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Soil Quality Study Of Pomelo (*Citrus Maxima* (Burm) Merr) Plantation in Padanglampe Village, Pangkajene Regency

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Abstract

Pamelo orange plants represent a significant horticultural commodity with substantial economic value and are extensively cultivated in Pangkajene Regency. The quality of Pamelo fruit in Padanglampe Village varies, with some fruits being sweet and others slightly sour, suggesting that differing soil conditions may influence fruit quality. This study aims to investigate the soil quality of Pamelo plants in Padanglampe Village, Ma'rang District, Pangkajene Regency. A quantitative descriptive method was employed, involving the collection of secondary data, field surveys, primary data collection through soil sampling, and laboratory analysis of minimum data sets (pH, total nitrogen, available phosphorus, organic carbon, and exchangeable potassium). Soil quality indices were analyzed using statistical tests, including principal component analysis (PCA). The findings indicated that soil pH was slightly acidic, organic carbon content was low, and nitrogen, phosphorus, and potassium levels were categorized as medium. Correlation tests revealed a significant negative correlation at the 1% alpha level between bulk density and porosity, while organic carbon and soil pH were positively correlated at the 5% alpha level. The scree plot showed three eigenvalues corresponding to the main components in PCA1, PCA2, and PCA3 analyses, which can be further examined to determine the Soil Quality Index (SQI) value. The SQI-PC1 value of 0.55 was categorized as moderate, while the SQI-PC2 and SQI-PC3 values were classified as very low. However, the comprehensive soil quality index (CSQI) value was 0.97, indicating outstanding soil quality. This finding suggests that Padanglampe Village has highly favorable soil conditions for pomelo cultivation, though improved management practices are needed to sustain optimal production. The primary strength of this study lies in integrating chemical and physical soil indicators into a single comprehensive index, providing a more holistic assessment of land suitability for pomelo cultivation. Based on these findings, it is recommended that farmers prioritize areas with high SQI values as primary zones for pomelo development and implement sustainable soil management practices, particularly by increasing soil organic matter content and applying appropriate fertilizer management, to maintain soil quality and ensure the long-term sustainability of pomelo production.

Keywords: Horticulture, Land Suitability, PCA, SQI

1. Introduction

Soil quality refers to the soil's ability to function effectively in maintaining plant productivity, preserving and safeguarding water availability, and supporting human activities. Since soil quality cannot be measured directly, it is necessary to assess physical, chemical, and biological indicators that collectively provide a comprehensive evaluation of an area's soil quality (Martunis et al., 2016). Specifically, soil quality is the capacity of soil to function naturally or within the constraints of a managed ecosystem to support animal and plant productivity, maintain or improve air and water quality, and promote human habitation and health (Suleman et al., 2016).

In horticultural agriculture, the balance among soil physical properties (such as texture, bulk density, and porosity), soil chemical properties (including pH and nutrient availability), and soil biological activity is crucial for successful plant growth and productivity. An imbalance in any of these components can impair overall soil function, resulting in reduced yields and lower-quality agricultural

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products.

Padanglampe Village is located in Ma'rang District, Pangkajene and Kepulauan Regency, South Sulawesi Province. Given its agricultural potential, this village is recognized as the largest centre for pomelo farming in South Sulawesi (Fadhil & Ashoer, 2019). With an area of approximately 10.68 km², Padanglampe Village is the main centre for pomelo cultivation in Pangkep Regency. The area of land planted with Pamelo Orange in Padanglampe Village is 265 hectares with a total production of approximately 2,385 tons. Based on these data, Pamelo Orange productivity in this area can be calculated at 9 tons per hectare, indicating the potential of Padanglampe Village's land as a main center for Pamelo Orange development (BPS, 2024). However, not all land in the Pangkajene and Kepulauan Regency has uniform soil conditions and is suitable for Pamelo Orange cultivation. Variations in productivity and fruit quality found in the field indicate differences in soil quality between planting locations. This condition indicates the need for a comprehensive soil quality study to ensure that the soil's physical and chemical characteristics in the production centre area truly support optimal growth of Pamelo Orange. (Khairan et al., 2024).

Soil quality cannot be measured directly, so an assessment based on physical, chemical, and biological soil indicators is necessary (Martunis et al., 2016). The physical and chemical properties of the soil are important factors that determine the level of soil quality for pomelo plants. This relationship makes the soil sensitive to various management activities and climate change, is acceptable to many communities, is easy to apply across various land conditions, and is a soil indicator that can be used to assess soil quality (Jannah et al., 2021). These indicators are then used in the assessment of the Soil Quality Index *(SQI), a quantitative method that evaluates soil fertility conditions based on several key*arameters (Shah et al., 2022). Research (Fajeriana et al., 2025) examined *the Soil Quality Index* in dragon fruit plantations in Aimas, Southwest Papua, and found that the SQI is effective at identifying soil quality limitations, particularly nitrogen and phosphorus content. However, this research was conducted on dragon fruit commodities that have different physiological characteristics from woody annual horticultural crops, such as pomelo, and has not linked the SQI value with land suitability and plant development zoning. Therefore, this study fills this gap by applying the SQI approach to Pamelo orange cultivation in Padanglampe Village, thereby yielding results that are more commodity-specific and applicable as a basis for sustainable land management. Soil quality assessment using the SQI is essential for determining the soil's quality relative to pomelo plants' specific needs. Furthermore, the SQI also serves as a basis forffective and sustainable land planning and management (Rachman et al., 2016).

This study aims to: 1) analyze the physical and chemical characteristics of soil used for planting orange pomelo in Padanglampe Village, Ma'rang District, Pangkajene and Islands Regency; 2) assess the Soil Quality Index (SQI) using Principal Component Analysis (PCA) as the basis for evaluating soil quality; 3) identify the soil quality level for the growth and cultivation of orange pomelo; and 4) provide sustainable land management recommendations to support improved productivity and the sustainability of orange pomelo cultivation.

2. Material and Methods

This research was conducted in Padanglampe Village, Ma'rang District, Pangkajene and Kepulauan Regency, South Sulawesi Province, with geographical coordinates of 4°44.053' S -4°43.437' S -4°44.045' S and 119°36.165' E - 119°36.957' E, and an elevation of 8 meters above sea level. Soil sample analysis was conducted in the Soil Fertility Chemistry Laboratory and Soil Physics Laboratory of the Department of Soil Science, Faculty of Agriculture, Hasanuddin University. The research took place from February to September 2025.

The land unit map was created in ArcGIS 10.8 by combining several data layers (Overlays), including soil type data (REPPROT, BIG) and land cover. The creation of this land unit map aims to facilitate the determination of points at the research location (Figure 1). Research points were determined using the *purposive sampling method*. There are 5 soil sampling points, with the sampling point code TP and the soil layer symbol, the letter L followed by a number indicating the sampling number, for example TP1L1, which indicates the i-th soil sampling point and the i-th layer.

Soil profiles were created at each research location. Soil profile excavations were conducted to identify horizons and other characteristics. Soil profiles were created by excavating the soil to a depth of 0–100 cm. Disturbed soil samples were collected from each soil profile layer, while intact soil samples were collected using a ring sampler.

The minimum data set (MDS) used to assess soil quality includes texture, porosity, bulk density, pH, available P, available K, total N, and organic C. Data on physical, chemical, and biological properties of the soil were processed using the Soil Research Institute procedures (BPT, 2005).

2.1. Soil Quality Index (SQI) Calculation

The minimum data set obtained from laboratory soil analysis was then used for soil quality assessment. The data were processed using XL-Stat (2025) and Smart-Stat (2016). The analysis results were then calculated using the Soil Quality Index (SQI) equation according to (Cude, 2001)and (Aprisal et al., 2019):

$$SQI = \sum_{i=1}^{N} Wi \times Si$$

where Wi is the relative weight of each indicator and has a value ranging between 0 and 1, and Si is the value of each soil indicator. Wi represents the Component Score Coefficient (CSC) obtained from the PCA results. The Si value is standardized using Eq.

$$x = \frac{x - \bar{x}}{\sigma}$$

where z, x, x̄ and σ each refer to the standard value, soil indicator value, soil indicator mean, and soil indicator standard deviation. Therefore, the SQI equation based on Principal Component (PC) is as follow:

$$SQI - PC = \sum_{i=1}^{N} CSC \times z$$

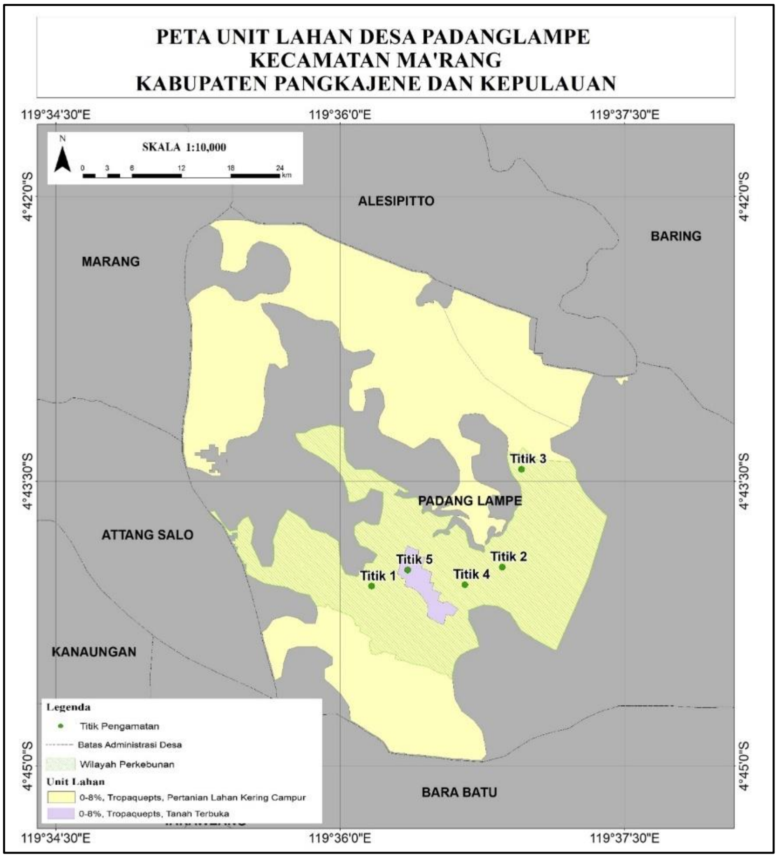


Figure 1. Land unit map and sampling point location study

2.2. Calculation of Soil Quality Index (SQI) Using Principal Component Analysis (PCA)

The soil quality index for each principal component is calculated using the (Abdel-Fattah et al., 2021)following equation:

Equation 1

SQI-PC1= (BD_Wi1 x BD_Z) + (Porosity_Wi1 x Porosity_Z) + (Sand_Wi1 x Sand_Z) + (Dust_Wi1 x Dust_Z) + (Liat_Wi1 x Clay_Z) + (pH_Wi1 x pH_Z) + (N_Wi1 x N_Z) + (P_Wi1 x P_Z) + (K-dd_Wi1 x K-dd_Z) + (C-O_Wi1 x C-O_Z)

Equation 2

SQI-PC2= (BD_Wi2 x BD_Z) + (Porosity_Wi2 x Porosity_Z) + (Sand_Wi2 x Sand_Z) + (Dust_Wi2 x Dust_Z) + (Clay_Wi2 x Clay_Z) + (pH_Wi2 x pH_Z) + (N_Wi2 x N_Z) + (P_Wi2 x P_Z) + (K-dd_Wi2 x K-dd_Z) + (C-O_Wi2 x C-O_Z)

Equation 3

SQI-PC3= (BD_Wi3 x BD_Z) + (Porosity_Wi3 x Porosity_Z) + (Sand_Wi3 x Sand_Z) + (Dust_Wi3 x Dust_Z) + (Liat_Wi3 x Liat_Z) + (pH_Wi3 x pH_Z) + (N_Wi3 x N_Z) + (P_Wi3 x P_Z) + (K-dd_Wi3 x K-dd_Z) + (C-O_Wi3 x C-O_Z)

2.3. Calculation of Comprehensive Soil Quality Index (CSQI)

The cumulative total of the soil quality index is calculated using the equation:

CSQI = (SQI-PC1 X Variability PC1) + (SQI-PC2

2.4. Determination of Soil Quality Index Classification

The classification of the soil quality index using the method of Aprisal et al. (2019) can be seen in Table 1. The complete research flow diagram is shown in Figure 2.

Table 1. Criteria quality land based on the mark index quality land

Soil quality criteria	Mark	Class
Very Good (SB)	0.80-1.00	1
Good (B)	0.60-0.79	2
Medium (S)	0.35-0.59	3
Low (R)	0.20-0.34	4
Very Low (SR)	0.00-0.19	5

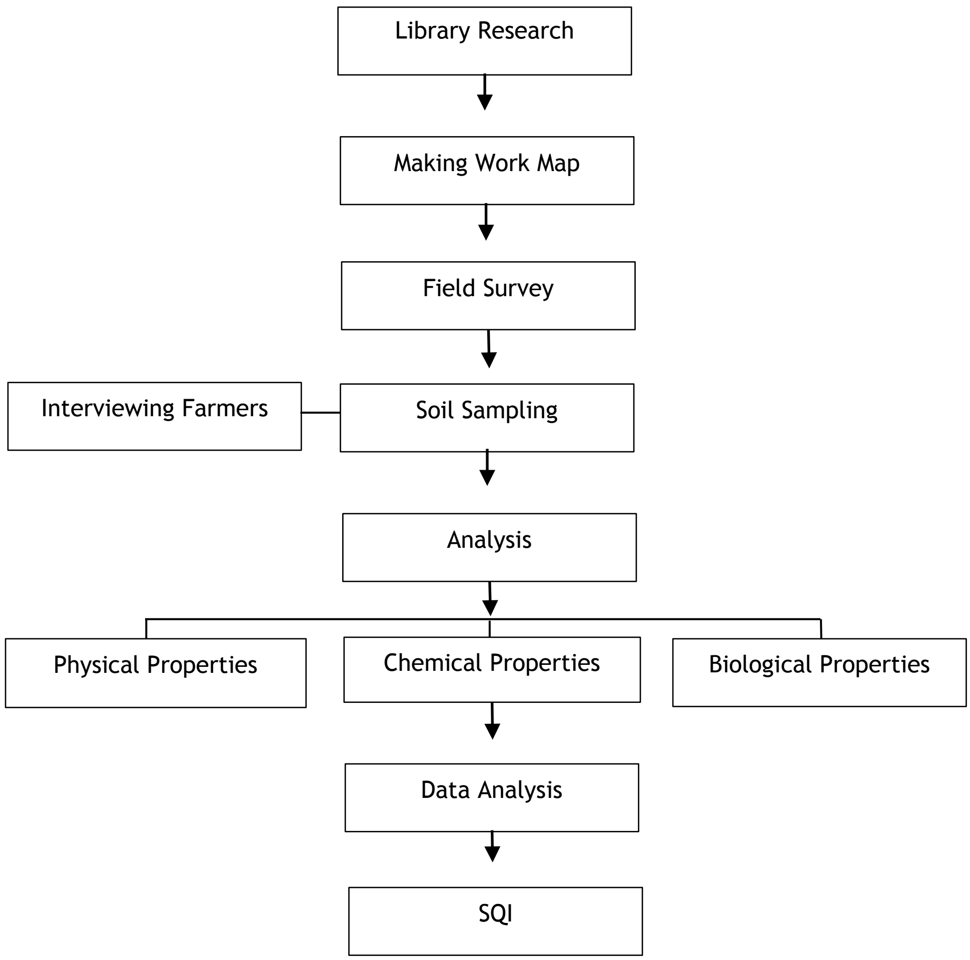


Figure 2. Research flow diagram

3. Results and Discussion

The results of the analysis of soil physical properties indicate that the bulk density is 1.12-1.38 g cm^{-3}. Soil texture shows a dominance of clay fractions, classified as clay, silty clay, and clay loam. Meanwhile, the porosity values range from 21.48% to 50.72% (Table 2). The soil's chemical properties indicate that the pH is 4.97-6.48, within the acidic to slightly acidic range; the total N is 0.10-0.36%, within the low to medium range. The available P value is in the range of 9.16-12.22 ppm, with low and medium criteria; likewise, the K-dd value is in the range of 0.16-0.32 cmol kg -1, with low and medium criteria; the C-Organic value is in the range of 0.59-2.28%, with low and medium criteria (Table 3).

Standard deviation shows the minimum, maximum, average (mean), and standard deviation (standard deviation) values of each soil physical and chemical property parameter (Table 4). These data describe variations in soil characteristics at the study site, including bulk density, porosity, texture (sand, silt, clay), soil pH, total nitrogen content, available phosphorus, exchangeable potassium, and organic carbon.

Table 4 shows that the standard deviation value is smaller than the mean value of the tested variable, so the data. This condition indicates that the variability or diversity of the data collection is low, so the level of data consistency is high. In the context of statistical analysis, this can be interpreted as indicating that the system or phenomenon being observed is well-stabilized, because the differences between individual values are relatively small.

The smaller the standard deviation relative to the mean, the stronger the indication that the data are uniformly distributed and representative of their average. This finding is reinforced by the test's feasibility, as assessed by a Chi-square analysis with an alpha value of <5% (Table 5). The data can therefore be analyzed using PCA.

The results of the correlation test between test variables showed a negative correlation at the 1% alpha level between Bulk Density and Porosity, while C-Organic and Soil pH had a positive correlation at the 5% alpha level. The complete results are shown in Table 6.

Table 2. Characteristics Characteristic Soil Physics

Sample Code	Parameter					
	Bulk Density	Porosity	Texture			
			Sand	Dust	Look	Texture Class
	g cm $^{-3}$	(%)	(%)	(%)	(%)	
TP1L1	1.21	50.06	15	45	40	Dusty Look
TP1L2			17	25	58	Look
TP2L1	1.23	50.17	13	38	49	Look
TP2L2			16	35	49	Look
TP3L1	1.12	50.60	33	34	33	Clayey Loam
TP3L2			11	31	58	Look
TP4L1	1.18	50.72	16	31	53	Look
TP4L2			9	38	53	Look
TP5L1	1.38	21.48	23	14	62	Look
TP5L2			28	28	45	Look

Description: TP (sampling point code) and L (soil layer symbol) followed by a number to indicate the i-th soil sampling number and i-th layer.

Table 3. Characteristics: Chemical Properties of Soil

Sample Code	Parameter				
	Soil pH	N-total (%)	P-available (ppm)	K-exchangeable (cmol kg $^{-1}$)	C-Organic (%)
TP1L1	6:12 AM	0.26(S)	10.90(S)	0.32(S)	2.06(S)
TP1L2	5.90 AM	0.22(S)	10.74(S)	0.16(R)	2.01(S)
TP2L1	5.61 AM	0.36(S)	11.41(S)	0.25(S)	2.28(S)
TP2L2	5.70 AM	0.26(S)	10.19(S)	0.18(R)	2.01(S)
TP3L1	6.24 AM	0.30(S)	12.22(S)	0.22(S)	1.89(R)
TP3L2	5.61 AM	0.23(S)	10.15(S)	0.21(S)	1.88(R)
TP4L1	6.48 AM	0.28(S)	11.70(S)	0.23(S)	2.13(S)
TP4L2	5.65 AM	0.25(S)	11.12(S)	0.21(S)	2.01(S)
TP5L1	5.10(M)	0.16(R)	9.70(S)	0.19(R)	1.26(R)
TP5L2	4.97(M)	0.10(R)	9.16(S)	0.16 (R)	0.59(SR)

Note: Criteria based on Soil Research Institute (2005); SR = Very Low, R = Low, S = Medium, T = High, ST = Very High, SM = Very Sour, M = Sour, AM = Slightly Sour, N = Neutral, Al = Slightly Alkaline, A = Alkaline.

Table 4. Standard Deviation Soil Characteristics

Variable	Minimum	Maximum	Mean	Standard deviation
BD	1,120	1,380	1,224	0.091
Porosity	21,480	50,720	44,606	12,191
Sand	9,000	33,000	18,100	7,622
Dust	14,000	45,000	31,900	8,465
Look	33,000	62,000	50,000	8,857
Soil pH	4,970	6,480	5,738	0.473
N-total	0.100	0.360	0.242	0.072
P-available	9,160	12,220	10,729	0.940
K-dd	0.160	0.320	0.213	0.048
C-Organic	0.590	2,280	1,748	0.489

Source: Primary data after processing, (2025).

Table 5. Feasibility of Parameter Test for PCA Analysis

Chi-square (Observed value)	**-Inf**
Chi-square (Critical value)	30,612
DF	45
Alpha (α 5%)	0.00

Table 6. Matrix Pearson Correlation between Trait Parameters Physique and Soil Chemistry

Variables	BD	Porosity	Sand	Dust	Look	Soil pH	N-total	P-available	K-dd	C-Organic
BD	**1**									
Porosity	-0.909**	1								
Sand (%)	0.321	-0.511	1							
Dust (%)	-0.546	0.676*	-0.367	1						
Clay (%)	0.245	-0.207	-0.502	-0.619	1					
Soil pH	-0.763*	0.786**	-0.115	0.482	-0.365	1				
N-total	-0.690*	0.817**	-0.339	0.605	-0.297	0.673*	1			
P-available	-0.729*	0.733*	-0.042	0.479	-0.429	0.842**	0.841**	1		
K-dd	-0.349	0.418	-0.279	0.607	-0.424	0.498	0.560	0.484	1	
C-Organic	-0.763*	0.886**	-0.531	0.556	-0.092	0.763*	0.928**	0.780**	0.615	1

Description: n=10, alpha 5%=0.632 and alpha 1%=0.765
*significant at 5% alpha level and **significant at 1% alpha level

The scree plot shows the eigenvalues of each principal component in the PCA (Principal Component Analysis) analysis (Figure 2). The graph shows that components 1 to 3 have eigenvalues above 1, while starting with variable 4 and beyond, the eigenvalues approach 0 or are less than 1. The first variable has the highest eigenvalue, around 6, and explains 61% of the total data variation. This finding indicates that most of the information from all variables can be represented by the first component. The second variable has an eigenvalue of around 2, with an additional contribution of 17%, so that the first two variables cumulatively explain 78% of the data variation. Furthermore, the third variable has an eigenvalue of less than 1.5 and contributes an additional 10% of the variation, so that the total information explained by the three principal variables reaches 88%. Meanwhile, the relationship between variability and cumulative values (PCA1-PCA3) can be seen in Table 7.

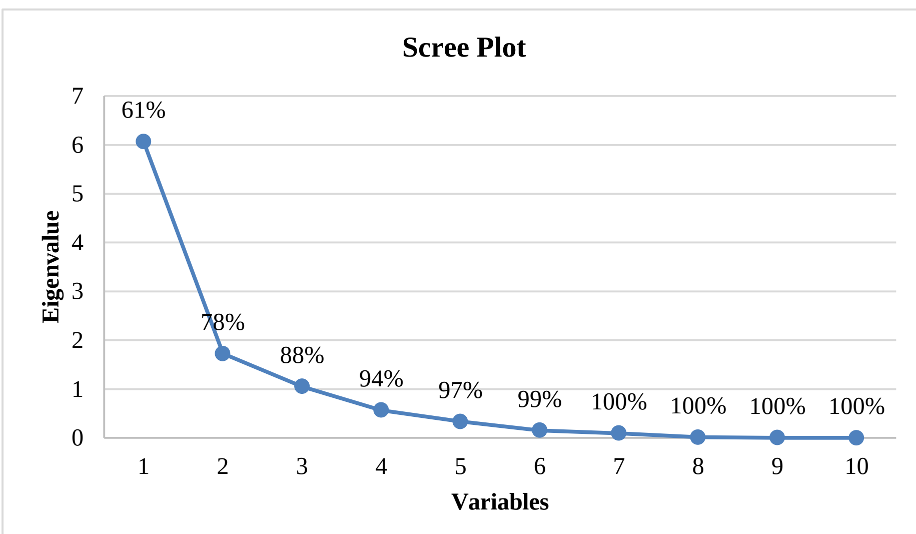


Figure 2. Scree Plot for various components considered for principal component analysis with eigenvalues greater than 1.

Table 7. Eigenvalues, Percentage of Variation, and Cumulative Percentage of Principal Components (PCA)

	PCA1	**PCA2**	**PCA3**
Eigenvalue	6,069	1,724	1,050
Variability (%)	60,690	17,237	10,501
Cumulative %	60,690	77,927	88,428

Based on the results of the principal component analysis (PCA), three factors (PCA1, PCA2, and PCA3) were obtained with eigenvalues greater than 1. The table above shows the results of the PCA analysis of the three principal components. The first component (PCA1) has an eigenvalue of 6.07 and contributes 60.69% of the total data variation. The second component (PCA2) has an eigenvalue of 1.72 and accounts for an additional 17.24%, bringing the first two components to 77.93% of the total variation. Furthermore, the third component (PCA3) accounts for an additional 10.50% of the variation, with an eigenvalue of 1.05, so that the three principal components cumulatively cover 88.43% of the information in the data.

The weight values indicate each variable's contribution to the three main components of the PCA. These weights indicate the extent to which a variable influences each component. For example, organic carbon, porosity, and soil pH have high weights on the first component, indicating their important role in explaining overall variation in soil quality (Table 8).

Table 8. Variable Weight Values (Wi) for PCA

Variable	Component Matrix		
	W1	**W2**	**W3**
BD	-0.852	0.099	-0.271
Porosity	0.928	-0.218	0.117
Sand	-0.361	0.838	0.379
Dust	0.756	0.179	-0.550
Look	-0.398	-0.875	0.191
Soil pH	0.851	0.133	0.306
Total	0.906	-0.052	0.061
P-available	0.865	0.209	0.327
K-dd	0.673	0.164	-0.546
C-Organic	0.928	-0.270	0.061

The variables with the highest weights are porosity (0.928), organic C (0.928), total N (0.906), and soil pH (0.851), which means that PC1 is dominated by chemical and physical parameters that reflect soil fertility and structure. In the second component (PC2), sand (0.838) and clay (-0.875) have the most significant influence, indicating that PC2 reflects variations in soil texture. Meanwhile, in the third component (PC3), the most influential variables are total N (1.634), organic C (1.088), and available P (0.724), which indicates that this component better reflects aspects of soil fertility based on the main nutrient content. This interpretation is important for formulating a comprehensive soil quality index that combines physical and chemical characteristics.

The matrix component shows the standardized values (z-scores) for each variable across the three main components, along with Soil Quality Index (SQI) values for each component (PC1, PC2, PC3) and the comprehensive CSQI value. These values are calculated from PCA weights and the standardized values of the variables to assess soil quality quantitatively. The CSQI is used to classify soil into specific quality categories such as very good, good, moderate, low, and very low.

The Comprehensive Soil Quality Index (CSQI) is obtained from the sum of the soil quality index values of each principal component (SQI-PC1, SQI-PC2, and SQI-PC3) based on the standard value (z) and weight of each soil parameter. The CSQI value is 0.97, which falls within class 1, e.g., the "Very Good" category (Table 9).

Table 9. Variable Standardization Values (z_i), Principal Component Values, and Comprehensive Soil Quality Index (CSQI) Values.

Variable	standardized values			soil quality index			Comprehensive SQI
	z1PC1	**z2PC2**	**z3PC3**	**SQI-PC1**	**SQI-PC2**	**SQI-PC3**	**CSQI**
BD	-0.154	-0.154	0.066	0.131	-0.015	-0.018	0.235
Porosity	0.447	0.447	0.456	0.415	-0.098	0.053	0.748
Sand	-0.407	-0.144	-0.669	0.147	-0.121	-0.254	0.223
Dust	1,548	-0.815	0.721	1,169	-0.146	-0.396	2,075
Look	-1.129	0.903	-0.113	0.449	-0.790	-0.022	0.685
Soil pH	0.808	0.342	-0.271	0.687	0.046	-0.083	1,257
N-total	0.249	-0.305	1,634	0.226	0.016	0.100	0.426
P-available	0.182	0.012	0.724	0.157	0.002	0.237	0.312
K-dd	2,247	-1.113	0.777	1,512	-0.182	-0.424	2,694
C-Organic	0.638	0.065	1,088	0.593	-0.018	0.066	1,088
Total				0.55	0.13	0.07	0.97

The results of the study showed that the bulk density at TP1–TP4 ranged from 1.12 to 1.23g/cm³, while at TP5 it reached 1.38g/cm³. The difference in bulk density was due to minimal soil cultivation, which caused the soil to experience natural compaction. Compared with previous studies (Fajeriana et al., 2025), the lower bulk densitof 1.11–1.15g/cm^3 indicates a moderate level of soil compaction. It is still within acceptable limits for agricultural land, reflecting a relatively good soil structure and having not experienced excessive compaction, so it is still able to support root growth, water movement, and air exchange in the soil. However, this moderate bulk density value still needs to be managed well by implementing sustainable soil management practices for monoculture citrus farming systems, such as adding organic matter and reducing mechanical stress on the soil in order to improve soil texture and structure, which can also reduce the bulk density value (Ahmad *et al.*, 2018). This finding aligns with the view of Waruwu & Bulolo (2024) that bulk density is influenced by soil texture, organic matter content, and land management practices. A higher bulk density indicates that the soil is denser, which can reduce itability to retain and conduct water and inhibit root growth (Akbar et al., 2024). In addition, the bulk density is closely related to soil porosity because it reflects the distribution of pore spaces in the soil. TP5 has a low porosity of 21.48%, in line with the increase. Soil compaction is caused by a decrease in soil organic C content (Table 3). Organic matter plays an important role in improving soil physical properties, primarily by increasing soil pore space (Ariyanto et al., 2021) and enhancg soil aggregate stability, thereby creating an ideal soil structure for plant growth (Dariah et al., 2015). Bulk density is used to describe the level of soil density, where the higher the bulk density, the denser the soil is, so it is a key parameter of soil physical properties that affects porosity, infiltration, runoff, and erosion, and is an important basis in evaluating the effectiveness of soil management (Fajeriana et al., 2024).

In addition to the less supportive physical properties in TP5, the pH is also the lowest, ranging from 4.97 to 5.10; therefore, the land in TP5 has not been optimally utilized for Pamelo plants. According to Ririska et al. (2023), the lack of ground cover plants can lead to the loss of natural buffer functions that maintain soil pH through the input of organic litter, making the soil more vulnerable to pH decreases due to erosion and leaching. This finding contrasts with the pH values in TP1-TP4 land, which range from 5.61 to 6.48 and are suitable for the growth of Pamelo plants. In addition, pH and C-organic values affect the availability of total nitrogen (N-total) in TP1-TP4 land, which is classified as moderate (0.22–0.36%), whereas in TP5 it is categorized as low (0.10–0.16%). The results of the correlation test (Table 6) show a positive correlation between pH and C-organic values, as well as between pH and NPK nutrient availability in the soil.

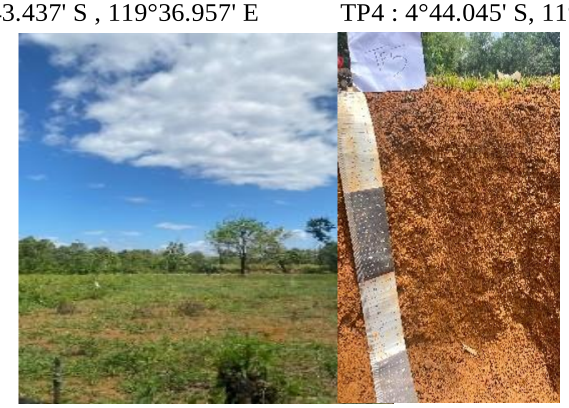
Pomelo plants require optimal phosphorus (available P) availability for root and flower formation. P availability in TP1-TP5 is moderate (9.16–11.70 ppm) and tends to decrease with increasing soil acidity. Available P availability is strongly influenced by pH; the higher the soil acidity, the lower the phosphorus availability. P content is also influenced by the soil parent material, where ultra-basic parent material contains available phosphorus (Bapelitbangda & COT, 2023). K-dd values at the study sites are low to moderate, with contents in TP1-TP4 ranging from 0.16–0.32 cmol/kg, while in TP5, it is lower (0.16–0.19 cmol/kg). This difference is due to the low organic matter content and the degree of soil weathering. Potassium availability is influenced by soil development and the type of parent material. Low K values at several cultivation points indicate the need for potassium fertilization, given its role in fruit formation and plant resilience. The organic carbon content in TP1-TP4 ranged from 1.88–2.28% (moderate), while in TP5 it was lower (0.59–1.26%). Variations in bulk density values supported this difference. High bulk density in TP5 indicates denser soil with limited pore space, inhibiting air circulation and microbial activity, leading to lower organic carbon accumulation. Soil organic carbon is related to soil density; the higher the organic carbon content, the lower the density (Ibrahim et al., 2015).

The soil quality index shows the highest SQI value in SQI-PC1, with a value of 0.55 in the medium category, and the SQI values of PC2-PC3, with values of 0.1-0.13 in the very low category. The decrease in the soil SQI value in SQI PC2-PC3 is in line with the low value of soil chemical characteristics, especially potassium and soil organic C (Table 3). According to the study by Dewi et al. (2021), a decrease in the soil quality index is closely associated with low potassium levels, as this nutrient plays an important role in plant physiological processes and enhances the efficiency of other nutrient utilisation. In addition, the low C-organic content indicates limited organic matter as an energy source for soil microorganisms, thereby reducing the soil's ability to maintain moisture and nutrient availability (Farrasati et al., 2019).

Based on the *Comprehensive Soil Quality Index* (CSQI) calculation, the value obtained was 0.97, which is classified as very good. The soil quality in Padanglampe Village is classified as very good in supporting the productivity of Pamelo plants (Figure 3), although TP3 and TP5 showed low levels of organic matter (Table 3). The taste quality of the Pamelo fruit is currently still categorized as very good, although the results from TP3 are slightly sour. To maintain and improve soil quality and sustainable Pamelo production, land improvement management is needed through the addition of organic matter and potassium fertilizer.

TP1 : 4°44.053' S , 119°36.165' E TP2: 4°43.953' S, 119°36.855' E

TP3: 4°43.437' S , 119°36.957' E TP4 : 4°44.045' S, 119°36.658' E



TP5: 4°43.967' S, 119°36.357' E

Figure 3. Location of Pamelo Orange Plantation in Soil Profiles TP1, TP2, TP3, TP4, and TP5 in Marang District, Pangkep Regency.

4. Conclusion

The SQI-PC1 value of 0.55 is classified as moderate, while SQI-PC2 and SQI-PC3 fall within the very low category (0.1–0.13). However, the CSQI value, which results from the integration of SQI-PC1, SQI-PC2, and SQI-PC3, reached 0.97 and is classified as very good. This finding confirms that, overall, the soil conditions at the research site are of optimal quality and support the growth and development of Pamelo plants. The distribution of soil quality index values at TP1, TP2, and TP4 indicates the highest level of soil suitability for Pamelo cultivation. Therefore, these three points are recommended as priority areas for Pamelo development in Padanglampe Village. Land use in this location is expected to sustainably increase plant productivity with a relatively low risk of soil degradation, thereby providing direct benefits to farmers and to local planners of horticultural commodity development.

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