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The Assessment of Paddy Soil Fertility Status Based on Soil Fertility Index (SOFIX) in Tuban Indonesia

Abd. Aziz Amin[1*], Lutfi Nimatus Salamah[1], Attabik M. Amrillah[1], Hideki Okuda[2], and Andi Kurniawan[1]

[1]Faculty of Fisheries and Marine Science, Brawijaya University, Malang Indonesia Indonesia; e-mail: abd.azizamin@ub.ac.id
[2]Graduate School of Life Sciences, Ritsumeikan University, Japan

ABSTRAK

Padi merupakan salah satu komoditas pertanian utama yang dibudidayakan oleh petani di Kabupaten Tuban, Indonesia. Untuk meningkatkan produktivitas padi, evaluasi kesuburan tanah sangat penting dilakukan guna menentukan pemupukan yang tepat dan seimbang. Penelitian ini bertujuan untuk menilai status kesuburan tanah sawah di Kabupaten Tuban dengan menggunakan metode Soil Fertility Index (SOFIX) untuk mengidentifikasi keterbatasan unsur hara dan memberikan rekomendasi pengelolaan yang sesuai. Sampel tanah dikumpulkan dari lahan pertanian yang terintegrasi dengan sistem pertanian organik. Hasil penelitian menunjukkan jumlah bakteri yang rendah serta aktivitas sirkulasi nitrogen dan fosfor yang lemah. Parameter kimia, termasuk karbon total, kalium total, nitrogen total, dan fosfor total juga berada di bawah tingkat optimal. Temuan ini menunjukkan bahwa tanah sawah di Kabupaten Tuban berada pada kondisi kesuburan rendah. Oleh karena itu, penambahan bahan organik direkomendasikan untuk meningkatkan aktivitas mikroba, memperbaiki siklus hara, dan memulihkan kesuburan tanah guna mendukung produksi padi yang berkelanjutan.

Kata kunci: tanah sawah, kesuburan tanah, bahan organik, SOFIX

ABSTRACT

Rice is one of the main agricultural commodities cultivated by farmers in Tuban Regency, Indonesia. To improve rice productivity, evaluating soil fertility is essential for determining appropriate and balanced fertilization. This study aimed to assess the fertility status of paddy soils in Tuban Regency using the Soil Fertility Index (SOFIX) method to identify nutrient constraints and recommend suitable management practices. Soil samples were collected from agricultural areas integrated with organic farming systems. The results showed low bacterial number and weak nitrogen and phosphorus circulation activities. Chemical parameters, including total carbon, total potassium, total nitrogen, and total phosphorus, were also below optimal levels. These findings indicate that the paddy soils in Tuban Regency are in a low-fertility condition. Therefore, the application of organic materials is recommended to enhance microbial activity, improve nutrient cycling, and restore soil fertility for sustainable rice production.

Keywords*:* paddy soil, Soil fertility, organic materials, SOFIX

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1. INTRODUCTION

Rice is a one of the strategic commodities in Indonesia (Bowo and Nurayati, 2016). Rice is a very important food crop of the population in Indonesia (Sutardi et al., 2022). One of the national rice barns is in Tuban Regency (Ratnasari, 2021). The agriculture-integrated areas in the Tuban Regency create to increase rice productivity. This area was integrated with another sector to be organic systems. Organic rice field management is strongly influenced by the level of soil fertility; therefore, the evaluation of soil fertility is important. Paddy soil with soil fertility will increase productivity, otherwise low soil fertility will decrease rice productivity (Haque et al., 2021). Low fertility in the soil implies a lack of qualities that allow it to provide sufficient amounts of nutrients and compounds (Bashagaluke et al., 2018). Decreasing soil fertility occurs when the quantities of nutrients removed from soil (Tan et al., 2005). Declining of such as indicator of soil fertility is reducing of soil biodiversity such as soil microorganisms, organism and activity of biological aspect in soil (Tibbett et al., 2020). Indicators of soil fertility consisted of physical, chemical and biological (Adhikari et al., 2014).

Basically, biological factors such as microorganisms have important role in soil fertility (Pholkaw et al., 2020).

In Tuban and other agricultural regions of East Java, conventional soil fertility evaluation methods have typically focused on chemical and physical indicators, such as soil pH, cation exchange capacity (CEC), total nitrogen, available phosphorus, and organic carbon content. These traditional methods have been widely used by local agricultural agencies and research institutions to assess soil nutrient status and fertility level. However, while these approaches effectively describe the nutrient composition and physicochemical properties of soil, they often fail to capture the biological aspect of soil fertility, including microbial biomass, diversity, and enzymatic activity that directly influence nutrient cycling and organic matter decomposition. To overcome these limitations, the Soil Fertility Index (SOFIX) was developed as a more comprehensive approach integrating biological, chemical, and physical properties of soil. The main advantage of SOFIX compared to conventional methods lies in its ability to quantify the biological functions of soil, especially the role of microorganisms and their activity as the main determinant of fertility. Moreover, SOFIX provides standardized reference values based on a large database of soil samples, allowing more accurate benchmarking of soil fertility status under various land management systems. This method is therefore considered more suitable for evaluating the fertility of paddy soils in organic and sustainable agricultural systems such as those in Tuban Regency. To overcome these limitations, the Soil Fertility Index (SOFIX) was developed as a comprehensive method that integrates biological, chemical, and physical properties of soil (Adhikari et al., 2014). The distinctive advantage of SOFIX compared to traditional methods lies in its biological-based assessment, which focuses on microbial biomass and activity as key determinants of soil fertility. SOFIX considers microorganisms not only as indicators but as active agents that regulate nutrient transformation and sustainability. Additionally, the SOFIX database, constructed from approximately 8,000 agricultural soil samples, provides standardized reference values for optimal soil conditions, including total carbon (25,000 mg/kg), total nitrogen (1,500 mg/kg), total phosphorus (1,100 mg/kg), and total potassium (2,500–10,000 mg/kg). This allows more accurate benchmarking and comparison of soil fertility status across regions and farming systems.

Generally, evaluating soil fertility is important to assess quantity of organic matter, total microbial soil, decomposition of organic matter, nutrient circulation (Adhikari et al., 2014). Soil Fertility assessment is important to identify problem areas or require appropriate specialized management (Pandit and Balla, 2006). One way to evaluate soil fertility status is to use Soil Fertility Index (SOFIX) database (Adhikari et al., 2014; Sasongko et al., 2020).

SOFIX developed based on the biological aspect of soil fertility (Adhikari et al., 2014). The concept of SOFIX, microorganisms and its activities are the main factors that determine soil fertility. In this article, we characterize soil conditions based on SOFIX parameters for assessment paddy soil.

In previous studies, SOFIX was used to evaluate the condition of soil fertility and organic farming systems (Adhikari et al., 2014). SOFIX has built on the importance of the biological, chemical, and physical qualities of the soil. The fundamental factor determining soil fertility is the circulation activity of nitrogen and phosphorus (Babur, 2018).

A SOFIX baseline was constructed from around 8000 agricultural soil samples that were evaluated. According to According to the SOFIX database, the optimal to sustain bacterial biomass and activity of 6×108 cells/g-soil, soil conditions for soil samples include total carbon (TC) 25,000 mg/kg, total nitrogen (TN) 1500 mg/kg, total phosphorus (TP) 1100 mg/kg, and total potassium (TK) 2500 to 10000 mg/kg. Using biomass resources, Organic Standard land was created based on the SOFIX database. The essential elements (nitrogen, phosphorous, and potassium) are present in sufficient amounts, and ordinary organic soils include a wide variety of microbial organisms (Pholkaw et al., 2019). Therefore, this study aimed to assess paddy soil fertility status-based soil fertility index (SOFIX) in Tuban Indonesia.

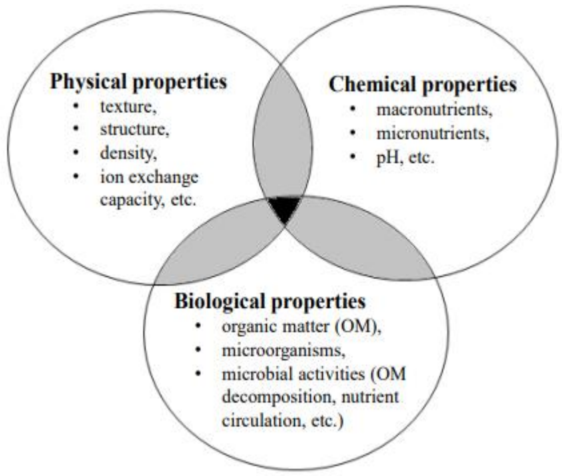

Figure 1. Schematic Illustrates the Biological, Chemical, and Physical Elements that Determine Soil Fertility (Adhikari et al., 2014)

2. METHODOLOGY

2.1. Estimation of Soil Microbial Number

To estimate of soil microbial number followed method from (Aoshima et al., 2006). Environmental DNA (eDNA) and the low stirring approach were used to estimate the total number of bacteria in the soil 8.0 mL of eDNA buffer, 1 mL of 20% sodium dodecyl sulfate (SDS) solution, and 1 g of soil material were combined. As a result, the suspension was agitated for 20 minutes at 1,500 rpm, then centrifuged for 10 minutes at 6,000 g. After centrifuging the supernatant at 18,000 g for 10 minutes, it was combined with a

24:1 (v/v) mixture of chloroform and isoamyl alcohol. The crude nucleic acid was processed using a combination of 500 mL of aqueous phase and 300 mL of isopropanol, followed by 20 minutes of centrifugation at 18,000 rpm. The residue was dissolved in 1 TE buffer (10 mM Tris-HCl and 1 mM EDTA, pH 8.0). KODAK 1 D 3.6 Image Analysis Software (Eastman Kodak Company, CT, USA) was used to measure eDNA based on the intensity of the band after 1% agarose gel electrophoresis.

2.2. Estimation of Material Circulation Activity (Phosphorous and Nitrogen)

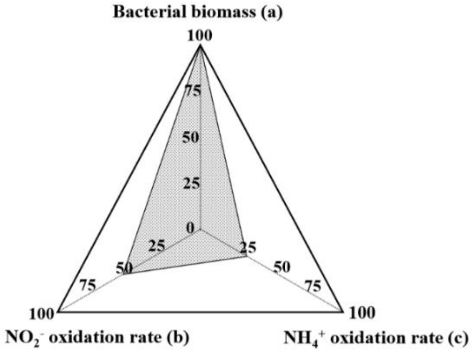

Figure 2. N Circulation Activity is Calculated Using a Radar Chart (Adhikari et al., 2014)

According Adhikari et al., 2014, states that the ammonium and nitrite oxidation rates in the soil were measured by adjusting the water holding capacity to 60% to estimate Nitrogen circulation activity. The soil's bacterial biomass, ammonium oxidation rate, and nitrite oxidation rate were all assessed in this study. Following that, the soil sample was treated with ammonium sulfate or sodium nitrite (60 g N g-1 dry soil). A soil sample that had not been treated with sodium nitrite or ammonium sulfate was incubated at 25°C in a control experiment. After three days, the percentage of excess N reduction was estimated using the rate of ammonium or nitrite oxidation. Bacterial biomass is determined as 100 points for 6.0 108 cells per gram of soil and 0 points for 2.0 108 cells per gram of soil. The results of (Figure 2).

The inner triangle's area on the radar chart is determined as follows:

$$\text{Area} = \frac{(a \times b) + (b \times c) + (c \times a)}{4} \times \frac{\sqrt{3}}{100}$$

The size of the inner triangle in the radar chart is determined where a, b, and c are the scores of bacterial counts, ammonium oxidation rate, and nitrite oxidation rate, respectively. The relative area of the inner triangle was calculated to examine nitrogen circulation activity as follows:

$$\text{N } cactivity\ (point) = \frac{Area\ of\ the\ inner\ triangle}{Area\ of\ the\ outer\ triangle} \times 100$$

The soluble P generation from organic P in the soil is used to assess the activity of phosphorous (P) circulation. Phytate served as the substrate. First, a phytate solution (pH 7.0) containing 3.9 mg of phosphorus was combined with 1.0 g of soil sample, and the combination was incubated at room temperature for three days with a 6-% water holding capacity. A control experiment (without phytate) was carried out concurrently. Before molybdenum blue analysis, the soluble phosphorous (SP) from the incubated 1.0 g soil sample was extracted with 20 mL of distilled water. The P circulation activity was defined as the increase in soluble phosphorus in the soil following three days of phytate application. The circulatory activity was assessed in points, with 0 being the lowest.

Table 1. SOFIX Contents Parameter

No	Parameter	Type of Analysis	Recommendation SOFIX Value
1	NO3-	Chemical analysis	≥10 mg/kg
2	NH4+		≥10 mg/kg
3	K+		≥50 mg/kg
4	Soluble P		≥50
5	EC		0,2 – 1,2
6	pH		5,4 – 6,5
7	Total carbon (TC)	Evaluation of biomass	≥25.000 mg/kg
8	Total nitrogen (TN)		≥1.500 mg/kg
9	Total Phosphorous (TP)		≥1.100 mg/kg
10	Total Potassium (TK)		2.500 – 10.000 mg/kg
11	C/N ratio		10 - 20
12	C/P ratio		23 - 24
13	Bacterial number	Soil bacterial activity	6 × 10^8 cell/gr-1 soil
14	Ammonium oxidation	Nitrogen circulation	≥41 points
15	Nitrite Oxidation		≥71 points
16	Nitrogen circulation activity		≥ 38 points
17	Phytase activity	Phosphate circulation	≥30 points
18	Water holding capacity	Physical analysis	400 – 500 ml/kg
19	Water content		≥20%

2.3. Assessment of Soil Fertility Status Based on Soil Fertile Index (SOFIX)

Soil fertile index is an evaluation method to measure of indicators of soil health as a number through diagnosing and analysing the three indicators of microbe number, nitrogen activity and phosphorous activity in the soil environment (Adhikari et al., 2014). The soil fertility index (SOFIX) was created with the relevance of biological components in soil fertility in mind (Adhikari et al., 2014). All parameters of SOFIX were used to analyse of soil sample, parameters include of chemical analysis, evaluation of biomass, soil bacterial activity, nitrogen and phosphate circulation and physical analysis (Table 1).

3. RESULTS AND DISCUSSION

3.1. Analysis of Soil Microbial Number

Effectiveness of the performance of the to investigate soil fertility status in the soil is the analysis of bacterial activity. Soil microbial number was analysed by using the environmental DNA (eDNA) method. The eDNA method is a method for calculating the number of bacteria. The eDNA method is to evaluate the number of soil microorganisms by calculating the amount of DNA in the microorganisms in the soil (Adhkari et al., 2014; Aoshima et al., 2006). Soil microorganisms are regarded as key indicators of soil health and quality (Kai et al., 2016). Analysis of soil microbial number shows average soil microbial number 3,37 $\times 10^8$ cell/g-1 soil representing from soil. The figure of gel electrophoresis was shown in Figure 3. Based on the suggested setting for SOFIX. The recommended number of total bacteria per gram of soil for organic farming is >6.0×10^8 cells/g-soil. The following six classes of bacterial biomass concentrations in soil were identified: Extremely low cell density (>1.0×10^8 cells/g), very low cell density (1.0×10^8 to 2.9×10^8 cells/g-soil), low cell density (>3.0×10^8 to 4.4 ×10^8 cells/g), medium cell density (4.5×10^8 to 5.9×10^8 cells/g-soil), moderate cell density (6.0×10^8 to 9.9×10^8 cells/g-soil), and very high cell density (10.0×10^8 cells/g-soil) (Adhkari et al., 2014).

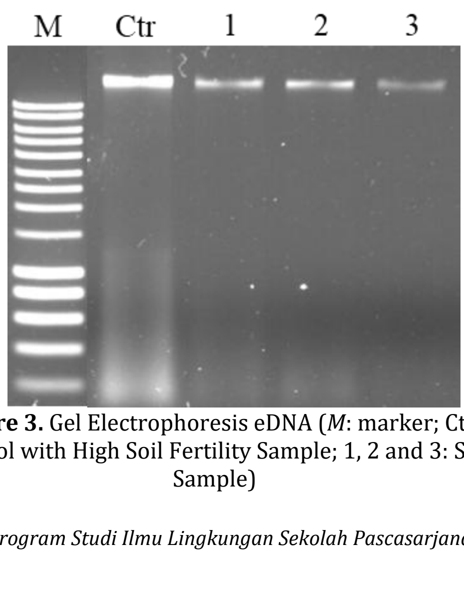

Figure 3. Gel Electrophoresis eDNA (*M*: marker; Ctr: Control with High Soil Fertility Sample; 1, 2 and 3: Soil Sample)

3.2. Analysis of Material Circulation Activity (Phosphorous and Nitrogen)

Materials circulation activities are important in soil fertility (Li et al., 2022). Materials circulation consists of nitrogen (N) and phosphorous (P). Nitrogen and phosphorous are the two most limiting plant nutrients in soil for plant growth (Adhkari et al., 2014; Morgan and Connolly, 2013). In material circulation processes, microorganisms play an essential role in the transformation and cycling of nutrients such as nitrogen and phosphorus. These microorganisms decompose organic matter, convert complex nitrogen and phosphorus compounds into simpler, plant-available forms (such as nitrate and phosphate), and thus maintain soil fertility. In other words, microorganisms do not “recognize” these nutrients but rather use and transform them as part of their metabolic processes. Nitrogen has an important role for rice plants by promoting rapid plant growth, improving yield levels and grain quality through increasing tiller number, enhancing leaf area development, supporting grain formation and filling, and facilitating protein synthesis. Figure 4 displays the outcomes of nitrogen circulation activities. The findings demonstrate that the soil sample still met SOFIX requirements. A series of repetitive processes called the nitrogen cycle include the movement of nitrogen through both living and non-living substances. While combining the scores of bacterial biomass, ammonium oxidation rate, and nitrite oxidation rate to represent the N circulation activity shown in Figure 5.

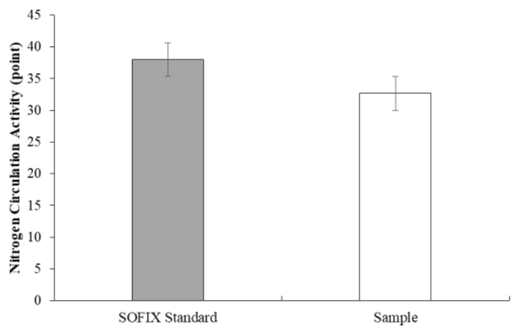

Figure 4. Nitrogen Circulation Results

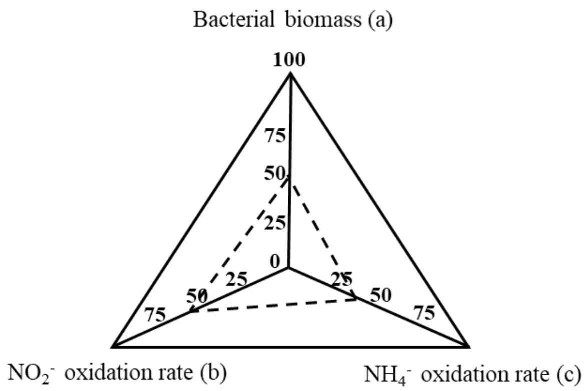

Figure 5. Radar Chart Used to Calculate n Circulation Activity

Table 2. SOFIX Assesment Value

No	Parameter	Recommendation SOFIX Value	Assement Value	Evaluation
1	NO^{3}-	≥10 mg/kg	11	↑
2	NH^{4}+	≥10 mg/kg	40	↑
3	K+	≥50 mg/kg	40	↓
4	Soluble P	≥50	45	↓
5	EC	0,2 – 1,2	0,3	↑
6	pH	5,4 – 6,5	7	↑
7	Total carbon (TC)	≥25.000 mg/kg	16300	↓
8	Total nitrogen (TN)	≥1.500 mg/kg	227	↓
9	Total Phosphorous (TP)	≥1.100 mg/kg	631	↓
10	Total Potassium (TK)	2.500 – 10.000 mg/kg	651	↓
11	C/N ratio	10. 20	72	↑
12	C/P ratio	23 - 24	26	↑
13	Bacterial number	6×10^{8} cell/gr	3,7	↓
14	Ammonium oxidation	≥41 point	50 points	↑
15	Nitrite Oxidation	≥71 points	25 points	↓
16	Nitrogen circulation activity	≥ 38 points	33	↓
17	Phytase activity	≥30 points	20	↓
18	Water holding capacity	400 – 500 ml/kg	450 ml/kg	◯
19	Water content	≥40%	38%	↓

On the other hand, the average phosphorous circulation activity resulted in a 20 point score (Figure 6). In contrast, the SOFIX high value for P circulation activity was 100 points. According to Adhkari et al. (2014) and Morgan and Connolly (2013), The capacity of the soil to provide soluble phosphorus from the organic phosphorus in the soil solution is measured by phosphorus circulation activity. Phosphorus is an essential nutrient for plants in both organic and inorganic forms, and phytate is an important source of organic phosphorus in soil (Issifou et al., 2022). According to Alori et al. (2017), soil microorganisms convert organic phosphorus (such as phytate) into inorganic phosphates.

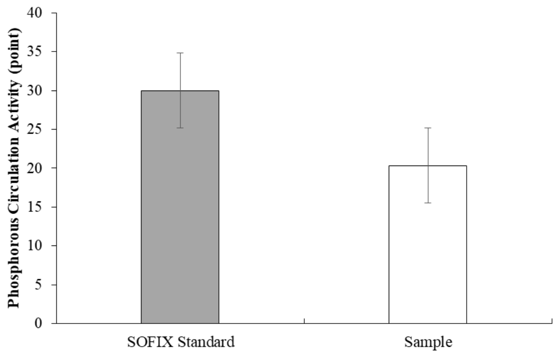

Figure 6. Phosphorous Circulation Results

3.3. Soil Fertility Status Based on Soil Fertile Index (SOFIX)

The results assessment of paddy soil based on SOFIX showed in Table 2. All parameters of soil sample were analysed based on SOFIX. Parameters include chemical analysis, evaluation of biomass, soil bacterial activity, nitrogen and phosphate circulation and physical analysis. Based on the SOFIX recommendation values, the paddy soil samples indicate that bacterial activity needs to be improved through the addition of organic fertilizers. The SOFIX method emphasizes maintaining adequate soil microbial biomass and activity as a key factor in sustaining soil fertility. Therefore, supplementing the soil with organic fertilizers such as compost or manure can help provide nutrients and energy sources for microorganisms, thereby enhancing biological activity and improving the overall fertility of the paddy soil.

4. CONCLUSION

This study showed that Paddy Soil Fertility Status in Tuban Indonesia was categorized in low soil fertility based on SOFIX analysis. This is suggested that this is caused by the agrochemical effect. The agrochemical used effect on availability of total microorganisms number, then this caused low fertility soil. Therefore, to recover the soil fertility need to investigate suitable organic materials. The suitable organic material will enhance of soil microorganisms in low fertility agricultural soil. Added of organic materials have effect on soil organic carbon. Increase of total carbon was also increase of total bacterial number.

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