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Research Article

Evaluation and improvement of rice field quality in Seririt District, Buleleng Regency, Bali Province, Indonesia

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Abstract

The decline of land quality has an impact on the decline of productivity which in turn reduces production. This kind of thing happened to rice fields in the research area of Seririt District. The objective of this study was to evaluate the rice field quality in Seririt District, Buleleng Regency, Bali Province. The study used a survey method to take soil samples, followed by laboratory analysis for each homogeneous land unit (HLU). The HLU was determined by overlapping soil type maps, slope maps, and utility maps. Parameters analyzed were bulk density, texture, porosity, water content, organic C, pH, cation exchange capacity (CEC), base saturation (BS), nutrients (total N, available P, and available K), and biomass C. The results of the laboratory analysis were compared with the criteria for soil quality based on ten minimum data sets (MDS) for each HLU. The results showed that the soil quality at the study site is classified as very good in HLU I with a soil quality index (SQI) of 18. This HLU is located in Rangdu and Ringdikit villages, with an area of 125.15 ha. Good SQI was observed on HLUs II, III, IV, V, VII, and VIII, respectively, located in Banjar Asem, Lokapaksa, Pangkung Paruk, Bestala, Ume Anyar, Mayong, Joanyar, the SQI value of 22-25 is 2,321.49 ha with the limiting factors of total N, total P, texture, and bulk density. The suggested rice field management plan is the addition of organic, nitrogen, and phosphate fertilizers.

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Introduction

The problem with rice fields in Seririt District, Buleleng Regency of Bali Province is the decrease in productivity caused by intensive land use and management that has not been in accordance with soil conservation principles. The decrease in productivity of rice fields can be caused by (1) the depletion of nutrients carried by the harvest is more than the nutrients provided through fertilisation or the addition of nutrients from irrigation water, which are not sufficient for the needs of plants; (2) the excess of certain nutrients and lack of other nutrients due to unbalanced fertilisation, and (3) the decrease in soil organic matter content. This situation can reduce soil quality and land productivity so that rice production and quality decrease. Soil that does not function properly causes a decrease in soil quality and fertility. High soil fertility indicates high soil quality and vice versa. Soil fertility assessment is the key to sustainable planning of a particular area (Juarti, 2016; Arthagama and Dana, 2020; Sumarniasih et al., 2021).

Seririt District is one of nine districts in Buleleng Regency, with an area of 11,178 ha. The dominant agricultural commodity in Seririt District is rice, which has the highest production compared to other commodities, with an average production is

7.19 t ha^{-1} (Central Bureau of Statistics Buleleng, 2021). However, rice production in Seririt District during the last ten years fluctuated, from 2011 until 2021 respectively 27,237 t, 30,187 t, 27,138 t, 26,421 t, 26,829 t, 25,390 t, 23,840 t, 26,998 t, 25,782 t, 23,109 t , followed by a decrease of the planted area is 3,642 ha, 3,395 ha, 4,370 ha, 3,562 ha, 3,851 ha, 4,009 ha, 3,502 ha, 3,607 ha, 3,411 ha, and 3,602 ha respectively (Central Bureau of Statistics Buleleng, 2021). Production fluctuations due to land degradation and land conversion. Meanwhile, land management without paying attention to the carrying capacity of the environment will reduce soil quality, so soil productivity is not optimal. Low soil fertility is one of the causes of the reduction in production (Mutiara and Yovita, 2019), so it needs management that can restore soil fertility by adding organic matter (Aura, 2016).

This study aimed to evaluate the rice field quality in Seririt District, Buleleng Regency, Bali Province, Indonesia, by identifying limiting factors and analysing the soil's physical, chemical, and biological properties for land management plans.

Materials and Methods

The research was conducted on rice fields in Seririt District, Buleleng Regency. The sample points were determined based on the results of overlapping maps of land use, slope, and soil type based on the Geographic Information System (GIS). The field survey was conducted to determine the physical conditions namely type of land use, land management, and ground cover vegetation in each homogeneous land unit (HLU). Soil samples were collected from each HLU for laboratory analysis to determine physical, chemical, and biological properties. Soil physical properties measured were texture (measured by pipette method), bulk density and porosity (measured by ring sample method), and water content (measured by gravimetric method). Soil chemical properties measured were pH (measured by a pH meter), cation exchange capacity and base saturation (measured by the extraction NH_4OAc 1N pH 7 method), organic C (measured by the Walkley and Black method), total N (measured by Kjeldhall method), available P and K (measured by Bray-1 method), and microbial biomass C (Dane and Topp, 2002). The scoring of the data from the soil analysis was carried out to evaluate the quality of the soil by calculating the soil quality index (SQI) based on the ten minimum data sets (MDS) method (Lal, 1994). The limiting factors range from no limiting factor to extreme weighted on a scale of 1 to 5 (Table 1). The calculation of SQI was carried out by adding the scores obtained for each HLU presented in Table 2. The calculation of soil quality was as follows:

$$SQI = SPP + SCP + SBP$$

where: SQI = soil quality index; SPP = soil physical properties; SCP = soil chemical properties; and SBP = soil biological properties.

Land management plans were determined based on the results of the evaluation of soil quality in each homogeneous land unit (HLU). After knowing the limiting factors, the management was planned with the aim of improving the quality of rice field soil in the research location. The soil quality index (SQI) is an index calculated based on the value and weight of each soil quality indicator. Soil quality indicators are selected from the characteristics that indicate the functional capacity of the soil. Soil quality is the capacity of the soil to maintain plant productivity, maintain water availability and support human activities. Good soil quality will support the function of the soil as a medium for plant growth, regulate and share water flow and support a good environment.

Table 1. Limiting factors and relative weighting of soil quality index (SQI).

Indicators	**Limiting Factor and Relative Weight**				
	None	**Slight**	**Moderate**	**Severe**	**Extreme**
	1	**2**	**3**	**4**	**5**
Bulk Density (g cm^{-3})	<1.2	1.3-1.4	1.4-1.5	1.5-1.6	>1.6
Soil Texture	L	SiL, Si, SiCL	CL, SL	SiC, LS	S, C
Porosity (%)	>20	18-20	15-18	10-15	<10
Water content of field capacity (%)	>30	20-30	8-20	2-8	<2
Organic C (%)	5-10	3-5	1-3	0.5-1	<0.5
pH	6.0-7.0	5.8-6.0	5.4-5.8	5.0-5.4	<5.0
CEC (me 100 g^{-1})	>40	25-40	17-24	5-16	<5
Base Saturation (BS)(%)	>70	51-70	36-50	20-30	<20
Total N (%)	>0.51	0.51- 0.75	0.21-0.50	0.10-0.20	<0.10
Available P (ppm)	>35	26-35	16-25	10-15	<10
Available K (ppm)	>1.0	0.6-1.0	0.3-0.5	0.1-0.2	<0.1
Biomass C (mg CO_2 kg^{-1})	>25	20-25	10-20	5-10	<5

Remarks: L= loam; Si = silt; S = sand; C = clay. Source: Lal (1994).

Table 2. Soil quality criteria based on ten minimum data sets (MDS).

Soil Quality	Relative weight	Cumulative Weight (SCI)
Very good	1	<20
Good	2	20-25
Moderate	3	26-30
Bad	4	31-40
Very bad	5	>40

Source: Lal (1994).

The soil quality index was calculated using the criteria of Mausbach and Seybold, which can be adapted to field conditions using Minimum Data Set (MDS) analysis (Juarti, 2016).

Results and Discussion

Eight homogeneous land units (HLU) were obtained from overlapping maps used as soil sampling points. The map of homogeneous land units is presented in Figure 1, and the characteristics of HLU in the Seririt District are presented in Table 3 and Figure 1.

Soil physical properties

The physical properties of the soil observed were soil texture, soil bulk density, porosity, and water content of field capacity. The results of the analysis of the physical properties of the soil are presented in Table 4. The results of the analysis of soil texture showed that soil in HLU IV has a clay texture. Soils in HLUs I, II, V, and VI have a loamy texture, and soil in HLU III has a sandy loam texture. This textured soil has good drainage and aeration because it has macro pores in the sand fraction and good water holding capacity because it has micropores in the clay fraction (El-Ramady et al., 2014). Soils in HLUs VII and VIII have a clay texture that is dominated by clay fractions. Clay textured soils have low macro pores, so their infiltration capacity is low, but clay textured soils have high aggregate stability affects soil C stocks (El-Ramady et al., 2014). Soil texture greatly determines the rate of infiltration and the ability of the soil to hold water. Soils dominated by sand have high infiltration and easily pass water, so the ability to hold water is small (Juarti, 2016; Kurniawan et al., 2019).

The soil has a bulk density value of 0.96-1.58 g cm^{-3} with a relative value (1) to a weight limiting factor with a relative value (4). The different bulk densities are caused by differences in organic matter content and soil texture. This is in accordance El-Ramady et al. (2014) that organic matter, texture, structure, types of clay minerals, depth of plant roots, and types of soil fauna cause differences in bulk density in each HLU. The porosity value that ranges from 34.72% to 55.37% is not an obstacle because the soil texture at the study site is dominated by clay fraction, so the ability of the soil to hold high water with a large number of micropores. This impacts the availability of water, air, and optimum nutrients in the soil (El-Ramady et al., 2014). The results of the analysis showed that the soils have the water content of the field capacity of 8.24-19.10% with a moderate limiting factor (3) because the soil texture is dominated by clay fractions. According to El-Ramady et al. (2014), the availability of clay textured water is greater than clay and sand, in addition to being influenced by the amount of soil organic C is classified as medium and high, also by humus which has a high water holding capacity.

Table 3. Characteristics of homogeneous land units on rice fields in Seririt District, Buleleng Regency, Bali Province, Indonesia.

HLU	Village	Soil Types	Slope (%)	Area (ha)	Coordinate X	Coordinate Y
I	Kalisada	Grayish brown Alluvial (Entisols)	0-8	125.15	266,719.75	9,092,874.77
II	Banjar Asem	Brown Latosol and Litosol (Inceptisols and Oxisols)	0-8	84.69	267,793.49	9,092,269.22
III	Lokapaksa	Brown Latosol and Litosol (Inceptisols and Oxisols)	15-25	119.19	269,962.45	9,088,137.04
IV	Pangkung Paruk	Brown Latosol and Litosol (Inceptisols and Oxisols)	8-15	263.40	269,094.20	9,090,.105.16
V	Bestala	Yellowish brown Latosol (Ultisols)	15-25	99.43	276,660.63	9,089,222.30
VI	Ume Anyar	Greyish brown Regosol (Entisols)	0-8	961.98	271,360.37	9,093,833.88
VII	Mayong	Greyish brown Regosol (Entisols)	15-25	230.59	275,935.00	9,088,572.25
VIII	Joanyar	Greyish brown Regosol (Entisols)	8-15	562.18	274,357.03	9,090,563.96

HLU = Homogeneous Land Unit.

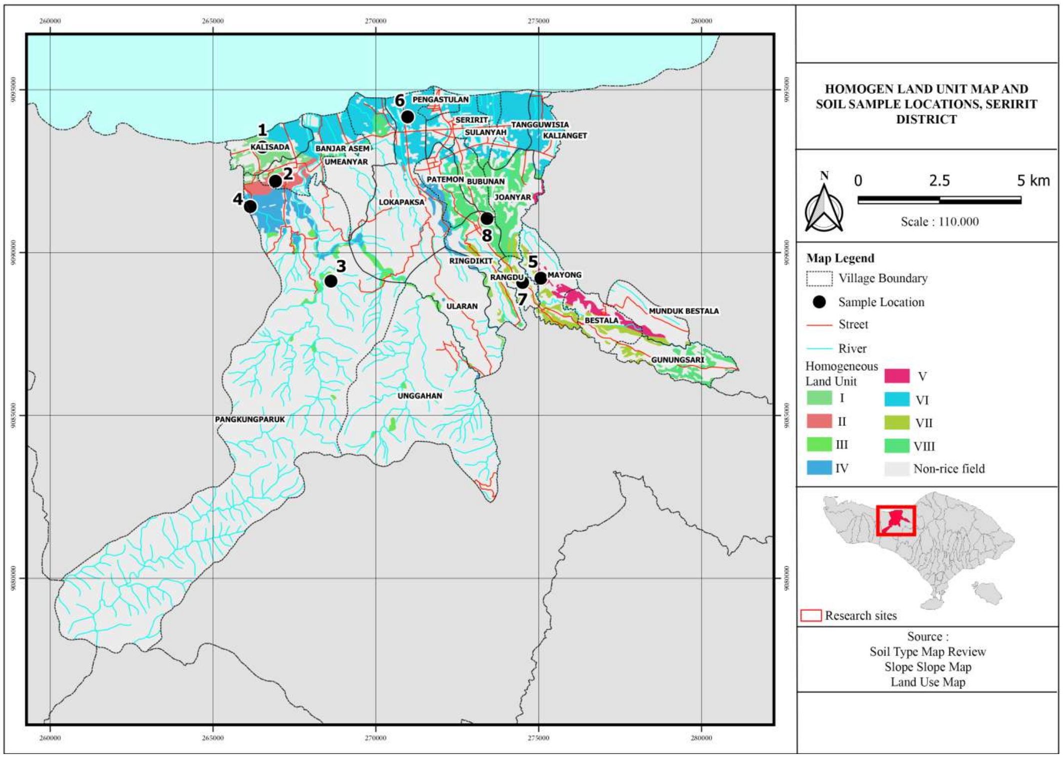

Figure 1. Homogeneous land units on rice fields in Seririt District, Buleleng Regency, Bali Province, Indonesia.

Table 4. Soil physical properties on rice fields in Seririt District, Buleleng Regency, Bali Province, Indonesia.

HLU	Texture	Bulk density (g cm^{-3})	Porosity (%)	Field capacity (%)
I	CL$_{(3)}$	0.96$_{(1)}$	55.37$_{(1)}$	19.80$_{(3)}$
II	CL$_{(3)}$	1.50$_{(3)}$	39.00$_{(1)}$	10.87$_{(3)}$
III	SL$_{(3)}$	1.36$_{(2)}$	43.68$_{(1)}$	11.70$_{(3)}$
IV	L$_{(1)}$	1.58$_{(4)}$	32.71$_{(1)}$	9.48$_{(3)}$
V	CL$_{(3)}$	1.13$_{(1)}$	41.00$_{(1)}$	10.47$_{(3)}$
VI	CL$_{(3)}$	1.34$_{(2)}$	47.60$_{(1)}$	8.24$_{(3)}$
VII	C$_{(5)}$	1.15$_{(1)}$	51.27$_{(1)}$	12.84$_{(3)}$
VIII	C$_{(5)}$	1.48$_{(3)}$	34.72$_{(1)}$	8.87$_{(3)}$

Remarks: Numbers in parenthesis indicate limiting factors: (1) None, (2) Slight, (3) Moderate, (4) Severe, (5) Extreme. HLU = Homogeneous Land Unit.

Soil chemical properties

The soil chemical properties are presented in Table 5. The cation exchange capacity (CEC) varies from moderate to very high (22.79-40.73 me 100 g^{-1}). This is due to differences in texture, organic matter content, and soil pH in each HLU, supported by El-Ramady et al. (2014) that the CEC value is influenced by several factors, namely: soil organic matter, texture and clay type, and soil pH. The soil texture which is dominated by the clay fraction, also causes the CEC value to be high. In addition, organic matter has a considerable influence on the CEC. This is because humification produces organic colloids that have a high surface area. At high CEC, base saturation (BS) is also high. The BS was classified as very high (81.48-99.01%) because the bases in each HLU did not experience leaching due to low rainfall. According to El-Ramady et al. (2014), nutrients become relatively optimal at pH 6-7, whereas in a near neutral atmosphere, the ion exchange complex is dominated by basic cations, so the exchange of nutrients is quite effective. The soil pH value in each HLU can be classified as neutral, except for HLU I, which is slightly acid (6.35), and HLU V is slightly alkaline (7.53). According to El-Ramady et al. (2014), the optimum pH for the availability of nutrients is around 7 because all macro elements are maximally available, while micronutrients are not maximum except for Mo, so the possibility of microelement toxicity is suppressed. At a pH below 6.5, P, Ca, and Mg deficiency can occur as well as B, Mn, Cu, Zn and Fe toxicity, while at a pH above 7.5, P, B, Fe, Mn, Cu, Zn deficiency can occur, Ca and Mg, as well as B and Mo toxicity. In assessing soil quality in terms of soil pH, several soil sampling points have good and moderate soil criteria. This is because the pH of the soil ranges from slightly acid, neutral, and slightly alkaline. This was revealed by Suleman et al. (2016) that soil that has a neutral soil pH is soil with healthy criteria, while soil that has an acidic or alkaline soil pH is soil with unhealthy criteria. The organic C content ranged from low to high (1.71-3.73%). The difference in the amount of organic C is influenced by the return or application of organic matter to the soil.

Table 5. Soil chemical and biological properties on rice fields in Seririt District, Buleleng Regency, Bali Province, Indonesia.

HLU	CEC (me 100 g^{-1})	BS (%)	pH	Organic C (%)	Nutrients			Biomass C (mg CO_2 kg^{-1})
					Total N (%)	Available P (ppm)	Available K (ppm)	
I	45.77 (VH) (1)	90.05 (VH)(1)	7.53 (AS)(1)	3.73 (H)(2)	0.51 (H) (2)	214.80 (VH)(1)	1.250.65 (VH) (1)	16.39 (3)
II	28.83 (H) (2)	86.15 (VH)(1)	6.76 (N)(1)	2.16 (M)(3)	0.30 (M) (3)	23.19 (M)(3)	2.129.20 (VH) (1)	21.39 (2)
III	29.94 (H) (2)	92.54 (VH)(1)	7.18 (N)(1)	2.18 (M)(3)	0.20 (M) (4)	15.87 (M)(3)	1.718.35 (VH) (1)	20.89 (2)
IV	40.73 (VH) (1)	96.77 (VH)(1)	7.00 (N)(1)	1.71 (L)(3)	0.16 (L) (4)	20.70 (M)(3)	2.361.76 (VH) (1)	21.89 (2)
V	30.93 (H) (2)	91.43 (VH)(1)	6.35 (SA)(1)	3.01 (H)(3)	0.35 (M) (3)	7.91 (VL)(5)	1.348.84 (VH) (1)	18.89 (3)
VI	33.56 (H)(2)	92.90 (VH)(1)	6.63 (N)(1)	2.95 (M)(3)	0.33 (M) (3)	23.00 (M)(3)	1.018.09 (VH) (1)	25.90 (1)
VII	22.79 (M)(3)	99.01 (VH)(1)	6.88 (N)(1)	3.08 (H)(2)	0.39 (M) (3)	18.30 (M)(3)	1.113.70 (VH) (1)	21.89 (2)
VIII	35.27 (H) (2)	81.48 (VH)(1)	6.88 (N)(1)	2.97 (M)(3)	0.12 (L) (4)	48.71 (VH)(1)	1.095.61 (VH) (1)	26.40 (1)

Remarks: HLU = Homogeneous Land Unit, CEC = Cation Exchange Capacity, BS = Base Saturation, VH = Very High, H = High, M = Medium, R = Low, N = Neutral, SA = Slightly Acid, AS = Slightly Alkaline VL = Very Low.

According to Diara (2017), the value of organic C in the soil is highly dependent on management practices that affect the entry and loss of carbon material, namely net primary production, organic residue quality, soil management residue management, and livestock management. The low content of organic matter in the top layer occurs due to intensive land management (Suleman, 2016).

The total N content of the soil at each location is classified as low to high due to differences in organic C content and washed through the solution and transported along with the harvested crop. According to the results of studies by Patti et al. (2013) and Yuliani et al. (2017), the application of fertilizers containing N can replace the loss of N in the soil. According to Hermawan (2003), the application of organic matter and inorganic fertilizers can increase the total N, available P, and available K in the soil. The low levels of total N in the two study sites (HLUs IV and VIII), are caused by the low and moderate levels of organic matter in the soil. The low N content in the soil is also caused by the nature of N, which is easily lost, and the lack of organic matter (El-Ramady et al., 2014). The available P values are classified as very low (HLU V), moderate (HLUs II, III, IV, VI, VII) to very high (HLUs I and VIII). This is due to the application of fertilizers that can replace the loss of P in the soil at each location with different or site-specific doses. This is in accordance with the results of Waskita's research that adding high P fertilizer into rice fields further increases the available P in the soil (Pakpahan et al., 2019). In addition, the high amount of organic matter in several research locations also affected the availability of P in the soil (Table 5). The very low value of available P is due to the slightly acid pH (6.35). The maximum availability of P in most soils is in the pH range between 6.5-7.0 (El-Ramady et al., 2014). In rice plants, phosphorus (P) is very important at the time of tiller formation (Suleman et al., 2016). The available K values are classified as very high, influenced by the high and low CEC of the soil; the greater the CEC of the soil, the greater the ability to bind and retain potassium in the soil low (Weil and Brady, 2017). The available K content is very high due to irrigation water in the rice fields. The potassium content in rice fields is generally higher than in dry land because irrigation water is a supplier of K (Subandi, 2013).

Biomass C

The observed biomass C is presented in Table 5. Lodhiyal and Lodhiyal (2003) stated that in general, biomass is the total organic material content of a living organism at a certain place and time (Arora et al., 2014). Based on the results of respiration measurements and the soil biomass C calculation approach in the rice fields of the research location, the biomass C value is classified as high to moderate. The biomass C values are high at HLUs VI and VIII (25.90 and 26.40 mg CO_2 kg^{-1}), and at HLUs II, III, IV, and VII are low, namely: 21.39; 20.89; 21.89; 21.89 mg CO_2 kg^{-1}. While soils in HLUs I and V have the lowest biomass C values (16.39 and 18.89 mg CO_2 kg^{-1}). The low content of biomass C in the soil is because there was no addition of compost as a food source for soil microorganisms. Soil management practices that reduce soil degradation are needed to improve soil quality and maintain agricultural productivity (Shokati and Ahangar, 2014). It is also necessary to treat soil according to field conditions because it can affect the organisation of the soil microstructure, including the distribution of micro aggregates with different mechanical strengths (Artemyeva and Kogut, 2016).

Soil quality index (SQI)

Based on the physical, chemical, and biological properties of the soil, the soil quality in rice fields in Seririt District is presented in Table 6. Good soil quality is found in HLUs I and VI with an area of 1,087.14 ha, while soils in HLUs II, III, IV, V, VII, and VIII have medium soil quality with an area of 1,359.50 ha. The low SQI value indicates that the limiting factor for soil quality is less; in other words, the soil quality gets better; on the contrary, the higher the SQI, the soil quality gets worse, and the limiting factor for soil quality gets bigger.

Table 6. Soil quality index on rice fields in Seririt District, Buleleng Regency, Bali Province, Indonesia.

HLU	SQI	Relative Weighting	Soil Quality
I	18	1	Very Good
II	24	2	Good
III	24	2	Good
IV	23	2	Good
V	25	2	Good
VI	22	2	Good
VII	24	2	Good
VIII	24	2	Good

Remarks: HLU = Homogeneous Land Unit; SQI = Soil Quality Index.

The difference in the SQI values in rice fields at each HLU in Seririt District is caused by texture, bulk density, organic C, CEC, total N, available P, and biomass C. The soil quality status map is the final result of this research. Rice fields in Seririt District have good soil quality with an area of 1,087.14 ha and a medium area of 1,359.50 ha.

The distribution of soil quality is presented in Figure 2, which contains information on the status of soil quality and its distribution. Good soil quality is indicated by green polygons, while moderate soil quality is indicated by yellow polygons. Good quality soil will ensure the sustainability of soil functions, both production functions and ecological functions. Determining the soil quality index will be useful for developing sustainable land management plans (Juarti, 2016). Good soil quality will support the function of the soil as a medium for plant growth, regulate and share water flow and support a good environment (Juarti, 2016).

The rice field improvement in Seririt District is based on the results of the analysis of soil quality and the limiting factors. The formulation of land management Plans is useful for improving poor soil quality in order to increase productivity again and achieve a sustainable agricultural system. Important factors that need to be considered in improving soil quality are land management systems because they can affect the organization of the soil microstructure, including the distribution of micro aggregates (Artemyeva and Kogut, 2016) and the use of appropriate and balanced fertilizers.

The recommended land management system at the research site is the application of organic matter throughout the HLU to improve nutrient availability and soil bulk density. This is in accordance with Sumarniasih and Antara (2021) that to increase soil fertility and quality, it is necessary to manage land by giving organic fertilizers, adding organic materials such as manure, and using plant residues in compost so that soil fertility and quality well improve. Good land management and fertilization can maintain soil quality conditions. Urea fertilizer was given to HLUs II, III, IV, V, VI, VII, and VIII because the levels of total N in the HLU had a moderate to severe limiting factor so that it could improve soil quality. P fertilizers should be given at HLUs II, III, IV, V, VI, and VII due to the low available P content in those HLUs. Evaluation of soil fertility status is needed as an effort to determine the potential and direction of production land management in agricultural crop cultivation and to determine the fertility factors that limit the land (Mujiyo et al., 2017). The problem of low soil fertility and poor plant nutrition affects not only crop yields but also crop quality (Njira and Nabwami, 2015). The maintenance of soil organic matter and soil tillage is important for soil quality and agricultural productivity (Ayuke et al., 2019). Increasing global demand for food led to the intensification of agricultural practices, such as tillage management that reduce soil degradation that is needed to improve soil quality and maintain agricultural productivity. Soil has the main function of a place to grow and produce plants. The ability of soil as a growing medium will be optimal if it is supported by good physical, chemical, and biological properties, usually indicating the level of soil fertility (Shokati and Ahangar, 2014).

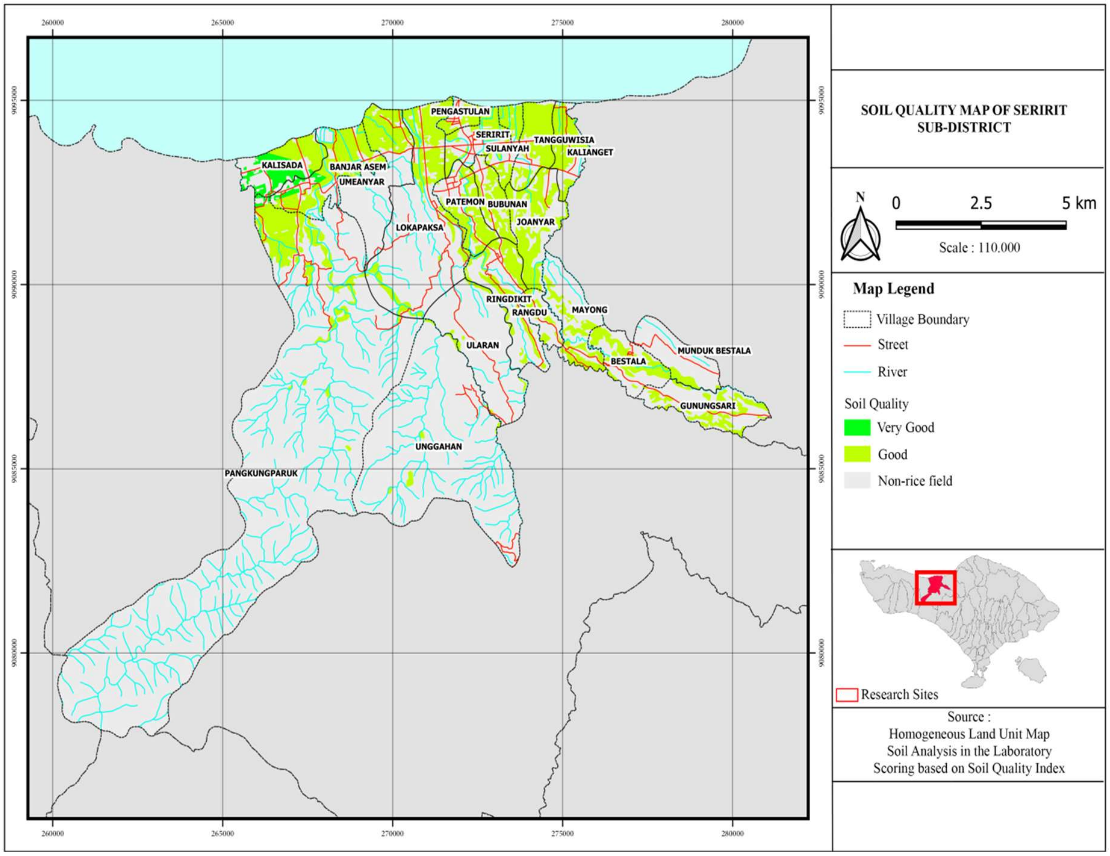

Figure 2. Map of soil quality on rice fields in Seririt District, Buleleng Regency, Bali Province, Indonesia.

Conclusion

Rice fields in Seririt District have very good soil quality covering an area of 125.15 ha. Very good soil quality is found in HLU I (Kalisada Village), with SQI values of 18. While good soil quality is found in HLUs II, III, IV, V, VI, VII and VIII (Banjar Asem, Lokapaksa, Pangkung Paruk, Bestala, Ume Anyar, Mayong, Joanyar) with an SQI value of 22-25, with the limiting factors of total N, total P P, texture, and bulk density. Good land management and fertilisation can maintain soil quality conditions. The management plan for the rice field in Seririt District recommended adding organic matter and fertilising with Urea and TSP.

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