JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2024, 25(2), 126–139
https://doi.org/10.12911/22998993/176772
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.11.23
Accepted: 2023.12.11
Published: 2024.01.01

Assessing the Effect of Rice Management System on Soil and Rice Quality Index in Girimarto, Wonogiri, Indonesia

Muhammad Rizky Romadhon[1*], Mujiyo Mujiyo[1], Ongko Cahyono[1], Widyatmani Sih Dewi[1], Tiara Hardian[2], Akas Anggita[2], Khalyfah Hasanah[2], Viviana Irmawati[1], Nanda Mei Istiqomah[1]

[1] Department of Soil Science, Faculty of Agriculture, Universitas Sebelas Maret, Ir. Sutami Number 36, Surakarta 57126, Central Java, Indonesia

[2] Department of Agrotechnology, Faculty of Agriculture, Universitas Sebelas Maret, Ir. Sutami Number 36, Surakarta 57126, Central Java, Indonesia

* Corresponding author's e-mail: rizkyrom554@student.uns.ac.id

ABSTRACT

Excessive chemical input in rice management systems has an impact on reducing soil quality and rice quality. The research that links soil quality with rice quality is needed to produce recommendations for improving rice cultivation to make healthy rice. This study aimed to determine the index values of soil and rice quality in organic, semi-organic, and conventional paddy fields as well as their relationship to formulate recommendations for land improvement. This research used descriptive explorative methods and purposive sampling to determine the soil and rice samples. This data was then analyzed according to the method for determining the soil quality index and rice quality based on principal component analysis. The results reveal low soil and rice quality in various rice cultivation systems. Organic management of paddy fields has the highest index among other cultivation systems, with a value of 0.36, and tends to approach the moderate index. For the rice quality values, the organic system of paddy fields has the highest value (0.28) and tends to come with the status of moderate rice quality. There is a very significant correlation between soil quality and rice (r=0.80; p-value <0.001; n=54), that high-quality soil will produce high-quality rice too. The soil and rice quality in the organic system are the best compared to other systems. This condition proves that applying organic materials can increase soil quality and improve the quality of rice.

Keywords: environmental health, food security, metals, sustainable agriculture, zero hunger.

INTRODUCTION

Agricultural producers can generate healthy rice due to public understanding of healthy food (nutrition in food). Since Indonesians use rice as a staple, rice items are in high demand. Good soil produces good rice. Therefore, organic farming is implemented (Dewi et al., 2022). Statistics Indonesia predicts 31 million tonnes of rice consumption in 2020 based on population demand. Multiple Indonesian districts need 200 tons of organic rice per month. In 2021, the exports to Europe, the US, and Malaysia will reach 341.1 tons each quarter (Statistic Indonesia, 2022). Organic agriculture avoids synthetic pesticides and fertilizers (Supriyadi et al., 2021). The addition of organic matter in organic farming provides plant nutrition. Organic matter affects soil and plant biomass. Additionally, organic farming uses eco-friendly insecticides (Kurniawan et al., 2023). Organic farming improves soil quality, land sustainability, and crop quality. Higher fiber and protein content is found in organic farming. Organic rice with fiber reduces heart disease, stroke, cholesterol, and cancer risk (Liu et al., 2021). The high dietary fiber in organic rice helps it retain water as well as oil and is gluten-free (Qi et al., 2015). As a carbohydrate source, celiac and obesity sufferers worldwide choose organic rice. Organic 100-gram rice contains 79.34 grams of carbs and

6.6 grams of protein. Its high nutritional value and fiber content make organic rice a promising crop (Wen et al., 2017). Conventional rice production practices remain in most Indonesian rice fields (Istiqomah et al., 2023). Conventional farming uses chemical fertilizers, herbicides, and pesticides, which pollute land, ecosystems, and humans with 10% N_2O emissions (Arunrat et al., 2021). Sylvia and Zein (2021) found polluted rice in paddy fields in one industrial region, mainly with Al, Fe, Mn, and Zn. Plants absorb soil metals (Oliver and Gregory, 2015) and could harm humans if eaten (Zwolak et al., 2019). According to the Annual Report of the Food and Drug Information Center (Indonesian National Agency of Drug and Food Control, 2019), 325 food poisoning incidents have been documented. According to Zeng et al. (2021), pesticides disrupt enzymes and hormones, damage tissues, cause chronic and acute poisoning, as well as cancer.

Wonogiri Regency, one of the most agricultural regions in Central Java, has 98,082 hectares of agricultural land, corresponding to 53.8% of the total area (Statistic Indonesia, 2016). The presence of unfiltered irrigation water in the area still limits organic agriculture development. Chemical fertilizer and pesticide residues in irrigation water alter soil pH and plant nutrition availability (Adamczyk-Szabela et al., 2015). Later, soil acidity decreases plant nutrient availability and salt content increases, damaging soil structure (Xie et al., 2022). Therefore, Girimarto agricultural property must be surveyed for soil quality.

The comparison of soil organic matter and chemicals has to be conducted in order to assess soil quality. To measure soil quality for organic crop production, soil samples and plant tissue samples were analyzed. Previous soil quality studies rarely examined crop product quality. In PPOWW (Organic Agriculture Association of Wono Agung Wonogiri) fields, soil and organic rice quality data is limited. To assess the Girimarto organic agricultural soil quality, a soil survey is needed. The ratio of organic matter to chemicals in soil shows its quality. Organic farming assessment includes soil quality examination of soil and plant tissue samples for crop production. The research on paddy soil quality has mainly examined the chemical characteristics of the soil and macronutrient availability. There is no metal-content-based soil quality research. Understanding soil quality elements to improve rice quality is the novel aspect of this research. This study examined soil and rice quality in different production techniques and how soil quality influences rice quality.

MATERIALS AND METHODS

Materials

The research was carried out on organic rice fields owned by PPOWW-assisted farmers as well as semi-organic and conventional rice fields owned by PPOWW partner farmers. All rice fields are located in Girimarto District, Wonogiri Regency, Indonesia. Research materials include work maps, geographic system applications, soil and rice samples. Mapping of land units is made by overlaying the Rupa Bumi Indonesia (RBI) map, which is a base map of regions in Indonesia and Girimarto Subdistrict, then overlaid with a map that characterizes the sources of the diversity of paddy fields in Girimarto. The sources of this environmental diversity include soil types, land slopes, and cultivation systems. Table 1 shows the overlay results from each diversity source map. It will become a land mapping unit (LMU) to determine sampling points on the work map (Figure 1).

Methods

The research adopted an explorative, descriptive approach to analyze and classify the quality of soil and rice through observation and sampling in the field. Afterward, a scoring analysis was conducted to assess the soil and rice quality. The results were then analyzed cumulatively and presented through the interpretation of the observed soil and rice variables that has been analyzed. The observed soil variable (Table 2) were based on environmental conditions and soil morphology, as well as data from laboratory analysis, which are recapitulated to facilitate assessing soil quality. The observed rice variable (Table 4) were adjusted based on the parameters needed to determine rice quality. There were 18 LMUs with 3 repetitions, so there were 54 sample points.

Soil quality index analysis

Using PCA and MDS, soil quality index (SQI) was computed and the SQI results were classified (Cantu et al., 2007; Mulyono et al., 2019). The statistical analysis of the laboratory

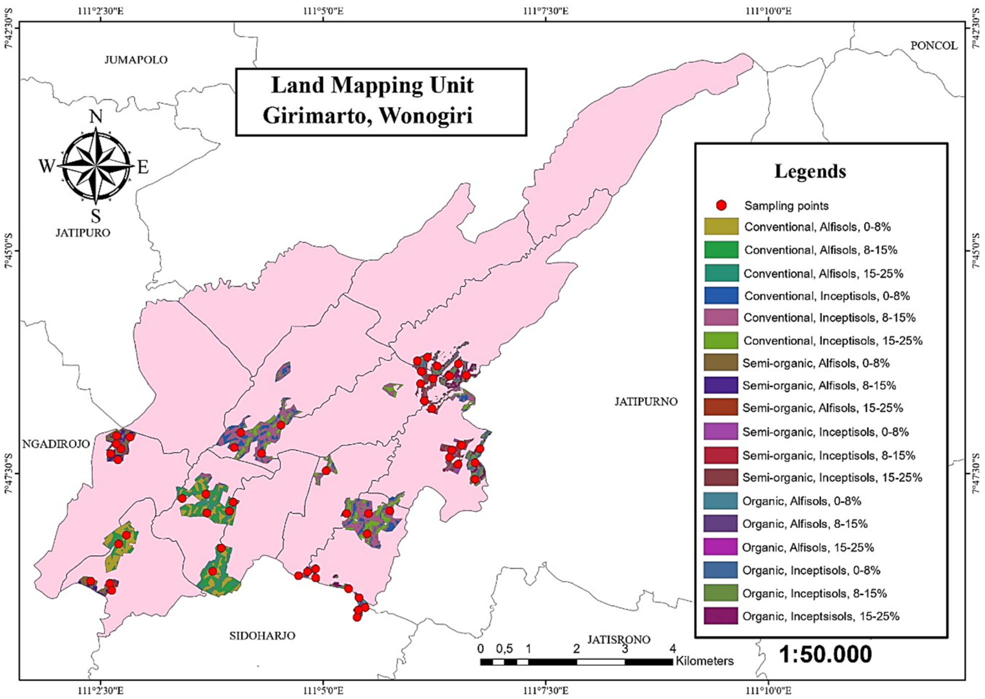

Figure 1. Land mapping unit

Table 1. Land mapping unit

LMU	Cultivation systems	Soil types	Slopes
1	Conventional	Alfisols	0-8%
2	Conventional	Alfisols	8-15%
3	Conventional	Alfisols	15-25%
4	Conventional	Inceptisols	0-8%
5	Conventional	Inceptisols	8-15%
6	Conventional	Inceptisols	15-25%
7	Semi-organic	Alfisols	0-8%
8	Semi-organic	Alfisols	8-15%
9	Semi-organic	Alfisols	15-25%
10	Semi-organic	Inceptisols	0-8%
11	Semi-organic	Inceptisols	8-15%
12	Semi-organic	Inceptisols	15-25%
13	Organic	Alfisols	0-8%
14	Organic	Alfisols	8-15%
15	Organic	Alfisols	15-25%
16	Organic	Inceptisols	0-8%
17	Organic	Inceptisols	8-15%
18	Organic	Inceptisols	15-25%

results was conducted by principal component analysis (PCA) to reduce the dimensions of the data set (Nehrani et al., 2020; Zhan et al., 2020). As MDS, the outcomes of parameter classification on each PC are chosen. Determining the correlation among indicators is the objective, as it will subsequently impact the SQI calculation (Table 3). Correlation tests were also conducted to ascertain the relationship between soil quality parameters and SQI.

$$\text{SQI} = \sum_{i=1}^{n} 1 = Wi \times Si^{n} \qquad (1)$$

Table 2. Soil quality indicators scoring

Indicators		Limiting factors and relative scores				
		1	2	3	4	5
Physics	Particle density (gr/cm^3)	>1.6	1.5-1.6	1.4-1.5	1.3-1.4	<1.3
	Bulk density (gr/cm^3)	>1.5	1.4-1.5	1.3-1.4	1.2-1.3	<1.2
	Porosity (%)	>20	18-20	15-18	10-15	<10
	Water content (%)	>30	<2	2-8	9-20	20-30
	Electrical conductivity (dS/m)	<3	3-5	5-7	7-10	>10
	Penetration (kg/cm^2)	>2.5	2-2.5	1.5-2	1-1.5	<1
Chemical	pH	<5 and >8.2	5.0-5.4 and 7.8-8.2	5.4-5.8 and 7.4-7.8	5.8-6.0 and 7.0-7.4	6.0-7.0
	Total-N (%)	<0.1	0.1-0.2	0.21-0.5	0.51-0.75	>0.75
	Available-P (ppm)	<10	10-15	16-25	16-35	>35
	Available-K (mg/100g)	<0.1	0.1-0.2	0.3-0.5	0.6-1	>1
	Organic-C (%)	<0.5	0.5-1	1-3	3-5	5-10
	C/N ratio	<5	>25	16-25	5-10	11-15
	Cation exchange Capacity (me/100g)	<5	5-16	17-24	25-40	>40
	Base saturation (%)	<20	21-30	31-50	51-70	>70
	Potential redox (mV)	0-100	101-200	201-300	301-400	>400 and <(-100)
	Al (ppm)	>50	40-50	35-40	20-35	<20
	Fe (ppm)	>53	53-19	19-5	5-3	<3
	Mn (ppm)	>20	15-20	10-15	5-10	<5
	Zn (ppm)	>50000	25001-50000	14001-25000	901-14000	1-900
Biology	C-Microbes biomass (µg/g)	>25	20-25	10-20	5-10	<5
	Soil respiration (Mg/hour m^2)	<9.5	9.5-16	16-32	32-64	>64

Note: Source – Indonesian Ministry of Agriculture (2023).

where: SQI – soil quality index, Wi – weighting index, Si – score index, n – number of soil quality indicators.

Rice quality index analysis

The results of laboratory analysis were then statistically analyzed using the principal component analysis (PCA) method to reduce the dimensions of the data set so that the determinants of rice quality could be identified. The following analysis is Pearson's correlation. The goal was to determine the correlation between indicators, which would later affect the rice quality index (RQI) calculation (Table 5). It was also conducted to determine the relationship between rice quality parameters and RQI.

$$\text{RQI} = \sum_{i=1}^{n} 1 = Wi \times Si^{n} \quad (2)$$

where: RQI – rice quality index,Wi – weighting index, Si – score index, n – number of rice quality indicators.

Table 3. Soil quality class criteria

Value	Class criteria
0.80–1.00	Very high
0.60–0.79	High
0.40–0.59	Moderate
0.20–0.39	Low
0.00–0.19	Very low

Note: Source – Cantu et al. (2007); Mulyono et al. (2019).

Data analysis

The parameters resulting from the analysis of soil and rice quality in various cultivation systems were then tested by ANOVA to determine the effect of the diversity of paddy field cultivation systems on SQI and RQI. If there is a significant value, a further test Duncan multiple range test (DMRT) is carried out to determine the average difference in the magnitude of the influence of the SQI and RQI cultivation systems. The relationship between SQI and RQI was determined using

Table 4. Rice quality indicators scoring

Indicators	Limiting factors and relative scores		
	1	2	3
Carbohydrate content (g/100g)	<10	>30	10–30
Rice dietary fiber content (g/100g)	<0.4	0.4–0,5	>0.5
Protein content (g/100g)	<8	8–8.9	>8.9
Fat content (g/100g)	>0.28	0.077–0.28	<0.077

Note: Source – Bhattacharya (2013); Hernawan and Meylani (2016); USDA (2019).

the Pearson correlation test between each index and each parameter, then became the basis for determining the relationship and was used as the basis for the formulation of determining factors.

Table 5. Rice quality class criteria

Value	Class criteria
0.66–1	High
0.33–0.66	Moderate
0.00–0.33	Low

Note: Source – Hernawan and Meylani (2016).

RESULTS AND DISCUSSION

Result

Soil quality index

The results of the PCA analysis show that 17 indicators are the main components of the MDS out of 21 indicators of soil quality (Table 6). In PC 1, it is represented by 57.20%, which consists of 8 indicators (moisture content, N-total, available-P, available-K, organic-C, CEC, microbial C biomass, respiration). PC 2 is represented by 12.10% of 2 indicators (pH and C/N ratio). On PC 3, it is represented by 9.70% composed of 4 indicators (particle density, Fe, Mn, and Zn). On PC 4, it is represented by 7.20% consisting of 2 indicators (base saturation and Al). On PC 5, it is represented by 4.90% and only consists of 1 indicator, namely soil penetration. All 17 indicators were maintained as MDS. The indicator that becomes the MDS was then calculated for its index weight (Wi). They obtained the Wi value by dividing the proportion value by the cumulative value. The next step was determining the SQI score by multiplying the Wi value with the MDS indicator score. The results of the SQI calculation are presented in Figure 2.

Rice quality index

The results of the PCA analysis showed that there were only 2 PCs that had eigenvalues ≥ 1. On the basis of the selection of the PCs, there were 4 rice characteristic indicators as MDS. The results of the PCA analysis are presented in Table 7. The results of the PCA analysis showed that of the total rice quality indicators used as observations in this study, 4 indicators were selected as the main components or MDS to determine the value of rice quality. In PC 1, which represents 67.60% of the total data for rice quality, 3 indicators were selected (carbohydrate, fiber, and protein) – PC 2, which means 22.50% and only consists of 1 indicator, i.e. fat. The four PC-chosen indicators were maintained as MDS. The indicator that becomes the MDS was then calculated for its index weight. The value of Wi was obtained by dividing the proportion value by the cumulative. The next step was determining the RQI value by multiplying the Wi value with the MDS indicator score. The results of the RQI calculation were presented in Figure 3.

Relationship between soil and rice quality

In this research, the relationship between SQI and RQI becomes a fundamental idea for formulating recommendations for the solutions that can be given to environmental improvement. The recommendations are based on the limiting factors found after determining the relationship between the two aspects. The results of the Pearson correlation analysis between SQI and RQI are presented in Table 8. The correlation value shows R=0.80, meaning that the condition of soil and rice quality are interrelated.

The results of the ANOVA test (Table 9) showed that the paddy cultivation system significantly affected soil quality (F-count = 48.535, p-value = 0.000, n = 54). A significant effect was then carried out by DMRT and obtained differences in average soil quality in several rice cultivation systems.

Table 6. PCA analysis results on each SQI indicator

Eigenvalue	12.006	2.533	2.041	1.508	1.032
Proportion	0.572	0.121	0.097	0.072	0.049
Cumulative	0.572	0.692	0.790	0.861	0.910
Variable	PC1	PC2	PC3	PC4	PC5
Particle density	0.134	-0.307	***0.442**	-0.114	0.072
Bulk density	0.073	-0.021	0.632	0.232	-0.029
Porosity	0.024	-0.346	-0.274	-0.345	0.508
Water content	***0.264**	0.147	-0.094	-0.028	0.166
Electrical conductivity	-0.027	0.273	0.039	-0.600	-0.206
Penetration	0.148	0.334	-0.061	0.346	***0.366**
pH	0.213	***0.284**	0.055	-0.275	0.230
Total-N	***0.271**	-0.163	0.009	0.076	-0.062
Available-P	***0.257**	-0.031	0.105	-0.176	-0.101
Available-K	***0.236**	-0.202	0.045	-0.079	-0.373
Organic-C	***0.286**	0.010	0.070	-0.015	-0.030
C/N ratio	0.202	***0.277**	0.149	-0.323	-0.078
Cation exchange capacity	***0.285**	0.019	0.016	-0.020	0.042
Base saturation	0.236	0.212	0.014	***0.260**	0.043
Potential redox	0.040	0.404	-0.264	0.099	-0.399
Al	-0.225	-0.177	-0.119	***0.054**	-0.293
Fe	-0.270	-0.010	***0.169**	-0.058	-0.124
Mn	-0.232	0.198	***0.294**	-0.006	0.155
Zn	-0.241	0.187	***0.230**	-0.063	0.049
C-Microbes Biomass	***0.279**	-0.104	0.053	0.059	-0.077
Soil respiration	***0.262**	-0.165	-0.134	0.070	-0.193

Note: * = MDS.

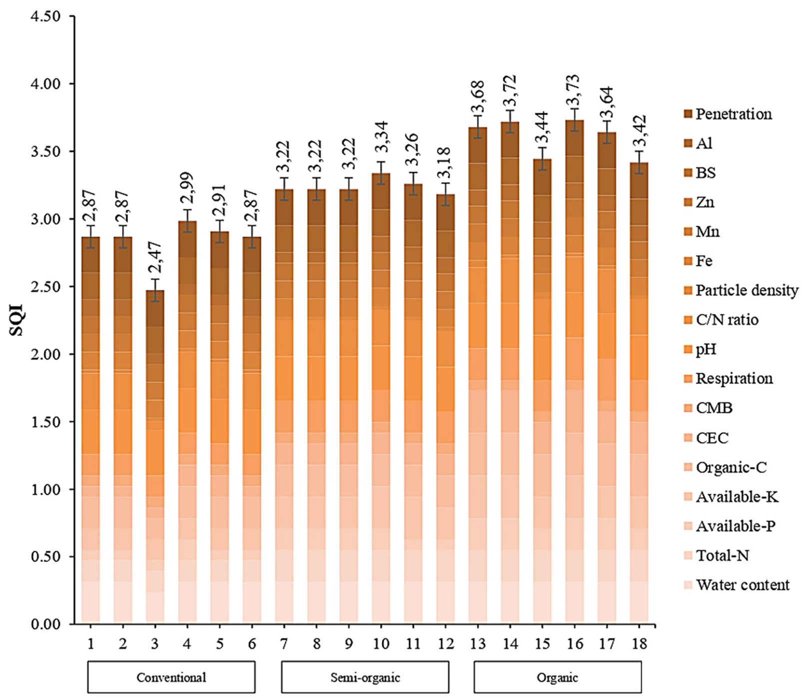

Figure 2. SQI value at each LMU: CEC – cation exchange capacity; CMB – carbon microbes biomass; BS – base saturation

Table 7. PCA analysis results on each RQI indicator

Eigenvalue	2.7023	1.0001
Proportion	0.676	0.225
Cumulative	0.676	0.901
Variable	PC1	PC2
Carbohydrate content	***-0.542**	-0.463
Rice's dietary fiber content	***0.580**	0.187
Protein content	***0.508**	-0.146
Fat content	-0.334	***0.854**

Note: * = MDS.

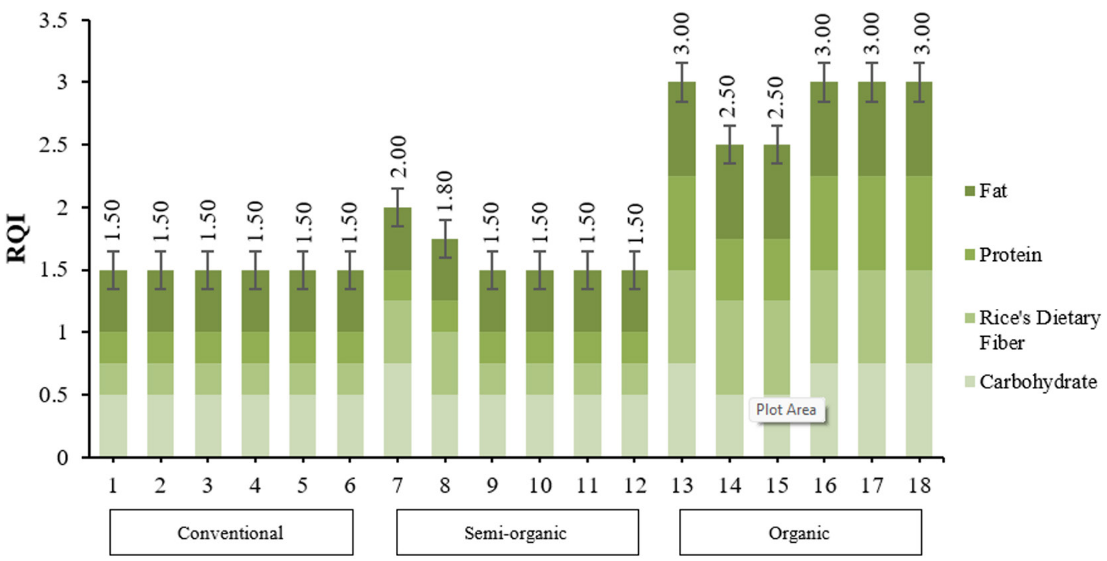

Figure 3. RQI value at each LMU

Table 8. The correlation value between SQI and RQI

Parameter		SQI	RQI
Soil quality index	Pearson Correlation	1	
	Sig. (2-tailed)		
	N	54	
Rice quality inde	Pearson Correlation	0.80**	1
	Sig. (2-tailed)	0,00	
	N	18	54

Note: ** – significantly correlated.

DISCUSSION

Soil quality index (SQI)

The results showed low soil quality in various rice cultivation systems in Girimarto. Organic system has the highest index among other cultivation systems, with a value of 0.36, and tends to approach the moderate index. Semi-organic, with an average index of 0.32, was higher than conventional. The lowest index is the conventional, which is equal to 0.28. Even though they have different SQI values, all of them are equally classified as low index. Chemical reactions in soil are very complex. Many exchanges of cations and anions process occur in the soil lattice (Herawati et al., 2021). Therefore, improving soil fertility takes quite a long time (Dewi et al., 2022). This is due to the need for adequate time to change several soil characteristics: physics, chemistry, and biology (De Laurentiis et al., 2019).

Table 9. Effects of environmental diversity sources on SQI and RQI

Environmental diversity	Cultivation system	Soil types	Slope
SQI *P-value* (*sig.*)	0.000^{**}	0.685^{ns}	0.584^{ns}
RQI *P-value* (*sig.*)	0.000^{**}	0.930^{ns}	0.908^{ns}

Note: ns = non significant; * = significant; ** = very significant.

The difference in SQI results explains that the land management process (rice cultivation) affects the quality of the land (Figure 4). Physic, chemistry and biology of soil are related to each other. By providing treatment into the cultivation system, it will affect these three soil indicators. Good treatment of the soil has a positive impact on the three soil indicators, and vice versa (Al Viandari et al., 2022). This statement explains the mechanisms of soil processing that can result in improvements in the nutritional quality of the soil. Paddy field management, especially organic, will enhance nutrient quality and increase soil quality over time (Mujiyo et al., 2018). Wihardjaka (2021) proved that organic paddy fields in Jatisrono, Wonogiri have greater SQI than other land uses. Long-term, consistent land management on a wide scale affects soil quality by altering structure, porosity, chemistry, and biology (N, P, K, CEC, and BS) (Xiao et al., 2017). Organic systems have the greatest average SQI and differ from conventional and semi-organic systems (Figure 5). The organic system has a 27.56% SQI difference from the conventional, whereas the semi-organic system has 14.49%. Assessing soil quality is essential to keeping up plant nutrients. Soil chemical indicators are most commonly used to measure soil quality. The soil pH at the study site ranged from 6.31 to 6.98, which is neutral. Soil pH measures soil acidity or H^+ and OH^- concentrations. The total N content of soil is low to moderate, ranging from 0.17% to 0.42%. High-organic matter soil maintains N levels (Dewi et al., 2017). The P level in the research region ranged from 3.27 to 18.45 ppm, low to high. Due to Ca and Mg adsorption, the soil has low P content, and element P leaches easily. The most important nutrient in agriculture is soil P (Cahyono and Minardi, 2021). In line with the result of Pearson correlations between

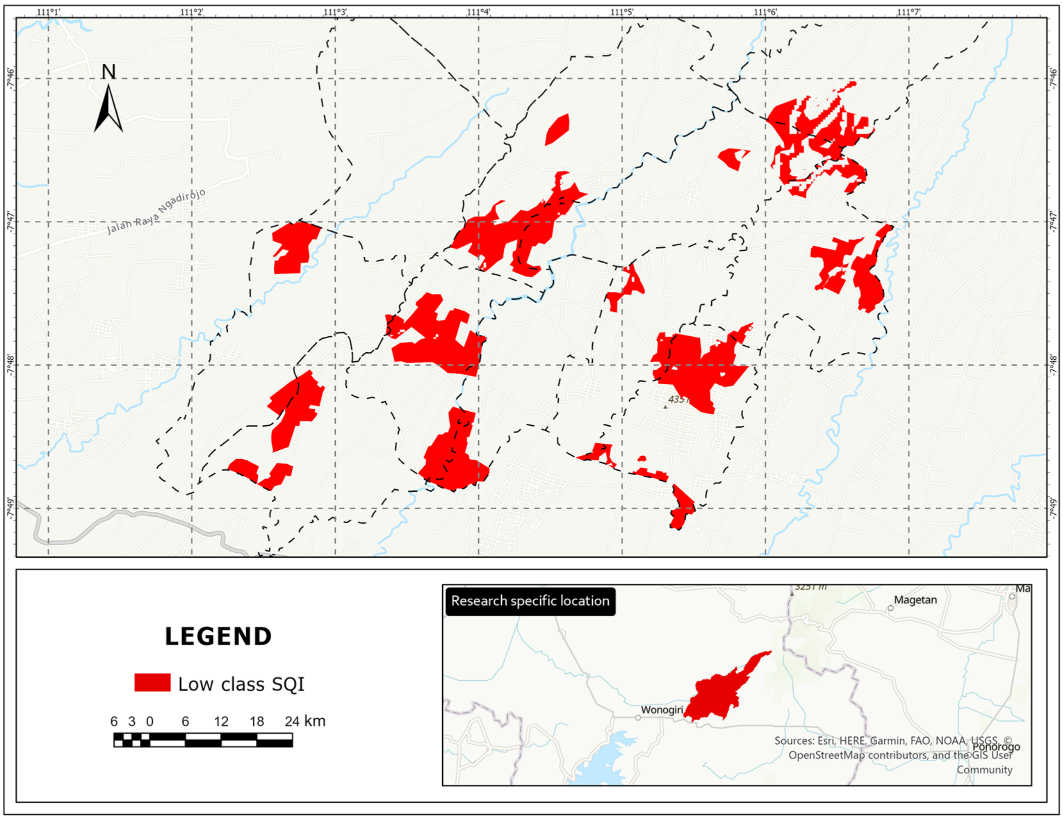

Figure 4. Map of SQI in various rice cultivation systems

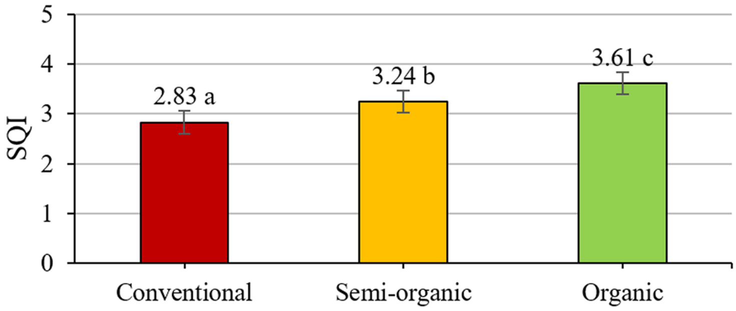

Figure 5. Average SQI in various rice cultivation systems

determinants factor with SQI, Total-N (r = 0.92; p-value <0.001; n = 54), available-P (r = 0.93; p-value <0.001; n =54), organic-C (r = 0.96; p-value <0.001; n =54), CEC (r = 0.93; p-value <0.001; n = 54), c microbe biomass (r = 0.94; p-value <0.001; n = 54) and soil respiration (r = 0.90; p-value <0.001; n = 54) has a significant correlation.

Organic matter release and mineralization during decomposition increase essential nutrient availability, especially on soil quality determinants like nitrogen (N) (index 0.16-0.24), phosphorus (P), and potassium (K) (index 0.24-0.31) (Fitria and Soemarno, 2022). Under aerobic conditions, organic materials input to the soil during cultivation, accelerates microbial development (Naknim et al., 2016). Soil organic matter is measured by the population of microorganisms, based on soil management (Ghosh et al., 2012). Organic farming had the greatest soil respiration quality index (0.24–0.31). Organic (0.24-0.31) farming systems have the largest CEC range, followed by conventional (0.08-0.16) and semi-organic (0.16) agricultural systems. Soil CEC values also affect soil quality (r=0.93). According to Ramos et al. (2018), organic farming had the greatest soil respiration quality index (0.24–0.31). Organic (0.24–0.31) farming systems have the largest CEC range, followed by conventional (0.08–0.16) and semi-organic (0.16) agricultural systems. Soil CEC values also affect soil quality (r=0.93). Low Organic-C content reduces soil negative charge and inhibits cation exchange. Soil respiration and C-microbial biomass show that Organic-C content affects biological qualities, as well as chemical properties. High soil respiration releases CO_2 from soil fauna and bacteria' heterotropic metabolic activity (Xu and Shang, 2016).

Rice quality index

Dietary fiber and protein in rice farmed in different systems (Figure 6) revealed lower rice quality. Differing cultivating systems yield varied rice quality indices. Organic field management has the highest index (0.28), followed by semi-organic (0.16) and conventional (0.15). ANOVA demonstrated that lowland cultivation altered rice quality (F-count = 39,000, p-value = 0.000, n = 54). DMRT found disparities in rice quality across multiple farming systems (Figure 7). Each cultivation style produces rice with a different quality index, indicating that land management changes rice quality. The organic rice field farming approach will increase soil and crop quality over time (Khoerunnisa et al., 2022). According to Mujiyo et al. (2022), organic paddy fields produce better rice in Girimarto District, Wonogiri.

The data showed low rice fiber and protein. Fiber content of rice is 0.29–0.66 g/100g. The research found 4.48 to 9.74 g/100g rice protein. Rice quality differs greatly between rice system strategies. Compared to conventionally farmed rice, organic rice has 59.81% and 62.46% more fiber and protein. Semi-organic produced rice contains 64.48% less fiber and 18.61% less protein than organic rice.

The organic system scored the greatest RQI. It differed dramatically from semi-organic and conventional farming systems, which had similar RQI values. Compared to the traditional system, the organic system has 88.66% RQI. Not considerably different from the conventional system, the semi-organic system has an RQI of 8.66%. As per Pearson correlation between determinants and RQI, rice dietary fiber (r = 0.97; p-value <0.001; n =54) and protein (r = 0.84; p-value <0.001; n =54) are significantly correlated.

If the soil contains adequate carbon and nitrogen to make fiber and protein (Cui et al., 2020), rice will be of better quality (Barrett et al., 2020). The rice with high protein content is preferable (Xu et al., 2021). Rice plant food stores will contain nitrogen, amino acids, and other nutrients

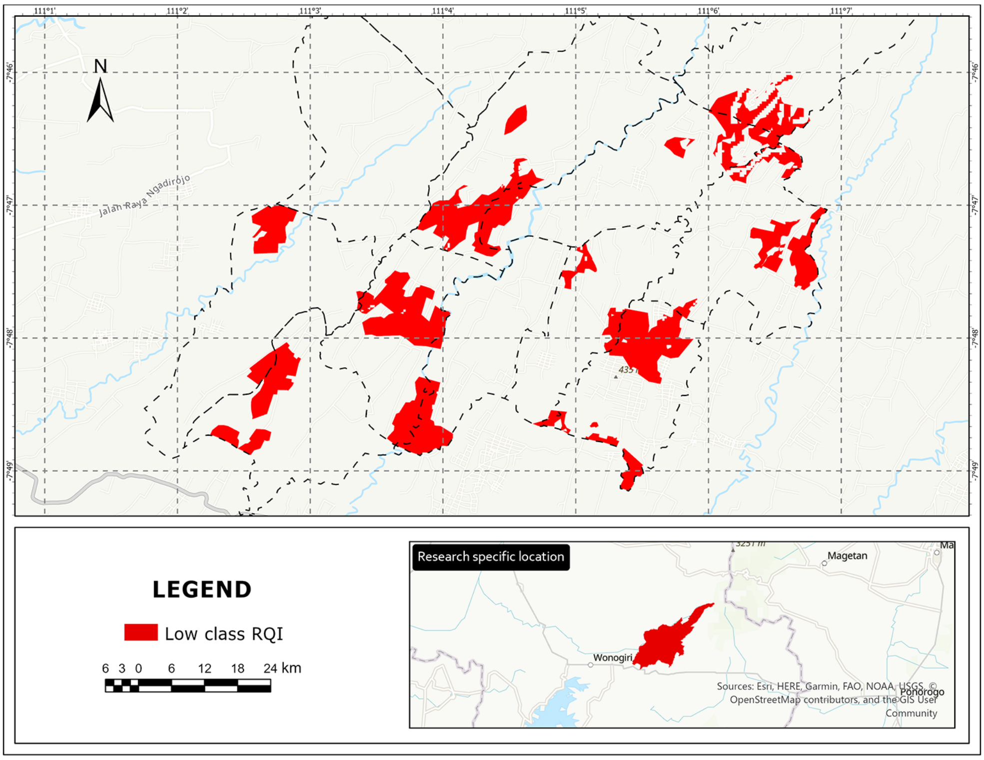

Figure 6. RQI map on various rice cultivation systems

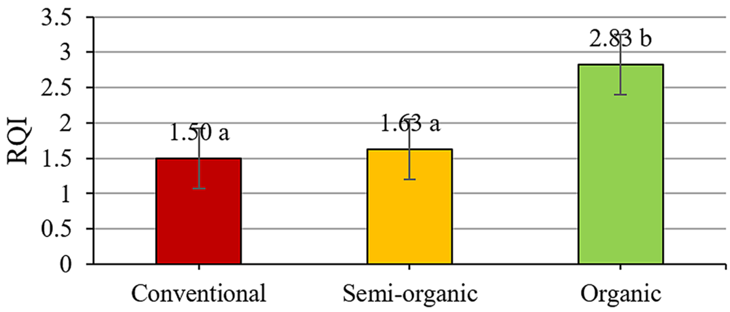

Figure 7. Average RQI in various rice cultivation systems

needed for primary protein synthesis (Iqbal et al., 2020). Apart from plant breeding, maintaining the soil environment and nutrient levels is crucial to growing quality rice. Rice milk grain formation also depends on water availability (Kumar, 2021). Incorrect milk grain formation in rice plants means poor rice grain production (Xu et al., 2020). Rice planting requires sufficient water, not excess (Shufen et al., 2019).

Dietary fiber, a plant tissue component, resists hydrolysis in the digestive tract and small intestine (Soliman, 2019). Water-soluble and insoluble dietary fibers are characterized by their digestibility as well as solubility. Insoluble dietary fiber is not soluble in hot or cold water. Soluble dietary fiber slows digestion and extends fullness by decreasing blood glucose emergence, requiring less insulin to move glucose into cells and convert it into energy. Insoluble dietary fiber prevents digestive tract illnesses, such as hemorrhoids, diverticulosis, and colon cancer (Tanes et al., 2021). The cell walls of many food plants contain fiber (Canteri et al., 2019). Lignin polymers and carbohydrates including cellulose, hemicellulose, and pectin make up the cell wall (Rezende et al., 2021).

Protein is a macronutrient that forms biomolecules. Protein contains mainly nitrogen (Wu et al., 2020). A number of these components determine the rice protein content (Tsujimoto et al., 2019). The degradation process releases matrix-bound nitrogen elements, which are quantified. Liu et al. (2021) found that environmental variables, particularly soil quality, greatly affect rice protein content. This emphasizes the significance of soil management to maintain nitrogen levels for plant development and food quality.

Relationship between soil and rice quality

There is a very significant correlation between soil and rice quality. The positive correlation between soil and rice quality (r = 0.80; p-value <0.001; n = 54) explains that land with high-quality values will also produce rice with high-quality values. Conversely, if the soil has low-quality value, it will produce rice with low-quality value.

The Pearson correlation demonstrates a substantial correlation between SQI and RQI determinants. The following variables were found to be significantly correlated: total-N (r = 0.76; p-value <0.001; n =54), available-P (r = 0.77; p-value <0.001; n =54), organic-and (r = 0.81; p-value <0.001; n =54), CEC (r = 0.77; p-value <0.001; n =54), and microbe biomass (r = 0.77). Thus, rice dietary fiber correlates with all SQI factors. Aligned data demonstrate that all SQI determinants correlate with rice protein. The following variables were found to be significantly correlated: total-N (r = 0.90; p-value <0.001; n = 54), available-P (r = 0.85; p-value <0.001; n = 54), organic-and (r = 0.92; p-value <0.001; n = 54), CEC (r = 0.94; p-value <0.001; n = 54), as well as microbe biomass (r = 0.92). As a whole and per determining factor, soil and rice quality are related, considering the chemical and biological properties that determine soil quality also determine rice quality. The result discovered a significant correlation (p-value <0.01).

Recommendations for improving SQI and RQI

Soil quality must be improved to reduce hazards (Agbede and Oyewumi, 2023), improve productivity, and enhance food security (Rosariastuti et al., 2018). Reducing the proportion of metals in the soil is also required to decrease soil degradation (Romadhon et al., 2023). Then, it will improve soil quality and produce healthy food products (Punyalue et al., 2018). The rice quality and food security will reach and sustain public health (Dewi et al., 2022). Six criteria (N-total, available-P, organic-C, CEC, biomass C microbes, and soil respiration) limit soil quality in paddy agriculture systems. Two parameters – fiber and protein – limit rice quality. The researchers made recommendations to improve soil and rice quality based on these limiting variables. Recommendations on land management (Romadhon and Aziz, 2022), which are based on indicators directly related to soil quality and several indicators with low scores. The SQI reduction was substantially linked with reduced available-P. According to this study, rice field soil has low to very low available-P. It will hinder plant growth if not fertilized (Cahyono, 2019).

Phosphorus fertilizers improve P availability. It also assured with organic fertilizers (Latif et al., 2023). Organic matter in the soil replaces the P anion (H_2PO_4-) in the adsorption complex. It will also boost organic P mineralization into inorganic P. Adding rice husk charcoal can boost nutritional availability, especially P and K. Fang et al. (2015) found that husk charcoal and organic fertilizers boost element P availability. Rock phosphate or natural phosphate rock can also be used to guarantee P supply in nature. Phosphate rock will store P for a long time. Due to weathering and mineralization, plants can receive missing P nutrients. Inorganic P nutrient fertilization is another P deficient land improvement option. Inorganic fertilizers must be dosed properly (Oechaiyaphum et al., 2020).

Using biological agents to fix nutrient deficits is another effective land improvement method. Adding organic matter to soil increases beneficial microbes (Rao et al., 2019). Farmers also use arbuscular mycorrhizae to support stressed plants. Mycorrhizae protect roots and reach the water absorption places that roots cannot (Riaz et al., 2021). Due to its affinity for P, mycorrhizal hyphae exchange organic acids to break down P, which plants cannot use. These organic acids are found in dead mycorrhizal hyphae (Herawati et al., 2021), which provide organic-C to the soil and help create soil aggregates. The chemical is glomalin (He et al., 2020). The separated soil particles will be bonded together using glomalin to form soil aggregates, improving soil water retention.

CONCLUSIONS

Soil and rice quality is comparatively low in the paddy fields of the study area. Organic cultivation yields the highest value for soil quality, while conventional yields the lowest. Analogously, distinct values result from comparing the grade of rice quality in various paddy fields. Unlike conventional one, organic rice produces the highest quality rice.

Acknowledgments

The authors thank the Department of Soil Science Master Program of Universitas Sebelas Maret Surakarta and Wono Agung Wonogiri Organic Farming Association (PPOWW). This work was funded by the Institute for Research and Community Services (LPPM) of Universitas Sebelas Maret trough Applied Excellence Research Scheme (PUT) for the 2023 fiscal year with grant Number: 228/UN27.22/PT.01.03/2023

REFERENCES

1. Adamczyk-Szabela, D., Markiewicz, J., Wolf, W. M. 2015. Heavy metal uptake by herbs. IV. Influence of soil pH on the content of heavy metals in Valeriana officinalis L. Water, Air, & Soil Pollution, 226, 1-8.
2. Agbede, T.M., Oyewumi, A. 2023. Effects of biochar and poultry manure amendments on soil physical and chemical properties, growth and sweet potato yield in degraded Alfisols of humid tropics. Chiang Mai University Journal of National Science, 22(2), e2023023.
3. Al Viandari, N., Wihardjaka, A., Pulunggono, H., Suwardi, S. 2022. Sustainable Development Strategies of Rainfed Paddy Fields in Central Java, Indonesia: A Review. Caraka Tani: Journal of Sustainable Agriculture, 37(2), 275-288.
4. Arunrat, N., Pumijumnong, N., Sereenonchai, S., Chareonwong, U., Wang, C. 2021. Comparison of GHG emissions and farmers' profit of large-scale and individual farming in rice production across four regions of Thailand. Journal of Cleaner Production, 278, 123945.
5. Barrett, E.M., Foster, S.I., Beck, E.J. 2020. Whole grain and high-fibre grain foods: How do knowledge, perceptions and attitudes affect food choice?. Appetite, 149, 104630.
6. Bhattacharya, K. R. 2013. 13 - Analysis of rice quality. Woodhead Publishing Series in Food Science, Technology and Nutrition, Rice Quality. Woodhead Publishing-Elsevier, 431-530.
7. Cahyono, O. 2019. Pengaruh Cekaman Kekeringanpada Pertumbuhan dan Hasil Beberapa Varietas Kedelai (Glycine Max L Merr) Lokal. Jurnal Ilmiah Agrineca, 19(1), 63-73.
8. Cahyono, O., Minardi, S. 2021. Effect of fast dissolved phosphorus fertilizer on the growth, seed product, and phosphorus uptake efficiency of soybean (Glycine max L.). AGRIVITA, Journal of Agricultural Science, 44(1), 21-30.
9. Cantú, M.P., Becker A., Bedano J.C., Schiviano H.F. 2007. Evaluación de la calidad de suelos mediante el uso de indicadores e índices en la Pampa Argentina. Ciencia Suelo., 25, 173-178.
10. Cui, J., Zhu, Z., Xu, X., Liu, S., Jones, D. L., Kuzyakov, Y., Shibistova, O., Wu, J., Ge, T. 2020. Carbon and nitrogen recycling from microbial necromass to cope with C: N stoichiometric imbalance by priming. Soil Biology and Biochemistry, 142, 107720.
11. De Laurentiis, V., Secchi, M., Bos, U., Horn, R., Laurent, A., Sala, S. 2019. Soil quality index: Exploring options for a comprehensive assessment of land use impacts in LCA. Journal of Cleaner Production, 215, 63-74.
12. Dewi, W.S., Komariah, E.P., Pratama, Y.O., Woro, R., Prasasty, A.E.P. 2017. Improving yield of organic black rice by azolla and biochar. Proceeding Book, 506.
13. Dewi, W.S., Romadhon, M.R., Amalina, D.D., Aziz, A. 2022. Paddy soil quality assessment to sustaining food security. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 1107(1), 012051.
14. Dewi, W.S., Amalina, D.D., Romadhon, M.R. 2023. Microbial Biofilm for Soil Health, Plant Growth, and Productivity under Multi Stress. A Review. In IOP Conference Series: Earth and Environmental Science IOP Publishing, 1162(1), 012008.
15. Fang, Y., Singh, B., Singh, B.P. 2015. Effect of temperature on biochar priming effects and its stability in soils. Soil Biology and Biochemistry, 80, 136-145.
16. Fitria, L., Soemarno, S. 2022. Effects of Lime and Compost on Chemical Characteristics and Soil Hydraulic Conductivity of Alfisols at ATP Jatikerto Coffee Plantation. Caraka Tani: Journal of Sustainable Agriculture, 37(1), 48-61.
17. Ghosh, S., Wilson, B., Ghoshal, S., Senapati, N., Mandal, B. 2012. Organic amendments influence soil quality and carbon sequestration in the Indo-Gangetic plains of India. Agriculture, ecosystems & environment, 156, 134-141.
18. He, J.D., Chi, G.G., Zou, Y.N., Shu, B., Wu, Q.S., Srivastava, A.K., Kuča, K. 2020. Contribution of glomalin-related soil proteins to soil organic carbon in trifoliate orange. Applied Soil Ecology, 154, 103592.
19. Herawati, A., Syamsiyah, J., Mujiyo, M., Rochmadtulloh, M., Susila, A. A., Romadhon, M. R. 2021. Mycorrhizae and a soil ameliorant on improving the characteristics of sandy soil. SAINS TANAH-Journal of Soil Science and Agroclimatology, 18(1), 73-80.
20. Hernawan, E., Meylani, V. 2016. Analisis karakteristik fisikokimia beras putih, beras merah, dan beras hitam (Oryza sativa L., Oryza nivara dan Oryza sativa L. indica). Jurnal Kesehatan Bakti Tunas Husada: Jurnal Ilmu-Ilmu Keperawatan, Analis Kesehatan Dan Farmasi, 15(1), 79-91.
21. Indonesian National Agency of Drug and Food Control. 2019. Annual Report of the Food and Drug

Information Center. Jakarta: NADFC

22. Indonesian Ministry of Agriculture. 2023. Technical manual 3rd edition: chemical analysis of soil, aquatic plants and fertilizers. Soil And Fertilizer Instrument Standard Testing Center. Ministry of Agriculture: Bogor.
23. Iqbal, A., Qiang, D., Alamzeb, M., Xiangru, W., Huiping, G., Hengheng, Z., Nianchang, P., Xiling, Z., Meizhen, S. 2020. Untangling the molecular mechanisms and functions of nitrate to improve nitrogen use efficiency. Journal of the Science of Food and Agriculture, 100(3), 904-914.
24. Istiqomah, N.M., Cahyono, O., Mujiyo, M., Ariyanto, D.P., Maro'ah, S., Romadhon, M.R., Irmawati, V. 2023. Assessment of potential soil degradation on various land uses in Keduang Watershed. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 1241(1), 012014.
25. Khoerunnisa, K., Putry, R., Salsabila, S., Darmawan, M., Nahdatulia, Y., Budisantoso, I. 2022. Growth and Flavonoids Content of Black Rice (Oryza sativa L. indica) with Compost Tea of Oyster Mushroom Waste. Caraka Tani: Journal of Sustainable Agriculture, 37(2), 289-298.
26. Kumar, S. 2021. Saving water for ecological integrity: Agricultural perspective of Per drop more crop. Int. J. Environ. Sci. Nat. Res, 28, 1-7.
27. Kurniawan, I. D., Kinasih, I., Akbar, R. T. M., Chaidir, L., Iqbal, S., Pamungkas, B., Imanudin, Z. 2023. Arthropod Community Structure Indicating Soil Quality Recovery in the Organic Agroecosystem of Mount Ciremai National Park's Buffer Zone. Caraka Tani: Journal of Sustainable Agriculture, 38(2), 229-243.
28. Latif, J.A., Putra, R.E., Alfianny, R. 2023. Quail (Coturnix coturnix japonica) Fermented Manure as a Fertilizer to Support Azolla microphylla Growth Rate. Caraka Tani: Journal of Sustainable Agriculture, 38(1), 113-124.
29. Liu, Y., Zhang, H., Yi, C., Quan, K., Lin, B. 2021. Chemical composition, structure, physicochemical and functional properties of rice bran dietary fiber modified by cellulase treatment. Food Chemistry, 342, 128352.
30. Mujiyo, M., Sumarno, S., Suryono, S., Sutopo, N.R. 2018. Aplikasi Pupuk Organik Diperkaya Mikrobia Pada Usaha Pembibitan Tanaman. PRIMA: Journal of Community Empowering and Services, 2(2), 44-49.
31. Mujiyo, M., Puspito, G. J., Suntoro, S., Rahayu, R., Purwanto, P. 2022. The Effect of Change in Function from Paddy Field to Dry Land on Soil Fertility Index. Environment and Natural Resources Journal, 20(1), 42-50.
32. Mulyono, A., Suriadikusumah, A., Harriyanto, R., Djuwansah, M. R. 2019. Soil quality under agroforestry trees pattern in upper Citarum watershed, Indonesia. Journal of Ecological Engineering, 20(1), 203-213.
33. Naknim, V., Kutanan, W., Lomthaisong, K. 2016. Identifying the origin of forensic soil evidence using amplified ribosomal DNA restriction analysis of its bacterial community. J. Nat. Sci, 15, 115-128.
34. Nehrani, S.H., Askari, M.S., Saadat, S., Delavar, M.A., Taheri, M., Holden, N.M. 2020. Quantification of soil quality under semi-arid agriculture in the northwest of Iran. Ecological indicators, 108, 105770.
35. Oechaiyaphum, K., Ullah, H., Shrestha, R.P., Datta, A. 2020. Impact of long-term agricultural management practices on soil organic carbon and soil fertility of paddy fields in Northeastern Thailand. Geoderma regional, 22, e00307.
36. Oliver, M.A., Gregory, P.J. 2015. Soil, food security and human health: a review. European Journal of Soil Science, 66(2), 257-276.
37. Punyalue, A., Jongjaidee, J., Jamjod, S., Rerkasem, B. 2018. Legume intercropping to reduce erosion, increase soil fertility and grain yield, and stop burning in highland maize production in Northern Thailand. Chiang Mai University Journal of National Science, 17(4), 265-274.
38. Qi, J., Li, Y., Yokoyama, W., Majeed, H., Masamba, K.G., Zhong, F., Ma, J. 2015. Cellulosic fraction of rice bran fibre alters the conformation and inhibits the activity of porcine pancreatic lipase. Journal of Functional Foods, 19, 39-48.
39. Ramos, F.T., Dores, E.F.D.C., Weber, O.L.D.S., Beber, D.C., Campelo Jr, J.H., Maia, J.C.D.S. 2018. Soil organic matter doubles the cation exchange capacity of tropical soil under no-till farming in Brazil. Journal of the Science of Food and Agriculture, 98(9), 3595-3602.
40. Rao, D.L.N., Aparna, K., Mohanty, S.R. 2019. Microbiology and biochemistry of soil organic matter, carbon sequestration and soil health. Indian Journal of Fertilisers, 15(2), 124-138.
41. Riaz, M., Kamran, M., Fang, Y., Wang, Q., Cao, H., Yang, G., Deng, L., Wang, Y., Zhou, Y., Anastopoulos, I., Wang, X. 2021. Arbuscular mycorrhizal fungi-induced mitigation of heavy metal phytotoxicity in metal contaminated soils: A critical review. Journal of Hazardous Materials, 402, 123919.
42. Romadhon, M.R., Aziz, A. 2022. Determination of Flood Susceptibility Index Using Overlay-Scoring Data Method based on Geographic Information System (GIS) in Semarang City, Central Java, Indonesia. AgriHealth: Journal of Agri-food, Nutrition and Public Health, 3(2), 104-123.
43. Romadhon, M.R., Mujiyo, M., Cahyono, O., Maro'ah, S., Istiqomah, N.M., Irmawati, V. 2023. Potential soil degradation of paddy fields through observation approaches from various sources of

environmental diversity. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 1241(1), 012013.

44. Rosariastuti, R., Barokah, U., Purwanto, P., Supriyadi, S. 2018. Phytoremediation of Pb contaminated paddy field using combination of Agrobacterium sp. I3, compost and ramie (Boehmeria nivea). Journal of Degraded and Mining Lands Management, 5(4), 1381.
45. Shufen, C., Yicong, C., Baobing, F., Guiai, J., Zhonghua, S., Ju, L. Shaoqing, T., Jianlong, W., Peisong, H., Xiangjin, W. 2019. Editing of rice isoamylase gene ISA1 provides insights into its function in starch formation. Rice Science, 26(2), 77-87.
46. Statistic Indonesia. 2020. BPS-Statistic of Wonogiri Regency-2020
47. Statistic Indonesia. 2016. Wonogiri in Number. BPS-Wonogiri
48. Supriyadi, S., Vera, I., Purwanto, P. 2021. Soil Quality at Rice Fields with Organic, Semi-organic and Inorganic Management in Wonogiri Regency, Indonesia. Caraka Tani: Journal of Sustainable Agriculture, 36(2), 259-269.
49. Sylvia, D., Zein, Z.A. 2021. Analisis Logam Berat Pada Beras (Oryza Sativa L.) yang ditanam di Daerah Industri Karet Mekar Jaya. Jurnal Farmagazine, 8(1), 66-74.
50. United States Department of Agriculture. 2019. Food Data Central Search Result: Rice, white, long-grain, regular, unenriched, cooked without salt. SR LEGACY, 169757.
51. Wen, Y., Niu, M., Zhang, B., Zhao, S., Xiong, S. 2017. Structural characteristics and functional properties of rice bran dietary fiber modified by enzymatic and enzyme-micronization treatments. Lwt, 75, 344-351.
52. Wihardjaka, A. 2021. Dukungan pupuk organik untuk memperbaiki kualitas tanah pada pengelolaan padi sawah ramah lingkungan. Jurnal Pangan, 30(1), 53-64.
53. Wirawan, K.A., Susrusa, I.B., Ambarawati, I.G.A.A. 2014. Analisis Produktivitas Tanaman Padi di Kabupaten Badung Provinsi Bali. Jurnal Manajemen Agribisnis (Journal Of Agribusiness Management).
54. Xiao, L., Sun, Q., Yuan, H., Lian, B. 2017. A practical soil management to improve soil quality by applying mineral organic fertilizer. Acta Geochimica, 36, 198-204.
55. Xie, W., Yang, J., Gao, S., Yao, R., Wang, X. 2022. The Effect and Influence Mechanism of Soil Salinity on Phosphorus Availability in Coastal Salt-Affected Soils. Water, 14(18), 2804.
56. Xu, M., Shang, H. 2016. Contribution of soil respiration to the global carbon equation. Journal of plant physiology, 203, 16-28.
57. Xu, J., Henry, A., Sreenivasulu, N. 2020. Rice yield formation under high day and night temperatures—A prerequisite to ensure future food security. Plant, Cell & Environment, 43(7), 1595-1608.
58. Xu, Y., Chu, C., Yao, S. 2021. The impact of high-temperature stress on rice: Challenges and solutions. The Crop Journal, 9(5), 963-976.
59. Zeng, X., Du, Z., Ding, X., Jiang, W. 2021. Protective effects of dietary flavonoids against pesticide-induced toxicity: A review. Trends in Food Science & Technology, 109, 271-279.
60. Zwolak, A., Sarzyńska, M., Szpyrka, E., Stawarczyk, K. 2019. Sources of soil pollution by heavy metals and their accumulation in vegetables: A review. Water, air, & soil pollution, 230, 1-9.
61. Zhan, T., Zhang, Z., Sun, J., Liu, M., Zhang, X., Peng, F., Tsunekawa, A., Zhou, H., Gou, X., Fu, S. 2020. Meta-analysis demonstrating that moderate grazing can improve the soil quality across China's grassland ecosystems. Applied Soil Ecology, 147, 103438.