

Mapping Soil Fertility Status of Alluvial Formations Using the SFI Method and Kriging Interpolation Geographic Information Systems

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Article History:

Received : 28 November 2023

Revised : 19 May 2024

Accepted : 22 June 2024

Keywords:

Kriging interpolation,
MSFI,
paddy field,
soil fertility index,
soil mapping.

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ABSTRACT

Land degradation can be characterized by a decrease in soil productivity. Jember Regency has the potential to develop food crop commodities. A decrease in soil productivity can be caused by a decrease in soil fertility. The study aims to look at the index and distribution of soil fertility in rice fields in southern Jember. The SFI (soil fertility index) technique was utilized in this study to calculate the soil fertility index. SFI is broken down into multiple parts, including calculating the Minimum Soil Fertility Index (MSFI), weighting, and scoring, which are then incorporated into the SFI calculation. The determination of MSFI is done using principal component analysis (PCA). The results of the MSFI analysis involved spatial mapping using kriging analysis to determine the area distribution of each class. The soil fertility index of the research location ranged from 1.72 to 2.28, with a low-class area of 9,224.19 ha (99.522%) and a very low-class area of 44,266 ha (0.478%). Parameters that influence soil fertility levels include cation exchange capacity, total soil nitrogen, and soil organic carbon, with a cumulative value of 84.8%.

1. INTRODUCTION

Land degradation is a condition of decreased land productivity over a short or long period of time. Land degradation can be caused by several things, e.g., land conversion, erosion, mining activities, and excessive use of chemicals. According to (BPS Kabupaten Jember, 2022), national rice productivity increased by 0.11 ton/ha, and East Java Province was in 3rd place as the province with the highest rice productivity in Indonesia. Jember Regency, which is one of the regencies in East Java Province, has the potential to develop forest and plantation areas (Basuki et al., 2023). Jember Regency also had potential for developing food crop commodities. This is evidenced by Jember Regency being in 4th place as the district with the highest rice production in East Java Province (Sari et al., 2022). However, Jember Regency experienced fluctuations in productivity in 2017–2022. This can be seen in Figure 1.

Based on Figure 1, it is known that in 2017–2022, there were fluctuations in rice productivity in Jember Regency. This is caused by fluctuations in productivity in several areas in Jember Regency; some are located in South Jember, such as Kencong, Umbulsari, Semboro, and Jombang sub-districts (Sasminto et al., 2014). Rice productivity in several sub-districts in South Jember is presented in Figure 2. It is known that four districts in southern Jember, which are Kencong District, Umbulsari District, Semboro District, and Jombang District, experienced a fluctuation in productivity in 2019–2020. The fluctuations in rice productivity can be caused by a decrease in soil fertility. Soil fertility is one of the characteristics of the soil that is able to provide nutrients for plants to support productivity. The level of soil fertility is influenced by factors such as physical, chemical, and biological indicators (Basuki et al., 2024).

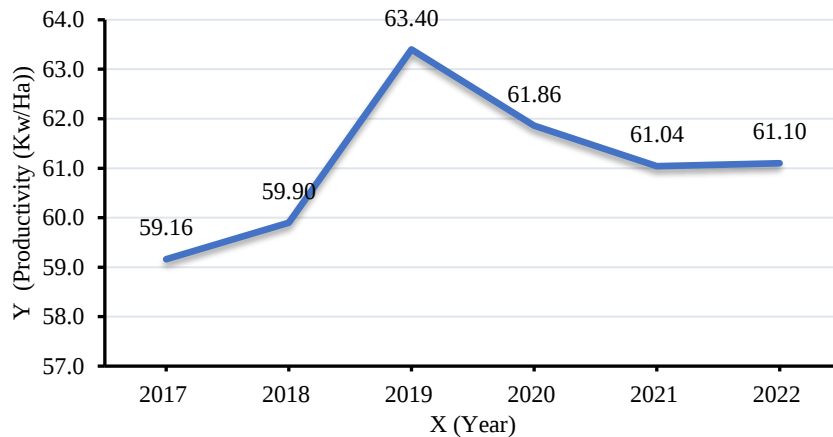


Figure 1. Rice productivity in Jember Regency 2017 –2022 (BPS Kabupaten Jember, 2022).

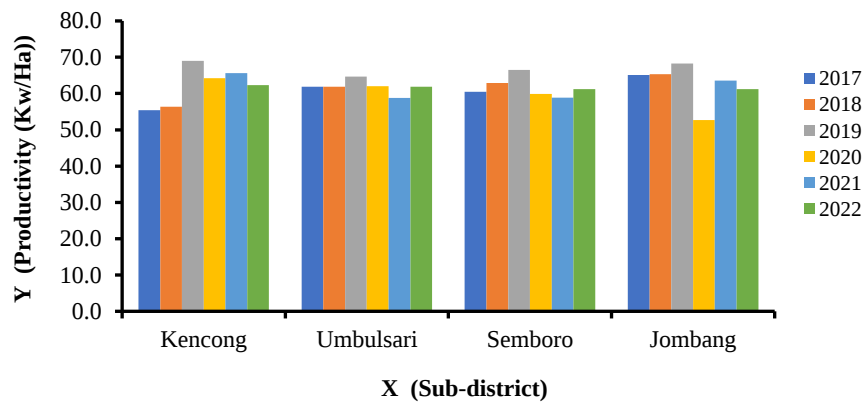


Figure 2. Rice productivity in several southern areas of Jember Regency (BPS Kabupaten Jember, 2022).

In the research conducted by [Sasongko *et al.* \(2022\)](#), he used the SFI (soil fertility index) calculation method, and this research is similar to the research of [Chuancheng *et al.* \(2020\)](#), utilizing geographic information systems, especially interpolation tools, to identify fertility status and fertilizer recommendations.

This current research has the main objective of identifying soil fertility through index assessment. The output from the research can be the first step in efforts to manage fertility and recommend fertilizers for sustainable agriculture.

2. MATERIALS AND METHODS

The study took place in South Jember from September 2022 to June 2023, and soil chemical analysis was performed at the Chemistry and Soil Fertility Laboratory of the Soil Science Study Program, Faculty of Agriculture, University of Jember. Soil samples, labels, and reagents to assess soil chemical characteristics were utilized in the study. Soil drills, plastic clips, stationery, laboratory equipment for assessing soil chemical characteristics, Minitab.18, and ArcGIS 10 software were all employed in the research. The research uses an exploratory descriptive method with a field survey approach and index rating analysis. The stages of this research are divided into 5 steps: soil sampling, laboratory analysis, soil fertility index calculation, interpolation, and statistical tests.

2.1. Soil sampling

Determining the point sample was carried out using the purposive random sampling method, namely a sampling method based on what needs to represent the research. The criteria used in determining sample points were the use of

rice fields with epiaquepst soil type based on the USDA soil classification, or gleisol in the national soil classification. Soil samples in the research area were taken using the purposive sampling method, with a total of 6 points taken. The soil is taken at a depth of 0–40 cm using a soil drill from the surface of the rice field, considering that the roots of rice plants have a maximum length of 35 cm and are supported by a solid boundary layer or plow tread layer of 40 cm. Each point is taken from a composite of five different locations diagonally, with a distance between points of approximately 400–600 meters. Each sampling point represents 1,544.74 ha of rice fields. A map of sampling points is presented in Figure 3.

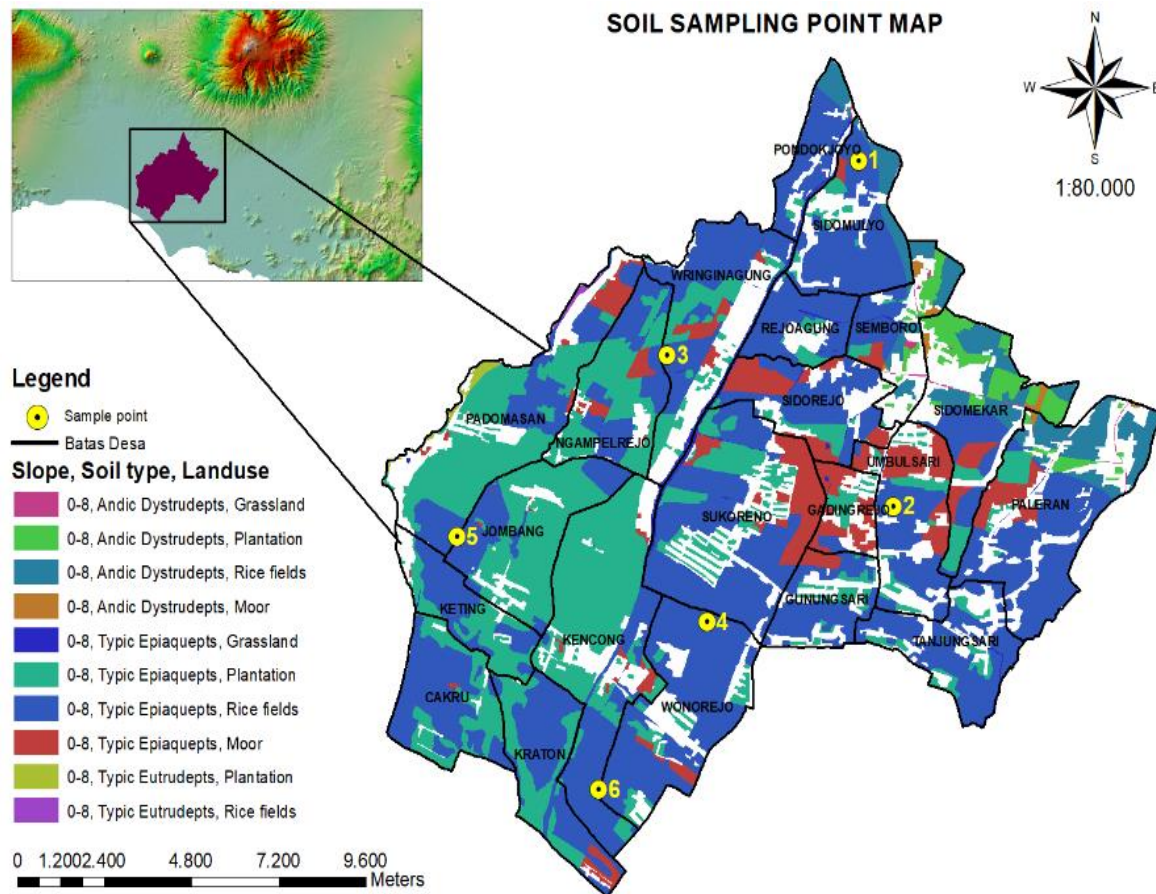


Figure 3. Soil sampling points (yellow points numbered 1 to 6)

2.2. Soil Analysis

The soil samples obtained were then prepared for laboratory analysis. Laboratory analysis conducted using the method as presented in table 1.

2.3. Calculation of the Soil Fertility Index (SFI)

The result of the laboratory analysis is then used to calculate the soil fertility status. The calculation of SFI used the soil fertility index (SFI) calculation method. The SFI calculation goes through three steps: determining the minimum soil fertility index (MSFI) variables, determining weights and scores, and integrating them into the SFI calculation (Mukherjee & Lal, 2014). The determination of MSFI uses the principal component analysis (PCA) method with Minitab 18 software. The results of PCA analysis will produce principal components (PC) (Shah *et al.*, 2022). PCA analysis will reduce variables into indicators that can explain data variance.

Tabel 1. Laboratory analysis methods

No.	Parameters	Method analysis	Reference
1.	pH	pH H ₂ O 1:5 (Sample: water)	(Basuki <i>et al.</i> , 2022)
2.	Organic carbon	Kurmis	(Gelaw <i>et al.</i> , 2015)
3.	Total-N	Kjhedal	(FAO, 2021)
4.	Available-P	Olsen	(Jerand <i>et al.</i> , 2016)
5.	Exchange cation	Extract NH ₄ OAC 1N pH7	(Gelaw <i>et al.</i> , 2015)
6.	CEC	Extract NH ₄ OAC 1N pH7	(Huerta <i>et al.</i> , 2020)
7.	Water content	Gravimetri	(Basuki & Sari, 2020)

The PC generated from the PCA analysis will then be selected based on the eigenvalue ≥ 1 . Each PC used will select the variable that has the highest weighting factor value in the PC. The variable with the heaviest weighting factor will then be referred to as the minimum soil fertility index (MSFI). MSFI is a variable that can explain the overall soil fertility value based on the SFI calculation method (Haryuni *et al.*, 2020). The SFI calculation method used the following equation.

$$SFI = \frac{\sum_{i=1}^n Sc_i}{N} \times 10 \quad (1)$$

$$Sc_i = c_j \times P_c \quad (2)$$

$$P_c = \frac{1}{n_c} \quad (3)$$

$$c_j = Si \times Wi \quad (4)$$

where Si is scoring index, Wi is weighting variable MSFI, and N is the number of MSFI variable.

To find out the c_j value in the SFI calculation method, weighting (Wi) and scoring (Si) are carried out on each MSFI variable. The weighting of each variable is carried out by dividing the proportion value of each PC by the cumulative value of the entire data used. Scoring is carried out by giving values to the results of laboratory analysis and the classification as presented in Table 2.

Table 2. Nutrient scoring criteria

No	Parameter	Score 1	Score 2	Score 3	Score 4	Score 5
		Very low	Low	Moderate	High	Very high
1.	pH	< 4.5	4.5-6.5	6.6 – 7.5	7.6 – 8.5	> 8.5
2.	CEC (me/100g)	<5	5-16	17-24	25-40	>40
3.	C-organic (%)	<1	1-2	2-3	3-5	>5
4.	N-total (%)	<0.1	0.1-0.2	0.21-0.5	0.51-0.75	>0.75
5.	P-available (ppm P)	<5	5-10	11-15	16-20	>20
6.	K (me/100g)	<0.1	0.1-0.3	0.4-0.5	0.6-1	>1
7.	Ca (me/100g)	<2	2-5	6-10	11-20	>20
8.	Mg (me/100g)	<0.3	0.4-1	1.1-2	2.1-8	>8

Source: (Suntoro *et al.*, 2023)

Table 3. Classification of soil fertility index

SFI	Class
1.00 - 2.00	Very low
2.01 - 4.00	Low
4.01 - 6.00	Moderate
6.01 - 8.00	High
8.01 - 10.00	Very High

Source: (Haryuni *et al.*, 2020)

The results of the SFI calculation will produce soil fertility index with range $1 \leq \text{SFI} \leq 10$. The calculated results were then divided into five soil fertility index classes: very high, high, moderate, low, and very low. Table 3 shows the categorization of soil fertility indexes utilized in this study.

2.4. Kriging Interpolation

The result of soil fertility index would be input into ArcGIS 10.8 software and interpolated to determine the spatial distribution of SFI. The interpolation used is kriging interpolation. The determination of spatial distribution in kriging interpolation method is based on the semivariogram structural model (Kurrahman *et al.*, 2022). The equation used in kriging interpolation is (Fitrianah & Purnama, 2019):

$$\hat{Z}(S_i) = \left[\frac{1}{2n(h)} \right] \sum_{i=1}^N [Z(x_i) - Z(X_i - h)]^2 \quad (5)$$

where $\hat{Z}(S_i)$ is variogram function, (h) is number of data pairs, $(x_i + h)$ is concentration value at location $(x_i + h)$, (x) is the grade value at location x_i and is a vector that expresses the distance between two corresponding points with value for experimental variogram calculations.

2.5. Statistical test

The statistical tests used in this study are correlation. The correlation used is the Pearson correlation (r) with the following equation (Purba & Purba, 2022).

$$r = \frac{n \sum X_i Y_i - \sum X \sum Y}{\sqrt{(n \sum X_i^2 - (\sum X)^2) (n \sum Y_i^2 - (\sum Y)^2)}} \quad (6)$$

where Y is dependent variable (soil fertility status), X is independent variable (soil parameter). Pearson correlation has a value range of $-1 \leq r \leq 1$. The following is a Pearson correlation classification (Table 4).

Table 4. Classification of Pearson correlation

Interval	Correlation class
0.80 – 1.000	Very strong
0.60 – 0.799	Strong
0.40 – 0.599	Moderate
0.20 – 0.399	Weak
0.00 – 0.199	Very weak

Source: (Purba & Purba, 2022)

3. RESULTS AND DISCUSSION

Laboratory analysis results were analyzed using PCA analysis to determine MSFI. PCA was performed using Minitab 18 software to determine MSFI. The results of the PCA analysis are presented in Table 5. Table 5 shows that PCA analysis resulted in 8 variables, and 3 of them had eigenvalues ≥ 1 . Each selected PC will be the variable with the highest weighting factor in the PC (Supriyadi *et al.*, 2016).

Table 5. Laboratory Analysis Results.

Sampling point	pH	C-Organic (%)	Total Soil Nitrogen (%)	Available-P (ppm)	K	Ca	Mg	CEC
						cmol(+)/kg		
1	7.2	3.0	0.11	20.67	0.67	3.46	3.37	26.78
2	7.6	1.9	0.12	16.50	0.65	4.95	3.48	34.92
3	7.4	2.3	0.16	26.51	0.75	4.58	3.86	34.51
4	6.6	1.8	0.14	5.87	0.67	2.35	3.19	23.34
5	7.3	2.7	0.14	5.16	0.71	4.16	3.28	32.40
6	7.6	2.2	0.09	25.87	0.71	3.74	3.32	30.85

The variable with the highest value in PC1 is CEC, PC2 is N-total, and PC3 is C-organic. PC1 to PC3 can represent 84.8% of the variability of the other 8 variables. The selected variable has the greatest influence on soil fertility at the research site, so the variable is referred to as MSFI (Mulyani & Suwanda, 2020). The results of the laboratory analysis of each MSFI were then ranked based on the ranking according to the Agricultural Research and Development Center and will produce a scoring index (S_i) (Mustofa *et al.* 2024). The weighting index (W_i) is obtained from the division between the proportion value of each PC and the cumulative value of the entire data used. Then the weight index (W_i) is multiplied by the scoring index (S_i) to produce a value of c_j . The calculation results are then integrated into the SFI formula to produce a soil fertility index. The calculation of the soil fertility index is presented in Table 6.

Table 6. Results from Principal Component Analysis (PCA)

Eigen analysis of the correlation matrix								
Eigenvalue	3.9507	1.7028	1.1265	0.8294	0.3906	0	0	0
Proportion	0.494	0.213	0.141	0.104	0.049	0	0	0
Cumulative	0.494	0.707	0.848	0.951	1	1	1	1
Eigenvectors								
Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
pH	0.44	-0.351	-0.097	0.082	-0.143	-0.664	0.321	0.319
CEC	0.461*	0.005	-0.248	0.308	-0.170	0.674	0.308	0.231
C-Organic	0.062	-0.191	0.789*	0.467	0.327	0.069	0.087	0.029
N-Total	0.061	0.745*	-0.036	0.117	0.267	-0.225	0.522	-0.179
P-Evailable	0.343	-0.242	0.215	-0.672	0.146	0.176	0.333	-0.403
K	0.287	0.378	0.445	-0.080	-0.720	-0.063	-0.207	-0.070
Ca	0.454	-0.062	-0.244	0.355	0.149	-0.121	-0.407	-0.634
Mg	0.424	0.285	0.046	-0.287	0.459	0.009	-0.450	0.492

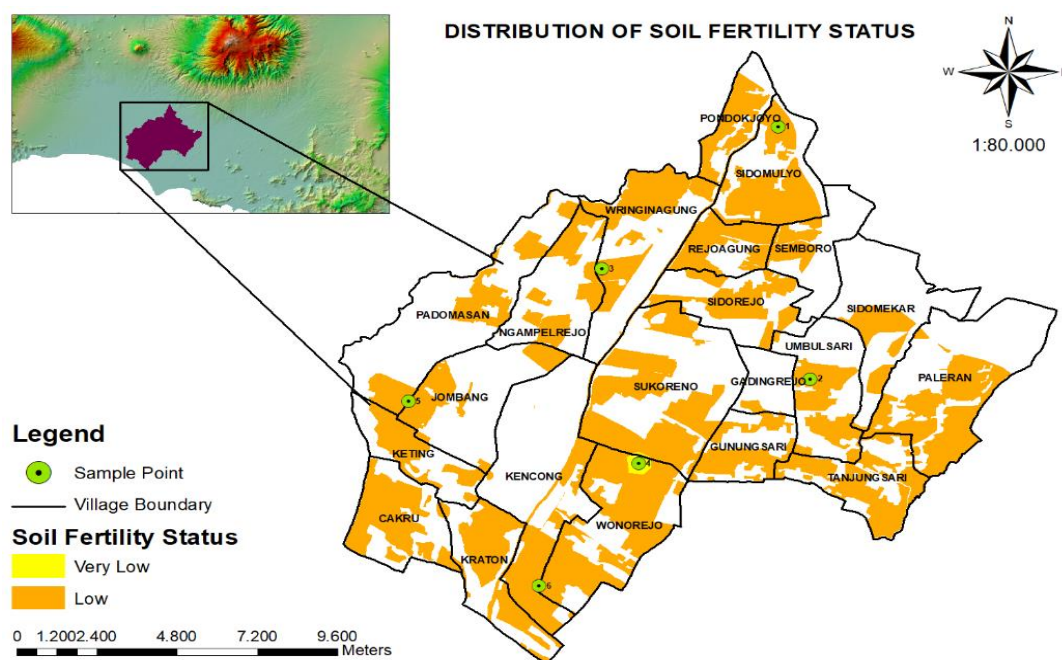


Figure 4. Distribution of soil fertility status.

Kriging interpolation is presented in Figure 4. The soil fertility index at the research location is extremely low. Points 1, 3, and 5 have soil fertility index values of 2.28; point 2 has a soil fertility index value of 2.11; point 6 has a soil fertility index value of 2.17; and point 4 has the least soil fertility index value of 1.72. The results of the soil

fertility index calculation are then interpolated to predict the value at a location using data from sample points (Alaboz *et al.*, 2021; Chuancheng *et al.*, 2020; Munyati & Sinthumule, 2021). The purpose of interpolation in this study is to determine the distribution of soil fertility index in the research location. The interpolation method used is the Kriging interpolation method, which uses semivariograms to predict the distribution of values at a location. Kriging interpolation results are influenced by three factors, namely the interval between points, the type of interpolation, and the number of samples (Chuancheng *et al.*, 2020). This research uses ordinary kriging interpolation with a spherical type. The distribution map of the soil fertility index using

Soil fertility status can be caused by several factors, including the intensive agricultural system at the research location, where rice is planted continuously every year. The rice planted is early-maturing rice with a relatively fast maturity of 90–110 days after harvest. The nature of early-maturing rice absorbs nutrients more quickly and in large quantities to produce productivity > 5 ton/ha. Another reason is that the straw is not returned to the fields but is burned or fed to livestock, especially cows and buffalo. Based on Figure 4, it is known that the soil fertility index at the research location has two classes, which are very low and low. The determination of soil fertility distribution with the interpolation method is determined by a tsemivariogram, where a semivariogram can provide a description of soil properties and inform spatial distribution (Chuancheng *et al.*, 2020). The domination of soil fertility in the study area is in the low class; the distribution of the soil fertility index is presented in Table 7.

Table 7. Soil fertility index calculation

MSFI	Wi	Sampling Point					
		1	2	3	4	5	6
CEC	0.583	4	4	4	3	4	4
Total-N	0.251	3	2	3	2	3	3
Organic-C	0.166	2	2	2	2	2	1
c_j		3.42	3.17	3.42	2.58	3.42	3.25
n_c		5	5	5	5	5	5
$P_c = 1/n_c$		0.2	0.2	0.2	0.2	0.2	0.2
$Sc_i = c_j \times P_c$		0.68	0.63	0.68	0.52	0.68	0.65
N		3	3	3	3	3	3
$SFI = (Sc_i/N) \times 10$		2.28	2.11	2.28	1.72	2.28	2.17
Class of soil fertility		Low	Low	Low	Very low	Low	Low

Based on Table 8, it can be known that the low-class soil fertility index dominates almost the entire research area with an area of 9224.19 ha, or 99.522% of the total area, while the remaining 0.478%, or 44.266 ha, is in the very low class. The differences in soil fertility index classes are influenced by soil properties, mainly by MSFI. MSFI variables consisting of CEC, N-total, and C-organic are the variables that most influence the soil fertility index. CEC will describe the ability of soil to bind nutrients; the greater the CEC value, the higher the soil fertility index.

Table 8. Soil fertility index distribution area

Class Soil Fertility	Area (Ha)	%
Very low	44.266	0.478
Low	9224.19	99.522

Table 9. Correlation between productivity of rice with soil fertility index

Correlation parameter	Value
Pearson correlation	0.201
p -value	0.703

Efforts that can be made to increase the CEC value are by applying organic materials, either in the form of manure, compost, or crop residues (Dengiz *et al.*, 2012). The application of organic matter can increase C-organisms in the soil (Mohammad & Adam, 2010). The high content of organic matter will increase land productivity. Organic matter is

also the main source of N in the soil, where the application of organic matter will maximize the activity of N-fixing microorganisms that can bind N from the air, thereby increasing the N content. Productivity in the study area was correlated with the soil fertility index resulting from calculations with the SFI method. The relationship between soil fertility and rice productivity is presented in Table 9. Based on table 9, it can be concluded that soil fertility and rice productivity are weakly correlated with a correlation value of 0.201. Soil fertility also has no significant effect on rice productivity, as can be seen from the p -value > 0.05 . This condition is in accordance with the research of Wulandari & Budiman (2022), which states that soil fertility is weakly correlated with rice productivity. Other factors that also determine rice productivity are rainfall, inputs (fertilizers, seeds, pesticides), cultivation techniques, land area, and pests and plant diseases. Land area (p -value = 0.00) and rainfall (p -value = 0.049) are two factors that have a substantial impact on rice productivity (Ishaq *et al.*, 2017).

4. CONCLUSION

The soil fertility index of the research location ranged from 1.72 to 2.28, with a low-class area of 9,224.19 ha (99.522%) and a very low-class area of 44,266 ha (0.478%). Parameters that influence soil fertility levels include cation exchange capacity, total soil nitrogen, and soil organic carbon, with a cumulative value of 84.8%.

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