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Research Article

A comparative study of soil fertility and biota population under organic, semi-organic, and conventional farming system of rice fields in Giriwoyo District, Wonogiri Regency, Indonesia

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Abstract
Continuous use of chemical fertilizers and farming practices in rice fields would reduce nutrient availability and biota population in the soil. Because soil biological linkages are sensitive to changes in soil function, changes in fauna and microbial populations can affect soil fertility. This study aimed to identify the condition of soil fertility and soil biota under various farming systems, namely organic, semi-organic, and conventional, and find the indicators that determine soil fertility index (SFI) in the research area. This research is a survey with the sampling method was purposive on the Land Mapping Unit (LMU) overlaid with thematic maps (land use, soil type, slope, and rainfall). The method analysis of SFI using Principal Component Analysis (PCA) and scoring methods were used for the effect of farming systems using One-way, continued by DMRT, and determinant factor using Pearson's. Correlation. The results illustrated that soil fertility was a moderate category. The highest SFI was in organic rice fields (0.69), then in semi-organic (0.62), and the lowest fertility was in conventional (0.59). Organic farming also showed the best soil biota conditions (0.27 individuals/liter of earthworms and 0.755 µ/g of microbial C biomass) compared to semi-organic (0.15 individuals/liter, 0.508 µ/g microbial C biomass) and conventional farming (0.11 individuals/liter, microbial biomass C 0.325 µ/g). Soil fertility and soil biota are positively correlated, meaning that the higher the soil fertility, the higher the density of soil biota. The soil indicators most determining fertility are total N, P-available, K-available, CEC, and organic C.

Keywords: Determining factors, Earthworm, Microbial C biomass, Plant nutrient, Soil ecosystem

INTRODUCTION

Rice as a staple food in Southeast Asian countries, especially in Indonesia, China, India, Vietnam, Thailand, and Japan, has increased the demand for its production. To obtain maximum production, rice is planted repeatedly after harvest as part of intensive farming operations. Continuously cultivating paddy fields without time and pause, followed by proper management according to land conditions, will decrease soil fertility, beginning with a deficit of nutrients. Soil fertility parameters are key elements of soil chemistry that determine the availability of nutrients for plants and soil microorganisms (AbdelRahman *et al*., 2022). Soil fertility is essential to plant growth, productivity, quality, and yield. Soil chemical fertility determines crop sustainability and indices nutrient availability to crops (Bhatt *et al*., 2019). Soil fertility directly influences the essential nutrient content of the soil (Kuppusamy *et al*., 2017). The research results of Shindo *et al*. (2020) show that rice plants that grow in a nutrient-deficient state have slow growth, fewer tillers, low chlorophyll content and lower rice yields (Shindo *et al*., 2020). Nitrogen deficiency leads to disruption of chlorophyll biosynthesis, which causes inhibition of plant growth and leaf chlorosis. Potassium and phosphorus deficiencies also cause reduced plant growth as well as brown tips on leaves (Sanchez *et al*., 2020). Another research by Santos *et al*. (2019) showed that nutrient deficiency significantly decreased the number of tillers and grain fertility, reducing grain yield (dos Santos *et al*., 2020).

Various rice farming systems applied by farmers and policies provided by stakeholders can determine the sustainability of agricultural land use through soil fertility and soil biota density in paddy fields. Pahalvi *et al*. (2021) stated that chemical fertilizers are often used in modern agriculture, which aims to increase production. However, in the end, chemical fertilizers negatively impact ecological balance and reduce productivity and soil sustainability. Applying chemical fertilizers causes environmental problems such as soil acidification, decreased biodiversity and soil biota populations, and damage to soil biological, physical and chemical characteristics (Iqbal *et al*., 2023). Organic farming systems show greater earthworm density than conventional rice fields (Solomou *et al*., 2013). The application of organic systems can increase the activity and diversity of soil microbes, which increases soil fertility compared to conventional systems (Bonanomi *et al*., 2017).

Research results by Chauhan (2014) conclude that Earthworms help farmers improve soil fertility through activities that mix the top layer with the bottom layer of soil so that nutrients from the bottom layer are carried to the root penetration area to be absorbed by plants. According to Subin *et al*. (2015), the presence of earthworms supports the availability of macronutrients such as phosphorus and potassium. The total P and exchangeable K content in the soil will be higher if there is a high population of earthworms compared to no earthworms. The results of research on agricultural land with a high earthworm population density showed that the nutrient content was also higher, namely, a total P content of 74.81mg/kg and K availability content of 385.74 mg/kg, while soil with a lower earthworm population density had a total P value of 67.36mg/kg. kg and K are interchangeable 322.03 mg/kg. This certainly increases plant productivity. Soil fertility increases as soil biota density increases. Soils with high organic matter is closely related to a high proportion of microbial communities in the soil and generally show good soil fertility Likus-Cieślik *et al*., 2023). Changes in fauna and microbial populations can change soil fertility because soil biological bonds are sensitive to changes in the soil functioning environment (Han *et al*., 2020). Variability in soil fertility can determine the influence that soil biota has on nutrient availability for plants (Gundale *et al*., 2014). The population density of soil biota is critical because it can affect soil fertility.

Tóth *et al*. (2018) showed the importance of soil biota fauna in the maintenance of soil fertility. They did not discuss how much soil biota conditions influence soil fertility (Tóth *et al*., 2018). Another research (Dai *et al*., 2017) also stated that the effect of organic matter application on soil biota is very important to understanding how soil fertility and ecosystems change. The existence of soil macrofauna is relatively closely related to organic matter in the soil, which is used as a source of energy to provide nutrients (Kooch *et al*., 2020). The present research hypothesises that soils with organic farming will have high organic matter content (in organic rice fields), ecosystem biota conditions, and high soil fertility (compared to semi-organic and conventional rice fields). So the objectives of the present study were to determine soil fertility and biota population as the relationship between the two, identify soil indicators that determine soil fertility (determining factors) and serve as a basis for determining management recommendations that are following the condition of rice fields to maintain the sustainability in the future.

MATERIALS AND METHODS

Study area

The research was conducted in Giriwoyo District, Wonogiri Regency, Central Java (Fig., 1) which is geographically located in 7°51'8.71"-7°58'55.90" LS and 110°53'56.59"-111°2'58.78" BT at an altitude of 173-410 meters above sea level (m asl) and has a total area of 10,060 ha with land use distribution including rice fields covering an area of 1,446 ha, dry land covering an area of 7,703 ha and others covering an area of 890 ha. Giriwoyo has Inceptisol soil type and slopes of 0 to 8% and 8 to 15%, with an average rainfall of 1,706 mm/year and 2,276 mm/year. The analysis included chemical and biological analysis of soil conducted at the Laboratory of Chemistry and Soil Fertility, Faculty of Agriculture, Sebelas Maret University of Surakarta.

The farming system of rice fields in the area is organic, semi-organic, and conventional. Fertilization in organic rice fields was done by applying organic manure (5 tons/ha) and liquid organic fertilizer (2.5 ml). Semi-organic rice fields use manure (1 to 2 tons/ha) applied in the initial soil process, petrogenic fertilizer (organic fertilizer) (160 kg/ha), phonska fertilizer (80 kg/ha), urea fertilizer (100 kg/ha). Conventional rice fields use urea fertilizer (150 kg/ha), phonska fertilizer (100 gr/ha), and ZA fertilizer (50 kg/ha).

Soil sampling and analysis

The research was conducted using an exploratory, descriptive method through the field survey approach and laboratory analysis results. Soil sampling was

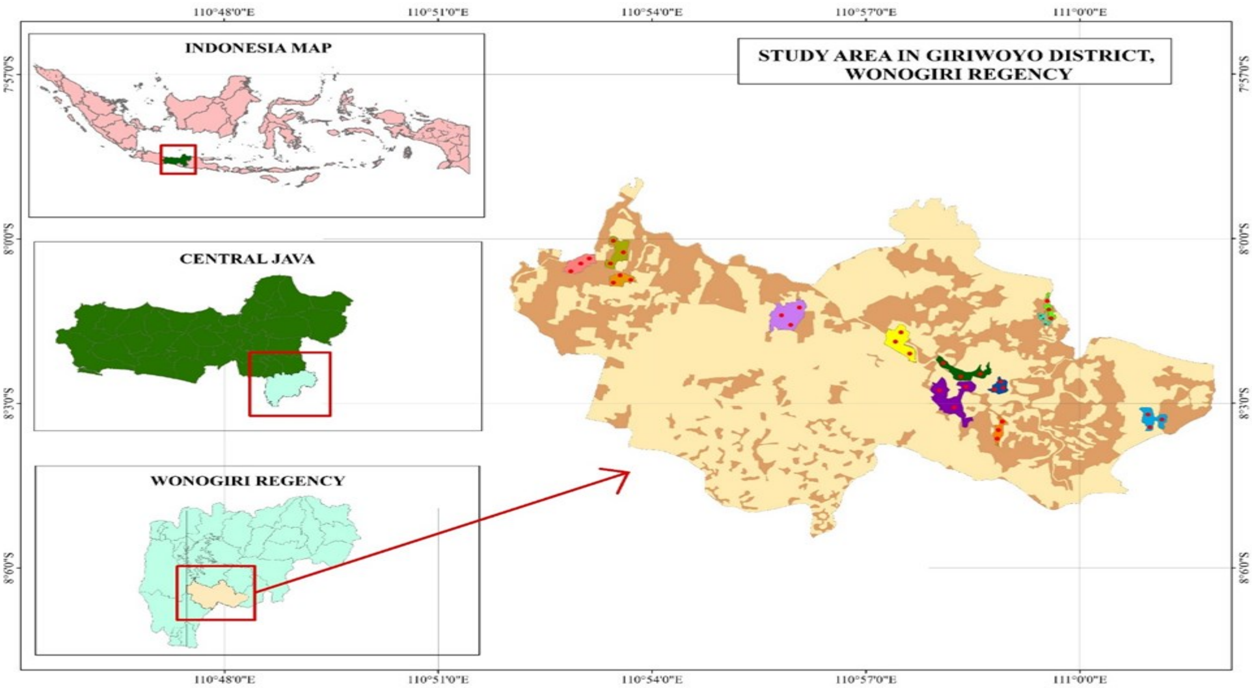

Fig. 1. *Map of study area in Giriwoyo District, Wonogiri Regency*

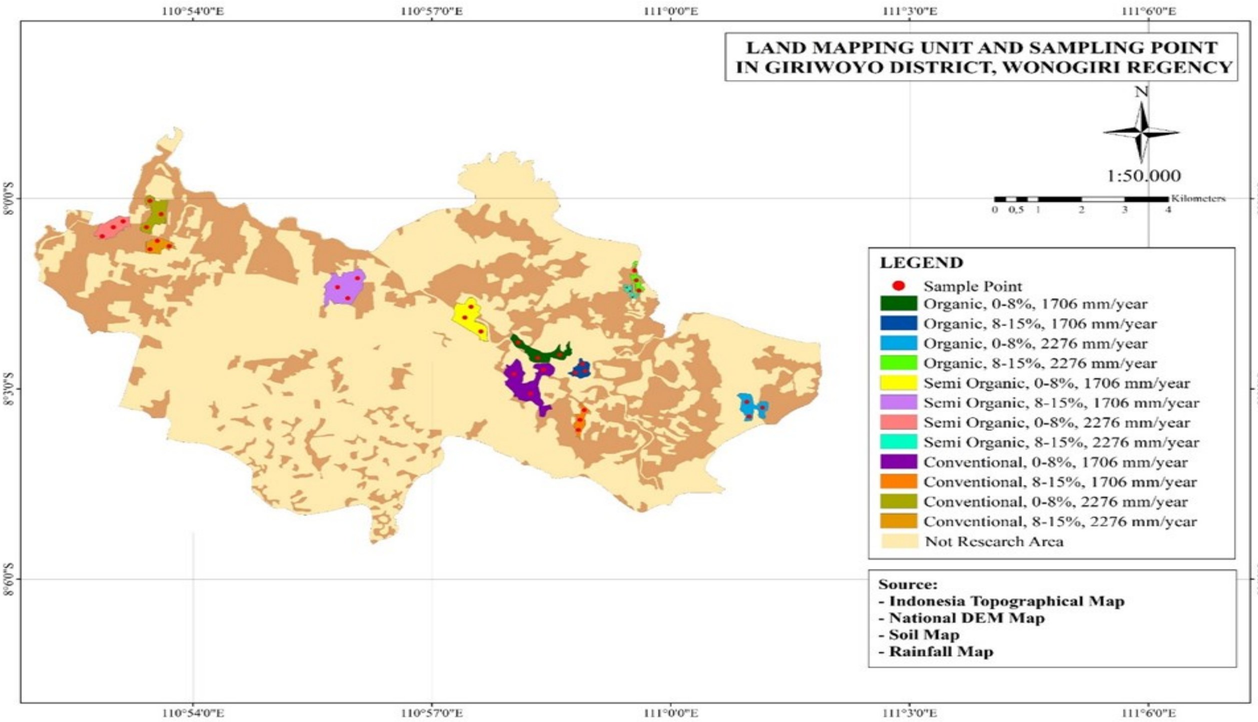

Fig. 2. *Soil observation and sampling points of soil fertility and soil biota research.*
Remark: Different color codes in the legend indicate the characteristics of each LMU

done using the purposive sampling method. Determination of soil sampling points was based on Land Mapping Unit (LMU) through overlaying land use maps, soil type maps, slope maps and rainfall maps which then obtained 12 LMU. The number of sampling points in each land unit was 3 replication points, so there were 16 (Fig., 2). Soil samples were taken at tillage depth (0 to 20 cm). Sampling was carried out using the soil sample method with the help of a soil drill. Soil samples were then analyzed in the laboratory according to the method of each observation parameter. The parameters analyzed in soil samples were soil pH by Electrometric method, total N by Kjeldahl method, Available P by Olsen method, Available K by 1 N ammonium acetate extraction method, Cation Exchange Capacity (CEC) by 1 N ammonium acetate extraction method following (ICALRRD, 2009), Base Saturation (1 N ammonium acetate extraction method, C-organic by

Walkey and Black method and C-microbial biomass by fumigation and extraction method (ICALRRD, 2007).

Data analysis

Soil Fertility Index (SFI) assesses soil fertility using chemical indicators, especially in agricultural land such as rice fields (Yang *et al*., 2017). The first step in calculating the soil fertility index is determining the soil fertility indicator or Minimum Soil Fertility Index (MSFI) through. Determination of the soil fertility index was carried out with Pearson Correlation Analysis the continued with Principal Component Analysis (PCA). PCA analysis was conducted to reduce data to obtain the main data that can explain most of the data variations so that data interpretation could be done quickly. PCA analysis produced Principal Component (PC) (Table 2), which was used as MSFI (Table 3). PC used as MSFI are PC with eigenvalue ≥ 1 or at least 60% of the cumulative value (Zhang *et al*., 2018). PCA analysis produces Principal Component (PC), which was then used as Minimum Soil Fertility Index (MSFI), which was the smallest data set to represent all soil fertility indicator values used. The MSFI obtained is then scored based on the scoring of soil fertility classes (Table 1) from ICALRRD, (2009). The scoring results were then included in calculating the soil fertility index (Mukashema, 2007).

Soil fertility index = $\left(\frac{SCi}{N}\right) x\ 10 \quad \frac{1}{nc}$ Eq. 1

from:

Where:

SCi : Cj x pc;

Cj : wi x si;

pc :

Description:

SCi : indicator score

N : number of MSFI indicators

cj : sum of score weights

pc: rating value

nc: number of marks used

wi: *weight index*

si: *scoring index*

SCi represented the scoring indicator, which is obtained through calculations cj x pc, cj is the class number, which varies from 1 to j depending on the number of classes for the MSFI interpretation, cj is obtained through calculations wi x si, where wi is weight index obtained from the purposive x cumulative equation, while si is the scoring index obtained from the MSFI parameter scoring results (Table 3) based on scoring from ICALRRD (2009) (Table 4); N is the number of MSFI indicators used (Table 3); pc represents the class probability, nc is the number of values used in determining the soil fertility class (Table 1).

The earthworm population density was calculated based on the equation (ICALRRD, 2007).

Table 1. Soil fertility score

Soil Fertility Value	Category
0.90-1.00	Very High
0.75-0.90	High
0.50-0.75	Moderate
0.25-0.50	Low
0.00-0.25	Very Low

Source: (Bagherzadeh *et al*., 2018)

Table 2. PCA results

Eigenvalue	4,4651	1,0942	1,0119
Proportion	0.558	0.137	0.126
Cumulative	0.558	0.695	0.821
Variable	PC1	PC2	PC3
Redox	-0.022	0.015	0.967
pH	0.142	-0.880	0.053
Total N	0.362	0.459	0.026
Available P	0.447	-0.081	-0.018
Available K	0.460	-0.057	-0.054
CEC	0.433	0.014	-0.016
Base saturation	0.214	0.065	0.241
C-organic	0.452	0.004	-0.016

Table 3. Minimum soil fertility index

No.	MSFI	Proportion	Cumulative	Wi
1.	Available P	0.558	0.821	0.136
2.	Available K	0.558	0.821	0.136
3.	CEC	0.558	0.821	0.136
4.	C-organic	0.558	0.821	0.136
5.	Base saturation	0.558	0.821	0.136
6.	Total N	0.137	0.821	0.167
7.	Redox	0.126	0.821	0.153

Earthworm population density = number of worms / number or volume of soil sample Eq. 2

Determination of earthworm population density was carried out by dividing the number of earthworm populations found in the area or volume of soil samples taken. Earthworms were collected using a 20 cm high PVC sample ring (ICALRRD, 2007) by immersing it in the ground. The sampling was carried out 3 times in each LMU. The earthworm population is calculated based on the number of worms obtained in each PVC ring. The volume of the soil sample used is the volume of the tube because the shape of the PVC ring is a tube.

Statistical analysis

Statistical analysis of the data was carried out with a one-way Analysis of Variance (ANOVA) test to determine the effect of rice field farming systems on soil fertility and soil biota. Followed by Duncan Multiple Range Test (DMRT) to determine differences in the effect of rice field farming systems on soil fertility index and soil biota. The determining factor is defined as the most dominant factor in influencing soil fertility and is used as a reference for appropriate land management recommendations to improve soil fertility. Determinants were determined through Pearson's correlation tests between parameters and soil fertility.

RESULTS AND DISCUSSION

Soil fertility characteristics and status

The PCA analysis (Table 2) showed that PC 1, PC 2 and PC 3 have an eigenvalue ≥ 1 and a cumulative percentage of 82.1% of the overall data to determine soil fertility. The indicators with the greatest and highest correlation values were taken from each selected PC. The 7 indicators as MSFI represented: available P, available K, CEC, base saturation (BS), C organic, total N and redox. MSFI data that were selected and then scored based on the assessment criteria (Table 1) (ICALRRD, 2009) are mentioned in Table 3.

Rice fields in the study area are classified as moderate soil fertility (Table 4). The highest soil fertility value was found in rice fields with an organic farming system with a value range of 0.65 to 0.71 with an average of 0.69. Semi-organic rice fields have a value range of 0.59 to 0.63 with an average of 0.63, while conventional rice fields have a value range of 0.57 to 0.63 with an average value of 0.59 (Fig. 3).

Effect of farming systems on soil fertility index

The application of different types of fertilizers in each farming system would affect the level of soil fertility. The organic rice fields were fertilized by applying 5 tons/ha of manure and 2.5 ml of liquid organic fertilizer. Semi organic rice fields used manure as much as 1 to 2 tons/ha applied in the initial soil process, petroganic ferlitizer as much as 160 kg/ha, phonska fertilizer as much as 80 kg/ha and urea fertilizer as much as 100 kg/ha. Conventional rice fields use urea fertilizer at 150 kg/ha, phonska fertilizer at 100 gr/ha, and ZA fertilizer at 50 kg/ha.

The results of ANOVA analysis showed that the rice field farming system significantly affected the soil fertility index in Giriwoyo District, Wonogiri Regency (F-

Table 4. Soil fertility scoring

Indicator of MSFI	Wi x Si											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
P Available	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.27	0.27	0.27	0.27
K Available	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.36	0.27	0.31	0.27
CEC	0.31	0.31	0.31	0.27	0.49	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Base Saturation	0.27	0.40	0.31	0.27	0.27	0.27	0.31	0.36	0.27	0.27	0.27	0.27
C-organic	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Total N	0.34	0.34	0.34	0.34	0.34	0.34	0.4	0.34	0.44	0.44	0.50	0.34
Redox	0.41	0.46	0.41	0.41	0.41	0.35	0.46	0.41	0.41	0.35	0.46	0.46
∑Wi x Si	2.01	2.19	2.06	1.96	2.17	2.05	2.19	2.19	2.44	2.39	2.50	2.29
SFI	0.57	0.63	0.59	0.56	0.62	0.58	0.63	0.62	0.69	0.68	0.71	0.65
Average SFI	0.59 (Conventional) (Average)				0.62 (Semi-organic) (Average)				0.69 (Organic) (Average)			

Remark: MSFI = Minimum Soil Fertility Index; CEC = Cation Exchange Capacity; SFI = Soil Fertility Index

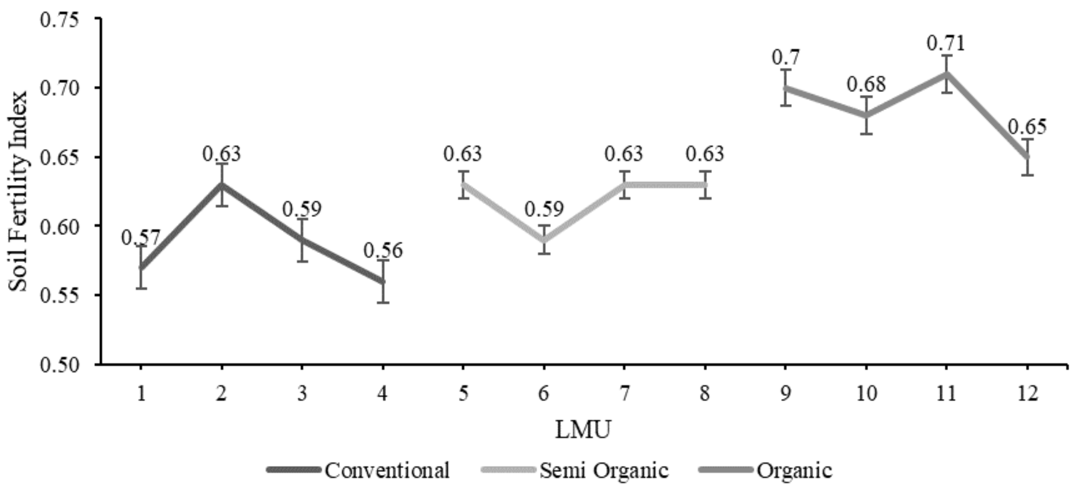

Fig. 3. *Distribution of soil fertility index in each land mapping unit*

count= 30.595; sig= 0.000). The value of soil fertility index in the organic rice field (0.69) was significantly (α≤0.01) higher compared to semi organic (0.62) and conventional (0.59). Fertilizers play a significant role in crop production and productivity, but the continuous use of unbalanced chemical fertilizers can decrease soil fertility. Excessively applied chemical fertilizers can decrease organic matter and soil fertility (Lu *et al*., 2020). The continuous use of chemical fertilizers causes nutrient imbalance in the soil (Ibukunoluwa Moyin-Jesu, 2015). Sharma *et al*. (2014) showed that applying organic fertilizers can supply many plant nutrients, improve soil fertility and contribute to substantial crop yields. Organic fertilizers can improve soil physical and chemical properties, such as structure, water retention, nutrients, and cation exchange capacity, improve soil biological properties positively, and increase crop yield and quality while lowering the risk of environmental damage (Wan *et al*., 2021).

Organic tillage has a much higher soil macronutrient content (Herencia and Maqueda, 2016). Adding organic fertilizers increases the organic carbon status and availability of N, P, K and S in the soil (Vasileva and Kostov, 2015). Based on the DMRT test, the soil fertility index value of organic rice field management was significantly higher than that of semi-organic and conventional rice field farming (Fig. 4). Villa *et al*. (2021) showed that the fertility soil is associated with a high decomposition rate of organic matter; therefore, the recycling of organic nutrients is faster, thus increasing the availability of nutrients in the soil. Long-term application of organic fertilizers can accelerate the activation of soil nutrients, improve soil nutrient content, maintain the balance of available nutrients, and increase soil fertility (Ning *et al*., 2017). Adding organic matter to a field can increase soil fertility (Ilmiah *et al*., 2021). Reducing chemical fertilization and increasing organic nutrient sources in to the soil is a sustainable approach to improving the soil's physical, chemical and biological properties. Such practices improve soil fertility and crop productivity in low-fertility soils (Han *et al*., 2021).

Effect of farming systems on soil biota

Because of its function in the decomposition of organic matter that might produce nutrients in the soil, soil biota is an important aspect of soil fertility. The level of soil fertility from the chemical and biological aspects is beneficial for farmers and for the survival of soil microor-

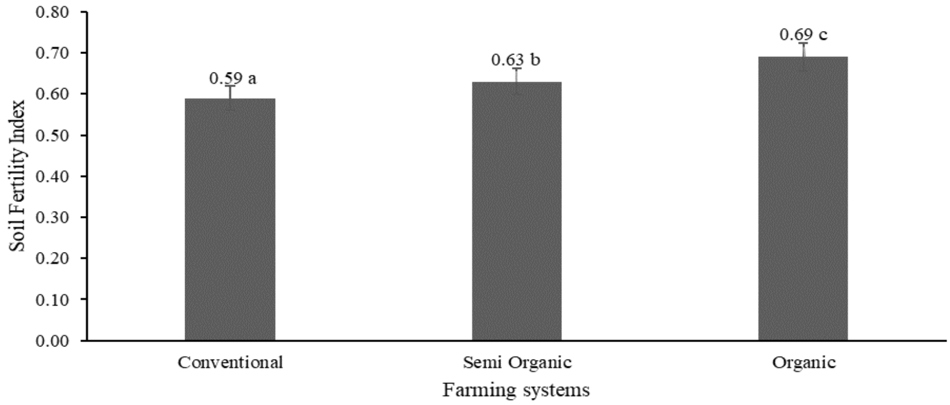

Fig. 4. *The distribution of soil fertility in various rice field farming systems*

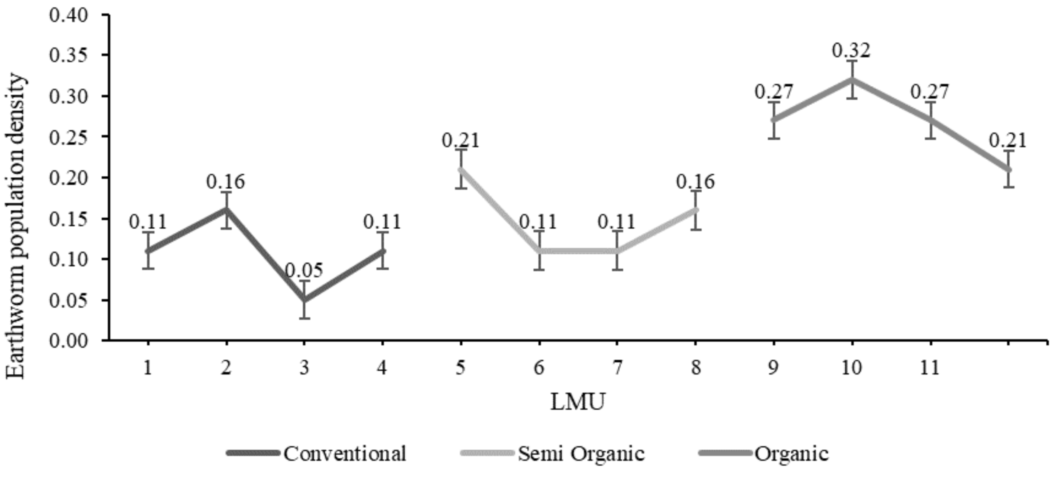

Fig. 5. *Distribution of earthworm population density in research area*

ganisms and the preservation of the ecosystem. In Giriwoyo district, the soil biota observed and analyzed were earthworms and C microbial biomass. Earthworms play an important role in decomposing organic matter and soil metabolism. Earthworms mineralize organic matter and release nutrients in an available form that plants can absorb (Ansari and Ismail, 2012). Earthworms can aid soil processes by influencing microbial community structure and nutrient mineralization (D. Zhu *et al*., 2021). The diversity and abundance of soil microbial or biomass plays an important role in soil fertility through carbon turnover and nitrogen cycling (Singh and Gupta, 2018). The highest earthworm population density values were found in rice fields with organic farming systems with a range of values from 0.21 to 0.32 individuals/liter with an average of 0.27 individuals/liter. Semi organic rice fields had a value range of 0.11 to 0.21 individuals/liter with an average of 0.15 individuals/liter, while conventional rice fields have a value range of 0.05 to 0.11 individuals/liter with an average of 0.11 individuals/liter (Fig. 5).

The results of ANOVA analysis showed that the rice field farming system had a very significant or actual effect on worm population density in Giriwoyo Wonogiri Regency (F-count= 7.528; sig= 0.002). The presence and activity of earthworms are influenced by the nature of the soil, land use, and soil management practices such as using fertilizers and pesticides (Hoeffner *et al*., 2021). The use of chemical fertilizer can have a negative impact on the activity and population of earthworms (Yahyaabadi *et al*., 2018). Based on the DMRT test, the population density of earthworms in organic rice field management was significantly higher than semi-organic and conventional rice field system (Fig. 6). Earthworm population density is strongly influenced by the food available in an ecosystem. Organic matter is food for earthworms (Capowiez *et al*., 2021). Contribution of organic matter from organic fertilizer positively influences the activity and population of earthworms in carrying out nutrient cycles and providing nutrients

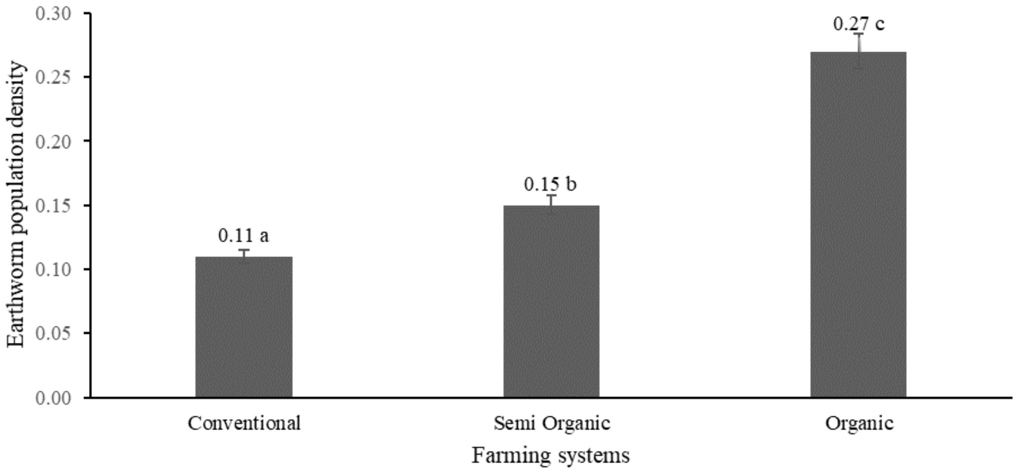

Fig. 6. *The average distribution of earthworms population density in rice fields*

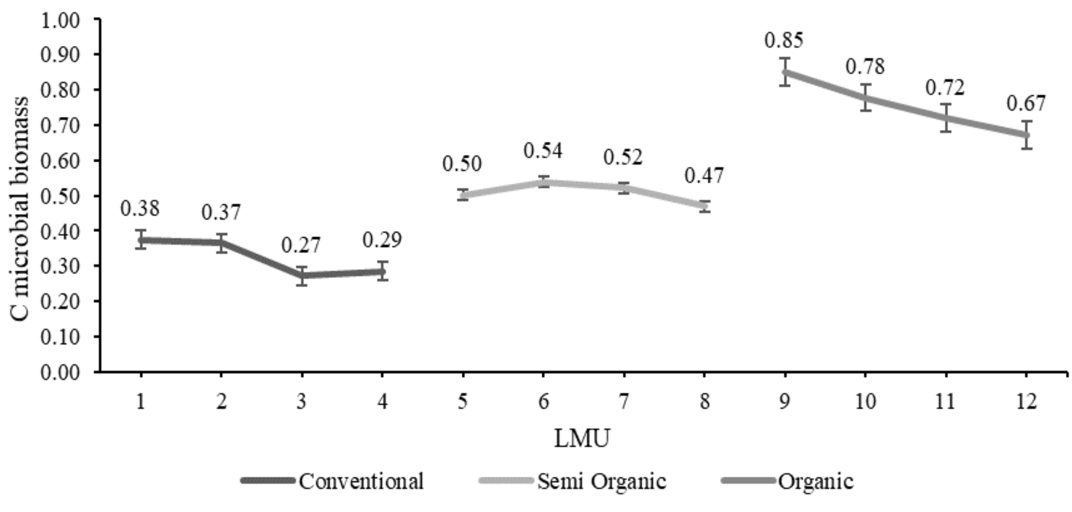

Fig. 7. *The distribution* of *C microbial biomass density in study area*

in the soil (Ahmed & Al-Mutairi, 2022).

The highest microbial biomass density value was found in rice fields with an organic farming system with a value range of 0.673 to 0.852 µg/g with an average of 0.755 µg/g. Semi organic rice fields had a value range of 0.470 to 0.538 µg/g with an average of 0.508 µg/g, while conventional rice fields had a value range of 0.272 to 0.375 µg/g with an average of 0.325 µg/g (Fig. 7).

The results of ANOVA analysis showed that the rice field farming system significantly affected C microbial biomass in Giriwoyo District, Wonogiri Regency (F-count = 145.902; sig = 0.000). The advantage of organic fertilizers is that they stimulate microbial activity and affect nutrient availability in the soil (Ma *et al.*, 2021). Applying organic fertilizers in the soil can increase soil biota and minimize the single use of chemical fertilizers (Bahadur *et al.*, 2014). Based on the DMRT test, C microbial biomass in organic rice field management was significantly higher compared to semi-organic and conventional rice field management (Fig. 8). The fertility effect on organic matter decomposition is directly proportional to the microbial growth rate in the soil, meaning that the more organic matter content, the more C microbial biomass in the soil (Mayer *et al.*, 2021). Long-term application of organic fertilizer results in higher abundance and diversity of soil bacteria and fungi and increases soil fertility in rice fields (Wang *et al.*, 2021). Bioenergy materials such as organic fertilizers can supply available energy to accelerate the multiplication of microorganisms and increase the activity of soil organisms and enzymes (Yang *et al.*, 2015).

Relationship between soil fertility and soil biota

Soil fertility was closely related to the presence of biota in the soil (Table 5). Soil biota and soil fertility are key interact factors (Luo *et al.*, 2017). Soil biota, such as worms and soil microbes, play an important role in the breakdown of organic matter, the improvement of soil structure, and the absorption and supply of nutrients in the soil. Soil animals and microbes are involved in signaling processes that contribute to agroecosystem integrity and maintain soil fertility and crop productivity (Ponge *et al.*, 2013). The diversity and functionality of soil biota are closely related to soil fertility (He *et al.*, 2021). Microorganisms and soil biota regulate nutrient dynamics in the soil (Groffman *et al.*, 2015).

Earthworm population density is significantly and positively correlated with soil fertility indices. Among bioindicators in agriculture, earthworms are one of the most frequently used to evaluate soil fertility (Fusaro *et al.*, 2018). The higher the density value of earthworms, the better the soil fertility index. This is due to the important role of earthworms in increasing the soil fertility index, including spreading organic matter and microorganisms to deeper soil layers and increasing soil aeration. Earthworms play an important role in soil fertility because they influence soil structure, soil aeration and drainage, decomposition of organic matter, and the continuity of soil nutrient cycles (Li *et al.*, 2021). Microbial activity affects the quantity and quality of soil organic matter availability, so an increase in microbial biomass can increase the rate of nutrient cycling and the amount of nutrients that will affect the increase in the soil fertility index. Soil microbial communities play an important role in maintaining soil fertility. They are considered indicators for evaluating soil fertility in a field (Zhu *et al.*, 2020), through mineralization and nutrient availability (Aponte *et al.*, 2013).

Determinants of soil fertility index

Determinants of soil fertility were obtained through a correlation test between soil fertility indicators and the results of the soil fertility index. The determining factor is determined from indicators that are significantly correlated with the soil fertility index (Mujiyo *et al.*, 2022). The determining factor analysis aimed to determine the

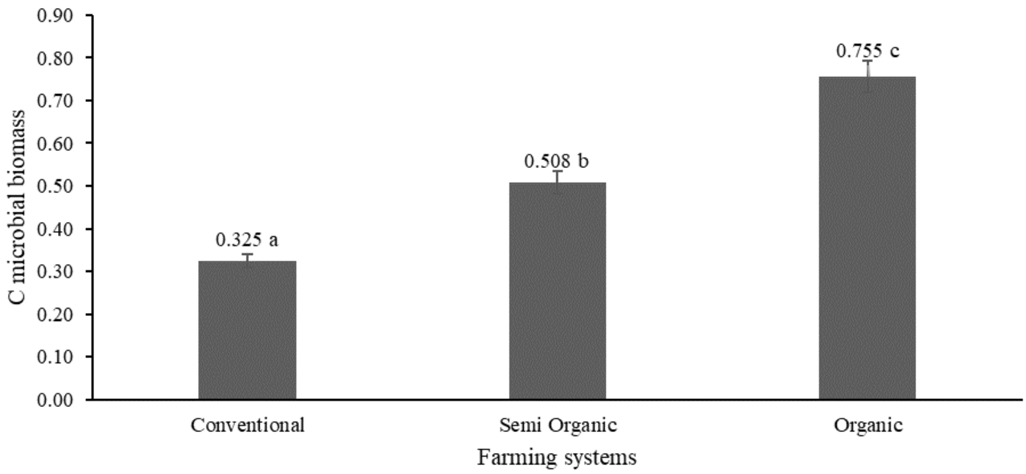

Fig. 8. *The average distribution of C microbial biomass density in rice fields*

Table 5. Relationship between soil biota and soil fertility index

	Earthworm population density	C microbal biomass	Soil fertility index
Earthworm population density	1		
C microbial biomass	0.610**	1	
Soil fertility index	0.525**	0.782**	1

Description: * = significant correlation at level <0.05; ** = significant correlation at level <0.01

Table 6. Relationship between soil fertility index and indicator factors and soil biota

	Total N	Available P	Available K	CEC	C organic	Earthworm population density	C microbial biomass	Soil fertility index
Total N	1							
Available P	0.623**	1						
Available K	0.686**	0.912**	1					
CEC	0.631**	0.839**	0.872**	1				
C organic	0.693**	0.928**	0.932**	0.857**	1			
Earthworm population density	0.443**	0.490**	0.580**	0.465**	0.604**	1		
C microbial biomass	0.621**	0.909**	0.877**	0.815**	0.944**	0.610**		
Soil fertility index	**0.780****	**0.761****	**0.788****	**0.702****	**0.827****	**0.525****	**0.782****	1

Description: *= significant correlation at level <0.05; **=significant correlation at level <0.01; the letters written in bold is determinant factors

indicators significantly correlated with changes in the soil fertility index to provide recommendations for improving the soil fertility index (Table 6). In our study, the determinant factors of soil fertility found are C-organic (r=0.827), Total N (r=0.780), Available P (r=0.761), Available K (r=0.788), and CEC (r=0.702). The soil biota as a biological aspect is also significantly correlated with soil fertility, including earthworm population density (r=0.525) and C microbial biomass.

Soil nutrients are the main limiting factor in fertility (Cai *et al*., 2019). Nitrogen, phosphorus and potassium are the main macronutrients that are closely related to soil fertility and plant growth (Song *et al*., 2018). The highest values of essential nutrients, CEC and C organic are found in rice fields with organic farming systems, affecting the highest average soil fertility index. The high content of organic matter in organic rice fields plays a role in reducing nutrient loss, this is because organic matter is able to bind nutrients, so that nutrients become available. Organic matter in the soil plays a key role in the nutrient cycle (Chaudhari *et al*., 2013). Organic matter can provide macronutrients for protein formation in plants and cation exchange capacity to exchange micronutrients (Wood *et al*., 2018).

Soil biota is positively and significantly correlated with soil fertility determinants. The higher the density of soil biota, the higher the N, P, K, CEC, and C organic values in the soil. The C and N contents in soil are interrelated with earthworms, which play a role in the soil nutrient cycle (Dobson *et al*., 2017). Earthworms are beneficial for transforming soil nutrients, thereby increasing soil fertility. Earthworm activities facilitate the rate of transformation of organic P into plant-available forms of P (Wu *et al*., 2012). Earthworm-mediated decomposition releases plant-available forms of nitrogen, phosphorus, and potassium (Zhou *et al*., 2021). Most of the mineral soil material digested by earthworms is returned to the soil as nutrients that plants easily utilize. Earthworms can provide N, P, K, Ca, and Mg that directly affect plant growth and yield and improve soil fertility (Nurhidayati *et al*., 2021).

Soil microbes form soil organic matter to maintain nitrogen and sulful cycling, their role as decomposers and releasing carbon dioxide (CO_2) in organic matter (Gougoulias *et al*. 2014). The presence and structure of soil microbial communities are largely correlated with changes in soil fertility, such as N, P, K, Ca, and Mg (Lammel *et al*., 2021). Some nutrients in soil, such as carbon, nitrogen, phosphorus, and sulfur cycles, are driven by microbes(Liu *et al*., 2020). Soil microorganisms can drive nutrient cycling by affecting soil organic matter, soil aggregation, porosity, and nutrient availability, with major implications on organic matter concentration and nutrient availability in the soil (Wen-wen *et al*., 2019). Soil microbes play a significant role in the decomposition of soil organic matter, nutrient cycling, and enzyme activity associated with soil fertility (Song *et al*., 2018).

Conclusion

This research not only assesses the soil fertility index in various rice field farming systems, which focus on soil chemical aspects but also evaluates it by considering biological aspects in the form of soil biota populations in terms of earthworm density and microbial biomass in the soil. The present study showed a significant effect of the rice field farming system on the fertility index and soil biota of the case study area, Giriwoyo District, Wonogiri Regency, Indonesia. The soil fertility index was included in the moderate class, with the highest average value in organic rice fields at 0.69, semi-organic rice fields at 0.62, and conventional rice fields at 0.59. Essential soil nutrients (N, P, K), CEC, and C organic are various factors determining soil fertility index. The same thing also happened to the density of soil biota, which had the highest results in organic rice fields. Soil biota, including worm population and C microbial biomass, has the highest average in organic rice fields. Earthworm population density in organic rice fields was 0.27 individuals/liter, while C-microbial biomass was 0.755 μ/g. Numerous suggestions to improve the soil biota and fertility index have been formulated in light of our findings. In organic farming systems, recommendations include utilizing a diverse selection of organic fertilizers and recycling harvest residues. It is necessary to convert inorganic or chemical fertilizers to organic fertilizers and provide organic materials in semi-organic and conventional cultivations. The addition of organic matter and utilizing biofertilizers to increase the density of soil biota. The use of organic fertilizers can promote sustainable agriculture by preserving soil microorganisms.

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Conflict of interest

The authors declare that they have no conflict of interest.

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