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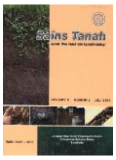

Nutrient status and soil fertility index as a basis for sustainable rice field management in Madiun Regency, Indonesia

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ABSTRACT

Agricultural development, specifically for crops, contributes significantly to national development. However, problems with water and low soil fertility are obstacles to this development. This study evaluated the nutritional status and soil fertility index as the basis for determining the direction of rice field management in Madiun Regency, East Java, Indonesia. The research method was conducted by surveying the soil characteristics followed by laboratory analysis. Soil samples were collected using stratified proportional sampling from 19 land units with 31 samples. The soil fertility index was determined using a principal component analysis test and calculated by dividing the weights by the minimum soil fertility index indicators. The study results show that the nutritional status of total N in the study area is low to high (0.13%–0.59%) and total P is very low to very high (12.18–73.66 ppm), whereas the status of exchangeable K is very low to very high (0.01–0.67 cmol.kg^{-1}), Cation Exchange Capacity is low to high (12.8–36.0 cmol.kg^{-1}), and organic carbon is low to very high (1.98%–6.54%). The soil fertility index ranges from medium to extremely high. The influential indicators are total P, total N, exchangeable K, and organic carbon. It is recommended that the rice field management system implement a "sustainable agricultural intensification" system that combines the two systems "intensification" and "sustainable agroecosystem." This system still uses proportional inorganic and organic fertilizers (manure, compost, and agricultural waste).

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1. INTRODUCTION

Agricultural commodities, especially food products, warrant considerable attention. Food commodities, especially rice (*Oryza sativa* L.), are the primary focus of government efforts to maintain the stability of food safety and security on a national level as the target of agricultural development (Purwaningsih, 2008). Rice is one of the most important staple food crops grown in India, China, and Southeast Asia. During the Green Revolution, the growth rate of rice production in this region was higher than human population growth, leading to a surplus of rice production (Janaiah, 2020). In 2013, rice fields in Indonesia covered an area of 13,769,913 ha with a productivity level of up to 5,146 tons.ha^{-1} (Santosa & Suryanto, 2015). Rice farming in Indonesia must grow substantially to offset the increase in the population's food needs, which is growing at a significant rate; therefore, it is no longer necessary to import rice. In 2023, rice production in Indonesia will be approximately 53.63 million tons with a population of 278.65 million people (BPS, 2023). Therefore, increasing rice productivity is extremely important to ensure national food security (Mariyono, 2018).

Low soil fertility is one of the primary challenges encountered in the development of agricultural systems in Madiun. The development of a sustainable agricultural rice system depends on local hydrological conditions (Obalum et al., 2011) and soil fertility (Suntoro et al., 2020). Soil fertility evaluation is important for assessing and monitoring land fertility to determine any nutrient shortage that presents an obstacle to plant growth (PPT, 1995). The purpose of determining soil fertility is to assess the soil characteristics and determine the main constraints on soil fertility (PPT, 1995).

Agricultural land depends strongly on the fertility and productivity of the soil. Soil fertility is one of the main obstacles to rice production in developing countries, especially in terms of nutrient availability, because soil fertility is closely related to soil characteristics and land management methods (Desavathu et al., 2018; Obalum et al., 2011). One problem that often arises in relation to soil fertility is the imbalance of nutrients in the soil (Roy et al., 2003). Proper plant nutrient balance is important for determining the nutritional status for sustainable agricultural production. The current agricultural system exploits nutrition through intensive tillage, planting without crop rotation, and the use of superior varieties and imbalanced nutrients with the addition of limited organic fertilizer, all of which create nutrient imbalance in the soil (Kumar et al., 2019). Research on soil fertility in Madiun by Muhammad and Wasit (2019) showed that chemical properties influence soil fertility; therefore, improving soil, water, and drainage management is necessary. Muhammad and Wasit (2019) described the soil properties that influence soil fertility while evaluating the nutrient status and soil fertility index as a basis for determining the direction of rice field management.

Soil surveying and mapping are methods that can be used in the field to determine the distribution of nutrient status and soil fertility index in a particular area. The main criteria used to determine the soil fertility index based on PPT (1995) include Cation Exchange Capacity (CEC), base saturation, organic C, total P, and exchangeable K. To determine the soil fertility level, it is necessary to evaluate the soil fertility potential through a laboratory analysis based on Buol et al. (2011). The soil mapping results show the distribution of soil fertility, which can be used as the basis for determining the future direction of land management. On the basis of this background, there is a need for research that maps nutritional status and soil fertility index to determine the direction of rice field management in the Madiun Regency of East Java Province. This study evaluated nutritional status and soil fertility index as the basis for determining the direction of rice field management in Madiun Regency, East Java, Indonesia.

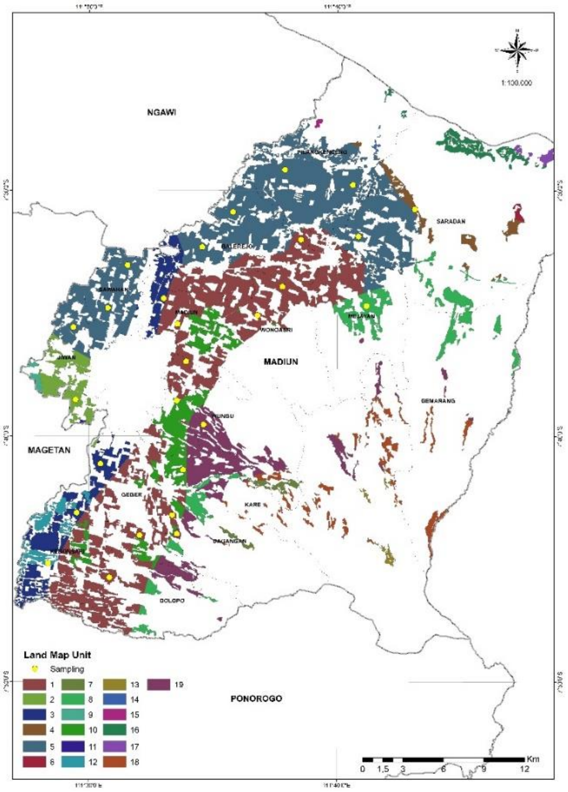

Figure 1. Map of Soil Units showing the sampling point

2. MATERIALS AND METHODS

2.1. Description of the Study Area

This study was conducted in Madiun Regency, East Java Province, Indonesia, which is at 7°44′04″–8°00′27″S and 110°12′34″–110°31′08″E. The topography is flat to hilly with a height of 52–1,185 m above sea level. Madiun Regency's climate type is type C, which is a temperate climate that is neither dry nor wet. Madiun Regency is influenced by a marine and mountain climate with temperatures ranging between 20°C and 35°C and an annual rainfall of 3,100–3,500 mm.year^{-1}; the highest monthly rainfall occurs in February, with 606 mm.month^{-1} and 23 days of rain. The longest and shortest sunshine was in July with 73.60% and January with 50.59%, respectively. Reddish–brown Mediterranean, grayish–brown alluvial, dark gray grumusol, reddish–brown latosol, and associations of reddish–brown Mediterranean and gray grumusol dominate the soil types in the research location. Geology includes the Madiun zone, which contains alluvial deposits of volcanic debris such as gravel, tuff, pumice, and sand. Land use is dominated by rice fields of approximately 30,951 ha or 30.62%, moorlands of 7,091.54 ha or 7.02%, plantations of 2,472 ha or 2.45%, and forests of 40,511 ha or 40.08% (BPS, 2020).

2.2. Soil Sample Collection

The research method was conducted by surveying soil characteristics followed by laboratory analysis. The survey used a physiography approach based on land map units from 19 land units with 31 samples (Hikmatullah et al., 2014). Soil samples were collected through stratified proportional sampling from every representative land unit (Fig. 1) and were transectionally determined from environmental and mapping observation results to ensure that they were sufficiently representative of the soil in the area. The collection of soil samples was based on technical indications from the survey and soil mapping (Hikmatullah et al., 2014). The direction of rice field management was based on a descriptive method. Soil analysis was conducted in the Soil Science Laboratory of the Faculty of Agriculture at Universitas Sebelas Maret.

2.3. Laboratory Analysis of the Soil Properties

The assessment of soil fertility status was based on an evaluation of soil properties, including CEC (ammonium acetate extract method), total N (the Kjeldahl method), total P (HCl extract method), exchangeable K (ammonium acetate extract), organic C (the Walkley and Black method), soil pH (pH meter and soil-to-water ratio of 1:2.5), and texture (pipette method).

Table 1. Soil Fertility Index Classifications

Value of Soil Fertility Index	Criteria
0.00-0.25	Very low
0.25-0.50	Low
0.50-0.75	Medium
0.75-0.90	High
0.90-1.00	Very high

Source: (Bagherzadeh et al., 2018)

Table 2. Soil properties in the Research Area

No. Sample	Village	total N		total P		exchangeable K		C organic		CEC		pH		Texture
		%	Class	ppm	Class	Cmol.kg^{-1}	Class	%	Class	Cmol.kg^{-1}	Class	value	Class	Class
1	Sukorejo	0.52	high	46.34	high	0.36	medium	3.29	high	33.2	high	6.73	Neutral	Silty clay loam
2	Banjarsari	0.5	medium	48.41	high	0.53	high	3.6	high	33.6	high	6.97	Neutral	clay
3	Sukolilo	0.27	medium	51.72	high	0.17	low	3.18	high	25.55	high	6.94	Neutral	clay
4	Rejosari	0.24	medium	33.29	medium	0.05	very low	2.17	medium	19.2	medium	7.08	Neutral	clay
5	Bagi	0.56	high	60.62	very high	0.35	medium	4.06	high	18.4	medium	7.11	Neutral	clay
6	Tulung	0.23	medium	34.12	medium	0.42	medium	3.29	high	26.85	high	6.66	Neutral	clay
7	Lebakayu	0.21	medium	46.54	high	0.30	medium	3.98	high	34.4	high	6.78	Neutral	clay
8	Babadan	0.21	medium	12.38	very low	0.12	low	3.42	high	36	high	7.01	Neutral	clay
9	Kresek	0.53	high	46.96	high	0.31	medium	4.02	high	27.6	high	6.79	Neutral	clay
10	Darmorejo	0.39	medium	52.55	high	0.17	low	4.51	high	14.8	low	6.49	Slightly acid	clay
11	Kincang Wetan	0.5	medium	63.93	very high	0.35	medium	4.02	high	22.12	medium	6.9	Neutral	Silty clay loam
12	Munggut	0.28	medium	33.29	medium	0.32	medium	3.25	high	32	high	6.33	Slightly acid	clay
13	Sirapan	0.41	medium	49.44	high	0.35	medium	2.57	medium	34	high	6.69	Neutral	clay
14	Rejosari	0.42	medium	39.09	medium	0.20	medium	4.72	high	16	low	7.15	Neutral	clay
15	Klangon	0.29	medium	34.32	medium	0.44	medium	6.54	very high	27.2	high	6.47	Slightly acid	clay
16	Kuwiran	0.24	medium	15.07	low	0.09	very low	3.77	high	26.8	high	6.45	Slightly acid	clay
17	Banjarsari	0.52	high	73.66	very high	0.49	medium	3.71	high	35.2	high	6.46	Slightly acid	clay
18	Randu alas	0.25	medium	33.29	medium	0.47	medium	3.45	high	27.2	high	6.42	Slightly acid	clay
19	Sumberejo	0.28	medium	50.68	high	0.10	low	2.83	medium	25.6	high	6.96	Neutral	clay
20	Kranggan	0.25	medium	47.16	high	0.67	high	5.48	very high	28	high	6.32	Slightly acid	clay
21	Kandangan	0.49	medium	24.81	medium	0.16	low	2.43	medium	12.8	low	5.93	Slightly acid	clay
22	Gandul	0.16	low	13,00	very low	0.17	low	4.75	high	18.4	medium	7.6	Slightly alkaline	clay
23	Tulung	0.17	low	12.18	very low	0.19	low	3.22	high	20.8	medium	6.6	Neutral	clay
24	Kedung jati	0.25	medium	30.19	medium	0.45	medium	4.68	high	34.4	high	7.22	Neutral	clay
25	Sambebendo	0.59	high	32.47	medium	0.59	high	3.98	high	23.6	medium	7.03	Neutral	Silty clay loam
26	Padas	0.13	low	19.42	low	0.19	low	4.38	high	14.4	low	6.01	Slightly acid	clay
27	Kepel	0.16	low	24.81	medium	0.01	very low	3.74	high	17.6	medium	6.35	Slightly acid	clay
28	Batok	0.18	low	32.47	medium	0.16	low	3.63	high	27.2	high	6.45	Slightly acid	clay
29	Glonggong	0.14	low	28.12	medium	0.12	low	1.98	low	22.4	medium	6.36	Slightly acid	Silty clay loam
30	Dolok	0.31	medium	26.25	medium	0.01	very low	4.31	high	18.4	medium	6.75	Neutral	Clay loam
31	Dawuhan	0.56	high	21.91	medium	0.15	low	1.98	low	26.4	high	6.36	Slightly acid	Silty clay loam

Remarks: CEC = Cation Exchange Capacity; class determination based on Eviati et al. (2023)

2.4. Determination of the Soil Fertility Index

The principal component analysis (PCA) test determines the soil fertility index. The results of the soil analysis were used to calculate the soil fertility index (parameters with a high PCA score) and to provide a minimum data set (MDS) (Chen et al., 2013). The soil fertility index was calculated by adding the results of the division of the number of weights with the minimum soil fertility index (MSFI) indicators (Mukashema, 2007). Soil fertility index values from 0 to 1 (0 ≤ SFI ≤ 1) (Table 1) (Bagherzadeh et al., 2018) using Equations 1 - 4.

$$p_c = \frac{1}{n_c} \quad \text{.......} \quad [1]$$

$$c_j = w_i \times s_i \quad \text{.......} \quad [2]$$

$$Sc_i = c_j \times p_c \quad \text{.......} \quad [3]$$

$$SFI = \left[\frac{\sum_{i-1}^{n} Sc_i}{N}\right] \times 10 \quad \text{.......} \quad [4]$$

where p_c is the probability for many classes; n_c is the number of classes; w_i is the weighting factor; s_i is the indicator score for variable i; c_j is the class for each sample; *SFI* is the soil fertility index; Sc_i is the total weight; and *N* is the number of MSFI indicators.

2.4. Data Analysis

Correlation between the variables was tested using Pearson's correlation test with Minitab 18 software. Soil fertility mapping was performed using inverse distance weighting and the Kriging interpolation method with ArcGIS software (Chen et al., 2020).

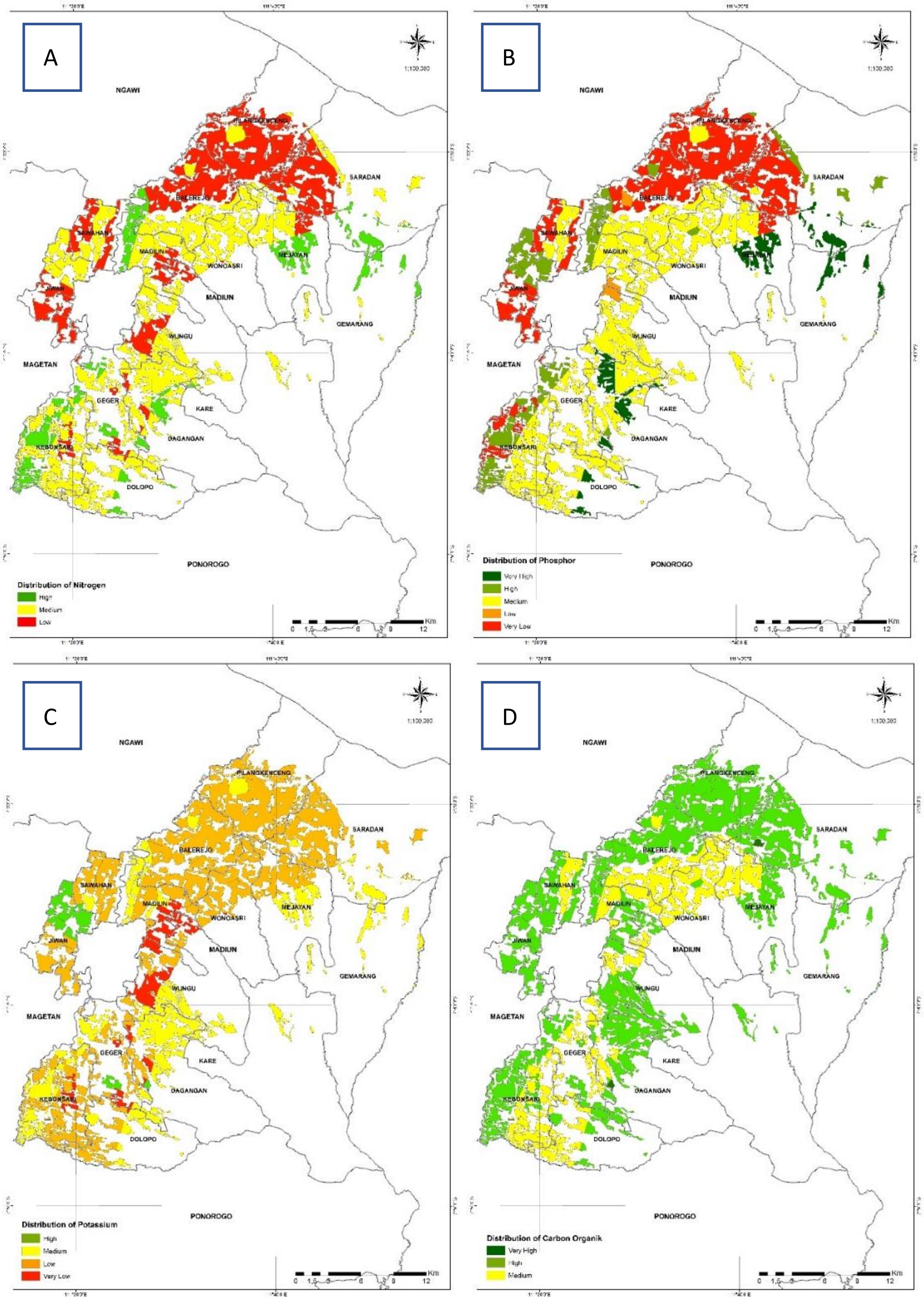

Figure 2: Map of Nutritional Status of (A) Nitrogen, (B) Phosphorus, (C) Potassium and (D) Organic Carbon Distribution

3. RESULTS

3.1. Soil Texture

The soil texture analysis showed that the soils of the study area can generally be classified as having a clay texture (Table 2). It is believed that the high clay content of the soil in the study area is due to weathering, which transforms coarse materials into finer materials. The clay texture in the study area is required for rice plants to grow. This clay texture can provide nutrients for rice plants (Zhao et al., 2021).

3.2. Cation Exchange Capacity

The CEC analysis results show a value in the range of 12.8–36.0 cmol.kg^{-1}, which can be classified as low to high (Eviati et al., 2023) (Table 2). From the observation, most results show a high CEC, which is thought to be due to the clay texture of the soil. Soil types with high clay and organic matter contents have a higher CEC than soil with a low clay fraction, which agrees with the research by Muhammad and Wasit (2019) in Madiun. The results show that low to high CECs are influenced by the texture and organic materials. This clay fraction has a large colloid surface area; therefore, the soil's CEC is also high (Molina, 2016). The CEC is also influenced by soil pH and organic matter.

The CEC is also influenced by soil pH, texture, and organic matter. These soil characteristics result in different CECs at the research location. This shows that soil with a high CEC can absorb and supply more nutrients than soil with a low CEC.

3.3. Nitrogen Content

The analysis results show that the nitrogen content in the soil ranges from low to high (Eviati et al., 2023) at 0.13%–0.59% but is dominated by a medium to high level (Fig. 2). The study results of Muhammad and Wasit (2019) show that the nitrogen content is low, which is different from the results of this study. There are several problems, one of which is soil management. Soil nitrogen content is largely influenced by the history of soil management. Excessive use of fertilizer with a large N content will leave a high amount of residue in the soil. At present, farmers strongly depend on the use of chemical fertilizers such as urea, which also supports elevated levels of N in the soil. Nitrogen is extremely important for growth and crop production, particularly in photosynthesis, where nitrogen increases the amount of chlorophyll (Muhammad & Wasit, 2019). Nitrogen encourages protoplasm, protein, and nucleic acid development. In addition to originating from chemical fertilizer, nitrogen in the soil comes from the supply of organic matter added to the soil. This organic matter in the soil significantly affects the availability of nutrients in the soil, both through the direct mineralization of nutrients, particularly N, and through the process of humification, which increases the soil's cation binding ability (Suntoro, 2003).

3.4. Total P Content

The value of total P in the analysis results displays criteria ranging from very low to very high (Eviati et al., 2023) or 12.18–73.66 ppm, but the dominant level is medium (Fig. 2). The availability of P in the soil is influenced by soil pH. A soil pH close to neutral makes it easier to exchange nutrients in the soil more effectively; therefore, nutrient availability, including P content, is optimal. P (Phosphor) is a nutrient that is essential for plant growth and plays a key role in energy transfer in the form of ADP and ATP, as well as in the photosynthesis process, genetic transfer, and transformation of sugar and starch. For a long time, the application of P fertilizer has been vital for resupplying P availability into the soil, although it does become partially unavailable because of fixation, both in acidic and alkaline soils. P is an essential nutrient that is needed in enormous quantities by plants. Therefore, the availability of P is essential for supporting plant growth. Most of the P in the soil is not available to plants, even when supplied through P fertilization, because it is mobile in nature and can react with other elements. This reduces the efficiency of P fertilization. However, the addition of organic fertilizer can increase P availability in the soil.

3.5. Potassium Content

The results of the exchangeable potassium analysis range from 0.01 to 0.67 cmol.kg^{-1}, which is very low to high, but the dominant level is medium (Fig. 2). Muhammad and Wasit (2019) showed the same results; the K content was classified as low to high. This is believed to be due to the factor of soil formation. Variations in the soil's K_2O content are determined by the conditions of soil formation. The observation results show that the soil in the study area is in a condition of moderate to advanced weathering. Soil with a moderate degree of weathering has a high K content, whereas soil that has experienced advanced weathering has a lower K content (Herdiansyah et al., 2022). The elevated level of K_2O in the study area is related to the high CEC of the soil. A higher CEC can increase the ability of the soil to absorb K, making the soil solution slow to release K, thus reducing the potential for leaching and leading to a buildup of K in the soil.

3.6. Organic Carbon Content

Organic carbon in the study area displays criteria ranging from low to very high (Eviati et al., 2023) or 1.98%–6.54% (Fig. 2). Likewise, research by Muhammad and Wasit (2019) shows low organic matter. Low levels of organic carbon are due to a high rate of decomposition of organic matter due to temperatures and moisture that are suitable for the development of decomposer organisms, as well as high rainfall levels and erratic rainfall in the study area, causing low organic matter content. This low level of organic matter has a negative effect, causing a decrease in soil fertility (Suntoro, 2003). The low level of organic carbon indirectly indicates low organic matter production at the research location. Additionally, low organic carbon content is caused by the activities of local farmers that include an excessively high intensity of tillage in planting and transporting the harvest residue, thus leading to a lack of vegetation at the location. A high organic carbon content is strongly influenced by the supply of organic matter into the soil through crop residue. The habitual practice of farmers leaving behind residual straw after harvesting the produce will increase the supply of organic matter to the soil.

Table 3. Analysis of Minimum Soil Fertility Index (MSFI) using PCA

Eigen value	2.1895	1.1747	0.9922	0.9494	0.451	0.2432
Proportion	0.365	0.196	0.165	0.158	0.075	0.041
Cumulative	0.365	0.561	0.726	0.884	0.959	1
Variable	PC1	PC2	PC3	PC4	PC5	PC6
N-total	0.446	**0.458***	0.376	-0.12	-0.531	0.393
P-total	**0.524***	0.248	0.203	-0.107	0.78	-0.057
K-excangeble	**0.561***	-0.203	-0.26	-0.218	-0.322	-0.652
C-organic	0.2	**-0.773***	0.194	-0.363	0.043	0.436
CEC	0.37	-0.026	-0.693	0.428	0.031	0.445
pH	0.186	-0.298	0.482	0.782	-0.061	-0.17

Table 4. Result of Weight Index (WI)

No	MSFI	Proportion	Cumulative	Weight index (Wi)
1	P-total	0.37	0.56	0.33
2	K-exchangeable	0.37	0.56	0.33
3	C-organic	0.20	0.56	0.17
4	N-total	0.20	0.56	0.17

3.7. Soil Fertility Index

In the study, there were two selected PCs: PC1 and PC2 with eigenvalue ≥1. The indicators used as MDS were determined on the basis of the indicators with the highest value on each PC (Table 3). The PCA results show that the indicators with the highest total N, total P, potassium, organic C, pH, and CEC values are found in PC1 and PC2. PC1 consists of total P and K, representing data for determining soil fertility, and PC2 represents total N and organic C. The six indicators analyzed (total N, total P, exchangeable potassium, organic carbon, CEC, and pH) can be reduced to four new indicators that can explain the soil fertility index (62.2%), which has high sensitivity to soil fertility in the study area (MSFI; Table 4).

The soil fertility index analysis results in the study area show medium to very high levels (Table 5 and Fig. 3). SFI results are determined by high total N and total P because of farmers' long-term inorganic fertilization patterns with relatively high doses. The types of inorganic fertilizers commonly used by farmers are urea, SP-36, KCl, and NPK Phonska compound fertilizers. Soil organic C content is also a determinant of the soil fertility index, considering that many farmers in the study area have practiced adding organic materials in the form of manure, compost, and plant residues (straw) to rice fields.

4. DISCUSSION

The soil fertility index in the study area is influenced by several soil chemical and physical properties and includes medium to extremely high levels (Table 5). This is because four factors sensitively influence soil fertility (organic C, total N and P, and exchangeable K). Low organic carbon affects other parameters such as N, P, K, and CEC. Khadka (2016) showed that organic matter affects the total N and the available P and K. Additionally, Siregar et al. (2017) stated that providing a source of organic matter had a significant effect on increasing pH, available P, CEC, and reducing soil Al.

The analysis results showed that the organic C content in the study area ranged from low to extremely high. This causes the soil fertility index to be medium to extremely high. A low level of organic carbon affects the ability of the soil to maintain its fertility through soil organism activities. Low organic carbon occurs because most farmers no longer use organic fertilizer (manure, green fertilizer, and compost), instead switching to inorganic fertilizer. These conditions will lead to a decline in soil organic matter, including a decrease in soil humus, which is the source of cation exchange in the soil. This makes the soil CEC much lower. Humus is a source of negative charge in the soil, thereby increasing the CEC (Suntoro, 2003). According to Michael (2020), the low potassium content in soil can be increased by almost 50% with the addition of organic matter.

Organic matter in the study area plays a key role in influencing the soil fertility index. This low organic matter will cause organic matter degradation; therefore, efforts are needed to increase the organic matter. One of the ways farmers can overcome the low organic matter degradation in rice field soil is to apply an organic rice planting system, one of the main components of which is the use of organic fertilizer. Using organic fertilizer to improve soil quality is synonymous with increasing organic matter content, and its outcome is an increase in soil fertility (Mujiyo et al., 2015).

Soil fertility is a fundamental parameter that determines the reproductive growth capacity, yield, and nutritional value of food crops (Ma et al., 2023). Pretty and Bharucha (2014) proposed the concept of sustainable intensification as a paradigm toward sustainable agricultural intensification, integrating two interdependent goals in using sustainable practices to improve human needs while contributing to the resilience and sustainability of the landscape, biosphere, and earth system.

Table 5. Soil fertility Index in Research Location

No	Village	C-organic	total N	total P	K-exchangeable	total weight	nc	pc	sci	SFI	Criteria
1	Sukorejo	3	4	3	2	2.849	5	0.2	0.57	0.95	Very high
2	Banjarsari	4	3	4	3	2.741	5	0.2	0.548	0.91	Very high
3	Sukolilo	4	2	4	2	2.349	5	0.2	0.47	0.78	High
4	Rejosari	3	2	3	1	1.741	5	0.2	0.348	0.58	Medium
5	Bagi	4	4	5	2	2.916	5	0.2	0.583	0.97	Very high
6	Tulung	4	3	3	3	2.524	5	0.2	0.505	0.84	High
7	Lebakayu	4	3	4	2	2.524	5	0.2	0.505	0.84	High
8	Babadan	4	3	1	2	1.873	5	0.2	0.375	0.62	Medium
9	Kresek	4	4	4	3	2.916	5	0.2	0.583	0.97	Very high
10	Darmorejo	4	3	4	2	2.524	5	0.2	0.505	0.84	High
11	Kincang	4	3	5	2	2.741	5	0.2	0.548	0.91	Very high
12	Munggut	4	3	3	2	2.307	5	0.2	0.461	0.77	High
13	Sirapan	3	3	4	2	2.349	5	0.2	0.47	0.78	High
14	Rejosari	4	3	3	2	2.307	5	0.2	0.461	0.77	High
15	Klangon	5	3	3	3	2.699	5	0.2	0.54	0.9	Very high
16	Kuwiran	4	3	2	1	1.873	5	0.2	0.375	0.62	Medium
17	Banjarsari	4	4	4	3	2.916	5	0.2	0.583	0.97	Very high
18	Randu alas	4	3	3	3	2.524	5	0.2	0.505	0.84	High
19	Sumberejo	3	3	4	1	2.133	5	0.2	0.427	0.71	Medium
20	Kranggan	4	3	4	4	2.958	5	0.2	0.592	0.99	Very high
21	Kandangan	3	3	3	2	2.133	5	0.2	0.427	0.71	Medium
22	Gandul	4	2	1	2	1.699	5	0.2	0.34	0.57	Medium
23	Tulung	4	2	1	2	1.699	5	0.2	0.34	0.57	Medium
24	Kedung jati	4	3	3	3	2.524	5	0.2	0.505	0.84	High
25	Sambendo	4	4	3	3	2.699	5	0.2	0.54	0.9	Very high
26	Padas	4	2	2	2	1.916	5	0.2	0.383	0.64	Medium
27	Kepel	4	2	3	1	1.916	5	0.2	0.383	0.64	Medium
28	Batok	4	2	3	2	2.133	5	0.2	0.427	0.71	Medium
29	Glonggong	2	2	3	2	1.783	5	0.2	0.357	0.59	Medium
30	Dolok	4	3	3	1	2.09	5	0.2	0.418	0.7	Medium
31	Dawuhan	2	4	3	2	2.133	5	0.2	0.427	0.71	Medium

Remarks: nc = number of class, pc = probability class, sci = scoring indicator, SFI = Soil Fertility Index

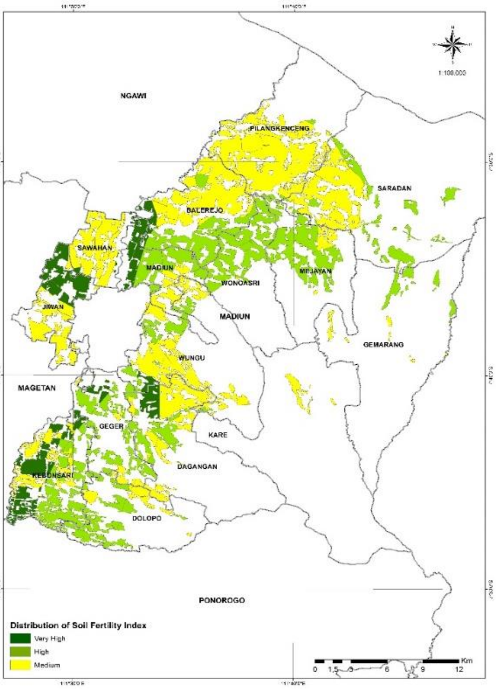

Figure 3. Map of Soil Fertility Index

This concept uses inorganic fertilizers N, P, and K and organic materials to sustain soil fertility. Khadka (2016) showed that organic matter influences total N and P and exchangeable K in soil through the mineralization process. Additionally, organic matter significantly affects increasing CEC, which is an important factor in ensuring sustainable soil fertility (Siregar et al., 2017).

The study results show a significant relationship between organic matter content and increased SFI (Fig. 4a). This indicates that the management of soil organic matter greatly determines SFI and ensures the sustainability of soil fertility. Although CEC was not included as the main determining factor of IKT in this study, it greatly determines soil nutrient retention. CEC is closely related to SFI (Fig. 4b). Solly et al. (2020) confirmed that soil organic matter contributes to CEC, and its influence is between 35% and 50% on CEC, especially in the top soil. The strength of the relationship between effective CEC and SOC content depends on soil pH; the effect is greater at pH >5.5. Nešić et al. (2015) emphasized that the CEC, in addition to determining the clay fraction, is determined by the humus content. It was proven that there is a relationship between soil organic matter and CEC (Fig. 4c).

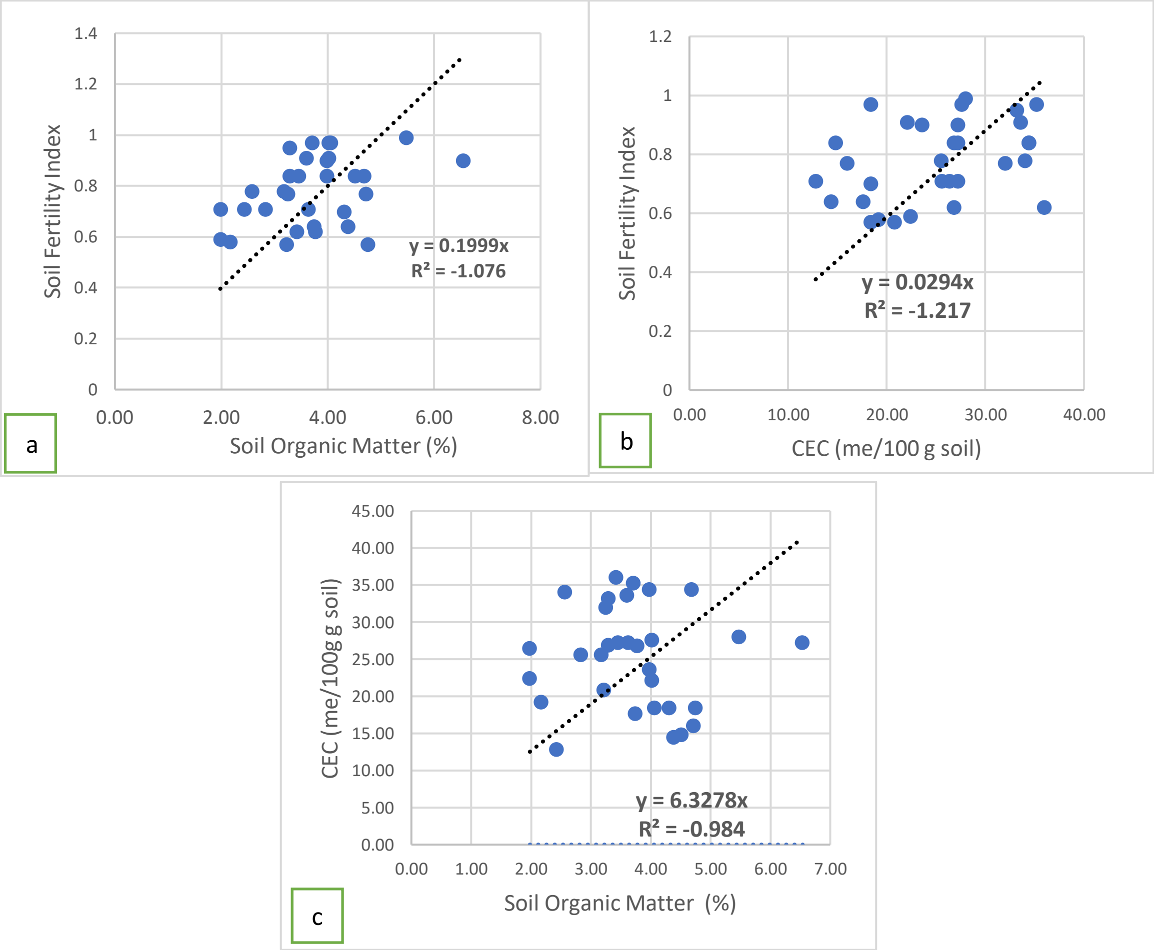

Figure 4. The relationship between: (a) soil organic matter content and SFI, (b) CEC and SFI, (c) soil organic matter content and CEC

Considering the aforementioned conditions, inorganic fertilizers N, P, and K still need to be added to restore the nutrients transported through plant products, and organic fertilizers are still very much needed to increase nutrient retention and sustain soil fertility. The direction of the future management system by implementing “sustainable agricultural intensification” is to combine the two systems of “intensification” and remain a “sustainable agroecosystem.” This system is a way to increase agricultural production without sacrificing natural resources and the environment. In practice, the use of inorganic N, P, and K fertilizers is conducted proportionally on the basis of the soil’s original N, P, and K nutrient content so that it is more efficient and does not pollute the environment. Additionally, the soil agroecosystem’s condition can be maintained using organic fertilizer. The application of organic fertilizer not only enriches soil organic matter but also supports good soil health and quality (Swain et al., 2019). The addition of soil organic matter increases the C (humus) content, which is important for increasing soil CEC (Stehouwer, 2004). In practice, implementing full organic farming without the addition of N, P, and K inorganic fertilizers, even though it ensures sustainable soil fertility, is a concern for many farmers. Therefore, a sustainable intensification system will provide guaranteed results and sustainable soil fertility. The implementation of this system can be enforced in stages through a semi-organic or full organic method using local sources of potential organic matter. Local potential organic fertilizer includes organic matter with a high nutrient content that is available at the location, such as animal manure, compost, crop residue straw, and green fertilizer. The application of organic matter in the form of animal manure, together with inorganic matter not only enriches the soil with soil organic matter but also supports good soil health and quality (Swain et al., 2019).

The application of a reasonable fertilizer and soil management technology based on local soil fertility is essential for rice production. In practice, a sustainable agricultural intensification system can be achieved by developing a semi-organic agricultural system that combines organic fertilizer with inorganic fertilizer, especially N, P, or K. The use of organic fertilizer, namely, straw left over from rice fields, can reduce the need for nutrients, especially K. The use of organic waste in rice fields has succeeded in substituting 33%, 50%, and almost all of the N, P, and K requirements, respectively (Makarim & Suhartatik, 2006).

5. CONCLUSIONS

The study results show that the nutrient status of total N in the study area is low to high (0.13%–0.59%) and total P is very low to very high (12.18–73.66 ppm), whereas the status of exchangeable K is very low to very high (0.01–

0.67 cmol.kg^{-1}), CEC is low to high (12.8–36.0 cmol.kg^{-1}), and organic carbon is low to very high (1.98%–6.54%). The soil fertility index ranges from medium to extremely high. The influential indicators are total P and N, exchangeable K, and organic carbon. It is recommended that the rice field management system implement a "sustainable agricultural intensification" system that combines the two systems "intensification" and "sustainable agroecosystem." This system still uses proportional inorganic and organic fertilizers (manure, compost, and agricultural waste).

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

References

Bagherzadeh, A., Gholizadeh, A., & Keshavarzi, A. (2018). Assessment of soil fertility index for potato production using integrated Fuzzy and AHP approaches, Northeast of Iran. *Eurasian Journal of Soil Science*, *7*(3), 203-212. https://doi.org/10.18393/ejss.399775

BPS. (2020). *Kabupaten Madiun Dalam Angka 2020*. Badan Pusat Statistik Kabupaten Madiun. https://madiunkab.bps.go.id/publication/2020/05/20/98c253721755925dae7b7c94/kabupaten-madiun-dalam-angka-2020.html

BPS. (2023). *Ringkasan Eksekutif Luas Panen dan Produksi Padi di Indonesia 2023 (Angka Sementara)* Directorate of Food Crops, Horticulture, and Estate Crops Statistics, BPS-Statistics Indonesia.

Buol, S. W., Southard, R. J., Graham, R. C., & McDaniel, P. A. (2011). *Soil genesis and classification* (6th, Ed.). John Wiley & Sons. https://doi.org/10.1002/9780470960622

Chen, S., Lin, B., Li, Y., & Zhou, S. (2020). Spatial and temporal changes of soil properties and soil fertility evaluation in a large grain-production area of subtropical plain, China. *Geoderma*, *357*, 113937. https://doi.org/10.1016/j.geoderma.2019.113937

Chen, Y.-D., Wang, H.-Y., Zhou, J.-M., Xing, L., Zhu, B.-S., Zhao, Y.-C., & Chen, X.-Q. (2013). Minimum Data Set for Assessing Soil Quality in Farmland of Northeast China. *Pedosphere*, *23*(5), 564-576. https://doi.org/10.1016/S1002-0160(13)60050-8

Desavathu, R. N., Nadipena, A. R., & Peddada, J. R. (2018). Assessment of soil fertility status in Paderu Mandal, Visakhapatnam district of Andhra Pradesh through Geospatial techniques. *The Egyptian Journal of Remote Sensing and Space Science*, *21*(1), 73-81. https://doi.org/10.1016/j.ejrs.2017.01.006

Eviati, Sulaeman, Herawaty, L., Anggria, L., Usman, Tantika, H. E., . . . Wuningrum, P. (2023). *Petunjuk Teknis Analisis Kimia Tanah, Tanaman, Air, dan Pupuk* (I. A. Sipahutar, H. Wibowo, A. F. Siregar, L. R. Widowati, & T. Rostaman, Eds. 3rd ed.). Balai Pengujian Standar Instrumen Tanah dan Pupuk, Kementerian Pertanian RI. https://tanahpupuk.bsip.pertanian.go.id/berita/juknis-analisis-kimia-edisi-3-acuan-prosedur-analisis-tanah-tanaman-air-dan-pupuk

Herdiansyah, G., Arifin, M., & Suriadikusumah, A. (2022). The Pedogenesis of Inceptisols on Southeast Toposequence of Mount Manglayang in West Java, Indonesia. *Indonesian Journal on Geoscience*, *9*(2), 195-208. https://doi.org/10.17014/ijog.9.2.195-208

Hikmatullah, Suparto, Tafakresnanto, C., Sukarman, Suratman, & Nugroho, K. (2014). *Petunjuk Teknis Pedoman Survei dan Pemetaan Tanah Tingkat Semi Detail Skala 1:50.000* (S. Ritung, D. Subardja, M. Anda, & E. Suryani, Eds. 1st ed.). Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Penelitian dan Pengembangan Pertanian. https://nasih.staff.ugm.ac.id/wp-content/uploads/PetunjukTeknis-Survei-dan-Pemetaan-Sumberdaya-Tanah-Tingkat-Semi-Detail-Skala-150.000.-2014.pdf

Janaiah, A. (2020). Growth Performance and Value Addition of Rice Industry in India: Potential Opportunities and Challenges. *International Journal of Current Microbiology and Applied Sciences*, *9*(6), 2020. https://doi.org/10.20546/ijcmas.2020.906.254

Khadka, D. (2016). Assessment of relationship between soil organic matter and macronutrients, Western Nepal. *Journal of Biological ,Pharmaceutical And Chemical Research*, *3*(1), 4-12. https://www.jobpcr.com/archive/JOBPCR-2016-3-1-043-4-12.pdf

Kumar, R., Naik, B., Gurumurthy, K., Raghu, A., Dhanjaya, B., Sindhu, H., & Patil, A. (2019). Soil fertility status of available micronutrients and mapping in Beguru Microwatershed of Tarikere Taluk of Chikkmagaluru District, Karnataka, India. *Journal of Pharmacognosy and Phytochemistry*, *8*(4), 2598-2601. https://www.ijcmas.com/special/9/D.%20Ravi%20Kumar,%20et%20al.pdf

Ma, G., Cheng, S., He, W., Dong, Y., Qi, S., Tu, N., & Tao, W. (2023). Effects of Organic and Inorganic Fertilizers on Soil Nutrient Conditions in Rice Fields with Varying Soil Fertility. *Land*, *12*(5), 1026. https://doi.org/10.3390/land12051026

Makarim, A. K., & Suhartatik, E. (2006). Budidaya padi dengan masukan in situ menuju perpadian masa depan. *Iptek Tanaman Pangan*, *1*(2006), 19-29. https://garuda.kemdikbud.go.id/documents/detail/394922

Mariyono, J. (2018). Productivity growth of Indonesian rice production: sources and efforts to improve performance. *International Journal of Productivity and Performance Management*, *67*(9), 1792-1815. https://doi.org/10.1108/IJPPM-10-2017-0265

Michael, P. S. (2020). Soil fertility status and sweet potato cultivation in composted mounds under humid lowland tropical climatic conditions. *Sains Tanah - Journal of Soil Science and Agroclimatology*, *17*(2), 8. https://doi.org/10.20961/stjssa.v17i2.43426

Molina, F. V. (2016). *Soil colloids: properties and ion binding* (Vol. 156). CRC Press. https://doi.org/10.1201/b15349

Muhammad, & Wasit, U. (2019). *Kajian kesuburan tanah di Kabupaten Madiun* Seminar Nasional Dalam Rangka Dies Natalis UNS Ke 43 Tahun 2019: Sumber Daya Pertanian Berkelanjutan dalam Mendukung Ketahanan dan Keamanan Pangan Indonesia pada Era Revolusi Industri 4.0 http://repo.unida.gontor.ac.id/1075/7/KAJIAN%20KESUBURAN%20TANAH%20DI%20KABUPATEN%20MADIUN.pdf

Mujiyo, Sunarminto, B. H., Hanudin, E., & Widada, J. (2015). Soil Fertility Status of Organic Paddy Experiment. *Sains Tanah-Journal of Soil Science and Agroclimatology*, *12*(2), 61–66.

Mukashema, A. (2007). *Mapping and Modelling Landscape-based Soil Fertility Change in Relation to Human Induction* [Thesis, ITC University of Twenty, Enschede, The Netherlands]. https://webapps.itc.utwente.nl/librarywww/papers_2007/msc/nrm/mukashema.pdf

Nešić, L., Vasin, J., Belić, M., Ćirić, V., Gligorijević, J., Milunović, K., & Sekulić, P. (2015). The colloid fraction and cation-exchange capacity in the soils of Vojvodina, Serbia. *Ratarstvo i povrtarstvo/Field and Vegetable Crops Research*, *52*(1), 18-23. https://doi.org/10.5937/ratpov52-7720

Obalum, E. S., Nwite, C. J., Oppong, J., Igwe, A. C., & Wakatsuki, T. (2011). Variations in selected soil physical properties with landforms and slope within an inland valley ecosystem in Ashanti region of Ghana. *Soil and Water Research*, *6*(2), 73-82. https://doi.org/10.17221/17/2010-SWR

PPT. (1995). *Petunjuk Teknis Evaluasi Kesuburan Tanah. Laporan Teknis No.14. Versi 1,0. 1. REP II Project*. CSAR.

Pretty, J., & Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Annals of Botany*, *114*(8), 1571-1596. https://doi.org/10.1093/aob/mcu205

Purwaningsih, Y. (2008). Ketahanan pangan: situasi, permasalahan, kebijakan, dan pemberdayaan masyarakat. *Jurnal Ekonomi Pembangunan*, *9*(1), 1-27. https://doi.org/10.23917/jep.v9i1.1028

Roy, R., Misra, R., Lesschen, J., & Smaling, E. (2003). Assessment of soil nutrient balance: Approaches and methodologies. . *FAO Fertilizer and plant nutrition bulletin*, *14*. https://www.fao.org/3/y5066e/y5066e.pdf

Santosa, M., & Suryanto, A. (2015). The growth and yield of paddy Ciherang planted in dry and wet season and fertillized with organic and inorganic fertilizers. *2015*, *37*(1), 24-29. https://doi.org/10.17503/agrivita.v37i1.251

Siregar, P., Fauzi, & Supriadi. (2017). Pengaruh Pemberian Beberapa Sumber Bahan Organik dan Masa Inkubasi Terhadap. *Jurnal Online Agroekoteknologi*, *5*(2), 256-264. https://talenta.usu.ac.id/joa/article/view/2541

Solly, E. F., Weber, V., Zimmermann, S., Walthert, L., Hagedorn, F., & Schmidt, M. W. I. (2020). A Critical Evaluation of the Relationship Between the Effective Cation Exchange Capacity and Soil Organic Carbon Content in Swiss Forest Soils [Original Research]. *Frontiers in Forests and Global Change*, *3*. https://doi.org/10.3389/ffgc.2020.00098

Stehouwer, R. (2004). Soil Chemistry And The Quality Of Humus. *BioCycle*, *45*(4), 41. https://www.biocycle.net/soil-chemistry-and-the-quality-of-humus/#:~:text=Humus%2C%20like%20the%20clays%2C%20will,is%20often%20toxic%20to%20plants.

Suntoro. (2003). *Peranan Bahan Organik Terhadap Kesuburan Tanah dan Upaya Pengelolaannya*. https://suntoro.staff.uns.ac.id/files/2009/04/pengukuhan-prof-suntoro.pdf

Suntoro, Mujiyo, Hery, W., & Ganjar, H. (2020). Cultivation of Rice (Oryza sativa), Corn (Zea mays) and Soybean (Glycine max) Based on Land Suitability. *Journal of Settlements & Spatial Planning*, *11*(1), 9-16. https://doi.org/10.24193/JSSP.2020.1.02

Swain, N., Mishra, A., Saren, S., Dash, P. K., Digal, M., & Mishra, B. B. (2019). Soil Fertility Status of Some Villages in Khordha and Bhubaneswar Block of Khordha District under North Eastern Ghat Agro Climatic Zone of Odisha, India. *International Journal of Current Microbiology and Applied Sciences*, *8*(1), 415-423. https://doi.org/10.20546/ijcmas.2019.801.043

Zhao, C., Chen, M., Li, X., Dai, Q., Xu, K., Guo, B., . . . Huo, Z. (2021). Effects of Soil Types and Irrigation Modes on Rice Root Morphophysiological Traits and Grain Quality. *Agronomy*, *11*(1), 120. https://doi.org/10.3390/agronomy11010120