Soil Fertility Index of organic, semi-organic, and conventional rice fields on 3 different soil types

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Abstract. In Indonesia, there are three management systems of rice fields, namely organic, semi-organic and conventional. The research aimed to determine the fertility index of rice fields with different management systems on different soil types (vertisol, ultisol, inceptisol). Each combination of the management system and soil type is taken three soil samples as a repetition. The soil parameters analyzed were pH H$_2$O, total-Nitrogen, available-P, available-K, exchangeable-Ca, exchangeable-Mg, soil organic carbon, Exchangeable-Al, cation exchange capacity, and base saturation. The soil fertility index was determined based on the Minimum Soil Fertility Index (MSFI). Data analysis used was Pearson's Correlation Analysis and Principal Component Analysis (PCA) to determine MSFI. The MSFI values were derived from indicators that have high scores on correlation analysis and PCA. The results showed that the fertility index of rice fields from 3 types of soil ranged from 0.46 to 0.57. Vertisol rice fields have the highest soil fertility index ranging from 0.52–0.57. Conventional management of inceptisol soil has the lowest soil fertility index of 0.46. Vertisol rice fields with organic management with a soil fertility index of 0.57 are the most ideal rice field management system.

1. Introduction
Rice growth and production are influenced by irrigation environment, soil characteristics, plant nutrition, cation exchange capacity [1]. Rice fields in Indonesia are managed organically, semi-organically, conventionally, and each management has its advantages and disadvantages. The continuous use of inorganic fertilizers can cause a decrease in the content of organic matter and nutrient density in the soil that affects the production of rice crops [2].

As the concern regarding adverse effects of organic fertilizer usage increase, the development of organic rice fields has arisen. The use of organic materials in rice fields will increase the soil's biological activity so that the soil's condition and fertility increase so that rice production increases [3]. Organic matter added as fertilizer increases soil pH value, Soil Organic Matter (SOM), and Total Nitrogen content in soil [4].

Each type of soil has different soil properties and characteristics due to forming factors and their use. Rice fields showed a change in the density of soil content (bulk density), higher pH value, and solubility levels for minerals Fe, Mn, and Al [5]. Characteristic rice fields with vertisol soil type are high clay content on the horizon, cracks (vertices) in the dry season, and a relatively neutral pH [6]. The nutrient content of Potassium (K) in rice fields with ultisol soil type is generally low, so there is often a shortage of element K in the rice fields ultisol [7–9]. Inceptisol has a low value in Soil Organic Carbon (SOC) and Nitrogen [10,11]. The nature and characteristics of soil formed in rice fields affect soil fertility status.
on rice fields. Decreased soil fertility can be a significant factor that affects decreased soil productivity [12]. The important soil fertility factor in productivity is the soil fertility in an area so that it needs to be evaluated to assess whether the soil still contains optimum nutrients for plants [13]. Soil fertility is measured using the soil fertility index based on the assessment which can provide information on soil nutrient distribution and identify the main limiting factors to agricultural production [14].

Research on soil fertility index has been done but still focused on a particular area of rice fields or management systems. The focus of this study is to know the value of soil fertility index and management recommendations based on determining different soil types (ultisol, vertisol, inceptisol) and various management (organic, semi-organic, and conventional). Data obtained from research can be used as a reference basis for recommendations for proper soil management for farmers and researchers in advanced research.

2. Materials and methods

2.1. Overview of the study area
The research site has the soil types ultisol, inceptisol, and vertisol which were managed organically, semi-organically, and conventionally. The location of the sample point was the location that has just been harvested.

Karangbangun Village, Jumapolo Subdistrict, Karanganyar Regency was the location chosen to represent the ultisol soil type. It is at an altitude of 318 meters above sea level. The second location was Gempol Village, Karanganom District, Klaten Regency. The second location represents the inceptisol soil type. Tegalsari Village, Weru Subdistrict, Sukoharjo Regency, was the last site describing the vertisol soil type.

2.2. Sample collection and determination
Soil sampling for laboratory analysis was done using purposive sampling (intentionally) at a depth of 0-30 cm [15]. Soil sampling was done by composite technique. Each soil type (Ultisol, Vertisol, Inceptisol) was represented by three management systems (organic, inorganic, and semi) with three replications. The total samples were 27.

The analysis method of chemical properties in the laboratory was referred to Balai Penelitian Tanah [16]. The pH was measured using electrometric methods. Total Nitrogen was measured using the Kjeldahl method [17]. The Available-P (A-P) on vertisol and inceptisol soils was measured using the Olsen method while on ultisol using Bray method [18]. Soil Organic Carbon (SOC) was measured using Walkley and Black methods [19]. Exchangeable-AL (Exch-Al) was measured through the Saturation of Potassium Chloride. Available-K (A-K), Exchangeable-Ca (Exch-Ca), Exchangeable-Mg (Exch-Mg), Cation Exchange Capacity (CEC), Base Saturation (BS) using ammonium acetate extraction method [20].

2.3. Evaluation index selection
Data were analyzed with Pearson Correlation Analysis to determine a correlation between variables tested. The study was continued by analyzing Principal Components Analysis (PCA) to find the Minimum Soil Fertility Index (MSFI) and using Minitab software, a soil fertility index assessment (SFI) [21].

2.4. Evaluation method
The MSFI was classified into fertility index classes based on Bagherzadeh et al. [22]. Soil Fertility Index calculation was calculated by summing the division result of the sum of weights by the number of MSFI indicators, such as the formula used by Mukashema [23].

\[ SFI = \left( \frac{\text{Sc}i}{N} \right) \times 10 \]

Note: Sci is MSFI weight amount; N is the number of MSFI used.
3. Result and analysis

The soil fertility index is a valuable indicator to help improve soil sustainability with proper management to increase agricultural production [24,25]. Soil fertility index was analyzed with the first step which was choosing soil fertility indicator or Minimum Soil Fertility Index (MSFI) through Pearson's Correlation Analysis (Table 1) and then continued with Principal Component Analysis [23].

3.1. Soil fertility index

Table 1. Pearson's correlation analysis

|        | ph | SOC   | T-N  | A-P   | A-K   | Exch-Ca | Exch-Mg | Exch-Al | CEC   |
|--------|----|-------|------|-------|-------|---------|---------|---------|-------|
| SOC    | 0.73*|       |      |       |       |         |         |         |       |
| T-N    | 0.089 | 0.635*|      |       |       |         |         |         |       |
| A-P    | 0.844*| 0.917*| 0.465|       |       |         |         |         |       |
| A-K    | 0.728*| 0.771*| 0.366| 0.765*|       |         |         |         |       |
| Exch-Ca| 0.692*| 0.487| 0.049| 0.637*| 0.667*|         |         |         |       |
| Exch-Mg| 0.785*| 0.291| -0.407| 0.539| 0.419| 0.722*|         |         |       |
| Exch-Al| -0.475| -0.11| 0.015| -0.316| -0.185| -0.435| -0.483|         |       |
| CEC    | 0.856*| 0.783*| 0.332| 0.866*| 0.847*| 0.867*| 0.641*| -0.353|       |
| BS     | 0.74*| 0.295| -0.389| 0.512| 0.45| 0.787*| 0.941*| -0.503| 0.614*|

Note: (SOC) Soil Organic Carbon, (T-N) Total Nitrogen, (A-P) Available-P, (A-K) Available-K, (Exch-Ca) exchangeable-Ca, (Exch-Mg) exchangeable-Mg, (Exch-Al) Aluminum Saturation, (CEC) Cation Exchange Capacity, (BS) Base Saturation, (*) significant correlation at level 0.05

Correlation analysis uses a level of 5% (α 0.05). Two indicators are said to have a strong correlation when Pearson correlation values are closer to 1 or |−1| or P-value less than α (0.05 or 5%). Based on the analysis in Table 1, many indicators are interrelated and have a solid correlation relationship. Among them are correlation between Soil Organic Carbon (SOC) and available-P (r=0.917), available-P and CEC (r=0.866), CEC and pH (r=0.856), pH and available-P (r=0.844), available-K and CEC (r=0.847) and others. The correlation between Soil Organic Carbon and available-P and Soil Organic Carbon and available-K shows that organic matter increases the available-P and available-K to the soil [26].

Table 2. Principal component analysis

| Variable     | PC1  | PC2  |
|--------------|------|------|
| Eigenvalue   | 6.0713| 2.2372|
| Proportion   | 0.607| 0.224|
| Cumulative   | 0.607| 0.831|

| Variable     | pH   | Soil Organic Carbon | Total Nitrogen | Available-P | Available-K | Exch-Ca | Exch-Mg | Exch-Al | CEC   | BS    |
|--------------|------|---------------------|---------------|-------------|-------------|---------|---------|---------|-------|-------|
| Value        | 0.38 | 0.315               | 0.083         | 0.365       | 0.335       | 0.348   | 0.312   | -0.195  | 0.387 | 0.312 |

Note: (SOC) Soil Organic Carbon, (T-N) Total Nitrogen, (A-P) Available-P, (A-K) Available-K, (Exch-Ca) exchangeable-Ca, (Exch-Mg) exchangeable-Mg, (Exch-Al) Aluminum Saturation, (CEC) Cation Exchange Capacity, (BS) Base Saturation.
The results of the PCA showed an eigenvalue value that has a value >1 is only equivalent to on PC2 with a value of 2.2372. Based on PC1 and PC2 in Table 2, the data to be retrieved presents 83.1% of the overall data. On PC1, the highest value was on the CEC indicator and PC2, and the highest value was on the N-total indicator. Based on Jolliffe [27], the components selected to present the data are the highest value components and have the highest correlation value. The MSFI decided the CEC and the indicator with the highest correlation, namely available-P and Exch-Ca, and indicators correlated with N-Total, namely the Soil Organic Carbon indicator. Five indicators are selected by MSFI, representing 83.1% of the data.

![Soil fertility index result](image)

**Figure 1.** Soil fertility index result

Based on the result that showed in Figure 1, the vertisol soil type with organic management has the highest SFI value of 0.57, which is classified as moderate. Meanwhile, vertisol soil with semi-organic management has the second-highest SFI of 0.55. Inceptisol land with conventional management has the lowest SFI value of 0.46, which is relatively low. The value of SFI in ultisol soil type either managed organically, semi-organically, or conventionally has an SFI value of 0.52, which is classified as moderate. Organically managed soils have a higher SFI value than semi-organic and conventional managed ones.

The difference in SFI value occurs due to the chemical properties of each type of soil and its management. The highest SFI value is in the vertisol soils type managed organically using 2 ton/ha of manure, Local Microorganism Solutions (LMS) 5 L/ha, Liquid Organic Fertilizer (LOF) 15 L/ha. Inceptisol soil with conventional management has the lowest SFI value that only used urea fertilizer and phonska as 300 kg/ha and SP36 as much as 70 kg/ha. Statement by Jolliffe [27] mentioned that the provision of organic fertilizer or the addition of organic matter continuously increase the fertility value of the soil, and this is following the results of the calculation of SFI that has been done where all organically managed soils have a better SFI value than conventionally managed. Differences in the addition of fertilizers and pesticides indirectly cause changes in the chemical properties of the soil even though the soil formed on the same parent material [28].

### 3.2. Management recommendations

In general, the constraints found at all three research sites are the very low P-value available and in inceptisol soil in the form of low Soil Organic Carbon values. As for recommendations, it is suggested to add organic materials to the soil that is managed organically and semi-organically. In semi-organic...
and conventional systems, phosphorus fertilizer is routinely used to maintain soil fertility in the best condition. We can use organic material to increase soil availability-P; one of them is Biochar. The addition of Biochar can bind phosphorus in soil stronger so that phosphorus is not easily fixed or tied to Aluminium (Al) and Ferrum (Fe) [29,30].

4. Conclusion

Based on the research that has been done can be concluded as follows indicators of chemical properties that can be used as determinants of SFI values in soil type factors and their management are indicators of Soil Organic Carbon, Total-N, Available-P, Exch-Ca, and CEC. Organically managed in vertisol soil has the highest Soil Fertility Index value of 0.57. Organic management is the best management because it has a higher soil fertility index value than other management with an SFI value of 0.57 on vertisol, 0.52 on ultisol, and 0.52 on inceptisol. Conventionally managed inceptisol soils have the lowest Soil Fertility Index value of 0.46. The addition of organic matter to the soil gives the soil a better SFI value than soil without organic matter addition.

References

[1] Haefele S M, Nelson A and Hijmans R J 2014 Geoderma 235–236 250–9
[2] Sugiyanta, Rumawas F, Chozin M, A, Mugnisyah W Q and Ghulamahdi M 2008 J. Agron. Indones.: Indonesian J. Agron. 36 196–203
[3] Sutanto R 202 Pertanian organik: Menuju pertanian alternatif dan berkelanjutan (Yogyakarta: Kanisius)
[4] Leszczyńska D and Kwiatkowska-Malina J 2011 Ecol. Chem. Eng. S. 18 501–7
[5] Kurniati, Sudarsono and Suwardi 2017 Indonesia. J. Trop. Soils. 21 27–32
[6] Ayal Y, Kaihatu S and Waas E D 2014 Prosiding Seminar Nasional: Mewujudkan Kedaulatan Pangan Pada Lahan pp 283–92
[7] Sekhon G S 1999 Proc. Indian Natl. Sci. Acad. B. 1999 65 83–108
[8] Rao C S, Rao A S, Rao K V, Venkateswarlu B and Singh A K 2010 Ind. J. Fert. 6 40–54
[9] Prasad R 2011 Advances in Agronomy 111 207–247
[10] Sudirja R, Solichin M A and Rosniawaty S 2007 Respon Beberapa Sifat Kimia Inceptisol Asal Rajamandala dan Hasil Bibit Kakao (Theobroma Cacao L.) Melalui Pemberian Pupuk Organik dan Pupuk Hayati (Bandung: Universitas Padjajaran)
[11] Yuniarti A, Damayani M and Nur D M 2019 J. Pertan Presisi 3 90–105
[12] Pinatih I D A S P, Kusmiyarti T B and Susila K D 2015 E-Jurnal Agroekoteknologi Tropika 4 282–92
[13] Singh R P and Mishra S K 2012 Indian J. Sci. Res. 3 97–100
[14] Khaki B D, Honarjoo N, Davatgar N, Jalalian A and Golsefidi H T 2017 Sustain. 9 1–13
[15] Hikmatullah and Suparto 2014 J Tanah dan Iklim 38 1–14
[16] Balai Penelitian Tanah 2009 Petunjuk Teknis: Analisis Kimia Tanah, Tanaman, Air, dan Pupuk (Bogor: Balai Penelitian Tanah)
[17] Sáez-Plaza P, Navas M J, Wybraniec S, Michałowski T and Asuero A G 2013 Crit Rev Anal Chem. 43 224–72
[18] Umaternate G R, Abidjulu J and Wuntu A D 2014 J MIPA. 3 6–10
[19] USDA 2003 Soil Survey Standard Test Method Organic Carbon http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.165.1882&rep=rep1&type=pdf
[20] Zhang Y, Xiao M and Dong Y 2012 Guang Pu Xue Yu Guang Pu Fen Xi. 32 2242–5
[21] Ikemura Y and Shukla M K 2009 J. Org Syst. 4 35–47
[22] Bagherzadeh A, Gholizadeh A and Keshavarzi A 2018 Eurasian J. Soil Sci. 7 203–12
[23] Mukashema A 2007 Mapping and Modelling Landscape-based Soil Fertility Change in Relation to Human Induction Case study: GISHWATI Watershed of the Rwandan highlands Thesis (Netherland: Internasional Institute for Geo-Information Science and Earth Observation Enschede)
[24] Andrews S S, Karlen D L and Cambardella C A 2004 Soil Sci. Soc. Am. J. 68 1945–62
[25] Shang Q, Ling N, Feng X, Yang X, Wu P, Zou J, Shen Q and Guo S 2014 Plant Soil 381 13–23
[26] Purwono and Purnamawati H 2007 Budidaya 8 jenis tanaman pangan unggul (Jakarta: Penebar Swadaya)
[27] Jolliffe I T 2002 Principal Components Analysis. Second. International Encyclopedia of Education (New York: Springer-Verlag New York Inc)
[28] Minardi S and Widijanto H 2013 Sains Tanah-Journal Soil Sci Agroclimatol 4 34–8
[29] Van Leeuwen J P, Lehtinen T, Lair G J, Bloem J, Hemerik L, Ragnarsdóttir K V, Gisladottir G, Newton J S and de Ruiter P C 2015 Soil 1 83–101
[30] Cheng C-H, Lehmann J, Thies J E, Burton S D and Engelhard M H 2006 Org Geochem 37 1477–88
[31] Tambunan S, Handayanto E and Siswanto B 2014 J. Tanah dan Sumber Lahan 1 89–98