International Journal of Design & Nature and Ecodynamics
Vol. 17, No. 6, December, 2022, pp. 929-936
Journal homepage: http://iieta.org/journals/ijdne

A Modified Soil Fertility Assessment Method Using Earthworm Density and Microbial Biomass C at Various Land Uses in Wonogiri, Indonesia

Widyatmani S. Dewi[1*], Alfiana Puspaningrum[2], Riris S.T. Tinuntun[2], Suntoro Suntoro[1], Mujiyo Mujiyo[1]

[1] Soil Science Department, Faculty of Agriculture, Universitas Sebelas Maret, Surakarta 57126, Indonesia
[2] Undergraduate Student of Soil Science Department, Faculty of Agriculture, Universitas Sebelas Maret, Surakarta 57126, Indonesia

Corresponding Author Email: widyatmanisih@staff.uns.ac.id

https://doi.org/10.18280/ijdne.170614

Received: 21 September 2022
Accepted: 10 December 2022

Keywords:
conventional methods, determinant indicators, minimum data set, modified method, soil biological indicator

ABSTRACT

Soil fertility is the integrative effect of chemical, physical, and biological soil properties. A modified soil fertility assessment method that adds biological indicators is essential since this indicator is sensitive to dynamic environmental changes and can better represent the reality of soil fertility compared to the conventional method, which only considers chemical soil properties. The research aims to compare the modified and conventional methods in assessing the soil fertility index at various land uses, namely gardens, paddy fields, and moorland, in the Girimarto district, Wonogiri, Indonesia. The collection of soil samples used purposive sampling with three repetitions on 12 land mapping units (LMUs) obtained from an overlay of land use maps, soil type maps, slope gradient maps, and rainfall maps. Soil fertility index (SFI) assessment is based on the Minimum Soil Fertility Indicators (MSFI), which are selected from Pearson correlation, PCA, weight, and score and followed by stepwise regression analysis. The research showed that the modified method represents the soil fertility level better than the conventional one. The soil fertility index on three land uses using the modified method is lower than the conventional method, i.e., between 0.33 to 0.40 and 0.55 to 0.72, respectively. The modified method is more sensitive to dynamic environmental changes due to the contribution of soil biological indicators to the SFI value. Therefore, the biological indicators can represent soil fertility levels closer to reality. Future research needs to validate the modified method in different soil types, land uses, and areas.

1. INTRODUCTION

Soil fertility is the capacity or ability of the soil to provide nutrients for plants in an amount that is available and balanced [1]. Evaluation of soil fertility aims to evaluate the availability of nutrients in the soil. In addition, soil fertility evaluation can be used to identify the response of plants to soil management practices [2]. Numerous researchers have studied soil fertility using a method involving soil analysis and calculating soil fertility index. The soil fertility index is most commonly calculated using soil chemical indicators such as pH, organic C, organic matter, total N, P, K, available N, P, K, CEC, and base saturation [3-6]. The evaluation of the soil fertility index has not considered the biological properties of the soil that can affect soil fertility. In this research, we call these assessments the conventional method. So, it is necessary to implement a modified method in the soil fertility index assessment since soil fertility is an integrative effect of soil's chemical, physical and biological properties.

In this research, we propose a modified method by adding soil biological indicators, specifically earthworm population density and microbial biomass C. Biological indicators can serve as an early indication of the effects of soil management practices [7, 8]. Earthworms and microbial biomass C respond well to changes in soil properties and environmental conditions [9]. Fertile soil conditions are directly evident from the abundance of earthworms. High nutrient availability is also indicated by the increased population and activity of soil microbes in the decomposition process of soil organic matter [10]. Therefore, adding biological indicators in the modified method is hoped to ensure a better soil fertility evaluation closer to reality.

Girimarto District, Wonogiri, Indonesia, is where 97.4% of the total administrative area is productive agricultural land. There are three types of agricultural land use in this area: paddy fields, moorland, and gardens. Paddy is continuously grown for a year in paddy fields by communities in the Girimarto District, with two to three growing seasons per year. Traditional methods of paddy cultivation typically involve high doses of inorganic fertilizer and pesticides. Organic fertilizer is infrequently used, and only a small number of farmers engage in organic rice farming. Dry land that is useful for farming is called moorland. To meet their daily needs, farmers grow annual crops like rainfed rice, corn, and cassava. When growing moorland crops, inorganic fertilizers are not used as intensively as they are when growing paddy rice. Gardens produce perennial trees such as teak (*Tectona grandis*), sengon (*Paraserianthes falcataria*), acacia (*Acacia mangium*), and other economically valuable trees. Farmers let the fallen litter remain on the soil surface and do not manage it. This land usually uses fertilizer very rarely, only in the first planting.

Managing productive agricultural land while neglecting soil conservation will result in a decline in soil fertility and quality [11], and over time, it will impact crop yields and decrease people's income [12]. Improper land management can happen because there is no accurate information regarding the soil fertility level in this area that farmers can use as a reference for managing agricultural land. However, it is crucial to evaluate soil fertility status and determine the best strategy for soil management practices.

In connection with the problems above, this study aims to determine the soil fertility level of different land uses in the Girimarto district through a comparison of methods for assessing the soil fertility index, modified by adding biological indicators, and conventionally using only chemical properties. In the modified method, the potential of microbial C biomass and earthworm population density will also be evaluated as good indicators of soil biology in assessing soil fertility. The results of this study are expected to produce the correct information for farmers to manage agricultural land, which pays attention to soil conditions chemically and biologically.

2. METHODOLOGY

2.1 Description of the studied area

The research was located in Girimarto District, Wonogiri Regency, Central Java Province, with coordinates 7°49'18.7"S 111°02'28.2"E and 7°42'47.8"S 111°09'42.0"E. Girimarto district has an administrative area of 6,057.3 ha [13]. The altitude is 100–600 m above sea level, with flat to very steep slope conditions. The topography includes an average incline of 30° and Alfisols and Inceptisols soil types. Girimarto district has an average annual rainfall of 2,250–3,250 $mm.y^{-1}$.

Land use in the Girimarto district consists of rice fields, dry land (moorland and gardens), yards and buildings, forest, grassland, and another land use [13]. In this study, we evaluated soil fertility index in paddy fields, moorland, and gardens because the community often uses this land as productive agricultural land. Paddy fields, with an area of 2,820 ha, are the largest and one of the main cultivation areas of farming communities. They are planted with rice (*Oryza sativa*) with intensive soil management, and sometimes they leave crop residues on the land. The garden, with an area of 831.5 ha, is one of the annual crop cultivation areas with *Paraserianthes falcataria* and *Tectona grandis*. Soil management in the gardens was carried out without fertilizer and only relied on plant litter. In contrast to gardens, moorlands were treated with inorganic fertilizer. There are seasonal crops in the moorland, such as corn (*Zea mays*) and cassava (*Manihot esculenta*), with an area of 801.5 ha.

2.2 Sampling point

Representative samples of *Tectona grandis* and *Paraserianthes falcataria* earthworms were collected from the garden area's soil. The cassava and corn plants' representative samples came from the moorland, while low land paddy fields are represented by the paddy field sample.

Samples were taken in gardens, rice fields, and moorlands based on LMUs. LMU is obtained from the overlay of land use maps, soil type maps, slope gradient maps, and rainfall maps (Figure 1). There were 12 LMUs. Soil samples and earthworm specimens were collected using a purposive sampling method with three replications for each LMU. Paddy fields have the most significant area, represented by 5 LMUs (15 sample points); moorland, with the second-largest area, has 4 LMUs (12 sample points); and gardens have the narrowest area, represented by 3 LMUs (9 sample points). Soil samples were collected using a soil drill to a depth of 30 cm. Meanwhile, the specimens of earthworms were collected using the monolith method with a size of 25 cm x 25 cm and a depth of 30 cm, and then the earthworm population density was calculated based on [14].

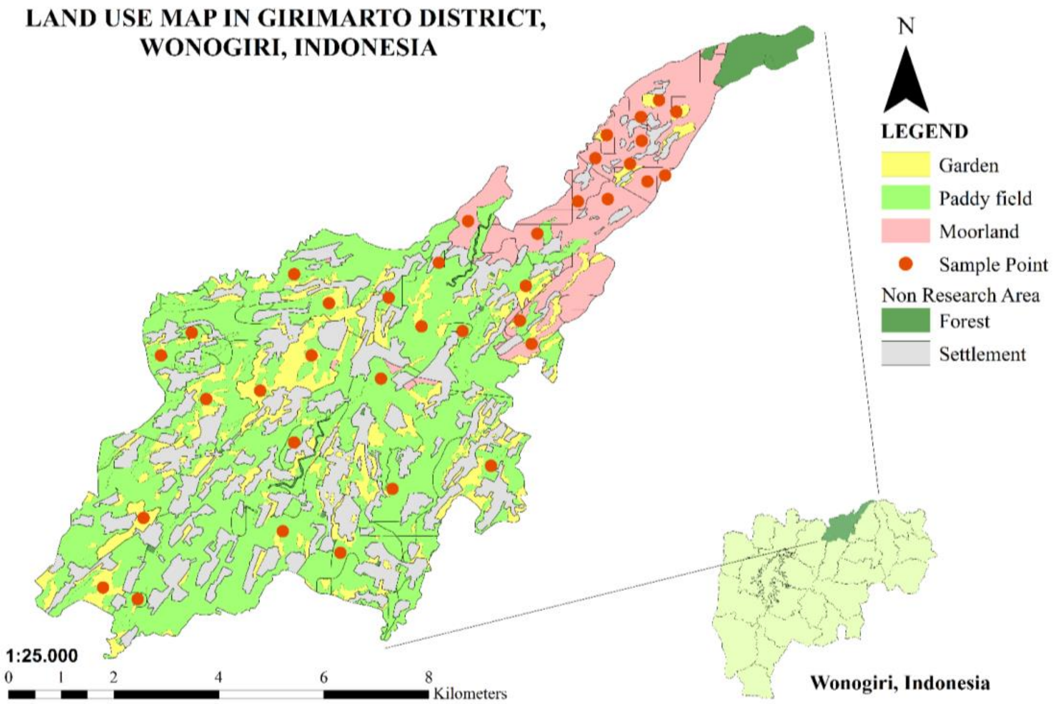


Figure 1. Land mapping units and sample collection points

2.3 Computation of Soil Fertility Index (SFI)

The analysis of the soil fertility index used three main steps: (1) selecting the soil indicators and determining their weight, (2) calculating the score of each indicator, and (3) integrating the indicator scores into the overall soil fertility index [15]. Soil analysis included soil pH, organic matter, total-N, available-P Olsen, base saturation, CEC, Ca, Mg [16], available-N [17], earthworms population density [14] and microbial biomass C [18]. Table 1 shows the different indicators used to evaluate modified and conventional methods of soil fertility index.

The soil fertility index for the two methods was calculated using the Minimum Soil Fertility Indicators (MSFI) based on the results of a Pearson's correlation test and Principal Component Analysis (PCA). The selected indicators as the MSFI in the PCA analysis had an eigenvalue >1 and a high-value weight [19] and showed a significant correlation between indicators (P-value<0.05). The significant correlation between indicators demonstrated a high sensitivity level representative of the soil's properties. The calculation of the soil fertility index is based on formulas below [20].

$$cj = wi \times si \tag{1}$$

cj is the MSFI weighting, *wi* is the index weight obtained from proportion divided by cumulative in PCA analysis, and *si* is the indicator score.

$$pc = \frac{1}{nc} \tag{2}$$

pc is the probability of SFI class for each MSFI indicator and *nc* is the number of SFI classes, namely five, according to [21].

$$SFI = \left(\frac{\Sigma_{i=1}^{n} Sci}{n} \right) \times 10 \tag{3}$$

Sci is the MSFI value obtained by multiplying the MSFI weighting (cj) (Eq. (1)) with the SFI class probability (*pc*) (Eq. (2)).

2.4 Data analysis

A one-way ANOVA test was carried out to discover any influence of land use on the soil fertility index. The result of the one-way ANOVA test, which showed a P-value < 0.05, was then followed by Duncan's multiple range test to find the difference between the SFI index.

It is essential to find the main determinant indicators to help develop a priority strategy to improve the soil fertility level at the research location. Stepwise regression is performed to find the main determinant indicators of SFI. The data sources were the minimum soil fertility indicators (MSFI). An MSFI with a highly significant correlation coefficient with the SFI is selected as the main determining indicator of the soil fertility index. If it was founded on more than two main determinant indicators, it was continued to calculate by stepwise regression. The main indicators with the highest R^2 adjusted were chosen as the main determinant indicators.

3. RESULTS AND DISCUSSION

3.1 Soil properties in Girimarto District, Wonogiri

Soil pH in the three different land uses slightly acidic with an average of 6.3. Land use has no significant effect (p>0.05) on pH (Table 2). Soils with slightly acidic pH also show that base saturation is lower than the CEC. The average base saturation is 24.29% with a low level, while the average CEC is 36.48meq.100g^{-1} with a high level (Table 2). Soil pH can reflect the condition of base saturation in the absorption complex [22]. The soil layer binds more H^+ and Al^{3+} ions than cations, making the soil pH acidic. The availability of Ca and Mg ions is also limited, causing the base saturation level to be lower, with the CEC value remaining high [23].

Soil organic matter (SOM) content is not affected (p>0.05) by differences in land use (Table 2). The average value of SOM is 2.43%, a moderate level. Immersing crop residues into the soil will increase the soil's organic matter content and serve as a source of nutrients [24]. The high SOM content will bind nutrients to the soil [25], as shown by a moderate level of total-N and available K content with an average of 0.25% and 0.46 meq.100g^{-1}, respectively. In contrast, available-P levels showed deficient levels with an average of 3.15 ppm. The low-level availability of P in the soil is related to acid soil pH, which causes the availability of P in the soil to be limited [26].

Table 1. Differences in indicators in the assessment of soil fertility index with conventional and modified methods

Soil indicators	Unit	Conventional method	Modified method	Analysis methods
pH	-	✓	✓	Potentiometry
Organic matter	%	✓	✓	Walkley & Black
Total-N	%	✓	✓	Kjeldahl
Available-P	ppm	✓	✓	Olsen
Base saturation	%	✓	✓	Flamefotometry
Cation Exchange Capacity (CEC)	meq.100g^{-1}	✓	✓	NH4OAc 1 N pH 7
K	meq.100g^{-1}	✓	✓	NH4OAc 1 N pH 7
Ca	meq.100g^{-1}	✓	✓	NH4OAc 1 N pH 7
Mg	meq.100g^{-1}	✓	✓	NH4OAc 1 N pH 7
Available-N	kg.ha^{-1}	✓	✓	Alkaline Hydrolisys
Earthworm population density (EPD)	individual.m^{-2}	-	✓	Monolith and hand sorting
Microbial biomass C (MBC)	µg.g^{-1}	-	✓	Soil respiration

Table 2. Chemical and biological properties of soil on various land uses in Girimarto district, Wonogiri

No.	Soil fertility indicators	*P-value*	Gardens	Paddy field	Moorland
1	pH	0.23	6.14a	6.44a	6.33a
2	Organic matter (%)	0.54	2.34a	2.64a	2.33a
3	Total-N (%)	0.80	0.27a	0.25a	0.24a
4	Available-N ($kg.ha^{-1}$)	0.04	84.09b	70.14ab	57.98a
5	Available-P (ppm)	0.22	2.91a	3.42a	3.14a
6	Available-K ($meq.100g^{-1}$)	0.60	0.45a	0.49a	0.44a
7	CEC ($meq.100g^{-1}$)	0.50	38.62a	38.36a	32.48a
8	Base saturation (%)	0.10	16.06a	29.74a	27.08a
9	Available Ca ($meq.100g^{-1}$)	0.00	2.94a	7.08c	4.99b
10	Available Mg ($meq.100g^{-1}$)	0.00	0.37a	0.65b	0.46a
11	Earthworm population density ($individual.m^{-2}$)	0.25	32a	50a	58a
12	Microbial biomass C ($\mu g.g^{-1}$)	0.05	0.37a	0.50b	0.50b

Notes: Numbers followed by the same letter in the same row are not significantly different at α 5%; CEC= cation exchange capacity.

Table 3. Pearson correlation of soil fertility indicators in Girimarto District, Wonogiri

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	1											
2	0.720*	1										
3	0.499	0.281	1									
4	-0.253	-0.186	0.549	1								
5	0.308	0.188	-0.214	-0.398	1							
6	-0.232	-0.190	-0.484	0.071	0.379	1						
7	-0.462	-0.240	-0.338	0.352	-0.140	0.145	1					
8	0.595	0.342	-0.005	-0.485	0.548	0.337	-0.679	1				
9	0.583	0.220	0.016	-0.271	0.633	0.379	-0.240	0.829**	1			
10	0.511	0.180	-0.020	-0.149	0.711*	0.491	-0.067	0.708*	0.961**	1		
11	0.089	0.153	-0.629	-0,864**	0.099	-0.103	-0.126	0.326	0.188	0.065	1	
12	0.456	0.176	-0.069	-0,553	0.713*	0.157	-0.458	0.813**	0.791*	0.672*	0.291	1

Notes: *) Significant (P-value <0.05); **) very significant (P-value <0.01); 1= pH; 2= organic matter (OM); 3= Total-N; 4= Available-N (AN); 5= Available-P (AP); 6= Available K; 7= CEC; 8= Base saturation; 9= Ca; 10= Mg; 11= Earthworm population density (EPD); 12= Microbial biomass C (MBC)

Meanwhile, land uses have a significant effect ($p<0.05$) on available-N, with values in gardens, paddy fields, and moorland being 84.09 $kg.ha^{-1}$, 70.14 $kg.ha^{-1}$, and 57.98 $kg.ha^{-1}$, respectively (Table 2). The available-N shows a poor state. Available Ca and Mg were significantly affected ($p<0.05$) by land uses, and this is in line with [27] research results. The highest available Ca was found in paddy fields, 7.08 $meq.100g^{-1}$, followed by moorland, 4.99 $meq.100g^{-1}$, and gardens, 2.94 $meq.100g^{-1}$. Likewise, the Mg content shows the highest value in paddy fields, 0.65 $meq.100g^{-1}$, followed by moorland, 0.46 $meq.100g^{-1}$, and gardens, 0.37 $meq.100g^{-1}$.

Analysis of soil biological indicators showed that land uses significantly ($p<0.05$) affected microbial biomass C but had no significant effect ($p>0.05$) on earthworm population density (Table 2). Garden had the lowest microbial biomass C content of 0.37 $\mu g.g^{-1}$ and was significantly different from paddy fields and moorland, each 0.50 $\mu g.g^{-1}$. The earthworm population density of three land uses had a low value with an average of 47 $individuals.m^{-2}$ is presumably related to low organic matter content and soil moisture, especially in gardens. According to [28], earthworms are likely found more in the fields with the high availability of organic matter in the soil, which enables the earthworms to obtain more food and transform it to become available nutrients for crops and soil microbes. The high availability of nutrients can stimulate the growth of beneficial microbes faster [29].

3.2 Minimum data set of soil fertility

A minimum data set of soil properties indicators is needed to evaluate the soil fertility index. The minimum indicator data set is selected from several measured soil properties correlated with one another (Table 3). The next step is to analyze the correlated indicators using Principal Component Analysis (PCA), where the PC's indicators with an Eigenvalue > 1 are selected as the minimum data set (Table 4).

Table 3 showed the indicators that positive and negative significant correlation (P-value <0.05), include: pH with organic matter (r= 0.720*), available-P with Mg (r= 0.711*), available-P with microbial biomass C (r= 0.713*), base saturation with Mg (r= 0.708*), Ca with microbial biomass C (r= 0.791*), and Mg with microbial biomass C (r= 0.672*). Whereas the indicators that showed highly significant correlation positive and negatively (P value <0.01), include: available-N with earthworm population density (r= -0.864**), base saturation with Ca (r= 0.829**), base saturation with microbial biomass C (r= 0.813*), and Ca with Mg (r= 0.961**).

These indicators potentially become a minimum data set of soil fertility index measurement. Based on the PCA, the minimum indicators used to analyze the soil fertility index include pH, organic matter, available-P, base saturation, Ca, Mg, earthworms population density and microbial biomass C (Table 4).

3.3 Comparison of soil fertility index evaluation methods

Although it is generally recognized that physical, chemical, and biological factors are critical for soil fertility, more attention is paid to chemical factors. Changes in the chemical and physical environment in the soil will affect biological processes and subsequently contribute to overall soil fertility [7]. We propose considering biological factors in evaluating soil fertility as modified methods in soil fertility assessments.

In this research, we compare two methods of soil fertility assessment, i.e., conventional and modified methods. The conventional methods of soil fertility assessments only use chemical properties as indicators. In contrast, besides using soil chemicals, modified assessment methods include soil biological properties in soil fertility assessment, i.e., earthworm population density and microbial biomass C. Earthworms were chosen as representatives of biological indicators because most farmers or communities recognize earthworms as indicators of fertile soil.

The PCA result showed that the minimum indicators used to analyze the soil fertility index conventionally include pH, organic matter, available P, base saturation, Ca, and Mg (Table 4). In this study, available-N was not one of the selected indicators for calculating soil fertility index using the conventional method because available-N was not significantly correlated with another chemical indicator. While the indicators used to assess soil fertility index using the modified method are all indicators used in conventional methods, plus indicators of earthworm population density and microbial biomass C. The available-N indicator is included in the modified method because it is significantly positively correlated with earthworm population density; this research result contrasts with [30], which showed no correlation between earthworms and soil chemical properties.

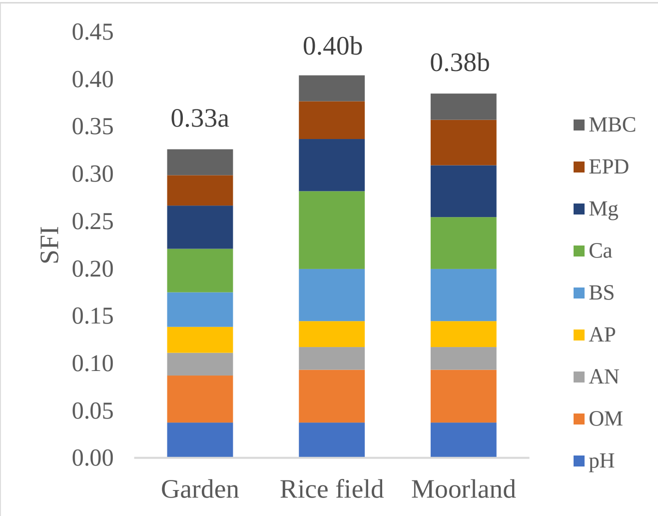
The comparison of PCA analysis for the two methods (Table 4) showed that the modified method had a higher cumulative value (86.5%) than the conventional method (83.8%). According to [31], if the cumulative value for all the components is high, the main component chosen will produce a more accurate result. Therefore, in determining the indicators for soil fertility index, the addition of biological indicators shows that it is more representative of soil properties than the conventional method used more frequently.

The choice of indicators in the main component was based on the eigenvalue value of more than one, the higher cumulative and weight value of each indicator [32]. The selected indicators are calculated as minimum soil fertility indicator, each having a weighted index (Wi). In modified methods (Table 4), there were five indicators in PC1: available-P, base saturation, Ca, Mg, and microbial biomass C, and they contributed Wi 0.123 each. There were two in PC2, available-N and earthworm population density, with Wi 0.108 each. In PC3, there were pH and organic matter with each Wi 0.804. Meanwhile, in the conventional method, there are two PCs, whereas, on PC1, there were four indicators, including available-P, base saturation, Ca, and Mg, each of which has a Wi of 0.188; and on PC2, there are two indicators, including pH and soil organic matter, with Wi each of 0.124.

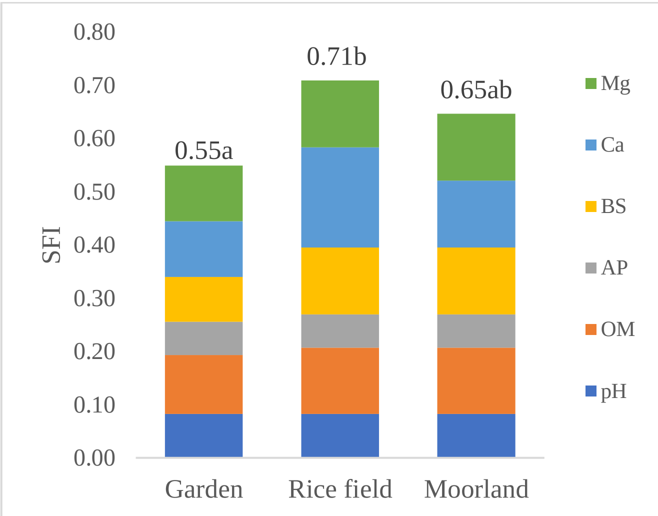
Table 4. Results of Principal Component Analysis (PCA) and indicator weight index of modified and conventional methods

Modified methods					Conventional methods			
Eigenvalue	4.8036	1.6799	1.3026	*Wi*	Eigenvalue	3.785	1.2452	*Wi*
Proportion	0.534	0.187	0.145		Proportion	0.631	0.208	
Cumulative	0.534	0.720	0.865		Cumulative	0.631	0.838	
Indicators	PC1	PC2	PC3		Indicators	PC1	PC2	
pH	0.140	0.143	**-0.539**	0.084	pH	0.389	**-0.495**	0.124
Organic matter	0.198	0.006	**-0.737**	0.084	Organic matter	0.253	**-0.725**	0.124
Available-N	-0.261	**0.611**	-0.04	0.108	Available-P	**0.376**	0.305	0.188
Available-P	**0.342**	0.108	0.257	0.123	Base saturation	**0.447**	0.044	0.188
Base saturation	**0.411**	0.001	0.009	0.123	Ca	**0.479**	0.226	0.188
Ca	**0.413**	0.210	0.143	0.123	Mg	**0.462**	0.288	0.188
Mg	**0.378**	0.319	0.179	0.123				
Earthworm population density	0.179	**-0.669**	0.004	0.108				
Microbial biomass C	**0.403**	-0.027	0.213	0.123				

Notes: Numbers in bold are selected PCs



(a) SFI value on various land uses in Girimarto District using modified method and contribution of each indicator to SFI



(b) SFI value on various land uses in Girimarto District using conventional method and contribution of each indicator

Figure 2. SFI value on various land uses in Girimarto District and contribution of each indicator to SFI
(Note: MBC= microbial biomass C, EPD=earthworms population density, BS=base saturation, AP=available-P, AN= available-N, OM=organic matter)

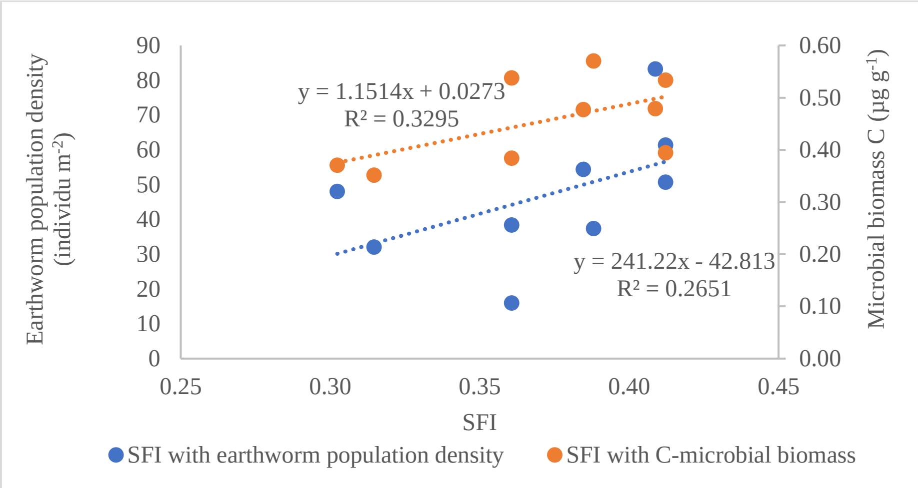


Figure 3. Relationship between earthworm population density and microbial biomass C with soil fertility index

The calculations of SFI showed that rice fields have a higher SFI value, and gardens showed the lowest SFI value, both in the modified (Figure 2a) and conventional methods (Figure 2b). It is probably due to the higher organic matter content in the rice fields than in the other land uses (Table 2). Rice fields receive organic waste and rice straw input from the rest of the harvested paddy grain. Applying organic fertilizers such as green manure, compost or vermicompost significantly affects plant growth [33]. It is a source of energy and nutrition for microorganisms to decompose and mineralize, thereby helping to increase soil nutrients [34].

Applying organic fertilizer simultaneously with NPK fertilizer can increase organic carbon and the availability of the nutrients N, P, and K in the soil [35]. Meanwhile, the low organic material input from the litter plant leads to an imbalance between the input and output of organic matter in gardens and moorland. The research results by Khalif et al. [36] show that gardens with a low variation of plants have a lower organic matter content than land used for mixed culture and land implementing an agroforestry system.

The assessment of the soil fertility index using the modified method shows a lower class (0.33-0.40) than the conventional method shows a middle class (0.55-0.71) (Figure 2a, 2b). The evaluation of the soil fertility index using the conventional method only provides a picture of soil fertility in terms of its chemical properties without considering the soil's biological indicators. According to the study [8], to measure the effects of soil management practices can use biological indicators such as soil respiration and earthworm abundance. Including earthworm population density and microbial biomass C in assessing soil fertility status is crucial because soil organisms quickly react to changes related to actual dynamic conditions in the field and can be used as early warning indicators of environmental changes. Therefore, evaluating soil fertility index using modified methods by adding soil biological indicators is better than using chemical properties only. It is suggested to use a modified method in assessing soil fertility level because it is more capable of assessing closer to actual soil fertility conditions than the conventional method.

There is a relationship between biological indicators and the soil fertility index, as evidenced by the linear regression pattern between the earthworm population density and the microbial biomass C with the soil fertility index (Figure 3). Based on this research result, earthworm population density contribute approximately 27% to the soil fertility index in Girimarto District, while microbial biomass C contributes 33%. With the relatively low contribution biological indicator on soil fertility index, it is suspected that almost all areas of moorland and garden is dry land, so the activity of earthworms is restricted by low moisture besides the low soil organic matter content. Therefore, soil fertility assessment can consider biological indicators since they react well to environmental dynamics change.

According to Pérès et al. [37], the earthworm indicator represents the population density of soil organisms in response to various environmental changes, including chemical changes and agricultural cultivation practices. The microbial biomass C indicator is sensitive to nutrient change, especially soil organic matter levels [31]. The lack of good sources of nutrients and energy, described by the low availability of soil organic matter, affects soil fauna due to insufficient food sources, which is related to the activity of earthworms and other soil fauna that consume plant litter [38].

The need for future research to evaluate that soil biological indicators are good soil fertility index must validate various soil types and land uses, soil management, season, and area. The biological indicators include population density and biomass, diversity, distribution, and activity or processes delivered by soil biota.

4. CONCLUSION

The modified method, which combines biological and chemical indicators, could determine a better soil fertility index in Girimarto District than the conventional method, which only uses chemical indicators. The earthworm population density and microbial biomass C are good potential biological indicators comparable to soil chemical indicators in assessing the soil fertility index. Future research needs to validate biological indicators and add on conventional methods of soil fertility index assessment in the same, or different land uses in other areas, such as different soil types and land management.

ACKNOWLEDGMENT

Thanks to Universitas Sebelas Maret for financially supporting this research through the 2022 Non-State Budget research grant in the Research Group's Human Resources Optimization scheme for the Achievement of International Reputation and Professorship. Thanks also to Tiara, who helped prepare research in the field.

REFERENCES

[1] Gnyawali, B., Mandal, U.K., Aryal, I. (2020). Soil fertility assessment of Sainamaina Municipality, Rupandehi, Nepal. The Geographic Base, 7: 43-53. https://doi.org/10.3126/tgb.v7i0.34268

[2] Akhmad, A., Dewi, W.S., Sagiman, S., Suntoro. (2018). The effect of mixed liming and NPK fertilizer to yield of some rice varieties on new openings of acid sulfate tidal swamp land. IOP Conference Series: Earth and Environmental Science, 142: 17. https://doi.org/10.1088/1755-1315/142/1/012078

[3] Li, L., Yang, T., Redden, R., He, W., Zong, X. (2016). Soil fertility map for food legumes production areas in China. Scientific Reports, 6(1): 1-14. https://doi.org/10.1038/srep26102

[4] Marbun, P., Nasutionc, Z., Hanum, H., Karim, A. (2020). Classification, physicochemical, soil fertility, and relationship to Coffee robusta yield in soil map unit selected. Coffee Science, 15: 1-9. https://doi.org/10.25186/.v15i.1818

[5] Enaruvbe, G.O., Osewole, A.O., Mamudu, O.P., Rodrigo-Comino, J. (2021). Impacts of land-use changes on soil fertility in Okomu Forest Reserve, Southern Nigeria. Land Degradation and Development; 32(6): 2130-2142. https://doi.org/10.1002/ldr.3869

[6] Zhu, Y., Guo, B., Liu, C., Lin, Y., Fu, Q., Li, N., Li, H. (2021). Soil fertility, enzyme activity, and microbial community structure diversity among different soil textures under different land use types in coastal saline soil. Journal of Soils and Sediments, 21(6): 2240-2252. https://doi.org/10.1007/s11368-021-02916-z

[7] Abbot, L.K., Murphy, D.V. (2007). What is Soil Biological Fertility? [In:] Abbot, L.K., Murphy, D.V. (Eds.), Soil Biological Fertility, A Key to Sustainable Land Use in Agriculture, pp. 1-16. Springer. The Netherlands. https://research-repository.uwa.edu.au/en/publications/soil-biological-fertility-a-key-to-sustainable-land-use-in-agricu-2.

[8] Krüger, I., Chartin, C., van Wesemael, B., Carnol, M. (2018). Defining a reference system for biological indicators of agricultural soil quality in Wallonia, Belgium. Ecological Indicators, 95(1): 568-578. https://doi.org/10.1016/j.ecolind.2018.08.010

[9] Hodson, M.E., Corstanjeb, R., Jones, D.T., Witton, J., Burton, V.J., Sloan, T., Eggleton, P. (2021). Earthworm distributions are not driven by measurable soil properties. Do they really indicate soil quality? PLOS ONE, 16(8): 1-17. https://doi.org/10.1371/journal.pone.0241945

[10] Xu, Y., Sun, L., Lal, R., Bol, R., Wang, Y., Gao, X., Ding, F., Liang, S., Li, S., Wang, J. (2020). Microbial assimilation dynamics differs but total mineralization from added root and shoot residues is similar in agricultural Alfisols. Soil Biology and Biochemistry, 148. https://doi.org/10.1016/j.soilbio.2020.107901

[11] Purwanto, B.H., Alam, S. (2020). Impact of intensive agricultural management on carbon and nitrogen dynamics in the humid tropics. Soil Science and Plant Nutrition, 66(1): 50-59. https://doi.org/10.1080/00380768.2019.1705182

[12] Maroeto, Suntoro, W.A., Djoko, S., Rossyda, P. (2017). Net farm income as reflection of critical land evaluation in welang watershed, Indonesia. Bulgarian Journal of Agricultural Science, 23(5): 826-833. https://www.agrojournal.org/23/05-21.html

[13] BPS-Statistic of Wonogiri Regency (2018). Wonogiri Regency in Figures 2018. Wonogiri, BPS-Statistic of Wonogiri Regency. https://wonogirikab.bps.go.id/publication/2018/08/16/bfb43fdb365c5941067c074a/kabupaten-wonogiri-dalam-angka-2018.html.

[14] Smetak, K., Johnson-Maynard, J., Lloyd, J. (2007). Earthworm population density and diversity in different-aged urban systems. Applied Soil Ecology, 37(1-2): 161-168. https://doi.org/10.1016/j.apsoil.2007.06.004

[15] Cheng, X., Yu, M., Wang, G.G. (2017). Effects of thinning on soil organic carbon fractions and soil properties in Cunninghamia lanceolata stands in eastern China. Forests, 8(6): 1-14. https://doi.org/10.3390/f8060198

[16] Eviati, S. (2009). Analisis Tanah. [In:] Prasetyo, B.H., Santoso, D, Widowati, L.R.(Eds.), Petunjuk Teknis: Analisis Kimia Tanah, Tanaman, Air dan Pupuk (2nd ed). Balai Penelitian Tanah, Bogor. http://balittanah.litbang.pertanian.go.id/ind/dokumentasi/juknis/juknis_kimia2.pdf?secure=true.

[17] Prasad, R. (1965). Determination of potentially available nitrogen in soils - A rapid procedure. Plant and Soil, 23(2): 261-264. https://doi.org/10.1007/BF01358352

[18] Santosa, E., Widati, S. (2007). Estimasi C-mikroba. [In:] Husen, E., Saraswati, R., Simanungkalit, R.D. M. (Eds.), Metode Analisis Biologi Tanah, pp. 151. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Bogor. http://balittanah.litbang.pertanian.go.id/ind/dokumentasi/buku/buku%20biologi%20tanah.pdf?secure=true

[19] Wang, F., Li, Q., Lin, C., He, C. (2018). Characteristics of soil fertility quality and minimum dataset for yellow-mud paddy fields in Fujian Province. Chinese Journal of Eco-Agriculture, 26(12): 1855-1865. https://doi.org/10.13930/j.cnki.cjea.180194

[20] Mukashema, A. (2007). Mapping and modelling landscape-based soil fertility change in relation to human induction. Thesis. International Institute for Geo-information Science and Earth Observation. Enschede, The Netherlands. https://www.itc.nl/library/papers_2007/msc/nrm/mukashema.pdf.

[21] 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 (EJSS), 7(3): 203-212. https://doi.org/10.18393/ejss.399775.

[22] Nguemezi, C., Tematio, P., Yemefack, M., Tsozue, D., Silatsa, T. B. F. (2020). Soil quality and soil fertility status in major soil groups at the Tombel area, South-West Cameroon. Heliyon, 6(2): 1-10. https://doi.org/10.1016/j.heliyon.2020.e03432

[23] Ng, J. F., Ahmed, O. H., Jalloh, M. B., Omar, L., Kwan, Y. M., Musah, A. A., Poong, K. H. (2022). Soil nutrient retention and ph buffering capacity are enhanced by calciprill and sodium silicate. Agronomy, 12(1): 219.

https://doi.org/10.3390/AGRONOMY12010219
[24] Chase, P., Singh, O.P. (2014). Soil nutrients and fertility in three traditional land use systems of Khonoma, Nagaland, India. Resources and Environment, 4(4): 181-189. https://doi.org/10.5923/j.re.20140404.01
[25] Gerke, J. (2022). The central role of soil organic matter in soil fertility and carbon storage. Soil Systems, 6(2): 33. https://doi.org/10.3390/SOILSYSTEMS6020033
[26] Panagos, P., Muntwyler, A., Liakos, L., Borrelli, P., Biavetti, I., Bogonos, M., Lugato, E. (2022). Phosphorus plant removal from European agricultural land. Journal Fur Verbraucherschutz Und Lebensmittelsicherheit, 17(1): 5-20. https://doi.org/10.1007/S00003-022-01363-3/FIGURES/8
[27] Akintola, O.O., Abodunrin, E.K., Odeyale, O.C., Falana, A.R., Ogunbanjo, A.R., Adeniran, T. (2022). Influence of land use types on physical and chemical properties in Oba Hill Forest Reserve, Iwo, South-western Nigeria. Journal of Applied Sciences and Environmental Management, 26(7): 1307-1377. https://doi.org/10.4314/jasem.v26i7.18
[28] Minarsih, S., Hanudin, E., Nurudin, M. (2021). The earthworm's diversity and their relationship to the soil physicochemical properties under the stands of perennial plant at the Mount Merapi forest, Yogyakarta, Indonesia. Biodiversitas Journal of Biological Diversity, 22(6): 3237-3244. https://doi.org/10.13057/biodiv/d220627
[29] Verbrighghe, N., Meeran, K., Bahn, M., Fuchslueger, L., Janssens, I.A., Richter, A., Sigurdsson, B.D., Soong, J.L., Vicca, S. (2022). Negative priming of soil organic matter following long-term in situ warming of sub-arctic soils. Geoderma, 410: 115652. https://doi.org/10.1016/J.GEODERMA.2021.115652
[30] Weldmichel, T.G., Szegi, T., Denish, L., Kumar Gangwar, R., Michéli, E., Simon, B. (2020). The patterns of soil microbial respiration and earthworm communities as influenced by soil and land-use type in selected soils of Hungary. Soil Science Annual, 71(2): 43-52. https://doi.org/10.37501/soilsa/122408
[31] Xie, L.W., Zhong, J., Chen, F.F., Cao, F.X., Li, J.J., Wu, L.C. (2015). Evaluation of soil fertility in the succession of karst rocky desertification using principal component analysis. Solid Earth, 6(2): 515-524. https://doi.org/10.5194/se-6-515-2015
[32] Fan, Y., Zhang, Y., Chen, Z., Wang, X., Huang, B. (2021). Comprehensive assessments of soil fertility and environmental quality in plastic greenhouse production systems. Geoderma, 385: 1-10. https://doi.org/10.1016/j.geoderma.2020.114899
[33] Arifah, S.M., Budiastuti, M.T.S., Dewi, W.S., Supriyadi. (2021). Vermicompost formulation based on soybean husk and cow manure on shallots. International Journal of Design & Nature and Ecodynamics, 16(3): 327-333. https://doi.org/10.18280/ijdne.160312
[34] Gu, S., Hu, Q., Cheng, Y., Bai, L., Liu, Z., Xiao, W., Gong, Z., Wu, Y., Feng, K., Deng, Y., Tan, L. (2019). Application of organic fertilizer improves microbial community diversity and alters microbial network structure in tea (Camellia sinensis) plantation soils. Soil and Tillage Research, 195: 104356. https://doi.org/10.1016/j.still.2019.104356
[35] Rathore, K., Tiwari, A., Kumar, R. (2020). Long term effect of inorganic fertilizers and organic manures on soil fertility status, microbial biomass carbon, and yield of rice on inceptisol. International Journal of Chemical Studies, 8(3): 1673-1677. https://doi.org/10.22271/chemi.2020.v8.i3w.9440
[36] Khalif, U., Utami, S.R., Kusuma, Z. (2014). Effect of planting Paraserianthes falcataria on C and N content of soil in Slamparejo village, Jabung, Malang. Journal of Soil and Science Resources, 1(1): 9-15. https://jtsl.ub.ac.id/index.php/jtsl/article/view/95
[37] Pérès, G., Vandenbulcke, F., Guernion, M., Hedde, M., Beguiristain, T., Douay, F., Houot, S., Piron, D., Richard, A., Bispo, A., Grand, C., Galsomies, L., Cluzeau, D. (2011). Earthworm indicators as tools for soil monitoring, characterization and risk assessment. An example from the national Bioindicator programme (France). Pedobiologia, 54: S77-S87. https://doi.org/10.1016/j.pedobi.2011.09.015
[38] Zhu, X., Lian, B., Yang, X., Liu, C., Zhu, L. (2013). Biotransformation of earthworm activity on potassium-bearing mineral powder. Journal of Earth Science, 24(1): 65-74. https://doi.org/10.1007/s12583-013-0313-6