

Original Research Paper

Soil Fertility Index on Various Rice Field Management Systems in Central Java, Indonesia

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Abstract: The purpose of this research was to assess the condition of soil fertility and compare the soil fertility index in various rice field management systems. This research was conducted from July until December 2018 in the rice fields of Girimarto District, Wonogiri Regency with a survey method and land sampling by purposive sampling (intentionally) at a depth of 0-20 cm rice fields with organic, semi-organic and conventional management systems. Soil samples were taken from 9 main points with 3 replications so that a total of 27 soil samples were obtained. The chemical properties of the soil tested by the laboratory are soil reaction (pH), Total Nitrogen (Total N), Available Phosphorus (Av-P), Available Potassium (Av-K), Cation Exchange Capacity (CEC), Base Saturation (BS), Soil Organic Carbon (SOC) and Aluminum Saturation (Al saturation). The results showed that three rice field management systems have the same soil fertility index criteria, which are medium. In organic rice fields that have implemented organic farming systems for 6 years, have a soil fertility index value of 0.630, semi-organic rice fields with a SFI value of 0.557 and also organic rice fields with a SFI value of 0.545. Soil fertility index of organic rice fields is significantly higher than that of semi-organic rice fields and conventional rice fields.

Keywords: Conventional, Organic Rice Fields, Soil Fertility Index

Introduction

Rice cultivation in Southeast Asian countries is considered one of the most important agricultural products. Indonesian soil with green rice fields and spread in large patches of land helps the spread of agriculture in the country with up to 10 million hectares of land in the country. It is an important part of the national economy. Therefore, yield of wetland rice is influenced by the level of soil fertility.

Soil fertility is the ability of the soil to supply essential elements for the growth, development and maturation of plants to produce high-quality plants with high yields in a sustainable manner. The aspect of soil fertility in a lowland rice cultivation is very necessary to be able to predict how much productivity of rice fields in order to produce optimum production (El-Ramady *et al.*, 2019; Kilmer, 1982; Saputra *et al.*, 2018). Long-term intensive cultivation leads to the decrease of soil organic carbon and soil fertility continuously (Qiu *et al.*, 2009; Wang *et al.*, 2002; Yu *et al.*, 2006). Decreasing soil fertility can be a major factor affecting soil

productivity, so the addition of nutrients in the soil through a fertilization process is very important in order to obtain profitable agricultural production (Pinatih *et al.*, 2015). Organic farming is an alternative choice that should be considered because in the long run it can increase and maintain the level of production and soil fertility (Prayoga, 2016).

Soil fertility is very important for agricultural production and soil fertility management practices (irrigation, fertilization and cultivation) (Fallahzade and Hajabbasi, 2012) and also a central issue in decisions about food security, poverty reduction and environmental management (Tilman *et al.*, 2002). Soil fertility is a major component of soil quality, so soil fertility research can be considered as an important prerequisite for managing rice fields. In addition, it uses a minimum data set to reduce costs to determine various indicators is very important to be assessed soil fertility (Yao *et al.*, 2013) from wetland soils during the transition from conventional wetland to organic rice management systems. The soil fertility index is a useful indicator to help improve the sustainability of a land with proper management so that

it can increase agricultural production (Andrews *et al.*, 2004; Shang *et al.*, 2014).

Girimarto Subdistrict Wonogiri Regency in Central Java is an area known for its organic rice production even though not all farmers have switched to organic farming systems. Farmers in Girimarto have started organic farming since 2013 and have passed the organic farming certification test, but there has been no research that discusses organic rice fields in Girimarto District. Based on this background, the researcher was interested in conducting a study on the comparison of rice soil fertility index with organic, semi-organic and conventional farming systems in Girimarto District so that people could find out the impact of agricultural systems that had been used for soil fertility.

Materials and Methods

Field Survey

Land analysis was conducted in Girimarto District, Wonogiri Regency, Central Java, Indonesia. Determination of the location of soil sampling was carried out by purposive sampling (intentionally) choosing 3 management systems namely organic, semi-organic and conventional rice fields. Soil sampling is done by purposive sampling (intentionally) at a depth of 0-20 cm taken by the diagonal method in which each soil sample represents 5 soil samples that have been first composed and taken as much as 1 kg. Each farming system is represented by 3 soil samples with 3 repetitions so that a total of 27 soil samples is obtained. Soil sampling was carried out using a composite technique according to Supriyadi and Pradika (2015) can represent the condition of each soil sampling point.

Soil Properties

Analysis of chemical properties of soil were conducted at Laboratory of Faculty of Agriculture, Sebelas Maret University, Indonesia. This research was held in October until December 2018. The soil properties were analyzed by H₂O pH (Electrometric), Soil Organic Carbon (Walkley dan Black), total of N (Kjeldahl method), available P (Olsen's method), available K (Flamefotometry), cation exchange capacity (Ammonium acetate extraction), base saturation (Ammonium acetate extraction), aluminum saturation (Saturation of Potassium Chloride) (Soil Research Center, 2009).

Statistical Analysis

The statistical test used in this study is the Pearson's Correlation correlation test with the Minitab 18 software to obtain the relationship between variables tested on 27 soil samples collected and analyzed during the land survey. To re-examine the results of this correlation analysis, the Principal Component Analysis (PCA) test

was also carried out as one of the analysis factors for soil. Parameters that have high PCA scores and high correlations will be continued with the calculation of the Soil Fertility Index.

Calculation of the value of the Soil Fertility Index can be calculated by summing the results of the division of the number of weights with the number of MSFI indicators such as the formula Mukashema (2007) below:

$$p_c = \frac{1}{n_c} \quad (1)$$

$$c_j = w_i \times s_i \quad (2)$$

$$Sc_i = c_j \times p_c \quad (3)$$

$$SFI = \left(\frac{\sum_{i=1}^n Sc_i}{N} \right) \times 10 \quad (4)$$

Where:

p_c = Probability for many classes

n_c = Number of classes

w_i = Weighting factor

s_i = The indicator score for variable i

c_j = Class for each sample

SFI = Soil fertility index value

Sc_i = Total weight

N = Number of MSFI indicators

The assessment of soil fertility class scores was carried out by measuring soil fertility indicators based on the assessment criteria for the results of the Soil Research Institute (2009). Whereas for SFI values vary from 0 to 1, which means that each SFI class only has a small difference range ($0 \leq SFI \leq 1$). SFI's classification based on Bagherzadeh *et al.* (2018) that can be seen in Table 1.

After knowing the value of the soil fertility index and its classification, it can be seen the extent of changes in soil fertility after conversion from conventional systems to organic rice fields. According to Rabia (2012) in Delsouz Khaki *et al.* (2017) an assessment of the status of soil fertility by using a land index can provide important information to improve strategies and effective techniques for sustainable agriculture in the future.

Table 1: SFI's classification

SFI value	Criteria
0,00-0,25	Very low
0,25-0,50	Low
0,50-0,75	Medium
0,75-0,90	High
0,90-1,00	Very high

Results and Discussion

Soil reaction (pH) analysis shows different values, in 6.26 organic rice fields, 6.14 semi-organic rice fields and 6.01 conventional rice fields all three are classified as rather sour. The pH value tends to rise from conventional rice fields to organic rice fields. The average pH value of organic and semi-organic rice fields is near neutral while conventional rice fields are still relatively acidic. This is in line with the opinion of Aishah *et al.* (2010) that the optimum pH for lowland rice plants ranged from 5.6 to 6.0. Total nitrogen analysis also shows the same class but different values, such as higher organic rice fields than semi-organic and conventional rice fields, respectively 0.36%, 0.28% and 0.30%. The CEC class is all classified as low, each from organic rice to conventional 13.20 me/100g, 13.67 me/100g and 12.56 me/100g. Low SOC content in semi-organic and conventional rice fields occurs because it is absorbed by plants. Semi-organic soil BS is higher than organic and conventional rice fields, respectively 31.32 me/100g, 26.71 me/100g and 23.67 me/100g. Available P in organic rice field (9.51 ppm) is higher than semi-organic rice field (5.70 ppm) and conventional rice field (5.00 ppm). Although all three are in the low category, the value of available P content is different because of the different types and amounts of fertilization. The high P content that is thought to be affected by fertilization is carried out at the beginning of cultivation (Supriyadi *et al.*, 2016). The value of available K in

organic and semi-organic rice fields is classified as medium with values of 27.42 cmol/kg and 21.18 cmol/kg, whereas for conventional rice fields it has a K value of 15.85 cmol/kg and a low classification. Aluminum saturation in the three management systems is classified as very low with organic rice values (2.78%), semi-organic rice fields (2.36%) and conventional rice fields (3.08%). The value of Al saturation is still within the threshold of tolerance to plant growth (Rahman *et al.*, 2008). Indicators of soil chemical properties in this study can be seen in the Table 2.

The results of the correlation analysis (Table 3) show that available P correlates strongly with total N. Nitrogen will increase root growth and development so that the plant is able to absorb P more effectively and also N is the main constituent of the phosphatase enzyme involved in P mineralization in the soil (Wang *et al.*, 2007; Homer, 2008). Soil Organic Carbon (SOC) is closely correlated with available K. This is in line with Ispandi and Munip (2004) statement that organic matter can affect the availability of K⁺, Ca²⁺ and Mg²⁺. Soil organic carbon with pH shows a positive value and there is a very strong correlation according to Ann *et al.* (2017) that pH can affect the rate of decomposition of organic matter, minerals and clay mineral formation. pH was also closely correlated with available P (r = 0.479) and available K (r = 0.587). Potassium availability is influenced by several factors such as soil fertility and soil pH (Gardner *et al.*, 1991).

Table 2: Analysis of chemical soil properties

Indicator	Organic rice field	Semi organic rice field	Conventional rice field
pH	6.26±0.05 ^{RS}	6.14±0.06 ^{RS}	6.01±0.06 ^{RS}
total N (%)	0.36±0.04 ^M	0.28±0.04 ^M	0.3±0.02 ^M
Available P (ppm)	9.51±0.37 ^L	5.70±2.12 ^L	5.00±1.87 ^L
Available K (cmol/kg)	27.42±2.84 ^M	21.18±2.59 ^M	15.85±5.27 ^L
SOC (%)	2.03±0.06 ^M	1.9±0.10 ^L	1.36±0.12 ^L
CEC (me/100g)	13.20±1.17 ^L	13.67±2.89 ^L	12.56±0.63 ^L
BS (me/100g)	26.71±4.02 ^L	31.32±4.55 ^L	23.67±7.05 ^L
Al Saturation (%)	2.78±0.82 ^{VL}	2.36±0.19 ^{VL}	3.08±0.60 ^{VL}

pH = soil reaction, Total N = Total Nitrogen, SOC = Soil Organic Carbon, CEC = Cation Exchange Capacity, BS = Base Saturation, VL = Very Low, L = Low, M = Moderate, RS = Rather Sour.

Table 3: Correlation analysis of soil chemical properties

	Total N	Available P	Available K	CEC	BS	SOC	pH
Available P	0.413*						
Available K	0.445*	0.693*					
CEC	0.112	0.133	-0.083				
BS	0.313	0.222	0.481*	-0.425			
SOC	0.027	0.409*	0.448*	0.341	-0.039		
pH	0.212	0.479*	0.587*	-0.01	0.305	0.29	
Al Saturation	0.154	0.146	-0.012	-0.134	-0.045	-0.134	-0.22

pH = soil reaction, Total N = Total Nitrogen, SOC = Soil Organic Carbon, CEC = Cation Exchange Capacity, BS = Base Saturation, *significant correlation at the 0.05 level

The soil fertility index is determined using Principal Component Analysis (PCA) statistical analysis and produces data called PC (principal component) (Table 4). PCA is a method that is able to transform variables into a new set of variables that can explain the diversity of data with a smaller amount. The selection rules for the main components are that (a) the eigenvalues of each major component are greater than 1 and (b) the cumulative proportion of all major components is more than 85% (Andrews *et al.*, 2002; Govaerts *et al.*, 2006; Xie *et al.*, 2015). PC analysis produces the Minimum Soil Fertility Index (MSFI) which is the smallest data set to represent all the values of the soil fertility indicators used. From each selected PC, one indicator is taken with the highest value.

The indicators with the highest values on PC1 to PC3 are available P, available K, BS and pH. PC1 consisting of available P and available K has an eigenvalue of 2.885 which represents 36.1% of the data to determine soil fertility. The BS analysis found in PC2 has a proportion of 20.3% to determine soil fertility. PC3 contained pH which represented 15.2% of data to determine soil fertility. The first to third major component (PC1 to PC3) has a cumulative presentation of 71.6%. If 8 indicators used as parameters (Total N, available P, available K, CEC, BS, SOC, pH, Al saturation) are reduced to four indicators then four new indicators can already explain 71.6% of the total variability of 8 indicators. The four indicators are called the Minimum Soil Fertility Index (MSFI). These four variables have a high sensitivity to soil fertility at the study site (Table 5).

Soil Fertility Index (SFI) is used to assess qualitative soil fertility classes by means of a parametric approach using parameters that are appropriate for each sample point of the soil (Saglam and Dengiz, 2015). The way to determine SFI is to use three main steps: (I) selecting soil indicators and determining their weights, (II) calculating the scores of each indicator and (III) integrating indicator scores into the overall soil fertility index (Cheng *et al.*, 2017). The soil fertility index is determined by collecting selected indicator data for each land function or Minimum Soil Fertility Index (MSFI) which is then reported based on the Soil Research Center assessment criteria (2009). The calculation of the soil fertility index is done by multiplying the weight index with the scoring index

and then summing it for all selected indicators such as the Mukashema's formula (2007).

Table 6 shows that the organic rice management system has a higher soil fertility index value compared to semi-organic and conventional rice fields management systems, namely the average SFI value of organic rice fields (0.630), semi-organic rice fields (0.557) and conventional rice fields (0.545). The three management systems have the same SFI category, which is medium. Research results from Andrews *et al.* (2002) show that organic farming management systems increase the available P content by 14% in the third and fourth years of the transition period. In a 3-year study, Gliessman *et al.* (1996) found a significant difference after the second year with the application of compost 18.5 t/ha/year and 37 t/ha/year. According to Herencia *et al.* (2008) the use of two different organic fertilizers (compost and manure) in the amount used in this study was able to increase soil fertility. Organic farming management systems have higher organic matter content, Nitrogen, P available and K available compared to conventional farming systems.

As can be seen in Table 7, p value = 0.018 (p < 0.05) is obtained, so it can be concluded that there is a significant difference between the average values of each rice field management system. Or in other words, the system change in the management of rice fields has a significant effect in increasing the index of soil fertility. Furthermore, to complete the ANOVA results, a DMRT (*Duncan's Multiple Range Test*) is seen in Table 8.

Table 4: Analysis of Minimum Soil Fertility Index (MSFI) using PCA

Eigenvalue	2.885	1.6278	1.2173
Proportion	0.361	0.203	0.152
Cumulative	0.361	0.564	0.716
Variable	PC1	PC2	PC3
Total N	0.335	0.121	-0.413
Available P	0.480*	-0.11	-0.242
Available K	0.538*	0,055	0.026
CEC	0.014	-0.658	-0.205
BS	0.309	0.504*	0.214
SOC	0.3	-0.481	0.085
pH	0.426	-0.037	0.323*
Al saturation	-0.018	0.222	-0.755

CEC = Cation Exchange Capacity, BS = Base Saturation, SOC = Soil Organic Carbon, PC = Principal Component, *selected indicator/MSFI

Table 5: Results of Weight index (Wi)

No.	MSFI	Proportion	Cumulative	Weight index (Wi)
1.	Available P	0.1805	0.716	0.129
2.	Available K	0.1805	0.716	0.129
3.	Base Saturation (BS)	0.203	0.716	0.145
4.	Soil reaction (pH)	0.152	0.716	0.109

Table 6: Soil Fertility Index in each farming system

Sample Point	Skoring Indeks (Si)				cj $\sum(wi \times si)$	nc	pc (1/nc)	Sci (cj x pc)	N	SFI (Sci/N)x10	Average SFI	Criteria SFI
	Av-P	Av-K	BS	pH								
1	2	2	2	3	1.134	5	0.2	0.227	4	0.567	0.630	Medium
2	2	3	2	3	1.263	5	0.2	0.253	4	0.632		
3	2	3	2	3	1.263	5	0.2	0.253	4	0.632		
4	2	3	2	4	1.372	5	0.2	0.274	4	0.686		
5	3	3	2	3	1.393	5	0.2	0.279	4	0.696		
6	2	3	2	3	1.263	5	0.2	0.253	4	0.632		
7	2	3	2	3	1.263	5	0.2	0.253	4	0.632		
8	2	3	1	3	1.118	5	0.2	0.224	4	0.559		
9	2	3	2	3	1.263	5	0.2	0.253	4	0.632		
10	2	2	2	3	1.134	5	0.2	0.227	4	0.567	0.557	Medium
11	2	3	2	3	1.263	5	0.2	0.253	4	0.632		
12	2	2	1	3	0.989	5	0.2	0.198	4	0.494		
13	2	2	1	2	0.880	5	0.2	0.176	4	0.440		
14	2	3	2	3	1.263	5	0.2	0.253	4	0.632		
15	2	3	2	3	1.263	5	0.2	0.253	4	0.632		
16	1	2	2	3	1.005	5	0.2	0.201	4	0.502		
17	2	2	2	3	1.134	5	0.2	0.227	4	0.567		
18	1	2	2	3	1.100	5	0.2	0.220	4	0.550		
19	1	2	2	3	1.100	5	0.2	0.220	4	0.550	0.545	Medium
20	1	2	2	3	1.100	5	0.2	0.220	4	0.550		
21	2	2	1	2	0.940	5	0.2	0.188	4	0.470		
22	2	3	1	3	1.191	5	0.2	0.238	4	0.596		
23	2	3	2	2	1.245	5	0.2	0.249	4	0.623		
24	2	2	2	3	1.232	5	0.2	0.246	4	0.616		
25	1	2	2	3	1.100	5	0.2	0.220	4	0.550		
26	1	2	1	2	0.808	5	0.2	0.162	4	0.404		
27	1	2	2	3	1.100	5	0.2	0.220	4	0.550		

pH = soil reaction, CEC = Cation Exchange Capacity, BS = Base Saturation, SOC = Soil Organic Carbon, Av-P = Available P, Av-K = Available K, pc = opportunities for many classes, nc = number of classes, wi = weighting factor, si = the indicator score for variable i, cj = class for each sample, SFI = soil fertility index value, Sci = total weight, N = number of MSFI indicators

Table 7: Results of ANOVA (*Analysis of Variance*)

Source	Sum Squares	Degree of Freedom	Mean squares	F-value	P-value
Factor	0,03738	2	0,018692	4,80	0,018
Error	0,09340	24	0,003892		
Total	0,13079	26			

Table 8: Result of DMRT (*Duncan's Multiple Range Test*)

Factor	Number of sample	Mean	Grouping
Organic rice field	9	0.6297	A
semi organic rice field	9	0.5574	B
Conventional rice field	9	0.5455	B

Note: numbers followed by different letters in the same column show significantly different in the DMRT test at the level $\alpha = 5\%$

The results of the grouping carried out with the DMRT test (Table 8) showed that the actual management system of semi-organic rice fields with conventional rice fields was not significantly different so that it was included in one group, namely group b. This shows that the change in management systems from conventional rice fields to semi-organic rice fields has not been significantly different. More time is still needed to transition and begin to reduce the use of chemical fertilizers. As for the organic management system with semi-organic rice fields and conventional rice fields, the

difference is already shown by the different notation results in the two systems. The management system that has been implemented needs to be maintained and further developed so that it can improve the index of soil fertility in Girimarto District.

The transition from conventional agriculture to organic farming will always be followed by changes in soil properties and chemical processes that affect soil fertility (Clark *et al.*, 1998). This change affects the availability of nutrients for plants either directly through irrigation channels or indirectly by fertilizing and

modifying microclimates (Bulluck *et al.*, 2002). Increases in organic matter during the transition period occur slowly, generally starting to increase after a few years (Drinkwater *et al.*, 1995; Werner, 1997) and can have a considerable impact on long-term productivity (Tiessen *et al.*, 1994). The amount of accumulation of organic matter in the soil and the content of essential nutrients depends on the level of decomposition of organic matter and the agricultural management system applied (Haynes and Naidu, 1998; Stockdale *et al.*, 2001).

A good soil fertility index is expected to be in line with the increase in rice production, below the results of rice production in Girimarto District, Wonogiri Regency, Central Java, Indonesia.

The results of the data in Table 9 show that organic rice fields produce rice production of 4.45 tons. These results have a higher value compared to other treatments. But these results are not much different from conventional rice fields because organic rice will increase the yield of conventional equivalent grain and has advantages in terms of quality and taste in rice. The selling value of organic rice is much higher compared to management both semi-organic and conventional. According to Ikemura and Shukla (2009) high quality food products are not only rich in nutrients but contribute to health care and community welfare through organic management. The rice production yield data is slightly different from the value of the soil fertility index. The SFI value of semi-organic paddy fields is higher than conventional paddy fields, but for conventional paddy rice production is higher than semi-organic paddy production. Already seen an increase in the value of SFI and rice production from conventional fields to organic fields.

The difference in soil fertility index in Girimarto District that is not too far away is suspected because the management period of the organic farming system has only been running for 6 years. But another thing that is more important than the value of land quality and rice productivity is sustainability and environmental balance. According to Ikemura and Shukla (2009), that organic farming is aimed at producing high quality food products that are not only rich in nutrients but also contribute to the health care and welfare of humanity. In this study organic rice fields have better environmental conditions, as evidenced by the higher diversity of vegetation, flora and fauna. Good environmental conditions reflect good ecosystem conditions. This is related to natural sustainability which can be utilized continuously.

Table 9: Rice production in Girimarto District, Wonogiri Regency, Central Java, Indonesia

Management systems	Production (tons/ha)
Organic rice field	4.45
Semi organic rice field	3.38
Conventional rice field	3.95

According to the Indonesian Agency for Agricultural Research and Development (2015) to produce an average of 6 tons of grain/ha, rice plants need 165 kg/ha of nitrogen, 19 kg/ha of phosphorus and 112 kg/ha of potassium or equivalent to 350 kg of urea, 120 kg of SP36 and 225 kg KCl. So based on fertilization that has been done before, for conventional rice fields it is necessary to add fertilizer dosage by 50 kg urea, 45 kg SP 36 and 150 kg KCl. As for semi-organic rice fields and organic rice fields, it is necessary to add organic material derived from rice straw and start adding azolla or mycorrhizae as biological fertilizer.

Conclusion

Based on the research that has been done, it can be concluded that the soil fertility index in Girimarto District which is managed organically has soil fertility index (0.630) semi-organic (0.557) and conventional (0.545) management with moderate criteria for all management systems. The soil fertility index of organic rice fields is significantly higher than that of semi-organic rice fields and conventional rice fields. This research shows that the transition from conventional rice to organic management systems takes a long time, it has been proven that during the 6 years the transition has change or improve the chemical properties of rice fields entirely. Selected chemical indicators that can be used in determining the soil fertility index in Girimarto District include available P, available K, BS and pH.

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Author's Contributions

Haryuni: Designed, collected and checked the analyzed data; prepared the draft manuscript and approved the final manuscript.

Atinnajah Kamalasari: Coordinated the study, analyzed the data and supervised the draft manuscript.

Hery Widijanto: Reviewed the draft manuscript and contributed in data interpretation.

Supriyadi: Coordinated the study, checked and analyzed the data and prepared the draft manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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