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Analysis of Soil Fertility Status and Capability Based on Slope and Land Use

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ABSTRACT

Declining soil fertility can be a major factor affecting soil productivity. Declining soil fertility can be caused by two factors, namely natural factors such as topography, and man made factors, such as land management. Assessment of soil fertility status is very important understand good soil fertility conditions that support agricultural and plantation activities. This study aims to determine the soil fertility status and the classification of soil fertility capability. This research was conducted through field survey on four land use units (LUUs) with 16 sampling points determined purposively. The obtained data were then combined to classify the level of status and ability of soil fertility using Fertility Capability Classification (FCC) method. The results showed that the overall LUUs have low fertility status criteria with base saturation (BS) as a heavy limiting factor, and potassium (K) and C-organic content as medium limiting factors. All LUUs, however, revealed almost the same FCC unit. Based on the FCC unit, soil fertility is constrained by some sandy texture soil types (S), with modifiers of acid soil reaction conditions (h), steep slopes (%), and some are constrained by low potassium (k).

1. INTRODUCTION

Soil acts as a growing medium for various types of plants and provides the various nutrients needed (Harista & Sumarno, 2017). Soil fertility levels vary in each location, depending on the nutrient content. The higher the nutrient content in a land, the greater the opportunity for plants on that land to grow optimally. Soil fertility refers to the ability of the soil to provide essential nutrients in an available and balanced form (Saida *et al*., 2023). However, nutrient needs cannot always be met, and that decreasing soil fertility is the main factor affecting land productivity. Batu *et al*. (2019) states that decreasing soil fertility is a major obstacle in crop production. The causal factors include natural factors, such as parent soil material, topography, soil age, climate, soil physical conditions, profile depth, and erosion.

The slope of the land is one of the natural factors that influences the decline in soil fertility. According to Kuswara & Mutiara (2018), land with a steep slope tends to experience high erosion that impacting on changes in soil structure, bulk density, and porosity. If this happens continuously, it will have an impact on decreasing soil fertility and reducing the top layer of soil, which can cause a lack of crop yields.

Differences in land use and slope affect the amount and quality of organic material which plays a very important role in maintaining soil fertility. Land use that is not balanced with soil and plant needs can cause degradation of the physical properties of the soil if too much organic material is added (Kawani *et al*., 2022). Apart from that, the change in land function every year from plantations to residential and tourism areas can affect the condition of soil fertility. Therefore, assessing soil fertility status is crucial to support agricultural and plantation activities. This research aims to evaluate and determine the status of soil fertility and the limiting factors of soil fertility based on variations in land use and slope. From the results of this research, it is expected that it can provide information about the status and capacity of soil fertility based on land use and slope, which will then be able to determine the factors limiting soil fertility.

2. RESEARCH MATERIALS AND METHODS

2.1. Research Location

This research was conducted in Jatiarjo Village, Prigen District, Pasuruan Regency (Figure 1). The boundaries of Jatiarjo Village included the North bordering Watuagung Village, the East bordering Purwosari District, the South bordering the state forest, and the West bordering Dayurejo Village. Based on the RBI (Rupa Bumi Indonesia) map, it is found that the area of Jatiarjo Village is around ±1,170.01 ha.

2.2. Tools and Materials

The tools needed in this research included laboratory equipment such as scales, oven, shaking machine, pH meter, glassware, and spectrophotometer. The tools needed in the field include a soil drill, cutter, measuring tape, and the GPS (Geographic Positioning System). The materials used for soil sample analysis in the laboratory were chemicals or reagents including 25% HCl, NH_4OAc pH 7 1N, 80% alcohol, 50% NaOH, concentrated H_2SO_4, liquid paraffin, concentrated H_2PO_4, $K_2Cr_2O_7$, $FeSO_4$ 1N, DPA, Whatman 42 filter paper, methyl red indicator, and distilled water.

2.3. Research Stages

The research was started from literature study by collecting literature as secondary data to obtain information about the area that will be used as a research location. Secondary data included information such as rainfall, slope map, administrative map, and soil type map. The field survey was performed to determine the location of soil sampling and ensure that the sample points match the information on the map.

2.3.1. Sampling Points

The soil sampling points was determined purposively through map overlay. Sample points were taken from 4 land use units (LUUs), namely mixed gardens, monoculture gardens, drylands (*tegalan*), and shrubs (Table 1). The sample points for each land unit map were determined based on the slope level ranging from gentle slope (8-15%) to very steep (> 45%). Three replication samples were taken for each LUU to represent the area.

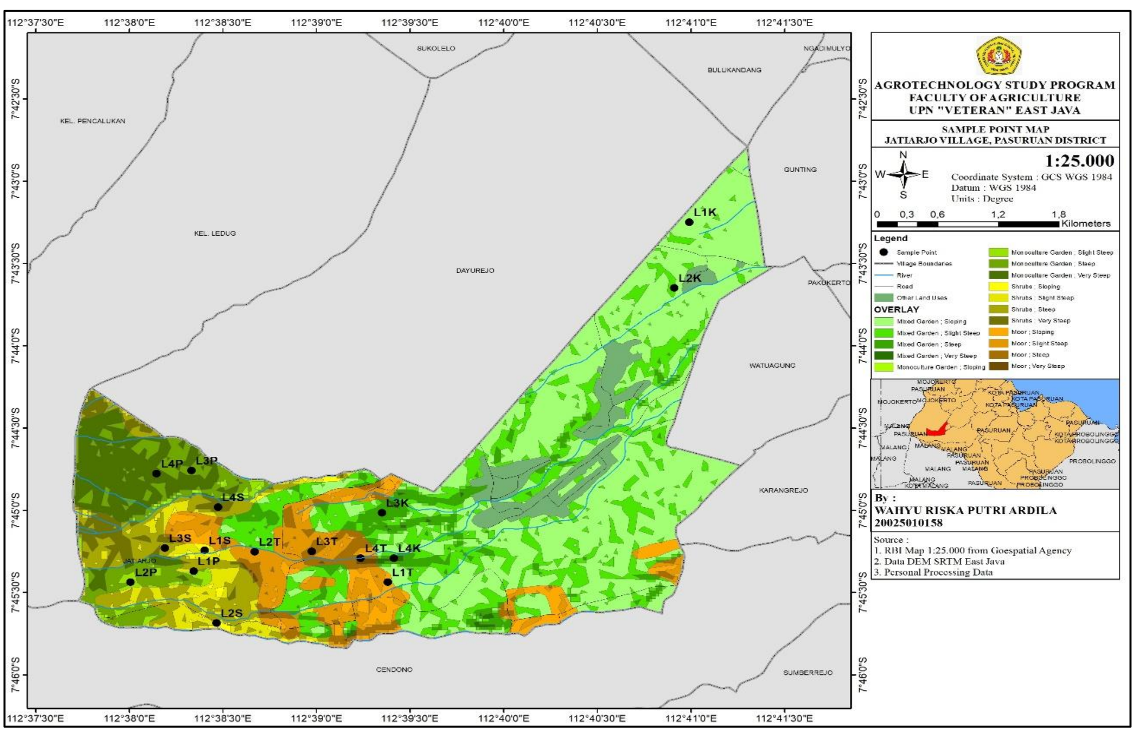

Figure 1. Map of research locations with 16 sampling points marked with black dots (●)

Table 1. Sampling point coordinates represent 4 LUUs and 4 slope levels

No	Sample Code	Description		Coordinate	
		Land Use Type	Slope Level	Longitude	Latitude
1	L1K	Mixed Gardens	8-15%	112.68319	-7.720825
2	L2K	Mixed Gardens	15-25%	112.68185	-7.727485
3	L3K	Mixed Gardens	25-45%	112.65583	-7.750252
4	L4K	Mixed Gardens	>45%	112.65689	-7.7548475
5	L1P	Monoculture Garden	8-15%	112.63907	-7.756156
6	L2P	Monoculture Garden	15-25%	112.63347	-7.757273
7	L3P	Monoculture Garden	25-45%	112.63888	-7.745989
8	L4P	Monoculture Garden	>45%	112.63579	-7.746304
9	L1S	Shrubs	8-15%	112.64005	-7.754069
10	L2S	Shrubs	15-25%	112.64111	-7.76143
11	L3S	Shrubs	25-45%	112.63653	-7.75383
12	L4S	Shrubs	>45%	112.64125	-7.749698
13	L1T	Drylands	8-15%	112.65636	-7.757279
14	L2T	Drylands	15-25%	112.64450	-7.754192
15	L3T	Drylands	25-45%	112.64961	-7.754172
16	L4T	Drylands	>45%	112.65394	-7.754858

Table 2. Criteria used to assess soil fertility status

No	CEC	Base Saturation	P_2O_5	K_2O	C-Organic	Fertility Status
1	High	High	High	High	High	High
2	High	High	High	High	Low	Medium
3	High	High	Medium	Medium	High	High
4	High	High	Medium	Medium	Low	Medium
5	High	High	High	Medium	Low	Medium
6	High	High	Low	Low	High	Medium
7	High	High	Low	Low	Medium	Low
8	High	Medium	High	High	Low	High
9	High	Medium	High	Low	High	Medium
10	High	Medium	Medium	Medium	Medium	Medium
11	High	Medium	High	Low	Low	Low
12	High	Low	High	High	Low	Medium
13	High	Low	High	Low	Low	Low
14	High	Low	Medium	Low	Medium	Low
15	Medium	High	High	High	Low	Medium
16	Medium	High	Medium	High	Low	Medium
17	Medium	High	Low	Medium	High	Low
18	Medium	Medium	High	High	Low	Medium
19	Medium	Medium	Medium	High	Low	Medium
20	Medium	Medium	High	Low	Low	Low
21	Medium	Low	High	High	High	Medium
22	Medium	Low	Low	Low	Low	Low
23	Low	High	High	High	Low	Medium
24	Low	High	High	Low	Low	Low
25	Low	High	Medium	Low	Low	Medium
26	Low	High	Low	Medium	Low	Low
27	Low	Medium	High	High	Low	Medium
28	Low	Medium	Low	Medium	Low	Low
29	Low	Low	Medium	Low	Low	Low
30	Very Low	High/Medium/Low	Low	Low	Low	Very Low

Source: Dierolf *et al.* (2001)

2.3.2. Soil Sampling

Soil sampling was carried out at two depths, namely 0-20 cm (top soil) and 20-40 cm. To represent the sampling area, 3 repetitions were carried out. The soil samples were then composited based on the depth and repetition of the soil sample points. There were 16 soil samples that were composited and analyzed in the laboratory.

2.4. Analysis Method

Methods for analyzing the status and ability of soil fertility included analysis of the physical and chemical properties of the soil and the results of field observations. Analysis of soil chemical properties included CEC and BS (NH_4OAc Extraction pH 7 1N), total P_2O_5 and total K_2O (HCl 25%), C-organic content (Walkey and Black), pH (H_2O). While, analysis of soil physical properties was soil texture using the pipette method. Land slope and elevation data were obtained from field observations. Rainfall data was obtained from NASA POWER for 2018 – 2022. Soil analysis was carried out at the Land Resources Laboratory, UPN "Veteran" East Java. The parameter criteria for determining soil fertility were based on the Djaenudin *et al*. (2011).

2.5. Determination of Soil Fertility Status

Soil fertility status was determined according the technical guidelines for evaluating soil fertility (Djaenudin *et al*., 2011). Based on laboratory tests for soil fertility parameters, the soil fertility status was obtained by matching the data with Table 2.

2.6. Soil Fertility Capability Classification

The soil properties of each category assessed in the research were presented in Table 3. Determining the classification of soil fertility capacity was carried out using the Fertility Capability Classification (FCC) method (Sampedro *et al*., 2003). The FCC assessment includes three main categories, namely type (topsoil texture), subtype (subsoil texture), and modifier (limiting factor). The type category describes the condition of the tillage layer at a depth of around 0-20 cm, while the subtype refers to the condition of the soil layer beneath it. Modifiers function as indicators of limiting factors. The combination of these three categories produces a soil fertility evaluation unit (FCC).

Table 3. Classification of soil fertility capabilities according to Sanchez *et al*. (2003)

TYPE **Top Soil Texture**	**SUB TYPE** **Sub Soil Texture**	**MODIFIERS** **Soil Properties as Limiting Factor**	
Class *S* Sandy: loamy sands and sands	**Class *S*** Sandy: loamy sands and sands	**Class *g* :** gley **Class *g** :** pergleyic	**Class *v* :** vertic **Class *k* :** low K
Class *L* Loamy: < 35% clay, but not loamy sand or sand	**Class *L*** Loamy: < 35% clay, but not loamy sand or sand	**Class *d* :** dry **Class *e* :** low CEC	**Class *b* :** base (high pH) **Class *s* :** salinity
Class *C* Clayey: > 35 % clay	**Class *C*** Clayey: > 35 % clay	**Class *a* :** Al toxicity **Class *h* :** acid	**Class *n* :** high Na **Class *r* :** gravel 15 - 35%
Class *O* Organic soil: >30% C-organic to a depth of 50 cm or more	**Class *R*** Rock or other hard root-restricting layer within 50 cm	**Class *i* :** high P fixation by iron **Class *x* :** high allophane	**Class r^+ :** gravel >35% **Class (%):** slope
UNITS **LC, (Slope)**			

3. RESULTS AND DISCUSSION

3.1. Soil Texture

Based on the results of soil texture analysis, it was found that Jatiarjo Village was dominated by loam texture. In the L1K land use unit (slope 8-15%), the clay fraction is dominant. This can occur due to the leaching of clay from the upper slopes, so that the clay settles on the lower slopes. Meanwhile, at LUU L2K (15-25% slope), the clay fraction decreased and the sand fraction increased. LUUs L3K, L4K, L1T to L4T have a loam soil texture. In some land uses, the clay fraction has decreased by 17.5% to 8% that can be caused by topographic conditions ranging from steep to very

Table 4. Soil texture of the 16 different land use units

Land Use Unit (Sample Code)	Sand	Silt	Clay	Soil Texture Category
L1K (Mixed Garden, Slope 8-15%)	21	26.5	52.5	Clay
L2K (Mixed Garden, Slope 15-25%)	44	28	28	Clay Loam
L3K (Mixed Garden, Slope 25-45%)	52	38	10	Loam
L4K (Mixed Garden, Slope >45%)	76.5	15.5	8	Sandy Loam
L1P (Monoculture Garden, Slope 8-15%)	60	28.5	11.5	Sandy Loam
L2P (Monoculture Garden, Slope 15-25%)	65.5	25.5	9	Sandy Loam
L3P (Monoculture Garden, Slope 25-45%)	56.25	32.50	11.25	Sandy Loam
L4P (Monoculture Garden, Slope >45%)	78	13	9	Sandy Loam
L1S (Shrubs, Slope 8-15%)	63.5	31	5.5	Sandy Loam
L2S (Shrubs, Slope 15-25%)	74.75	21.29	4.5	Sandy Loam
L3S (Shrubs, Slope 25-45%)	78.5	17	4.5	Sandy Loam
L4S (Shrubs, Slope >45%)	74.5	21	4.5	Sandy Loam
L1T (Drylands, Slope 8-15%)	47	35.5	17.5	Loam
L2T (Drylands, Slope 15-25%)	68.5	20.5	11	Sandy Loam
L3T (Drylands, Slope 25-45%)	53.5	33.5	13	Loam
L4T (Drylands, Slope >45%)	62	21.5	16.5	Sandy Loam

steep, resulting in clay leaching and followed by high rainfall (Haryati, 2014). Apart from that, planting without rotation also affects changes in soil fractions. At LUU L4K, L1S to L4S the texture is dominated by sandy loam. This is caused by human activities that change land use from shrubs to cultivated land and affect the composition and texture of the soil. Apart from that, it is also caused by vegetation that is less than optimal in stabilizing the soil.

3.2. Soil Chemical Properties

Table 5 shows soil chemical properties (pH, C-organic, CEC, potassium, phosphor, base saturation) for the 16 LUUs.

3.2.1. Soil pH

Analysis of soil pH in Jatiarjo Village shows the dominance of acid pH. L1K land has the highest pH (6.14, slightly acidic), while L1T has the lowest pH (4.97 acidic). Differences in pH are influenced by land management, use of inorganic fertilizers, land slope, and environmental factors such as acid rain. Land with a pH of 5.5-6.5 (L1K, L2K, L3K, L3T) is considered optimal for plant growth. This is based on research conducted (Camila *et al*., 2023) that the optimum soil pH value for plant growth is 5.5 to 6.5. However, steep slopes tend to lower soil pH, thereby affecting

Table 5. Chemical properties analysis results

Land Use Unit	pH	C-Organic	CEC	K_2O	P_2O_5	BS
L1K (Mixed Garden, Slope 8-15%)	6.14 (AM)	1.14 (L)	22.09 (M)	32 (M)	43.89 (H)	23.40 (L)
L2K (Mixed Garden, Slope 15-25%)	6.01 (AM)	1.44 (L)	24.23 (M)	35 (M)	42.82 (H)	21.33 (L)
L3K (Mixed Garden, Slope 25-45%)	5.55 (M)	2.28 (M)	29.06 (H)	38.5 (M)	45.74 (H)	25.89 (L)
L4K (Mixed Garden, Slope >45%)	5.45 (M)	2.23 (M)	22.38 (M)	38 (M)	35.71 (M)	20.18 (L)
L1P (Monoculture Garden, Slope 8-15%)	5.26 (M)	2.49 (M)	25.16 (H)	26 (M)	40.74 (M)	21.56 (L)
L2P (Monoculture Garden, Slope 15-25%)	5.06 (M)	3.10 (H)	24.75 (M)	23.5 (M)	39.70 (M)	21.63 (L)
L3P (Monoculture Garden, Slope 25-45%)	5.23 (M)	2.44 (M)	24.96 (M)	37.5 (M)	40.48 (M)	20.37 (L)
L4P (Monoculture Garden, Slope >45%)	5.29 (M)	1.97 (L)	24.47 (M)	29(M)	38.66 (M)	20.04 (L)
L1S (Shrubs, Slope 8-15%)	5.07 (M)	1.94 (L)	22.76 (M)	23.5 (M)	27.78 (M)	22.69 (L)
L2S (Shrubs, Slope 15-25%)	5.18 (M)	1.50 (L)	22.10 (M)	21.5(M)	29.21 (M)	21.51 (L)
L3S (Shrubs, Slope 25-45%)	5.17 (M)	1.70 (L)	22.57 (M)	20.5(L)	23.53 (M)	20.18 (L)
L4S (Shrubs, Slope >45%)	5.40 (M)	1.89 (L)	20.92 (M)	20.5(L)	22.11 (M)	19.97 (VL)
L1T (Drylands, Slope 8-15%)	4.97 (M)	1.61 (L)	21.81 (M)	19 (L)	32.73 (M)	23.18 (L)
L2T (Drylands, Slope 15-25%)	5.48 (M)	1.09 (L)	22.79 (M)	20.5(L)	29.46 (M)	21.81 (L)
L3T (Drylands, Slope 25-45%)	5.70 (AM)	1.19 (L)	22.99 (M)	21.5 (M)	27.31 (M)	22.68 (L)
L4T (Drylands, Slope >45%)	5.26 (M)	1.12 (L)	21.30 (M)	19.5(L)	26.92 (M)	21.10 (L)

Note: CEC = Cation Exchange Capacity; BS = Base Saturation; VL = Very Low; L = Low; M = Medium; H = High soil fertility and nutrient availability. Land that has a pH of less than 5.5, as in LUU LIT, can cause high Al solubility in the soil, making it toxic to plants. According to Prihantoro *et al*. (2023) stated that Al stress causes disruption of root growth so that nutrient and water absorption is hampered which has an impact on reducing plant growth. Liming is an important method to improve the quality of acid soil. Application of lime, especially dolomite which contains calcium (Ca) and magnesium (Mg), can increase soil pH, cation exchange capacity (CEC), and the availability of important nutrients such as phosphorus, nitrogen and potassium (Sudianto *et al*., 2018). Apart from improving the physical properties of soil, dolomite also plays a role in reducing levels of toxic heavy metals. Overall, liming has proven effective in increasing soil fertility and plant productivity (Holland *et al*., 2018).

3.2.2. C-Organic

Based on the results of C-organic analysis in Jatiarjo Village, it shows variations from low to high. In land use units L1K, L2K, L1T, L2T, L3T, L4T, L1P, L1S, L2S, L3S and L4S which are classified as low criteria, LUU L3K, L4K and L3P which have values ranging from 2.10 – 2.90% are classified as medium criteria and LUU L2P has a c-organic value of 3.10%, which is classified as high criteria. Differences in C-organic values at each SST are influenced by land management factors, slope slope, vegetation and human activities. Land with dense vegetation, abundant litter and the use of organic fertilizer in LUU L3K, L4K and L2P has medium to high organic C content (>2%), while land with minimal management (LUU L1T, L2T, L3T, L4T, L1S, L2S, L3S and L4S) is classified as low. According to (Husni *et al*., 2016) high organic C on low slopes is caused by the accumulation of organic material due to erosion from the top of the slope. However, lack of tillage activities, addition of fertilizer and litter can cause low C-organic content, which has an impact on reducing soil fertility. Low organic C content can be increased through adding organic matter to the soil. The organic materials used can be locally based using composted harvest residues and manure (Li *et al*., 2020), as well as the application of foliar forage which is useful for increasing soil fertility such as legume plants.

3.2.3. Cation Exchange Capacity

Analysis of Cation Exchange Capacity (CEC) in Jatiarjo Village shows moderate to high values, ranging from 19.50%–32.72%. High CEC is found on land with abundant organic material, such as mixed gardens on moderate slopes (25–40%), which supports the formation of humus as the main contributor to CEC (Fitrianai et al., 2020). In contrast, land with low pH, minimal organic matter, and a dominant sandy texture showed lower CEC, such as SST upland (21.81%–22.99%) and shrubs (20.92%–22.76%).

The main factors that influence the CEC value include organic matter, soil texture and clay minerals. Land with dense vegetation, abundant litter, and processing activities (for example, monoculture plantations with a dominance of pine trees) has a higher CEC due to better cation retention. On the other hand, on steep slopes, leaching and erosion reduce the CEC value, mainly due to the transport of clay and cations from the top layer (Syachroni, 2020; Tambunan *et al*., 2018).

From the research results, the majority of CEC values for each land use are in the low category. Low CEC values can be increased by adding organic materials such as compost, liming acidic soils, and applying biochar. These materials can increase CEC by improving soil pH, structure and colloid content. Organic matter can improve soil colloid activity, while biochar increases soil porosity and surface area.

3.2.4. Base Saturation (BS)

The results of the base saturation (BS) analysis in Jatiarjo Village showed low to very low values, with a range of 23.40–18.25%. Low base saturation (23.40–20.18%) was found in almost all land use units (LUU), while very low BS (18.25–19.34%) was found in the LUU of L3S and L4S shrubs. The low BS value is mainly caused by acidic soil pH, low organic matter content, and leaching of alkaline cations due to high rainfall and erosion on steep slopes. This is caused by the leaching of alkaline cations from the surface soil layer (Rahayu *et al*., 2014).

Topographic factors, such as slope slope, play an important role in determining the BS value. Soil on steep slopes experiences more intensive cation leaching, while soil on flatter slopes tends to have more stable BS. According to (Martunis *et al*., 2017), land with <50% BS is classified as infertile, so increasing BS through managing organic matter and controlling erosion is an important step to increase soil fertility.

3.2.5. K-Total

The results of the analysis of K-total content in Jatiarjo Village showed variations from low to high (19–38.5 mg/100g). The highest content was found in the L3K mixed garden LUU (50 mg/100g) due to good land management and the addition of fertilizer. In contrast, LUU L1T shows the lowest value (19 mg/100g) due to the lack of fertilization and the dominance of sandy texture which reduces the soil's ability to hold water and nutrients.

In LUU monoculture (L1P-L4P), the K content is moderate (average 29 mg/100g), but decreases in areas with a dominance of pine plants, steep slopes and suboptimal soil texture. The SST of drylands (L1T-L4T) and shrubland (L1S-L4S) showed low to moderate K values, influenced by low organic matter, agricultural intensification, and leaching of nutrients. According to (Listianto *et al*., 2023), the return of potassium from plant residues is very important to maintain soil K balance, while the mobile nature of K makes leaching easier. Land with low total K content can be increased by applying K fertilizer such as KCl, adding organic material, and managing the soil pH to keep it neutral. KCl fertilizer is effective in increasing K availability, while organic materials help release K from the non-available fraction. PH regulation is also important to prevent potassium fixation.

3.2.6. P-Total

The results of P_2O_5 analysis in Jatiarjo Village showed variations in phosphorus content from low to high (22.11–45.74 mg/100g). The highest values were found in mixed garden SST (L1K, L2K, and L3K) due to manure fertilization and decomposition of organic material, while the lowest values were in shrub SST (L4S) due to lack of land management and low organic matter. P elements in soil come from organic materials such as manure and plant residues (Aravindh *et al*., 2020). Moderate P content was found in SST dryland (L1T–L4T) and forest (L1P–L4P). The decline in P values at some SSTs is caused by lack of management, leaching of phosphorus on steep land, erosion, and acidic soil pH, which limits phosphorus availability to plants.

Low total P on some land can be overcome by applying phosphate fertilizer (SP-36 or TSP), using organic materials, and adjusting soil pH. Phosphate fertilizers can increase available P directly, while organic materials help release bound P. SP-36 fertilizer is effective in increasing P availability in acid soil. In addition, organic materials can increase the activity of phosphate solubilizing microbes, and liming can reduce P fixation by Al and Fe.

3.3. Soil Fertility Status

The assessment of soil fertility status in Jatiarjo Village is classified as medium and low, but in general the soil fertility condition in Jatiarjo Village is categorized as low fertility status based on the dominance of the classes presented in Table 6. Assessment of soil fertility status in Jatiarjo Village shows that the majority of land has low fertility. The main limiting factors include low organic C content, base saturation (BS), and total K levels. Low organic C is caused by lack of land management, erosion on steep slopes, and leaching of nutrients due to high rainfall. Organic C plays an important role in increasing fertility through the activity of soil organisms and the formation of soil aggregates. Organic matter plays an important role in forming soil granulation and supporting the formation of stable soil aggregates (Sitorus *et al*., 2018). Meanwhile, the BS value is low because the soil is acidic and the high sand fraction reduces the soil's capacity to store nutrients, thereby increasing the risk of cation leaching. The low K-total content is influenced by low cation exchange capacity (CEC), soil acidity levels, and high potassium mobility so that it is easily leached. According to (Harahap, 2018) the level of CEC can influence the speed of the soil solution in releasing potassium, which can increase or reduce the potential for potassium leaching in the soil. The efficiency of potassium fertilizer is also low due to acidic pH conditions and less than optimal irrigation systems.

Based on the soil fertility status obtained, it is classified as low criteria due to low organic C content, base saturation and total potassium. To increase soil fertility, it is necessary to add organic materials such as compost or manure which can improve the physical, chemical and biological properties of the soil. In addition, liming with dolomite can increase pH and BS thereby improving nutrient availability. Providing K fertilizer using such as KCl and biochar is also recommended to suppress potassium leaching and increase the efficiency of K element uptake by plants. Land management according to topography such as terracing and the use of cover vegetation is also important to prevent erosion and nutrient loss (Sidik *et al*., 2025).

Table 6. Classification of soil fertility status

Land Use Unit	CEC	BS	P_2O_5	C-Organic	Fertility Status
L1K (Mixed Garden, Slope 8-15%)	22.09 (M)	23.40 (L)	43.89 (H)	1.14 (L)	Low
L2K (Mixed Garden, Slope 15-25%)	24.23 (M)	21.33 (L)	42.82 (H)	1.44 (L)	Low
L3K (Mixed Garden, Slope 25-45%)	29.06 (H)	25.89 (L)	45.74 (H)	2.28 (M)	Low
L4K (Mixed Garden, Slope >45%)	22.38 (M)	20.18 (L)	35.71 (M)	2.23 (M)	Low
L1P (Monoculture Garden, Slope 8-15%)	25.16 (H)	21.56 (L)	40.74 (M)	1.61 (L)	Low
L2P (Monoculture Garden, Slope 15-25%)	24.75 (M)	21.63 (L)	39.70 (M)	1.09 (L)	Low
L3P (Monoculture Garden, Slope 25-45%)	24.96 (M)	20.37 (L)	40.48 (M)	1.19 (L)	Low
L4P (Monoculture Garden, Slope >45%)	24.47 (M)	20.04 (L)	38.66 (M)	1.12 (L)	Low
L1S (Shrubs, Slope 8-15%)	22.76 (M)	22.69 (L)	27.78 (M)	2.49 (M)	Low
L2S (Shrubs, Slope 15-25%)	22.10 (M)	21.51 (L)	29.21 (M)	3.10 (H)	Low
L3S (Shrubs, Slope 25-45%)	22.57 (M)	20.18 (L)	23.53 (M)	2.44 (M)	Low
L4S (Shrubs, Slope >45%)	20.92 (M)	19.97 (VL)	22.11 (M)	1.97 (L)	Low
L1T (Drylands, Slope 8-15%)	21.81 (M)	23.18 (L)	32.73 (M)	1.94 (L)	Low
L2T (Drylands, Slope 15-25%)	22.79 (M)	21.81 (L)	29.46 (M)	1.50 (L)	Low
L3T (Drylands, Slope 25-45%)	22.99 (M)	22.68 (L)	27.31 (M)	1.70 (L)	Low
L4T (Drylands, Slope >45%)	21.30 (M)	21.10 (L)	26.92 (M)	1.89 (L)	Low

Note: VL = very low; L = low; M = medium; H = height

Based on the soil fertility status obtained, it is classified as low criteria due to low organic C content, base saturation and total potassium. To increase soil fertility, it is necessary to add organic materials such as compost or manure which can improve the physical, chemical and biological properties of the soil. In addition, liming with dolomite can increase pH and BS thereby improving nutrient availability. Providing K fertilizer such as KCl and biochar is also recommended to suppress potassium leaching and increase the efficiency of K element uptake by plants. Land management according to topography such as terracing and the use of cover vegetation is also important to prevent erosion and nutrient loss (Sidik *et al*., 2025).

3.4. Soil Fertility Capability Classification

3.4.1. Interpretation of Types and Subtypes

Table 7 summarizes soil fertility capability based on the measurement during research. Based on the research results, the topsoil and subsoil soil textures in Jatiarjo Village show that the dominant soil texture is sandy loam. The soil in Jatiarjo Village has variations in texture in the upper (type) and lower (subtype) layers, with a dominant sandy loam (*L*) and loamy sand (*S*) textures, as well as several locations with a clay texture (*C*). Clayey soil (*C*) as in L1K has high water holding capacity but is difficult to process. In contrast, sandy loam (*L*) and loamy sand (*S*), which dominate several LUUs such as L4K, L2T, and L3S, have good drainage but are less able to hold water, so they require attention in water management (Asnawati *et al*., 2022). Loamy (*L*) textured soil is found at LUU such as L3K and LIT, with a balance of sand, silt and clay, providing a moderate infiltration rate and fairly good water holding capacity. Textural differences between the top and bottom layers in some LUUs, such as L1P and L4S, affect the ease of tillage as well as the water and nutrient holding capacity.

3.2.2. Interpretation of Modifiers

The interpretation results show that the limiting factors for soil fertility in all research locations are the acidity level (*h*) and potassium content (*k*). Soil acidity in Jatiarjo Village, with a pH classified as acidic to slightly acidic, is the main indicator of soil fertility. Soil with a pH of 5.5–6.5 is generally optimal for nutrient availability, while a pH that is too acidic limits nutrient availability (Harahap *et al*., 2021). The nutrient element potassium (K) in Jatiarjo Village shows medium to low status. The highest K-ex value was found in mixed gardens (L1K, 0.60 me/100g) and the lowest in the drylands (L1T, 0.19 me/100g). The low K-ex is influenced by high plant absorption and potassium solubility which causes loss of this element through water.

Table 7. Interpretation of Fertility Capability Classification (FCC)

LUU*	Type *)				Subtype*)				Slope	Modifier*)							FCC Class
	S	*L*	*C*	*O*	*S*	*L*	*C*	*R*		*d*	*e*	*g*	*h*	*k*	*m*	*r*	
L1K	-	-	*C*	-	-	-	*C*	-	8-15%	-	-	-	*h*	-	-	-	*Ch* (8-15%)
L2K	-	*L*	-	-	-	*L*	-	-	15-25%	-	-	-	*h*	-	-	-	*Lh* (15-25%)
L3K	-	*L*	-	-	-	*L*	-	-	25-45%	-	-	-	*h*	-	-	-	*Lh* (25-45%)
L4K	-	*L*	-	-	-	*L*	-	-	>45%	-	-	-	*h*	-	-	-	*Lh* (>45%)
L1P	-	*L*	-	-	-	*L*	-	-	8-15%	-	-	-	*h*	*k*	-	-	*Lhk* (8-15%)
L2P	-	*L*	-	-	-	*L*	-	-	15-25%	-	-	-	*h*	*k*	-	-	*Lhk* (15-25%)
L3P	-	*L*	-	-	-	*L*	-	-	25-45%	-	-	-	*h*	-	-	-	*Lh* (25-45%)
L4P	-	*L*	-	-	-	*L*	-	-	>45%	-	-	-	*h*	-	-	-	*Lh* (>45%)
L1S	-	*L*	-	-	-	*L*	-	-	8-15%	-	-	-	*h*	-	-	-	*Lh* (8-15%)
L2S	*S*	-	-	-	*S*	-	-	-	15-25%	-	-	-	*h*	-	-	-	*Sh* (15-25%)
L3S	*S*	-	-	-	*S*	-	-	-	25-45%	-	-	-	*h*	-	-	-	*Sh* (25-45%)
L4S	-	*L*	-	-	*S*	-	-	-	>45%	-	-	-	*h*	-	-	-	*LSh* (>45%)
L1T	-	*L*	-	-	-	*L*	-	-	8-15%	-	-	-	*h*	*k*	-	-	*Lhk* (8-15%)
L2T	-	*L*	-	-	-	*L*	-	-	15-25%	-	-	-	*h*	-	-	-	*Lh* (15-25%)
L3T	-	*L*	-	-	-	*L*	-	-	25-45%	-	-	-	*h*	*k*	-	-	*Lhk* (25-45%)
L4T	-	*L*	-	-	-	*L*	-	-	>45%	-	-	-	*h*	-	-	-	*Lh* (>45%)

*) Note: LUU = Land Use Unit (Notation description as in the previous Tables); *C* (clay texture;>35% clay); *L* (loamy texture; <35% clay); *S* (sandy texture; loamy sand and sand); *h* = acidic soil reaction, pH between 5.5 and 7.2; *k* = exchangeable K <0.20 cmol/kg soil or exchangeable K <2%

3.2.3. Unit Interpretation

The results of soil fertility analysis in Jatiarjo Village show similar problems in various types of land use. Most soils have a loam (*L*), sandy loam (*L*), or clayey loam (*L*) textures, with some locations showing a clay (C) or clayey sand (S) texture. The main limiting factors are acidic pH (modifier "h"), K element deficit (modifier "k"), and slope slope.

Mixed orchard land use shows the least constraints, with the dominant FCC unit being "Lh" (loam, acid). Some locations have a clay texture (Ch), which, although heavily processed, has a high water storage and cation exchange capacity. In contrast, shrubs and drylands show more diverse FCC units with acid conditions and textural variations, such as loamy sand (Sh) at certain slopes.

Monoculture gardens and drylands have more significant fertility limitations, such as accumulation of clay material, acid conditions, and low K-ex values (<0.20 me/100g), with FCC units such as “Lhk” or “Lh”. Improvement efforts are needed, especially for clay or acid textured soils on steep slopes.

4. CONCLUSION

The soil fertility status in Jatiarjo Village is classified as low class. Overall, land use units have criteria for low soil fertility status. Soil fertility capability classes result in fairly uniform FCC units, namely categories L (loam, sandy loam) and L (loam, clayey loam, sandy loam). Only on certain slopes which produce soil texture categories of C (clayey) and C (clayey), S (loamy sand) and S (loamy sand) and L (sandy loam) and S (loamy sand). On LUUs of L1T, L3T, L1P, and L2P are constrained by soil reaction conditions or pH which are classified as acid (marked with the modifier *h*), K nutrient deficit (K-ex <0.2 me/100g) which is marked with the modifier *k*, and slope conditions which are marked with modifier (%).

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AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
WRPA	✓	✓		✓	✓	✓		✓	✓	✓	✓			
P	✓	✓		✓						✓		✓		
FW	✓	✓								✓		✓		

C: Conceptualization
M: Methodology
So: Software
Va: Validation
Fo: Formal Analysis
I: Investigation
D: Data Curation
R: Resources
O: Writing - Original Draft
E: Writing - Review & Editing
Vi: Visualization
Su: Supervision
Fu: Funding Acquisition
P: Project Administration

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