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Mapping of soil fertility status in various types of land use in Ende Sub-District, Ende Regency, East Nusa Tenggara

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Abstract Mapping of soil fertility status in Ende Sub-district can be referenced for proper agricultural land management. Soil samples were collected from 48 observation points representing four land-use types (forest, plantation, meadow, and moor) and four slope classes on Alfisols under an annual rainfall of 1.102,34 mm. The average results revealed that soil fertility status across various land uses in Ende Sub-district ranged from moderate to high. Land use and slope variations significantly influenced soil fertility levels, indicating spatial differences in soil quality throughout the study area. The potential pH value, organic c, and cation exchange capacity are correlated with the SFI value. Which the value of the three parameters was highly indicated high fertility.

Keywords: Food security, Soil conservation, Soil health, Soil organic matter, Sustainable agriculture

Introduction

Indonesia is a country consisting of thousands of islands with a large population. The increasing growth in population and their needs leads to a greater demand for land to carry out various activities and the necessary infrastructure to support and fulfil these demands. The land is a landscape where all living things live their lives by utilizing the land itself (Ellis, 2021). Land use is defined as a human effort on land to obtain benefits from the land (Nedd *et al*., 2021). Land use types include developed land (settlement, industry, trade) and undeveloped land (agriculture, plantation, mining). Land use patterns in various forms and ways will impact the environment (Wang *et al*., 2022).

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Ende Sub-district is one of the sub-districts in Ende Regency. Most Ende Sub-district residents earn a living as a fisherman and farmers (Aje *et al*., 2023). In line with the development of agriculture, it turns out that agricultural activities can negatively affect soil function and decrease soil fertility (Sofo *et al*., 2022). Agricultural activities that cannot maintain soil organic matter content can cause a decline in agricultural productivity (Widhiyastuti *et al*., 2023). Mapping is an applied science that studies the topographic shape of the earth's surface and the objects on it (Santoso and Nasir, 2021). Mapping can be done to determine the boundaries of soil fertility areas. Areas with different regions and types of land use cause differences in soil fertility levels (Winazira *et al*., 2021). This mapping aims to help the community determine the boundaries of soil fertility areas so people can cultivate agricultural land better.

Soils used for agriculture have different levels of fertility. For this reason, special treatment is necessary to maintain soil fertility. The decline in soil fertility is because agricultural land is only planted with one type of plant for a long time without interspersed with other plant types (Furey and Tilman, 2021). In addition, infrequent fertilization is the cause of nutrient depletion in the soil. The results of evaluating soil fertility status can be used for agricultural land use planning. Soil fertility evaluation is assessing nutrient problems in the soil and making fertilization recommendations (Sumarniasih *et al*., 2021).

Evaluating fertility status to assess and monitor soil fertility is significant in determining which nutrients are limiting factors or constraints for plants. Assessment of soil fertility status evaluation can be done through a soil test approach where assessment using this method is relatively more accurate and faster. Analysis of soil chemical properties, which are soil fertility parameters, is determined as a criterion for soil fertility (Siregar *et al*., 2021). Previous research has discussed soil fertility in Kekawii III, Randotonda Village, Ende District, Ende Regency (Kuswara and Mutiara, 2018). The research was to determine the effect of land use on soil fertility in Ende Sub-district, Ende Regency.

Materials and methods

Research location

This research conducted in Ende Sub-district, Ende Regency, East Nusa Tenggara. Ende Sub-district is astronomically located in 121°32'15.50" - 121°42'8.20" E and 8°39'5.60" - 8°48'43" S. The research location, Ende sub-district, Ende Regency, East Nusa Tenggara showed in Figure 1. Ende sub-district has geographical conditions that support the cultivation of plantation crops, especially in hilly areas. The leading plantation crops in Ende sub-district

include coconut, coffee, and cacao. The production of coconut plantation commodities in Ende Sub-district reached 194.80 tons, coffee 958.20 tons, and cacao 505.01 tons in 2022 (CBS, 2022).

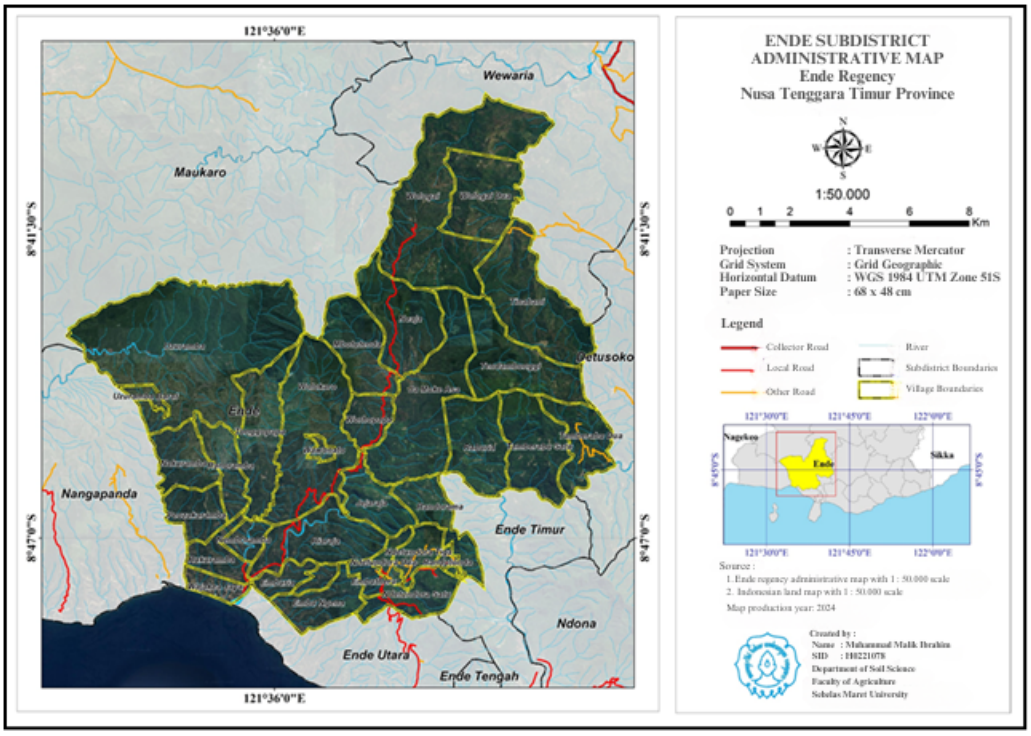


Figure 1. Ende subdistrict administrative map

Research design and sampling

The research used an exploratory, descriptive method and a survey approach. The determination of sample points was based on the purposive sampling method or soil sampling at a representative point. This research integrates qualitative and quantitative field data collection in the laboratory. Environmental diversity is the basis for making Land Map Units (LMU) consisting of soil type, rainfall, slope, and land use. LMU determination overlaps the administrative map with the environmental diversity map.

Table 1. Land map units

LMU	Slope (%)	Land Use	Rainfall (mm/year)	Soil Type
1	0 - 8	Forest	1102.34	Alfisols
2	0 - 8	Plantation	1102.34	Alfisols
3	0 - 8	Meadow	1102.34	Alfisols
4	0 - 8	Moor	1102.34	Alfisols
5	8 - 15	Forest	1102.34	Alfisols
6	8 - 15	Plantation	1102.34	Alfisols
7	8 - 15	Meadow	1102.34	Alfisols
8	8 - 15	Moor	1102.34	Alfisols
9	15 - 25	Forest	1102.34	Alfisols
10	15 - 25	Plantation	1102.34	Alfisols
11	15 - 25	Meadow	1102.34	Alfisols
12	15 - 25	Moor	1102.34	Alfisols
13	25 - 45	Forest	1102.34	Alfisols
14	25 - 45	Plantation	1102.34	Alfisols
15	25 - 45	Meadow	1102.34	Alfisols
16	25 - 45	Moor	1102.34	Alfisols

Source: Badan Informasi Geospasial (2022)

Based on these results, 16 LMUs were obtained (Table 1) and repeated 3 times based on Federer's formula for determining sample points (Prayogi *et al*., 2024). The formula for determining the sample point is Equation 1.

$$(k-1) \times (r-1) \geq 15 \quad \ldots\ldots\ldots\

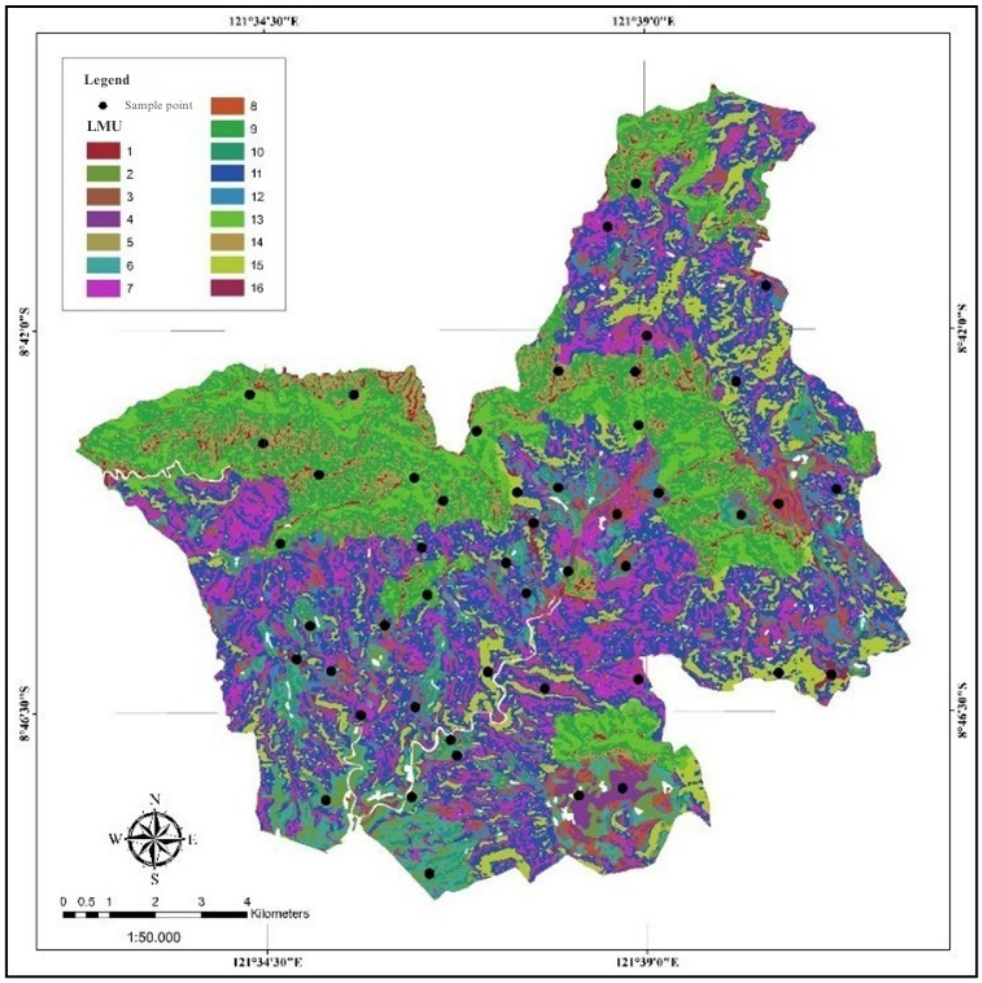


Figure 2. Land map units

Laboratory analysis

The parameters tested in this study consisted of soil chemical, physical, and biological properties. Soil analysis in the laboratory aims to determine the value of pH, total N, available P, available K, organic C, CEC, base saturation, ratio C/N, soil texture, and microbial biomass carbon in the analyzed soil samples which can then be used to determine the characteristics and the soil fertility. The analytical methods used in this study can be seen in Table 2.

Table 2. Parameters and methods of soil fertility observation

Soil properties	Soil parameters	Methods	Citation
Chemistry	pH (H_2O, KCl)	Electrometry	Suranta *et al*., 1999
	Total N	Kjeldahl	Suranta *et al*., 1999
	Available P	Olsen	Olsen, 1954
	Available K	1N Ammonium Acetate Extraction	Suranta *et al*., 1999
	Organic C	Walkley and Black	Walkley and Black, 1934
	CEC	1N Ammonium Acetate Extraction	Suranta *et al*., 1999
	Base saturation	1N Ammonium Acetate Extraction	Suranta *et al*., 1999
	Ratio C/N	Comparison	Suranta *et al*., 1999
Physics	Soil texture	Pipette	Suranta *et al*., 1999
Biology	Microbial biomass carbon	*Fumigation*	Jenkinson and Powlson, 1976

CEC: cation exchange capacity

Data analysis

Soil fertility

The Soil Fertility Index (SFI) begins with determining the Principal Component or main component using the PCA (Principal Component Analysis) method. The PCA method involves a correlation analysis stage in the form of Pearson Correlation Analysis to determine the relationship between parameters and the main components in PCA. Parameters with high PCA values and significant correlations are selected as the Minimum Soil Fertility Index (MSFI) or minimum data set to represent all soil fertility indicator values. The selected MSFI was then assessed based on the BPSI Soil and Fertilizer assessment criteria in Table 3.

The next step is to calculate the SFI value by dividing the scoring indicator (Sci) by the number of SFI indicators (N) presented in Equation 2 – 5 (Mukashema, 2007).

$$pc = \frac{1}{nc} \quad \text{.....(2)}$$

$$cj = wi \times si \quad \text{.....(3)}$$

$$Sci = cj \times pc \quad \text{.....(4)}$$

$$SFI = \frac{Sci}{N} \times 10 \quad \text{.....(5)}$$

Description:

pc : grade value
nc : total value used
wi : weight index

si : scoring index
cj : total weight
SFI : soil fertility index
Sci : scoring indicator
N : number of SFI indicators

Table 3. Soil fertility indicator value index

No.	Indicator	Value Index				
		1	**2**	**3**	**4**	**5**
1	pH	<5 and >8.2	5.0-5.4 and 7.8-8.2	5.4-5.8 and 7.4-7.8	5.8-6.0 and 7.0-7.4	6,0-7,0
2	Total N (%)	<0.1	0.1-0.2	0.21-0.5	0.51-0.75	>0.75
3	Available P (ppm)	<10	10-15	16-25	26-35	>35
4	Available K (me/100g)	<0.1	0.1-0.2	0.3-0.5	0.6-1	>1
5	Organic C (%)	<0.5	0.5-1	1-3	3-5	5-10
6	CEC (cmol(+)/kg)	<5	5-16	17-24	25-40	>40
7	Base Saturation (%)	<20	20-30	41-50	51-70	>70
8	Ratio C/N	<5	>25	16-25	5-10	11-15
9	Soil Texture	S, Si	LS	SL, L, SiL	SiC, CL, SCL	SiCL, SC, C
10	Microbial biomass carbon (µg/g)	<5	5-10	11-15	16-25	>25

CEC: cation exchange capacity; S: sand; Si: silt; LS: loamy sand; SL: sandy loam; L: loam; SiL: silty loam; SiC: silty clay; CL: clay loam; SCL: sandy clay loam; SiCL: silty clay loam; SC: sandy clay; C: clay

The results of the scoring calculation are then classified based on the SFI Classification according to Mujiyo *et al*. (2022) in Table 4.

Table 4. SFI classification

SFI Value	SFI Class
0.00 - 0.25	Very low
0.26 - 0.50	Low
0.51 - 0.75	Medium
0.76 - 0.90	High
0.91 - 1.00	Very high

Source: Mujiyo *et al*. (2022)

Determinant factor

Data from the SFI classification process were compared to determine significant differences in the data groups obtained using the two-way analysis of variance test. Suppose there is a significant difference in the analysis of the variance test. In that case, the DMRT (Duncan's Multiple Range Test) test is conducted at the 5% level ($\alpha = 0.05$) to determine which land management is significantly different. Then, the correlation test between parameters is carried out with the SFI to find out the determinants of soil fertility. This section should have the meaning of the state of the art of science and technology, the sophistication of viewpoints and approaches, the potential acquisition of novelties, new to science, and completeness of work, not only repeating previous research of the same type, not mutating methods and objects.

Results

Indicators of SFI

The results of the SFI indicator can be seen in Table 5. The actual pH value of the soil in the study area was slightly acidic to neutral, with the lowest actual pH value of 6.15 for forest land use and the highest actual pH value of 7.11 for moorland land use. The soil's potential pH value was very acidic to neutral, with the lowest potential pH value of 4.35 for forest land use and the highest potential pH value of 7.31 for plantation land use. The total N value of the study area was classified as moderate. The total N value in forest land use types was in the range of 0.24 - 0.49%, plantation land use was in the range of 0.24 - 0.49%, meadow land use was in the range of 0.26 - 0.40%, and moorland land use was in the range of 0.26 - 0.43%.

Available P values in forest land use types were in the range of 20.09 - 23.01 ppm, plantation land use was in the range of 20.29 - 23.11 ppm, meadow land use is in the range of 20.60 - 22.36 ppm, and moorland land use was in the range of 20.69 - 22.44 ppm. The available K results of the study area were classified as low to very high. The available K value in forest land use was in the range of 0.21 - 0.91 me/100 g, plantation land use was in the range of 0.16 - 1.35 me/100 g, meadow land use was in the range of 0.20 - 1.25 me/100 g, and moorland land use was in the range of 0.21 - 0.95 me/100 g.

The value of organic C in the study area is classified as low to moderate. Organic C values in forest land use types were in the range of 0.99-2.80%, plantation land use was in the range of 1.61-2.81%, meadow land use was in the range of 0.86-2.01%, and moorland land use was in the range of 1.52-2.84%. The CEC value of the study area is classified as high to very high. The CEC value in

the forest land use type was in the range of 30.92 - 43.93 cmol(+)/kg, plantation land use was in the range of 28.87 - 44.60 cmol(+)/kg, meadow land use was in the range of 27.69 - 46.63 cmol(+)/kg, and moorland land use was in the range of 31.84 - 53.30 me/100 g.

The base saturation value of the study area is categorized as very low to moderate. Base saturation values in forest land use types were in the range of 9.16-25.04%, plantation land use was in the range of 14.47-36.79%, meadow land use was in the range of 18.88-33.87%, and moorland land use was in the range of 12.03-32.05%. The C/N ratio value of the study area is classified as very low to medium. C/N ratio values in forest land use types were in the range of 3.63-6.7, plantation land use was in the range of 3.63-11.37, meadow land use was in the range of 2.13-6.19, and moorland land use was in the range of 4.33-11.06.

The soil texture of the study area is dominated by sandy loam. The clay content in forest land use types was in the range of 5.85-33.14%, plantation land use was in the range of 3.90-21.44%, meadow land use was in the range of 1.95-42.88%, and moorland land use was in the range of 7.80-60.43%. The microbial biomass carbon found to be low in medium. The value of microbial biomass carbon in forest land use types was in the range of 0.24-0.56 µg/g, plantation land use was in the range of 0.19-0.48 µg/g, meadow land use was in the range of 0.12-0.37 µg/g, and moorland land use was in the range of 0.10-0.37 µg/g.

The SFI analysis

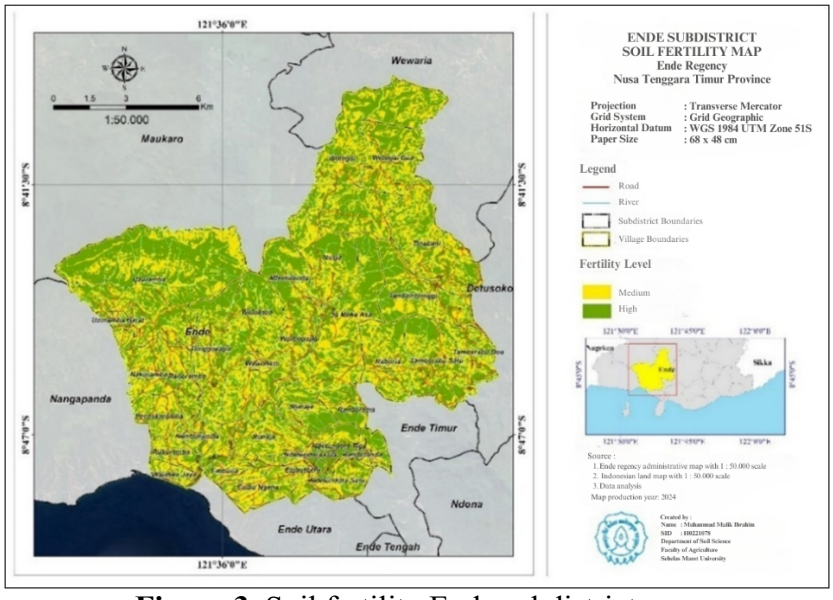


Figure 3. Soil fertility Ende subdistrict map

Table 5. Soil fertility indicator analysis results

Sample	Slope(%)	Land use	Indicator										
			pH (H_2O)	pH (KCl)	Total N (%)	Available P (ppm)	Available K (me/100 g)	Organic C (%)	CEC (cmol(+)/kg)	Base saturation (%)	Ratio C/N	Clay texture (%)	Microbial biomass C (μg/g)
1	0-8	Forest	6.43	4.70	0.30	20.35	0.24	1.33	33.18	21.71	4.45	15.59	0.39
2	0-8	Forest	6.47	4.60	0.36	20.09	0.80	1.29	30.92	23.63	3.63	17.54	0.55
3	0-8	Forest	6.63	4.51	0.24	20.22	0.34	1.25	31.98	19.66	5.32	13.65	0.56
4	0-8	Plantation	6.78	6.40	0.35	20.29	1.20	1.73	32.20	31.67	4.92	9.75	0.19
5	0-8	Plantation	6.82	6.49	0.35	21.76	0.75	2.12	33.84	26.58	6.04	13.65	0.20
6	0-8	Plantation	6.75	6.13	0.35	20.49	1.35	1.67	35.15	36.79	4.75	3.90	0.24
7	0-8	Meadow	6.70	6.58	0.37	20.60	0.29	1.99	35.27	25.73	5.37	7.80	0.28
8	0-8	Meadow	6.65	6.46	0.37	21.36	0.29	1.89	31.59	32.96	5.13	11.70	0.24
9	0-8	Meadow	6.92	5.94	0.37	21.37	0.30	2.01	30.97	26.85	5.42	1.95	0.32
10	0-8	Moor	6.45	5.92	0.32	20.81	0.64	1.80	53.30	18.03	5.70	21.44	0.17
11	0-8	Moor	6.44	6.00	0.31	21.73	0.82	1.58	51.23	19.99	5.10	43.27	0.27
12	0-8	Moor	6.57	5.68	0.31	21.38	0.78	1.62	50.82	21.17	5.20	29.24	0.23
13	8-15	Forest	6.15	4.65	0.29	20.26	0.91	1.14	42.31	16.87	3.90	25.34	0.48
14	8-15	Forest	6.20	4.66	0.29	20.36	0.29	1.11	40.85	17.68	3.75	17.54	0.36
15	8-15	Forest	6.64	4.35	0.24	20.98	0.37	0.99	41.26	13.63	4.19	11.70	0.43
16	8-15	Plantation	6.96	6.47	0.24	21.25	0.89	1.83	31.40	32.24	7.69	9.75	0.24
17	8-15	Plantation	6.77	6.42	0.36	20.95	0.85	1.92	28.87	33.40	5.37	7.80	0.48
18	8-15	Plantation	6.80	6.25	0.47	20.72	0.55	1.72	31.78	32.75	3.63	7.80	0.30

Sample	Slope(%)	Land use	Indicator										
			pH (H_2O)	pH (KCl)	Total N (%)	Available P (ppm)	Available K (me/100 g)	Organic C (%)	CEC (cmol(+)/kg)	Base saturation (%)	Ratio C/N	Clay texture (%)	Microbial biomass C (µg/g)
19	8-15	Meadow	6.83	6.32	0.39	22.17	0.46	1.77	37.51	28.57	4.50	13.65	0.34
20	8-15	Meadow	6.79	5.94	0.26	22.22	0.33	1.61	38.11	27.95	6.19	15.59	0.18
21	8-15	Meadow	6.77	5.46	0.37	21.23	0.21	1.73	37.88	18.88	4.67	22.61	0.30
22	8-15	Moor	6.39	5.73	0.31	22.27	0.44	1.52	31.84	32.05	4.85	60.43	0.20
23	8-15	Moor	6.61	6.22	0.38	21.81	0.86	1.63	34.08	31.76	4.33	29.24	0.22
24	8-15	Moor	6.82	5.90	0.36	21.12	0.61	1.61	33.42	31.42	4.46	15.59	0.21
25	15-25	Forest	7.04	6.52	0.48	22.68	0.26	2.72	40.82	20.13	5.72	15.59	0.30
26	15-25	Forest	7.10	6.58	0.42	23.01	0.29	2.80	41.57	22.25	6.75	7.80	0.33
27	15-25	Forest	6.96	6.07	0.42	22.67	0.47	2.75	42.72	25.04	6.60	5.85	0.44
28	15-25	Plantation	6.88	7.31	0.48	22.52	0.25	2.11	42.85	21.28	4.34	7.80	0.38
29	15-25	Plantation	6.90	6.50	0.36	23.11	0.16	1.77	44.60	19.26	4.88	11.70	0.21
30	15-25	Plantation	6.70	5.98	0.49	22.43	0.24	2.04	41.76	14.47	3.72	3.90	0.41
31	15-25	Meadow	6.70	5.80	0.26	21.43	0.25	0.96	33.51	33.87	3.69	7.80	0.18
32	15-25	Meadow	6.68	6.45	0.39	21.22	0.25	0.86	29.99	25.16	2.21	13.65	0.23
33	15-25	Meadow	6.77	6.07	0.32	21.90	0.20	0.97	27.69	29.82	3.01	11.70	0.27
34	15-25	Moor	6.44	5.84	0.38	21.32	0.95	2.54	44.33	22.97	6.75	23.39	0.30
35	15-25	Moor	6.57	5.49	0.26	22.26	0.23	2.84	46.75	23.72	11.06	23.39	0.24
36	15-25	Moor	7.11	6.43	0.43	22.44	0.21	2.27	41.63	18.97	5.28	17.54	0.10
37	25-45	Forest	6.65	6.98	0.49	21.14	0.23	2.33	43.93	9.16	4.78	19.49	0.26

Sample	Slope(%)	Land use	Indicator										
			pH (H_2O)	pH (KCl)	Total N (%)	Available P (ppm)	Available K (me/100 g)	Organic C (%)	CEC (cmol(+)/kg)	Base saturation (%)	Ratio C/N	Clay texture (%)	Microbial biomass C (µg/g)
38	25-45	Forest	6.58	6.28	0.37	21.00	0.25	2.30	40.29	11.42	6.25	21.44	0.24
39	25-45	Forest	6.60	6.18	0.43	21.16	0.21	1.77	39.91	10.61	4.11	33.14	0.24
40	25-45	Plantation	6.57	6.52	0.37	21.47	0.25	1.61	31.12	25.11	4.38	9.75	0.25
41	25-45	Plantation	6.50	6.13	0.25	21.97	0.53	2.81	33.08	24.46	11.37	7.80	0.33
42	25-45	Plantation	6.60	6.06	0.31	21.46	0.88	2.45	32.66	33.47	7.95	21.44	0.29
43	25-45	Meadow	6.44	6.23	0.26	21.84	1.25	0.89	46.63	28.95	3.45	37.04	0.37
44	25-45	Meadow	6.89	6.31	0.40	22.36	1.19	0.86	44.03	29.19	2.13	29.24	0.12
45	25-45	Meadow	6.84	6.24	0.26	21.57	1.01	1.11	41.72	29.76	4.26	42.88	0.22
46	25-45	Moor	6.60	6.08	0.38	21.17	0.43	1.96	48.74	25.13	5.21	9.75	0.37
47	25-45	Moor	6.42	6.74	0.31	20.69	0.21	1.75	49.46	12.03	5.65	7.80	0.33
48	25-45	Moor	6.57	6.18	0.32	21.91	0.32	1.55	46.92	16.62	4.80	21.44	0.20

Source: Data analysis

Table 6. The SFI determination

Sample	Si x Wi									Cj	nc	Pc	Sci	N	SFI	Fertility Class
	pH (H_2O)	pH (KCl)	Total N	Available P	Available K	Organic C	CEC	Ratio C/N	Texture							
1	0.46	0.09	0.57	0.28	0.31	0.28	0.47	0.12	0.31	2.88	5	0.2	0.576	9	0.64	Medium
2	0.46	0.09	0.57	0.28	0.41	0.28	0.47	0.12	0.31	2.98	5	0.2	0.597	9	0.66	Medium
3	0.46	0.09	0.57	0.28	0.31	0.28	0.47	0.47	0.31	3.24	5	0.2	0.647	9	0.72	Medium
4	0.46	0.46	0.57	0.28	0.52	0.28	0.47	0.12	0.31	3.45	5	0.2	0.691	9	0.77	High
5	0.46	0.46	0.57	0.28	0.41	0.28	0.47	0.47	0.31	3.71	5	0.2	0.741	9	0.82	High
6	0.46	0.46	0.57	0.28	0.52	0.28	0.47	0.12	0.31	3.45	5	0.2	0.691	9	0.77	High
7	0.46	0.46	0.57	0.28	0.31	0.28	0.47	0.47	0.52	3.81	5	0.2	0.762	9	0.85	High
8	0.46	0.46	0.57	0.28	0.31	0.28	0.47	0.47	0.52	3.81	5	0.2	0.762	9	0.85	High
9	0.46	0.37	0.57	0.28	0.31	0.28	0.47	0.47	0.31	3.51	5	0.2	0.702	9	0.78	High
10	0.46	0.37	0.57	0.28	0.41	0.28	0.59	0.47	0.31	3.73	5	0.2	0.747	9	0.83	High
11	0.46	0.46	0.57	0.28	0.41	0.28	0.59	0.47	0.52	4.03	5	0.2	0.807	9	0.90	High
12	0.46	0.28	0.57	0.28	0.41	0.28	0.59	0.47	0.41	3.75	5	0.2	0.749	9	0.83	High
13	0.46	0.09	0.57	0.28	0.41	0.28	0.59	0.12	0.41	3.21	5	0.2	0.641	9	0.71	Medium
14	0.46	0.09	0.57	0.28	0.31	0.28	0.59	0.12	0.31	3.00	5	0.2	0.600	9	0.67	Medium
15	0.46	0.09	0.57	0.28	0.31	0.18	0.59	0.12	0.31	2.91	5	0.2	0.582	9	0.65	Medium
16	0.46	0.46	0.57	0.28	0.41	0.28	0.47	0.47	0.31	3.71	5	0.2	0.741	9	0.82	High
17	0.46	0.46	0.57	0.28	0.41	0.28	0.47	0.47	0.31	3.71	5	0.2	0.741	9	0.82	High
18	0.46	0.46	0.57	0.28	0.41	0.28	0.47	0.12	0.31	3.35	5	0.2	0.670	9	0.74	Medium
19	0.46	0.46	0.57	0.28	0.31	0.28	0.47	0.12	0.31	3.25	5	0.2	0.650	9	0.72	Medium
20	0.46	0.37	0.57	0.28	0.31	0.28	0.47	0.47	0.31	3.51	5	0.2	0.702	9	0.78	High
21	0.46	0.28	0.57	0.28	0.21	0.28	0.47	0.12	0.31	2.96	5	0.2	0.592	9	0.66	Medium
22	0.46	0.28	0.57	0.28	0.31	0.28	0.47	0.12	0.52	3.27	5	0.2	0.654	9	0.73	Medium
23	0.46	0.46	0.57	0.28	0.41	0.28	0.47	0.12	0.41	3.45	5	0.2	0.691	9	0.77	High
24	0.46	0.37	0.57	0.28	0.41	0.28	0.47	0.12	0.31	3.26	5	0.2	0.652	9	0.72	Medium
25	0.37	0.46	0.57	0.28	0.31	0.28	0.59	0.47	0.31	3.63	5	0.2	0.726	9	0.81	High
26	0.37	0.46	0.57	0.28	0.31	0.28	0.59	0.47	0.31	3.63	5	0.2	0.726	9	0.81	High
27	0.46	0.46	0.57	0.28	0.31	0.28	0.59	0.47	0.31	3.72	5	0.2	0.745	9	0.83	High
28	0.46	0.37	0.57	0.28	0.31	0.28	0.59	0.12	0.31	3.28	5	0.2	0.655	9	0.73	Medium
29	0.46	0.46	0.57	0.28	0.21	0.28	0.59	0.12	0.31	3.26	5	0.2	0.653	9	0.73	Medium
30	0.46	0.37	0.76	0.28	0.21	0.28	0.59	0.12	0.31	3.36	5	0.2	0.672	9	0.75	Medium
31	0.46	0.37	0.57	0.28	0.31	0.18	0.47	0.12	0.31	3.06	5	0.2	0.613	9	0.68	Medium
32	0.46	0.46	0.57	0.28	0.31	0.18	0.47	0.12	0.31	3.16	5	0.2	0.631	9	0.70	Medium

Sample	Si x Wi									Cj	nc	Pc	Sci	N	SFI	Fertility Class
	pH (H_2O)	pH (KCl)	Total N	Available P	Available K	Organic C	CEC	Ratio C/N	Texture							
33	0.46	0.46	0.57	0.28	0.21	0.18	0.47	0.12	0.31	3.05	5	0.2	0.611	9	0.68	Medium
34	0.46	0.37	0.57	0.28	0.41	0.28	0.59	0.47	0.41	3.84	5	0.2	0.768	9	0.85	High
35	0.46	0.28	0.57	0.28	0.21	0.28	0.59	0.59	0.41	3.66	5	0.2	0.732	9	0.81	High
36	0.37	0.46	0.57	0.28	0.21	0.28	0.59	0.47	0.31	3.53	5	0.2	0.706	9	0.78	High
37	0.46	0.46	0.57	0.28	0.21	0.28	0.59	0.12	0.31	3.26	5	0.2	0.653	9	0.73	Medium
38	0.46	0.46	0.57	0.28	0.31	0.28	0.59	0.47	0.31	3.72	5	0.2	0.745	9	0.83	High
39	0.46	0.46	0.57	0.28	0.21	0.28	0.47	0.12	0.52	3.35	5	0.2	0.670	9	0.74	Medium
40	0.46	0.46	0.57	0.28	0.31	0.28	0.47	0.12	0.31	3.25	5	0.2	0.650	9	0.72	Medium
41	0.46	0.46	0.57	0.28	0.31	0.28	0.47	0.59	0.31	3.72	5	0.2	0.745	9	0.83	High
42	0.46	0.46	0.57	0.28	0.41	0.28	0.47	0.47	0.41	3.81	5	0.2	0.762	9	0.85	High
43	0.46	0.46	0.57	0.28	0.52	0.18	0.59	0.12	0.41	3.59	5	0.2	0.717	9	0.80	High
44	0.46	0.46	0.57	0.28	0.52	0.18	0.59	0.12	0.41	3.59	5	0.2	0.717	9	0.80	High
45	0.46	0.46	0.57	0.28	0.52	0.28	0.59	0.12	0.52	3.78	5	0.2	0.756	9	0.84	High
46	0.46	0.46	0.57	0.28	0.31	0.28	0.59	0.47	0.31	3.72	5	0.2	0.745	9	0.83	High
47	0.46	0.46	0.57	0.28	0.21	0.28	0.59	0.47	0.31	3.62	5	0.2	0.724	9	0.80	High
48	0.46	0.46	0.57	0.28	0.31	0.28	0.59	0.12	0.31	3.37	5	0.2	0.673	9	0.75	Medium

Source: Data analysis

Determinant factor

The determinant factor was determined through a correlation test with a significance of 0.05 to 0.01, it is found that 5 out of 11 parameters were significantly correlated at the 0.05 level and very significant at the 0.01 level (Table 7). The correlated parameters included potential pH, available K, organic C, CEC, and C/N ratio.

Table 7. Correlation of SFI with soil fertility indicators

Soil Parameters	Pearson Correlation
pH (H_2O)	0.141
pH (KCl)	0.**478****
Total N	0.010
Available P	0.247
Available K	**0.344***
Organic C	**0.525****
CEC	**0.339***
Base saturation	0.159
Ratio C/N	**0.514****
Soil Texture	0.130
Microbial biomass carbon	-0.250

Source: Data analysis

Results showed that 3 out of 5 parameters had significant differences with significance values of potential pH (p-value 0.005), organic C (p-value 0.035), and CEC (p-value 0.001) (Table 8). Based on these results, it can be concluded that the indicators determining Soil Fertility Index are potential pH, organic C, and CEC

Table 8. Analysis of variance results of land use on parameters

Land Use	pH Potential	Available K	Organic C	CEC	Ratio C/N
Significance	0,005	0,270	0,035	0,001	0,084

Source: Data analysis

The potential pH value in forest land use was significantly differed from that of plantations, meadows, and fields. The index of potential pH value in forest land use (5.51) was medium, while plantation land use (6.39), meadow (6.15), and moor (6.02) were a very high index value.

Table 9. DMRT land use test results on determining indicators

Land Use	pH Potential	Organic C	CEC
Forest	5.51a	1.82b	39.15a
Plantation	6.39b	1.98b	34.94a
Meadow	6.15b	1.39a	36.24a
Moor	6.02b	1.89b	44.38b

Source: Data analysis

Organic C value in meadow (1.39) was significantly differed with forest (1.82), plantation (1.98), and moor (1.89). The index of organic C value in all land uses is medium. The value of CEC in moorland was significantly differed from that of forests, plantations, and meadows. The index value of CEC in the land use of moor (44.38) was very high, while forests (39.15), plantations (34.94), and meadows (36.24) had a high index value.

Discussion

The SFI and its distribution by land use

Based on the determination of the Soil Fertility Index that had been carried out, it is found that the type of land use of moor was the highest average SFI value compared to other types of use with a value of 0.80, which has a high soil fertility category. The plantation land use type was an average SFI value of 0.78 with a high soil fertility category. Meadowland use type was an average SFI value of 0.76 with a high soil fertility category, while forest was an average SFI value of 0.73 with a medium soil fertility category. Soil fertility mapping in Ende Sub-district. The SFI in Ende Sub-district is divided into 2 categories: medium and high fertility. Most of the Ende Sub-district area is dominated by high Soil Fertility Index, 57.3% or 9,340 ha. Indicators that determine the SFI are potential pH, C-organic, and CEC. Increasing soil fertility in various types of land use in the Ende Sub-district can be done by applying agricultural lime, fertilizers, and organic materials (Wang *et al*., 2025).

The results of the SFI determination of the three land use types had a high fertility category, while the forest land use type had a medium fertility category. According to Naimnule and Halek (2023), soil organic matter content in forests is often low, which affects soil fertility. Dry environmental conditions can also cause this. Dry soils often have low nutrient content (Marschner, 2021). The moorland use type had a high soil fertility status. This can be caused by good land management or conservation of the land (Winazira *et al*., 2021). The high SFI value on the land is thought to be due to the condition of the land in the form of a moor with a slope of 0-8%. The organic C content and CEC value on the

land were high. CEC plays a role in exchanging and holding cations, affecting the nutrients that can be bound and provided to plants (Mindari *et al*., 2024). The slope of the land effects soil fertility because, on a high slope, the topsoil layer will be easily lost (Alemu *et al*., 2022).

Determinant factor

This acidic pH value is thought to be caused by dry conditions at the research location. Acidic soil reaction is a problem that is often found in dryland farming systems (Tshuma *et al*., 2021). The resulting potential pH value was lower than the actual pH value because the potential pH measures active and potential acidity, while the actual pH only measures active acidity (Yanti and Kusuma, 2022). Such results of total nitrogen are due to the fact that the land used for sampling were not affected by the use of fertilizers. Most of the N element is in organic form, so it is an insoluble compound and is not available to plants (Timofeeva *et al*., 2022). According to Che *et al*. (2022), nitrogen loss can be caused by several conditions, namely leaching, evaporation, and absorption by plants. The mobile nature of the P element in the soil causes this element to decrease in concentration in the soil solution quickly. The P content in the soil is generally low and differs by soil type. Young soils usually have a higher P content than old soils (He *et al*., 2021). The value of available P can be influenced by the content of organic matter in the soil (Mabagala, 2022). The high and low potassium content in the soil due to potassium nutrients are formed more stable than nitrogen nutrients and are more mobile than phosphorus nutrients (Yahaya *et al*., 2023). The high and low potassium content in the soil due to potassium nutrients in the soil are more stable than nitrogen nutrients and more mobile than phosphorus nutrients (Soumare *et al*., 2023). Potassium availability is dynamic due to the mechanism of release and absorption. Potassium is easily moved by rainwater, and temperature can accelerate the release and weathering of minerals when leaching potassium. Potassium is soluble and absorbed by plants or lost due to leaching (Sardan and Peñuelas, 2021). The content of organic matter in the form of organic C must be maintained so that the content of organic matter in the soil does not decrease with the decomposition process. Plant respiration, used by microorganisms, can cause low organic C content and transport during harvest (Beegum *et al*., 2023) low availability of organic C can cause plant growth to be less than optimal (Mattila and Vihanto, 2024).

The high CEC value in the study area is caused by soil pH that tended to be slightly acidic to neutral (6.15 - 7.11). The high CEC value at the research location is caused by soil pH, which tended to be slightly acidic to neutral (6.15 - 7.11). High CEC is also influenced by clay content and soil organic matter

content. This is due to the soils dominated by clay fraction and humus have high cation exchange and water-holding capacity (Bashir *et al*., 2021). Soils with high CEC values can store and provide nutrients better than soils with low CEC values (Amran *et al*., 2024). The low base saturation value at the research location is caused by the binding of bases by organic matter. This occurs due to the interaction between cations and functional groups in organic matter (Rahayu *et al*., 2024). Base saturation is caused by intensive leaching of base cations. Leaching of cations can inhibit the absorption of other cations. It resulted in soil nutrient imbalance (Jing *et al*., 2024). The high and low C/N ratio values are influenced by the organic matter content and the microorganisms' availability. The low C/N ratio value indicates an imbalance of C in the soil with N. This can cause N to become unavailable because N is released into the atmosphere as NH_3 (Lakshmy *et al*., 2023). A high C/N ratio value can limit nitrogen, which leads to plant nutrient deficiencies (Erlansyah *et al*., 2022). Soil texture at the research site showed a fairly good texture. Organic matter content is tended to increase with increasing clay content. The bond between organic matter and clay protects the material from decomposition (Soekamto *et al*., 2023). The ideal soil for agricultural use is a loamy soil texture (Amsili *et al*., 2021). The low microbial biomass carbon at the research site was influenced by the content of organic matter in the soil. Organic matter is a source of energy for soil microorganisms (Al Viandari *et al*., 2022). High microbial biomass carbon values indicate good soil microbial activity, while low values can indicate problems such as a lack of organic matter (Pambayun *et al*., 2023).

Strategy recommendations

Soil fertility is an essential aspect of the sustainability of agricultural productivity. The analysis results showed that soil fertility at the research location is in the medium and high range. Several parameters indicated such as potential pH value, organic C, and CEC. The ideal pH value for plants is in the range of 5.5 - 7.0, depending on the type of plant cultivated. The recommendation for land with a low pH value is to apply agricultural lime so that the soil pH can be normalized (Ruehlmann *et al*., 2021). Efforts that can be made to overcome low organic C content are the application of organic fertilizers that can increase the content of organic matter and improve the soil's physical, chemical, and biological properties (Kurniawan *et al*., 2023). Increasing the CEC value of land can be done by applying organic matter because the CEC value itself correlates with organic C content. An increase in humus due to a high amount of organic matter can increase the amount of soil colloids so that the CEC value becomes high (Li *et al*., 2022).

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Conflicts of interest

The authors declare no conflict of interest.

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