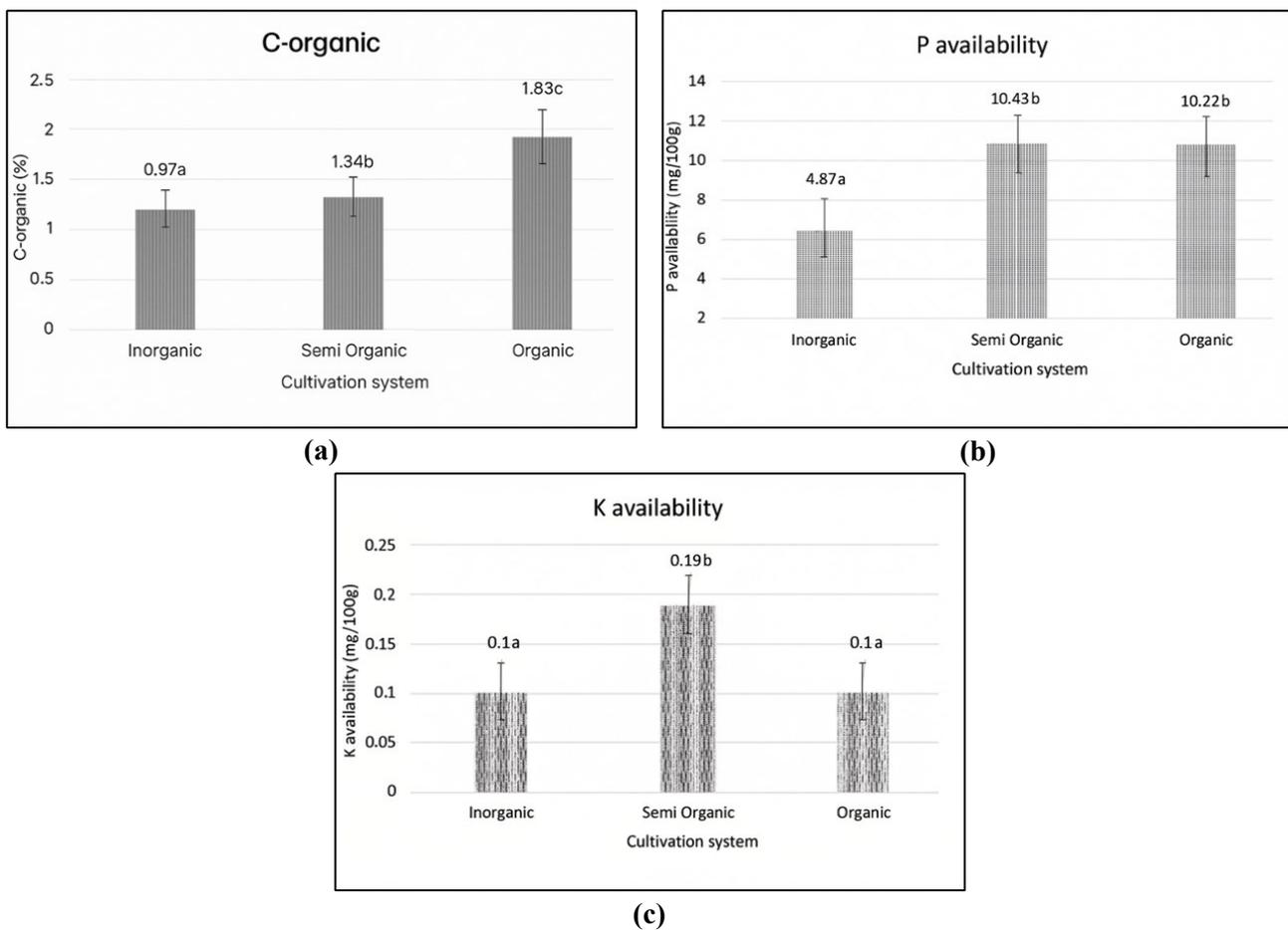


Figure 4. The average value of key factor indicators for land suitability in the study area including (a) organic carbon, (b) phosphor availability, and (c) K availability.

influence on the rice growing system if the land suitability class criteria had a substantial impact. The relationship between parameters and land suitability classes was examined using a Pearson correlation analysis and correlation analysis using R, which were considered as indicators of critical factors, between land suitability class and agricultural practice sustainability. Compiling recommendations for enhancing land suitability classes were formulated using key factor indicators as a guide (Figure 2).

3. RESULTS AND DISCUSSIONS

3.1. Land Suitability Class

The findings indicated that the Jatiroto Sub-district's land suitability class for rice cultivation was classed as quite appropriate (S2) and marginal (S3). S3 na;nr;rc was the lowest class due to constraints. Table 3 showed the distribution of the actual land suitability classes, with class S3 (na, nr,

rc) accounting for the largest area at 146.45 ha, class S3 (na, nr) at 28.69 ha, class S2 (na, nr, rc), for the smallest area at 13.09 ha (Figure 3). The designation of land suitability classes is based on the lowest class of parameters in each LMU, then continued with the parameters with the worst values in the LMU. These findings indicate that the Jatiroto area holds potential for rice cultivation, however, it faces challenges related to land and soil conditions. Effective soil management and the adoption of sustainable agricultural practices are necessary to enhance the region's potential and improve rice productivity. The topographical characteristics of Jatiroto, which include hilly areas, also influence the land suitability for rice cultivation. Areas with varying slopes tend to have less fertile soils, shallow soil depth, and are more susceptible to erosion [17].

3.1.1. Land Characteristics

The temperature characteristics in this region

were very suitable (S1) for rice cultivation, with a temperature range of 24–25 °C and air humidity of 83%. Temperature and humidity were measured at an average altitude of 250 m asl. Drainage classes were obtained in good and medium classes. Well drainage was obtained at LU 1, 3, and 6, while moderate drainage was obtained at LUs 2, 4, 5, and 7. The well drainage class was in class S2, which is quite appropriate, while the medium drainage class was in class S1, which is very appropriate. The soil textures identified in Jatiroto are sandy clay loam (slightly fine), sandy loam (slightly fine) and loam (moderate). The texture in this study was obtained in moderate to slightly soft class groupings. LUs 2, 4, and 5 had moderate texture class groupings, while LUs 1, 3, 6, and 7 were in slightly soft texture class groupings. The medium soil texture class grouping was dominated by the very soft sandy clay texture class, and the clay texture class was dominated the slightly soft texture class grouping. Effective soil depth was found to be between 34 and 51 cm. LU 1 and LU 2 contained the classes S3; S2 class at LUs 3, 4, 5, and 6; and LU 7 contained the S1 class (Table 3).

The cation exchange capacity (CEC) obtained in

this study was highest in LU 1, 21.6 cmol per kg, while the lowest was found in LU 4, 16 cmol per kg. Based on the land suitability class for rice, all LUs are in class S1, which is very appropriate. In the soil fertility criterion, the base saturation value in all LUs is low, ranging between 20–40%. This condition may be attributed to the limited occupancy of exchange sites by base cations, while a greater proportion is occupied by acidic cations, thereby leading to a low base saturation percentage [18]. The highest base saturation value was found in LU 4 at 38% in class S2 (very appropriate), and the lowest in LU 5 at 21.28% in class S3 (marginally adequate). The pH measurement results obtained indicated that the pH value of all LU is between 7–8. This finding indicates that the soil pH across all LUs falls within the S2 class (quite appropriate). The percentage of C-organic obtained in this study was in the range of 0.70–2.05%. Results showed that organic matter throughout the LU was present in very low to moderate classes. The analysis of C-organic in relation to organic farming in Jatiroto indicates a higher land suitability for rice cultivation compared to inorganic farming systems. According to Ritung et al., the ideal soil pH for rice

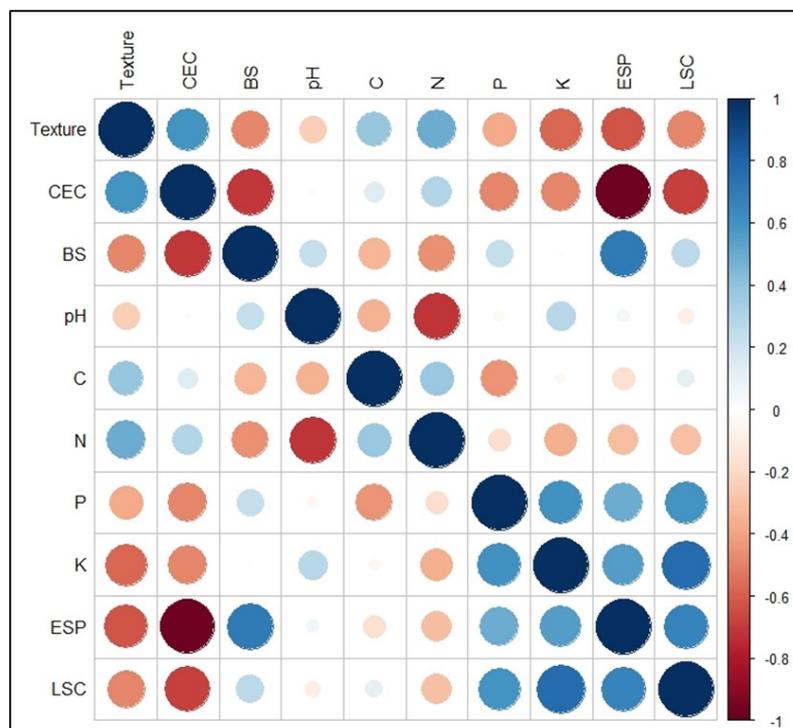


Figure 5. The relationship of land characteristics to land suitability classes (CEC = Cation exchange capacity; BS = Base saturation; C = C-organic; N = N-total; P = P-available; K = K-available; ESP = Exchangeable sodium percentage = Alkalinity; LSC = Land suitability class).

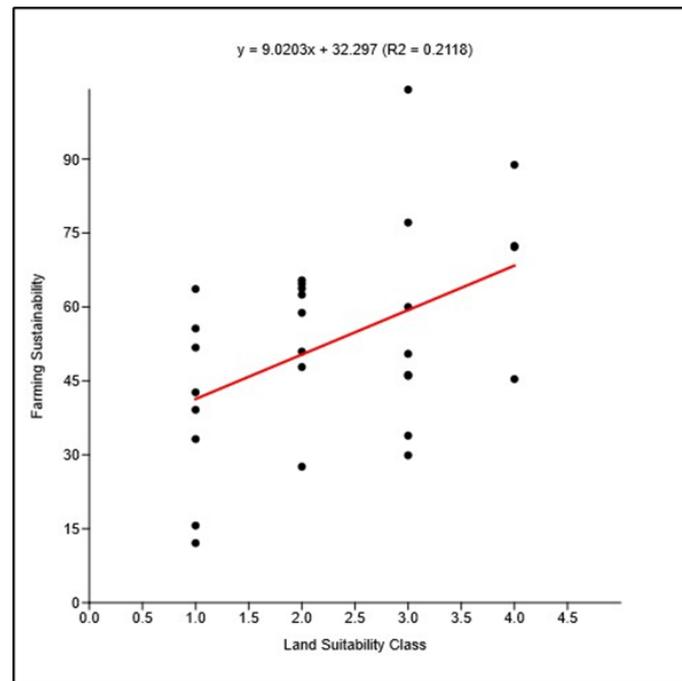


Figure 6. Distribution of agricultural practice sustainability and land suitability evaluation for rice.

plants is between 5.5 and 7.0. This pH value promotes the availability of macro and micronutrients required by plants. The optimal organic carbon level for rice growth is greater than 1.2%, as it increases cation exchange capacity and soil biological activity [19]. As a result, adequate pH and organic carbon values will boost rice productivity while also indicating soil conditions that do not require extensive adjustment.

The N-total levels obtained in this study ranged from the lowest 0.08 (LU 1) and the highest 0.3 (LU 5). In this study, the N-total value ranged from very low to moderate. In LU 1 to LU 7, the P-available values were 4.83, 6.87, 2.90, 10.60, 10.30, 10.14, and 10.29 ppm, respectively. The research results for K-available values ranged from very low to low. LUs 1, 3, and 5 were classified as S3, while LUs 2, 4, 6, and 7 were classified as S2. Table 3 showed the ESP level in Jatiroto Sub-district was very low, with ESP value less than 2%. The measurement results showed that the height of the puddle obtained from field measurements is below 25 cm, with a puddle duration of under 1 day. The land preparation parameters used in this study are surface rocks and rock outcrops. Field measurements on both parameters revealed a low percentage of surface rock and rock outcrops below 5%. Land preparation parameters fell into class S1 in the rice land suitability class.

3.1.2. Key Factor Indicators of Land Suitability in Study Area

The limiting factors of all LUs were contained in the base saturation parameter. The base saturation values from LU 1 to LU 7 were low. The assessment results for LU 4 fell into class S2 (quite appropriate), and other LUs fell into class S3 (marginally appropriate). Differences in farming systems affect the limiting factors for the actual suitability class in the Jatiroto Sub-district (p -value < 0.01). The organic farming system (LUs 6 and 7) showed limiting factors only in the base saturation parameter. Semi-organic farming system (LUs 3 and 4) had limiting factors in base saturation and available nutrients. In contrast, inorganic farming system had the most limiting factors: base saturation, C-organic, soil depth, total N, P-available, and K-available. Inceptisol soil has a high clay content [20] and a low level of organic matter [21]. The N-total results indicate the influence of adding organic matter addition on nutrient availability in the Inceptisol soil [22]. In addition, low base saturation is influenced by low nutrient cation values found in the soil [23]. Low nutrient cations such as Mg, Ca, and K affect the low base saturation percentage [24].

A correlation analysis was performed to establish the primary determinant of land suitability for rice in the study area. In this study, parameters in land

suitability assessment were analyzed through correlation tests with land suitability classes in each LMU. Major highlights or determining factors were selected based on their highly significant relationship (p -value < 0.01) with land suitability classes. The correlation analysis results (Figure 4) revealed three major critical factors (p -value <0.01): C-organic (0.600**), P-available (0.801**), and K-available (0.660**) and ESP. C-organic is a crucial criterion for rice land suitability class in Jatiroto Sub-district. The C-organic correlation (0.600**) result was consistent with the land suitability class, indicating that an increase in organic C will be positively correlated with an increase in land suitability. The percentage of organic rice fields was higher (1.83%) than semi-organic rice fields (1.34%) and inorganic rice fields (0.97%) (Figure 4). Sodic soils have high ESP values and are distinguished by colloidal clay dispersion and changes in aggregate stability [25]. It has limited permeability and infiltration rates, resulting in root penetration resistance and reduced nutrient uptake efficiency by plants. Meanwhile, rice plants (*Oryza sativa* L.), which require good aeration and drainage throughout the growth period, and the presence of high sodium levels can dramatically limit land suitability.

Organic matter application in rice fields affects other parameters, including P and K available [26]. P-available and K-available were the primary

determinants for land suitability classes in Jatiroto Sub-district, with r values of 0.801** and 0.660**, respectively. The P-available and K-available correlations were positive, indicating that efforts to increase land suitability can be undertaken by increasing P-available and K-available in the soil. Figure 5 illustrates that the findings of P-available parameters differed significantly from the farming systems. Semi-organic (10.43 me/100 g) and organic (10.22 me/100 g) farming systems had higher values than inorganic (4.87 me/100 g) farming system. According to Handono, constant and sustainable use of organic fertilizers on rice fields can maintain P-available levels in the soil [27].

3.2. Agricultural Practice Sustainability

3.2.1. Sustainability Status

The study's findings, as shown in Figure 6, indicate that land suitability conditions for rice cultivation were closely related to agricultural sustainability (p -value 0.014, R -value 0.460), with a positive value relationship, between land suitability variables and agricultural sustainability. This implies that an increase in land suitability class based on the agricultural system will result in better agricultural sustainability indicators. Land suitability classes are based on studies of soil properties that promote rice growth. With a

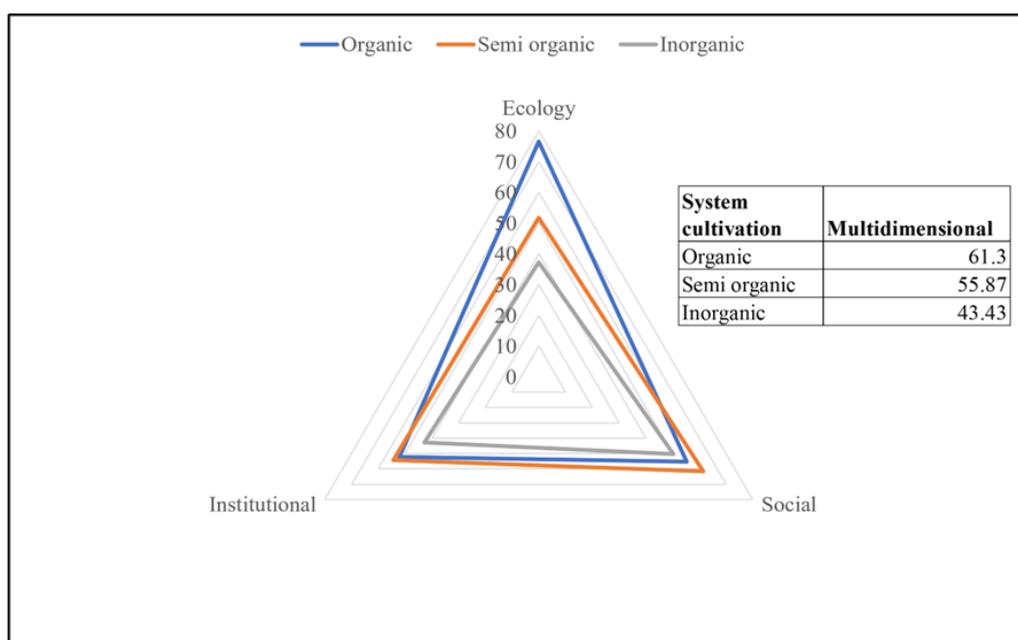


Figure 7. Diagram of the sustainability index of farming in Jatiroto Sub-district.

Table 4. Ecological, Social, and Institutional dimensions index value, Monte Carlo value, R-square and stress value.

Dimension	Index	Monte Carlo	Difference	R Square	Stress
Ecological	52.91	52.66	0.25	0.90	0.20
Organic	76.56	74.89	1.67	0.94	0.16
Semi organic	51.74	51.88	0.14	0.90	0.20
Inorganic	37.22	36.51	0.71	0.93	0.18
Social	54.58	54.17	0.40	0.90	0.19
Organic	55.20	54.79	0.41	0.93	0.16
Semi organic	61.48	60.71	0.76	0.93	0.16
Inorganic	50.33	50.15	0.19	0.91	0.17
Institutional	48.75	48.77	0.02	0.89	0.20
Organic	52.13	52.01	0.12	0.92	0.18
Semi Organic	54.39	54.02	0.37	0.94	0.16
Inorganic	42.74	43.11	0.37	0.91	0.19

significant correlation between land suitability classes and agricultural sustainability, farmers and policymakers can choose rice varieties that are adaptable to soil conditions, as well as the sorts of fertilizers and ameliorants to use in the soil. The dimensions analyzed for the farmer sustainability index include ecological (7 attributes), social (7 attributes), and institutional (7 attributes). The multidimensional sustainability results for agriculture in the organic farming system amounted to 61.30. The sustainability index value obtained in the semi-organic farming system was 55.87, while in the inorganic farming system, 43.43 was obtained (Figure 7). This condition shows that organic and semi-organic farming systems are pretty sustainable, while inorganic ones are less sustainable. The state of land suitability in inorganic farming system requires proper management to improve the sustainability status of farming in Jatiroto Sub-district.

The organic farming system had the highest ecological dimension of the agricultural sustainability index with a value of 76.56, followed by the semi-organic farming system with 51.74, and the inorganic farming system has the lowest value of 37.22 (shown in Table 4). The organic farming system in Jatiroto is considered superior to other systems due to its higher rice productivity. Additionally, the use of organic fertilizers contributes to improved land management practices.

Farmer training and capacity-building initiatives in organic agriculture further support better land stewardship. Based on these findings, we recommend more robust policy efforts to promote organic farming as a strategy for enhancing agricultural sustainability in the study area. The social dimension index of 54.58, indicates that this system is relatively sustainable. The organic system had a social dimension index value of 55.20 with a reasonably sustainable status, semi-organic system had a value of 61.48 with a fairly sustainable level, and inorganic system had a value of 50.33 with a reasonably sustainable level. In the institutional dimension, organic and semi-organic agriculture systems are fairly sustainable, according to the institutional dimension of the agricultural sustainability index, with values of 52.13 and 54.39, respectively. With an index score of 42.74, the inorganic cultivation approach is less sustainable. Overall, the agricultural sustainability index in the institutional dimension had a value of 48.75, indicating a less sustainable status. Table 4 showed all of the agriculture systems in all dimensions have R-square values more than 0.90 and stress values less than 0.25, meaning that the sustainability index results are acceptable.

3.2.2. Ecology

According to the results of ecological leverage research (Table 5), sensitive attributes in organic

farming system was found in pest and disease management characteristics and erosion frequency. Sensitive characteristic of semi-organic farming system included pest and disease management. In contrast, the sensitive attributes of inorganic farming system included the usage of chemical fertilizers and the frequency of erosion. A previous study by Herdananta et al. discovered four impediments to organic farming: irrigation systems, human resources availability, seed restrictions, and pest and disease management [28]. Farming sustainability can be improved by minimizing chemical fertilizers and gradually replacing them with organic fertilizers, particularly in inorganic agriculture.

Limited access to information on pest and disease management remains a significant challenge

in the development of organic agriculture within the study area. Currently, synchronized planting is still practiced by local farmers as a traditional method to reduce pest pressure on crop yields. We suggest that agricultural extension officers play a crucial role in enhancing farmers' knowledge of organic pest control methods. Furthermore, farmer groups serve as important channels for effective communication and knowledge dissemination in addressing pest and disease issues. Strengthening collaboration among farmers, farmer groups, and extension agents is essential to improving the sustainability of agricultural practices [29].

In addition to pest and disease management, erosion frequency also emerges as a critical variable in this study. Jatiroto Sub-district is characterized by hilly topography, which necessitates appropriate

Table 5. Leverage factor ecological, social and institutional dimensions in various farming systems.

Attributes	Organic (%)	Semi-organic (%)	Inorganic (%)
Ecological dimension			
Willingness to organic farming	4.08	2.87	3.15
Rice productivity	3.82	4.19	4.48
Organic matter	3.93	2.94	4.35
Use of inorganic fertilizer	3.61	4.41	5.28
Handling of pest and disease	8.44	5.05	3.49
Erosion frequency	8.14	3.60	5.34
Irrigation technique	4.17	2.76	3.92
Social dimension			
Young generation's willingness to farm	5.62	3.69	4.38
Relationship between farmers	4.65	6.27	5.51
Participation in agricultural extension	7.18	6.51	6.01
Agricultural extension and training	7.58	5.62	5.93
Cultivator relationship with owner	8.89	6.35	8.43
Land ownership	7.69	5.10	7.04
Level of education	4.22	1.65	2.62
Institutional dimension			
The existence of the extension	3.09	3.75	2.73
Relations with village institutions	4.90	4.75	5.13
Farmer group meeting	4.33	4.64	4.69
Involvement of farmer groups	4.42	3.31	4.71
The existence of farmer group	4.37	4.25	5.52
Marketing agency	4.16	5.16	6.75
The existence of village cooperative	2.28	4.42	4.19

land management strategies to maintain and enhance agricultural productivity. The agricultural landscape in the study area is predominantly shaped by terracing systems, implemented by farmers as an adaptive measure to reduce erosion risks and optimize land use according to the natural contours. These contour-based farming practices require careful attention to water and soil management [30]. Organic farming and agroforestry practices have been shown to contribute to soil stability and reduce erosion [31][32]. Therefore, we recommend the implementation of integrated land conservation strategies—particularly through the adoption of organic agriculture and agroforestry—to minimize erosion risks and support long-term agricultural productivity in this area.

3.2.3. Social

The social dimension has 7 attributes: education level, land ownership, rapid relationship with the owner, availability of agricultural extension and training, extension and agricultural intensity, the relationship between farmers, and the willingness of the younger generation to farm (Table 5). Based on the social dimension leverage analysis, the sensitive attributes of organic farming system was the relationship between cultivators and owners, land ownership, the availability of agricultural extension and training, and the intensity of agricultural extension and training. The semi-organic farming system had sensitive attributes such as intensity of agricultural extension and training and the relationship between farmers and landowners. In contrast, the sensitive attributes in the inorganic farming system was the relationship between farmer and landowner, land ownership, and the intensity of agricultural extension and training. The relationship between farmers and landowners is a sensitive attribute in various farming systems. The relationship between farmers and landowners is closely related to land ownership. Most of the land in Jatiroto Sub-district is privately owned by farmers who use it to grow rice. There is village granary land leased for agricultural cultivation. Farmers can only cultivate the land by renting it. The relationship between farmers and landowners can be improved in Jatiroto Sub-district by improving two-way communication to prevent miscommunication between landowners and

farmers [33]. The availability and intensity of agricultural extension and training are important social dimensions of rice farming sustainability in the Jatiroto Sub-district. Farmers require agricultural extension and training to improve their knowledge and skills in land cultivation [33][34]. Agricultural extension and training can persuade farmers to use the most up-to-date technology for efficiency and effectiveness in agricultural implementation to achieve the best results [35].

3.2.4. Institutional

There are 7 attributes used in the institutional dimension, namely the existence of village cooperation, marketing institutions, the existence of farmer groups, involvement in farmer groups, the intensity of farmer group meetings, the relationship between farmers and village institutions, and the existence of extension workers (Table 5). According to the results of the institutional dimension leverage analysis, almost all attributes in various farming systems had low percentage of RMS. However, sensitive attributes, such as marketing institutions (semi-organic and inorganic), relationships with village institutions (organic, semi-organic, and inorganic), and the existence of farmer groups (inorganic and organic) can still be improved. The sustainability of rice farming in Soreang Sub-district, Bandung Regency, reveals the results of sensitive attributes in legal and institutional dimensions such as agricultural extension, credit distribution, and farmer groups [36]. The concept of strengthening extension agencies in preparing strategic programs for agricultural stakeholders in managing farming can be applied with modifications tailored to the conditions and issues in the study area [37].

Based on the above findings (Table 5), it is important to emphasize the importance of integrated policy interventions that address biophysical and socio-economic constraints in order to improve the suitability and sustainability of rice land. Policies should prioritize the advancement of semi-organic and organic rice farming systems. Given their relatively higher sustainability performance, these systems warrant the implementation of incentive-based measures—such as subsidies for organic inputs, certification facilitation, and improved market access—to promote the transition toward

more sustainable agricultural practices. In addition, addressing socio-institutional constraints requires the enhancement of agricultural training and extension services, the improvement of landowner–tenant farmer relations through tenure reforms or formalized agreements, and the strengthening of institutional support aimed at increasing farmers' capacity, adaptive resilience, and long-term commitment to sustainable land management.

4. CONCLUSIONS

In Jatiroto Sub-district, rice farming systems on slopes of 0–15% were generally categorized in land suitability class S3, with the exception of semi-organic systems on 0–8% slopes achieving class S2. The predominant limiting factor across all systems was base saturation. Organic and semi-organic systems showed moderately sustainable status (61.30 and 55.87), while the inorganic system lagged at 43.43. Improvements should focus on reducing chemical fertilizer use, enhancing farmer–landowner relationships, and increasing participation in agricultural training. These findings highlight the importance of integrated land and sustainability assessments in hilly regions. Policy support for sustainable farming inputs and farmer education is crucial to enhance long-term viability. Further research is recommended to explore economic impacts and long-term changes in soil health across different farming systems.

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Conflicts of Interest

The authors declare no conflict of interest.

ACKNOWLEDGEMENT

This research supported by Institute for Research and Community Service (LPPM) - Universitas Sebelas Maret by contract number 371/UN27.22/PT.01.03/2025.

DECLARATION OF GENERATIVE AI

Not applicable.

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