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Soil quality status under Hazton's paddy farming: A case study in Banyumas Regency, Indonesia

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ABSTRACT

Soil quality is the ability of the soil to perform its function, such as providing nourishment to the plants. However, intensive paddy farming, such as Hazton's paddy farming method, is suspected to deteriorate soil quality status and degrade land sustainability. This study aimed to analyze soil quality under Hazton's paddy farming. This study was conducted on paddy fields in Banyumas Regency using a randomized block design with treatment consisting of 1) conventional method as a control, 2) Hazton's method + organic fertilizer, 3) Hazton's method + organic fertilizer + decomposer, and 4) Hazton's method + organic fertilizer + decomposer + leaf fertilizer. Soil quality was determined according to a minimum data set (MDS) that consisted of organic C, pH, total N, available phosphorus (P) and potassium (K), base saturation (BS), cation exchange capacity (CEC), bacterial density, soil respiration, and C/N ratio. The MDS was scored and calculated using the soil quality index formula and then classified from very low to very high (<0.19–1). This study highlighted that the soil quality in paddy farm using Hazton's method in Banyumas Regency ranged from low (0.444) to very low (0.308). The application of organic fertilizer is not sufficient enough to refill the nutrient pool equal to harvested plant biomass. This leads to soil quality deterioration and affects land sustainability. Therefore, yield and biomass production should be included as soil quality indicators in future studies. Additionally, further soil degradation can be avoided by continuously assessing soil quality and the necessary conservation measures for preventing and minimizing further land degradation can be applied.

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1. INTRODUCTION

Asian rice (*Oryza sativa* L.) is the primary food commodity of Indonesia that is consumed in large quantities as it is a staple food for the majority of the Indonesian population (Merang et al., 2020). In Indonesia, rice is mostly cultivated in wetlands, which are characterized as heavy and overburdened agricultural practices (Lakitan et al., 2018). Increasing rice demand has resulted in the urgent of increase in rice production through various efforts, including rice intensification through fertilization and mechanization (Lakitan et al., 2018; Liliane & Charles, 2020). However, the excess use of agrochemicals (such as fertilizer, herbicide, and pesticide) for the maximization of crop yield has adverse effects not only on human health, non-target organisms, and the environment but also on the soil quality (Elahi et al., 2019). Another rice intensification method that is applied in Indonesia (specifically in Central Java) is the Hazton's method, in which 20–30 seedlings (20–30 days old after seeding) are placed in each planting hole for a quicker harvest and good seedling adaptation (Kementan, 2016). A previous study reported that applying a high dose of fertilizer only increases plant height, and nitrogen (N) and potassium (K) contents in the rice plant tissue, not the total yield (weight of 1000 grains) (Robbani et al., 2018). This method might be harmful to the soil quality due to the excessive use of fertilizer.

Soil quality is the ability of the soil to perform its functions and provide multiple ecosystem services, such as maintaining crop productivity, preserving and maintaining water availability, and supporting human activities (M. Tahat et al., 2020; Martunis et al., 2016). Several factors drive soil quality deterioration, such as continuous N fertilizer application in paddy soil, leading to the suppression of certain beneficial bacteria and thus altering soil biodiversity and rice productivity (Nabiollahi et al., 2018). Soil quality status can be evaluated using the primary indicators of soil quality that are integrated with soil physical, chemical, and biological properties (Anup & Ghimire, 2019), either as a sole indicator or composite (integrated) indicators (Domínguez-Haydar et al., 2019; Mei et al., 2019). These indicators are then scored and compiled into a minimum data set (MDS), where the MDS represents the minimum indicators that can be used to assess soil quality (Juhos et al., 2019; Mei et al., 2019). The most common soil quality indicators are organic matter, pH, available phosphorus (P), and water storage. Also, some under-represented indicators exhibit great potential, specifically biological/biochemical indicators such as microbial biomass carbon (C), dehydrogenase activity, N mineralization potential, and the number of earthworms (Bünemann et al., 2018).

A previous study by Qi et al. (2022) demonstrated that soil organic C is a critical indicator for monitoring soil health and environmental pollution mitigation. The organic contents in soil are crucial for soil aggregate stability, soil microorganisms, and soil nutrient status (Naresh et al., 2017). The most important source of organic matter in the paddy field is the harvested biomass, such as rice straw (Huang et al., 2021). However, in most methods of paddy farming (conventional and Hazton's method), rice straw is usually harvested and moved from the field for other use, such as feedstock and burned as compost or biochar (Bhattacharyya et al., 2021; Truong et al., 2022). Due to these practices, paddy soil is heavily used for intensive paddy farming without additional organic matter input, which leads to major land degradation and soil fertility deterioration (Ali et al., 2019). Moreover, some major constraints that decrease rice production are poor growth conditions (low soil quality status), poor irrigation systems, and insufficient essential nutrients for plants (low soil fertility status) (Liliane & Charles, 2020; Livsey et al., 2019).

To monitor soil quality status under Hazton's paddy farming, continuous monitoring of the soil quality is important because soil quality changes in response to environmental changes and human interventions (Xie et al., 2020). Furthermore, the field productivity is determined by the soil fertility and management system, such as fertilization, land management, irrigation system, and returning organic material from the crop residues after harvest to the field (Delgado et al., 2021). Therefore analyzing soil quality status on paddy fields where Hazton's method is applied as a viewpoint for decision-makers in soil quality and fertility management is necessary (Lakitan et al., 2018; Liliane & Charles, 2020). Due to the high population pressure in some areas (e.g., Indonesia and Kenya), the soil degradation rate outpaces agriculture intensification (Mugizi & Matsumoto, 2020). This evidence is quite astonishing because the global population and food demand are intertwined and increase over time (Smith & Archer, 2020). Thus, assessment of the soil quality status under Hazton's paddy farming is important because information related to the soil quality status under Hazton's paddy farming remains unclear. Moreover, heavy tillage in paddy farming potentially degrades soil quality and reduces crop production that treats food security due to yield reduction (Gomiero, 2016). By assessing the soil quality status under Hazton's paddy farming, decision-makers can prevent further land degradation on the field where Hazton's paddy farming has been applied as well as food production deterioration, thus preventing food insecurity (Qi et al., 2022). A previous study by Wang et al. (2018) demonstrated that soil quality is a powerful tool for determining soil degradation status. This study aimed to analyze the soil quality status under Hazton's paddy farming in Banyumas Regency by determining the primary soil quality indicators of soil chemical, physical, and biological indicators to synthesize an MDS, In this study, the soil quality index was calculated, and the soil quality class was classified. The information about soil quality class can be beneficial for managers and decision-makers for managjng land sustainability for rice production.

Figure 1. Map of the study site: KO = conventional method (control); H = Hazton's method + organic fertilizer; HD = Hazton's method + organic fertilizer + decomposer; HDD = Hazton's method + organic fertilizer + decomposer + leaf fertilizer.

2. MATERIAL AND METHODS

2.1. Study site

This study was conducted on paddy fields in the Banyumas Regency from March to November 2019. Laboratory analysis was conducted at the Laboratory of Soil Science Department, Faculty of Agriculture, Universitas Sebelas Maret. Herein, a randomized block design was employed, with treatment consisting of 1) conventional method (KO) as a control, 2) Hazton's method + organic fertilizer (H), 3) Hazton's method + organic fertilizer + decomposer (HD), and 4) Hazton's method + organic fertilizer + decomposer + leaf fertilizer (HDD). A total of 12 sampling locations from the representative paddy fields (KO, H, HD, and HDD) were considered and there were three replications per treatment. The samples were collected from the rhizospheric zone at a depth of 10–15 cm. In each field, the soil samples were collected from five different points and were then composited into a plastic bag. Sample collection was performed at three different time points after the harvest period in 2019 (March, July, and September), representing the different seasons in Indonesia (rainy and dry seasons). Hazton's method has been applied in the field for over 2 years (since mid 2016). The average size of the experimental field was 15 × 8 m^2. Per treatment (KO, H, HD, and HDD), 350 kg/ha N fertilizer (urea) and 300 kg/ha compound fertilizer (N, P_2O, K, S; Phonska), 700 kg ha^{-1} organic fertilizer, 2–4 L ha^{-1} decomposer, and 120 g ha^{-1} leaf fertilizer (micro fertilizer) were utilized. The sampled field has a technical irrigation system and were located in Tinggarjaya Village (Figure 1), Jatillawang Sub-regency, Banyumas Regency, Central Java (109°04'12.0"–109°06'19.0" E and 7°31'55.71"–7°32'18.5" S), at 24–28 m above sea level. The average field temperature was 26.3°C and the annual rainfall was 1,842 mm/year. Furthermore, the soil type was Inceptisols (USDA Soil Taxonomy), with the geological type of alluvium (river sediment). The slope range was between 1% and 2% (flat).

2.2. Soil sampling and analysis

Soil samples were collected from four representative treatments of paddy fields (KO, H, HD, and HDD) with three replications in each representative field using a purposive sampling method. The samples were analyzed for physical (soil texture), chemical (soil pH, total N, available P, available potassium (K), cation exchange capacity (CEC), base saturation, and organic C, and biological (soil respiration and soil bacterial density: total and total N–fixing bacteria) indicators. The indicators were selected according to Moebius-Clune et al. (2016) for "Comprehensive Assessment of Soil Health" from Cornell University. These indicators were analyzed according to the guidelines set by Indonesia Soil Research Institute 2009 (Eviati & Sulaeman, 2009). Soil texture was analyzed using the pipette method and soil pH (pH H_2O) was measured using the pH meter. Total N was determined using the Kjeldahl method and available P was determined using the Olsen method (soil pH >5.5). The method of ammonium acetate extraction was employed to analyze soil available K, CEC, and BS. The extracted solutions were then measured *via* atomic absorbance spectrophotometry and flame photometry.

Table 1. Classification of soil quality index

Soil Quality	Range	Class
Very high	0.80 – 1	1
High	0.60 – 0.79	2
Moderate	0.35 – 0.59	3
Low	0.20 – 0.34	4
Very low	≤0.19	5

Remarks : classification of soil quality index according to Sofo et al. (2022) with modification

Organic C was analyzed using the Walkey and Black method. Soil respiration (CO_2 evolution) was analyzed using the titrimetric method. Total bacterial colonies were isolated using nutrient agar medium, whereas N–fixing bacteria were isolated using Jensen medium, both were enumerated using the standard plate count method.

2.3. Analysis of soil quality index

The obtained data were subjected to the principal component analysis (PCA) and then determined using the MDS from the selected soil physical, chemical, and biological indicators (Li et al., 2019). The selected indicators for the MDS was determined according to the eigenvalue in PCA; indicators within the eigenvalue with cumulative >75% (0.75) were selected. Pearson's correlation analysis was conducted to determine the correlation between each indicator and one-way analysis of variance was employed to determine the significant difference between the treatments. Duncan's multiple range test 5% was performed for *post hoc* test. The soil quality index was calculated using Equation 1 (Moebius-Clune et al., 2016) and thus classified according to the soil quality classification by Sofo et al. (2022) with modification (Table 1). Scoring of soil chemical properties was performed according to Eviati and Sulaeman (2009) with modification, each indicator classified as low was scored 1, 2 for moderate, and 3 for high. Evaluation of the total bacteria and N–fixing bacteria was performed according to Shen et al. (2016); bacterial population >10^6 colony forming unit (CFU g^{-1}) (total bacteria) and >10^3 CFU g^{-1} (N–fixing bacteria) considered as high. Soil respiration was scored according to Aryal et al. (2017), as the average of soil respiration in a primary forest in the tropic is >1 g CO_2 m^{-2} h^{-1}. All statistical analyses were conducted using Minitab 16.

$$\text{SQI} = \sum_{i=1}^{n} Wi\ x\ Si \qquad [1]$$

where: SQI = Soil Quality Index; *Si* = Score index of the selected indicators; *Wi* = Weight index of selected indicators; *n* = Number of Soil Quality Indicators.

3. RESULTS

According to the result, as classified based on Eviati and Sulaeman (2009), the soil quality indicators in the study site ranged from very low to moderate (Table 2), such as pH (5.9–6.5, slightly acidic), OC (1.54%–2.09%, very low), Av-P (6.81–7.62 mg kg^{-1}, low), BS (49.79–53.54%, moderate), a C/N (5.02–5.38, low), TN (0.31%–0.42%, moderate), Available-K (Av-K) (0.51–0.61 mg kg^{-1}, moderate), and CEC (21.77–27.36 $mmol^+$ 100 g^{-1}, moderate).

Table 2. Soil quality indicators at the study site

Indicator	KO	H	HD	HDD
Physical				
Texture	Sandy Clay	Sandy Clay	Sandy Clay	Sandy Clay
Chemical				
pH	5.9 ± 0.05^{a}	6.4 ± 0.05^{b}	6.4 ± 0.11^{b}	6.5 ± 0.10^{b}
OC (%)	1.54 ± 0.18^{a}	1.80 ± 0.23^{a}	1.76 ± 0.13^{ab}	2.09 ± 0.26^{b}
TN (%)	0.31 ± 0.04^{a}	0.34 ± 0.01^{ab}	0.36 ± 0.03^{ab}	0.42 ± 0.04^{b}
Av-P (mg kg^{-1})	6.81 ± 0.27^{a}	7.16 ± 0.27^{a}	7.32 ± 0.44^{a}	7.62 ± 0.39^{a}
Av-K (mg kg^{-1})	0.51 ± 0.08^{a}	0.53 ± 0.04^{ab}	0.55 ± 0.03^{ab}	0.61 ± 0.05^{b}
CEC (mmol^{+} 100 g^{-1})	22.92 ± 1.95^{a}	21.77 ± 1.55^{a}	25.87 ± 1.62^{b}	27.36 ± 1.32^{b}
BS (%)	49.79 ± 2.84^{a}	50.67 ± 7.35^{a}	50.05 ± 4.63^{a}	53.54 ±2.99^{a}
C/N	5.03 ± 0.96^{a}	5.38 ± 0.79^{a}	5.02 ± 0.37^{a}	5.13 ± 0.92^{a}
Biological				
TC NA (CFU g^{-1}) (10^7)	3.56 ± 4.97^{a}	4.63 ± 2.67^{a}	2.51 ± 1.43^{a}	7.53 ± 2.22^{a}
TC Jensen (CFU g^{-1}) (10^6)	1.23 ± 0.66^{a}	1.17 ± 0.62^{a}	2.91 ± 0.42^{b}	4.42 ± 0.43^{c}
SR (mg CO_2/m^2/h)	8.41 ± 1.22^{a}	9.90 ± 0.96^{b}	10.49 ± 0.77^{b}	11.22 ± 0.58^{b}

Remarks: OC = organic C; TN = total N; Av-P = available P; Av-K = available K; CEC = cation exchange capacity; BS = base saturation; TC NA = total colony at nutrient agar; TC Jensen = total colony at Jensen agar; SR = soil respiration; C/N = ratio between organic C and total N; CFU = colony forming unit. Conventional method (KO); Hazton's method + organic fertilizer (H); Hazton's method + organic fertilizer + decomposer (HD); Hazton's method + organic fertilizer + decomposer + leaf fertilizer (HDD). Means followed by different letter at the same line are significantly different as determined by Duncan Multiple Range Test (DMRT) at 5% significance level.

Table 3. Correlation between each indicator of soil quality at the study site

	pH	OC	TN	Av-P	Av-K	CEC	BS	TC NA	TC Jensen	SR
OC	0.569									
TN	0.542	0.588*								
Av-P	0.407	0.718**	0.301							
Av-K	0.029	0.570	0.523	0.470						
CEC	0.197	0.435	0.496	0.606*	0.692*					
BS	0.485	0.495	0.338	0.150	0.160	0.015				
TC NA	-0.048	0.561	0.196	0.393	0.499	0.338	-0.089			
TC Jensen	0.293	0.560	0.544	0.541	0.757**	0.932**	0.239	0.426		
SR	0.810**	0.773**	0.537	0.417	0.362	0.398	0.515	0.293	0.536	
C/N	-0.084	0.313	-0.577	0.352	0.004	-0.104	0.103	0.364	-0.043	0.172

Remarks: OC = organic C; TN = total N; Av-P = available P; Av-K = available K; CEC = cation exchange capacity; BS = base saturation; TC NA = total colony at nutrient agar; TC Jensen = total colony at Jensen agar; SR = soil respiration; C/N = ratio between organic C and total N; *5% significance level ($p < 0.05$); **1% significance level ($p < 0.01$).

There were no soil quality indicators classified as high to very high. Furthermore, the biological indicators such as soil respiration (SR) were also low (8.41-11.22 mg CO_2 m^{-2} h^{-1}). However, soil bacteria (total and N–fixing bacteria) were at the optimum level, approximately 10^6–10^7 CFU g^{-1}.

This study demonstrated that cultivation methods (K, H, HD, and HDD) affected soil quality indicators ($P < 0.05$). Moreover, significant differences were observed among the analyzed indicators after Student's *t*-test analysis ($P < 0.05$). Compared with control, the practice of Hazton's method, combined with organic fertilizer, decomposer, and leaf fertilizer (HDD) in paddy farming improved soil quality indicators by increasing soil pH closer to the neutral pH (6.5), OC (21.93%), TN (7.69%), Av-P (2.80%), Av-K (4.54%), CEC (4.53%), C/N (0.48%), total bacteria (21.77%), TC Jensen (32.78%), and SR (7.02%). The application of Hazton's method without the use of a micro fertilizer for leaf (HD) only improved soil pH, CEC, TC Jensen, and SR. Moreover, the application of Hazton's method combined with organic fertilizer (H) only improved soil pH and SR. The application of micronutrient in leaf and decomposer (either sole or mixed application) in Hazton's method improved the OC, TN, and Av-K, compared with HD and H, as well as all the analyzed indicators compared with control (KO).

This study finding proved that some soil quality indicators have a linear relationship, in which an increase in one indicator will lead to an increase in another indicator (Table 3). Three indicators have a positive correlation with OC, namely, available P, SR ($P < 0.01$), and total N ($P < 0.05$). The increasing organic C mineralization will release plant nutrients, increasing available-P and total N in the soil. CO_2 evolution was a sign of microorganisms' activity in decomposing organic C, thus increasing SR and resulting in the increased volume of CO_2 released by microorganisms. However, SR was correlated not only with organic C but also with pH ($P < 0.01$). Microorganisms need an optimal environmental condition (neutral pH) to grow and develop in their life cycle.

Table 4. Minimum data set of soil quality indicators at the study site

Eigenvalue	5.094	1.912	1.735
Proportion	0.463	0.174	0.158
Cumulative	0.463	0.637	0.795
Eigenvectors	PC 1	PC 2	PC 3
pH	0.236	**-0.477**	0.169
OC	**0.394**	-0.018	0.251
TN	0.315	-0.285	**-0.351**
Av-P	**0.323**	0.187	0.173
Av-K	**0.326**	0.267	-0.225
CEC	**0.334**	0.220	-0.318
BS	0.193	**-0.393**	0.252
TC NA	0.227	**0.425**	0.125
TC Jensen	**0.374**	0.154	-0.232
SR	**0.353**	-0.252	0.218
C/N	0.036	0.337	**0.651**

Remarks: OC = organic C; TN = total N; Av-P = available P; Av-K = available K; CEC = cation exchange capacity; BS = base saturation; TC NA = total colony at nutrient agar; TC Jensen = total colony at Jensen agar; SR = soil respiration; C/N = ratio between organic C and total N. Number in bold indicates the weight of soil quality indicators to determine minimum data set (MDS) for calculating soil quality index.

N-fixing bacteria were correlated with soil available P and CEC as essential nutrient sources for their life cycle ($P < 0.01$). Moreover, CEC was correlated with available P and K ($P < 0.05$) because CEC is the indicator of soil fertility in providing nutrients for plants.

Finally, the result of PCA analysis proved that PC1 to PC3 (the components from PCA) represented 79.5% of the data variance (Table 4). MDS should have consisted of C/N, pH, and OC. However, based on the scores of the indicators, several indicators had different scores (Table 5). As presented in Figure 2, SR and TN have high scores similar to OC in the first component. Additionally, total bacteria have a high score in the second component. These indicators play a vital role in enhancing the soil function, such as soil available K, CEC, and microbial activity (microbial density, N-fixing bacteria, and SR). Thus, we included all selected indicators and only eliminated soil texture because the soil in the study site is sandy clay (Inceptisols). Based on the MDS and soil quality index calculation (Table 6), the soil quality site was clasified as very low (KO, H, and HD) and low (HDD), with values of 0.303 and 0.444, respectively.

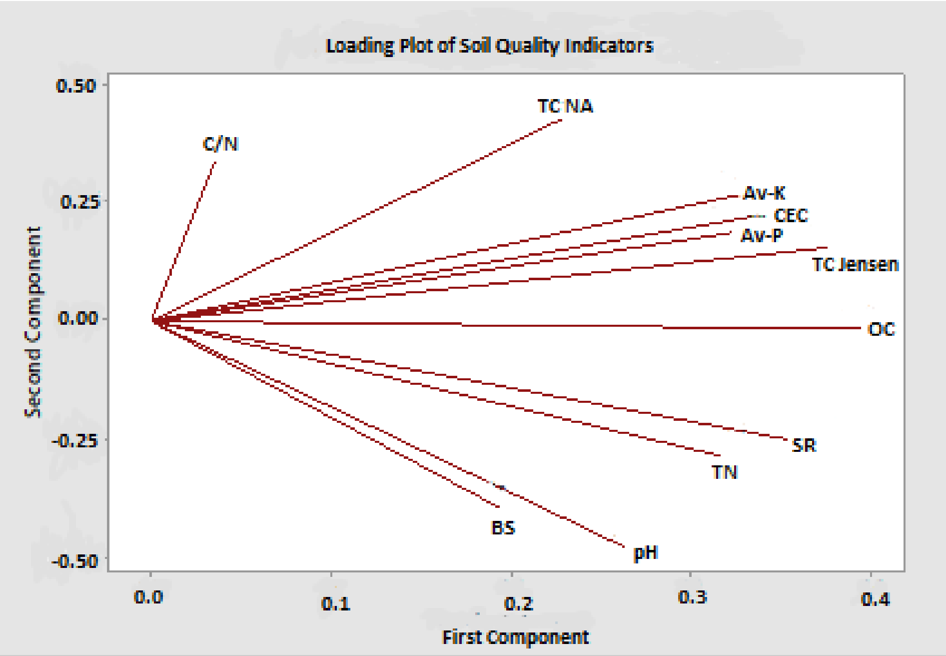
4. DISCUSSION

This study demonstrated that the soil quality status under Hazton's paddy farming in Banyumas Regency was low to very low according to the primary soil quality indicators. The soil quality at the study site was evaluated predominantly based on organic C, pH, and C/N. Organic C and C/N have a close relationship as the C/N stoichiometry regulating the soil organic C mineralization in paddy soil (Wei et al., 2020). Furthermore, an addition of organic fertilizer, decomposer, and leaf fertilizer in this study was not sufficient to boost soil quality. Plant residue such as harvested rice straws in Hazton's paddy farming is often not returned to the soil, which leads to a low substrate concentration for decomposition, as proven by the low SR rate. SR is a sign for microbes that actively decompose organic matter (Rui et al., 2016). A high amount of rice straw returned to the paddy soil would foster the fungal community, whereas a low amount of rice straw negatively bacterial community (Wang et al., 2021). This proves that insufficient organic material in the paddy field when practicing the Hazton's paddy farming leads to low soil quality, even though the bacterial density is high. Thus, returning harvested rice straw to the paddy soil is essential as a source of organic material. However, the impact on greenhouse gas emission needs to be studied further.

Table 5. Scoring of soil quality indicators at the study site

Minimum Data Set	KO	H	HD	HDD
pH	2	2	2	2
OC	1	1	1	1
TN	2	2	2	2
Av-P	1	1	1	1
Av-K	2	2	2	3
CEC	2	2	3	3
BS	2	2	2	2
TC NA	2	2	1	3
TC Jensen	1	1	2	3
SR	1	1	2	2
C/N	1	1	1	1

Remarks : OC = organic C; TN = total N; Av-P = available P; Av-K = available K; CEC = cation exchange capacity; BS = base saturation; TC NA = total colony at nutrient agar; TC Jensen = total colony at Jensen agar; SR = soil respiration; C/N = ratio between organic C and total N. Conventional method (KO); Hazton's method + organic fertilizer (H); Hazton's method + organic fertilizer + decomposer (HD); Hazton's method + organic fertilizer + decomposer + leaf fertilizer (HDD). Scoring of soil quality indicators was based on Eviati and Sulaeman (2009) with modification for chemical properties; total bacteria and N-fixing bacteria were according to Shen et al. (2016); soil respiration was scored according to Aryal et al. (2017).



Remarks: OC = organic C; TN = total N; Av-P = available P; Av-K = available K; CEC = cation exchange capacity; BS = base saturation; TC NA = total colony at nutrient agar; TC Jensen = total colony at Jensen agar; SR = soil respiration; C/N = ratio between organic C and total N.

Figure 2. Loading plot of soil quality indicators at the study site

Table 6. Soil quality index at the study site

Minimum Data Set	KO	H	HD	HDD
pH	-0.954	-0.954	-0.954	-0.954
OC	0.394	0.394	0.394	0.394
TN	-0.702	-0.702	-0.702	-0.702
Av-P	0.323	0.323	0.323	0.323
Av-K	0.652	0.652	0.652	0.978
CEC	-0.786	-0.786	-1.179	-1.179
BS	0.850	0.850	0.850	0.850
TC NA	0.850	0.850	0.425	1.275
TC Jensen	0.374	0.374	0.748	1.122
SR	0.353	0.353	0.706	0.706
C/N	0.651	0.651	0.651	0.651
Average of SQI	0.182	0.182	0.174	0.314
Classification of SQI	Very Low	Very Low	Very Low	Low

Remarks: OC = organic C; TN = total N; Av-P = available P; Av-K = available K; CEC = cation exchange capacity; BS = base saturation; TC NA = total colony at nutrient agar; TC Jensen = total colony at Jensen agar; SR = soil respiration; C/N = ratio between organic C and total N; SQI = soil quality index. Conventional method (KO); Hazton's method + organic fertilizer (H); Hazton's method + organic fertilizer + decomposer (HD); Hazton's method + organic fertilizer + decomposer + leaf fertilizer (HDD).

Another indicator that determined the soil quality status at the study site was the soil pH, which is a strong soil quality indicator owing to its considerable influence on soil biogeochemical processes that affect plant growth and biomass production (Neina, 2019). The pH use of the study site soil using the Hazton'n paddy farming method was higher than the conventional method used, even though the pH was within the neutral range. The use of organic fertilizer and decomposer combined with Hazton's method can increase paddy soil pH by preventing soil acidification. Concurrent application of synthetic fertilizer, such as NPK, decreases soil pH by 0.07 per year after application for 20 years (Wang et al., 2019). Further study related to organic farming using Hazton's method (excludes synthetic fertilizer) on the pH of paddy soil might be needed to elucidate the impact of organic fertilizer and decomposers on soil acidification prevention.

This study highlighted that farming methods greatly affect the soil quality status which is manifest through various indicators. A previous study reported that soil quality at different paddy fields in Merauke, Papua, was strongly determined by pH, OC, bulk density, particulate organic matter, and available N (Supriyadi et al., 2017). Another study has reported that soil quality under agroforestry management is determined by available P and K, BS, and pH

(Supriyadi et al., 2016). This indicates that the soil quality indicators vary, and subsequently the soil quality varies within agricultural management (Tang et al., 2019). The addition of organic fertilizer and decomposer to the paddy field, along with Hazton's method, strongly affects soil quality that is apparent from the C/N content, as C/N substantially influences the organic C composition and organic matter decomposition (Xia et al., 2021; Yates et al., 2019). Moreover, organic matter input increases bacterial density and enzymatic activity as organic C is a substrate (nutrient source) that enhances microbial activity (Zhang et al., 2019). The addition of organic fertilizer and decomposer increased the density of total and N–fixing bacteria at the study site, which was higher (10^7 CFU g^{-1} and 10^3 CFU g^{-1}, respectively) than in a previous study by Shen et al. (2016), which was only 10^6 CFU g^{-1} for total soil bacteria and 10^3 CFU g^{-1} for N–fixing bacteria. However, the density of bacteria was affected not only by the addition of organic matter but also by other factors such as season (dry or rainy season). Microbial density during the rainy season is higher than during the dry season (Ustiatik et al., 2022).

Moreover, we conclude that the low to very low soil quality status in the study site was primarily due to the lack of organic material and suggest returning the harvested rice straw to the soil as a natural source. The material will provide essential plant nutrients as it decomposes. Incorporating moderate rice straws incorporation with low N fertilizer has been reported to enhance soil microbial activity, mitigate greenhouse gas emissions, and improve forage yield (Zhang et al., 2019). Constant practice of Hazton's method for paddy farming at the study site without returning harvested rice straw to the soil will deteriorate the soil quality as the plant nutrient sources that are intensively used to boost and produce plant biomass are not replenished. However, further study of the long-term application of Hazton's method (10–20 years) will provide better clarity on the effect of Hazton's method on soil quality. The application of organic fertilizers and decomposers, as discussed in this study, is insufficient to restore the nutrient pool in the soil that is equal to the harvested plant biomass. The application of Hazton's method without returning harvested rice straw to the soil will lead to soil degradation, more extreme will treat land sustainability and food safety. A limitation of this study is that the yield parameter was not analyzed and included as an integral component of soil quality indicators. Future studies should focus not only on soil properties (physical, chemical, and biological properties) as soil quality indicators but also on yield and biomass production, as soil quality changes according to land management. By assessing soil quality under intensive paddy farming, managers (farmers) can gain a better perspective on how to manage the field and take measures to prevent further soil quality deterioration and degradation.

5. CONCLUSION

The soil quality status under Hazton's paddy farming method was low (0.444) to very low (0.308) as assessed using selected indicators and MDS. The primary soil quality indicators were soil pH, organic C, and C/N. The soil quality at the study site was low to very low, even after the addition of organic fertilizer, decomposer, and leaf fertilizer. Returning harvested rice straw to the soil may be required as an effort to increase the organic material input. The managers of such paddy farms must take these factors into consideration and take measures accordingly, intensive paddy farming deteriorates soil quality. Furthermore, improper management and overuse of paddy fields will lead to soil degradation and further impact food security.

Declaration of Competing Interest

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

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