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The relationship between soil fertility, phosphorus uptake, and crop yields of paddy (*Oryza sativa* l.) under different farming systems of rice field

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Abstract

This study aims to determine the influence of the differences in rice field farming systems on soil fertility index (SFI), phosphorus uptake, and crop yields of paddy, as well as provide appropriate and sustainable land management to ensure crop yields. To achieve these objectives, a descriptive-exploratory method through a survey conducted with purposive sampling in Girimarto District, Wonogiri Regency, Indonesia, was adopted. The sampling points were determined on a working map consisting of 6 land map unit (LMU), with 4 points per LMU. Parameters observed included C-microbial biomass, earthworm population, soil pH, N-total, P-available, K-available, P-total, Organic-C, soil oxidation-reduction, Cation Exchange Capacity (CEC), and Base Saturation (BS). Soil and plant sampling was conducted during the maximum vegetative phase. SFI was determined through Principal Component Analysis (PCA) and data scoring. Furthermore, data were analyzed using One-way Analysis of Variance (ANOVA), DMRT, and Pearson's correlation test. The results showed that organic farming system had a higher SFI (0.78) and P plant uptake (2.21%) compared to semi-organic and conventional methods. Soil management options suitable for the prevailing conditions include adding compost into non-organic system, maintaining organic rice field management, expanding organic cultivation area, and adding biofertilizers.

Keywords: Inorganic, Nutrients uptake, Organic farming, Land management impact

1. Introduction

The demand for rice is directly proportional to the population growth [1,2]. Based on data from the Central Statistics Agency (BPS), rice production in Wonogiri decreased by 2.6% to 10,977 tons in 2020 compared to 2019. Over the past decade, particularly in 2014, the production dipped to 5,935 tons (1.8%) compared to 2013. Rice production has been closely related to soil fertility. In fertile soil, nutrient availability sustains vigorous vegetative growth cycle, promoting healthy root systems, and yield high-quality crop, while poor soul fertility lead to decreased production. Soil fertility plays a crucial role in predicting the productivity of lowland rice cultivation [3] .Therefore, most farmers resort to continuous use of synthetic fertilizers to increase production. It is important to acknowledge the impact of chemical fertilizer on soil fertility [4,5].

Low soil fertility and nutrient deficiencies are significant constraints in achieving sustainable agricultural development [6] and optimal production levels. Phosphorus (P) is a critical macronutrient necessary for the growth of paddy crop [7].Furthermore, phosphate fertilizer influences both the quantity and quality of rice grain growth, with the number of panicles directly correlating to rice grains harvested [8]. P nutrients accelerate seed maturation, resulting in higher-quality yields and increased productivity. However, only a tiny portion of this nutrient is available to plants (approximately 0.01 to 0.2 mg/kg soil). It is important to acknowledge that soil organic matter content in compost and biofertilizers affects the availability of P in soil. The presence of organic matter binds Alumunium (Al) and Ferrum (Fe) concentrations in soil, thereby enhancing the accessibility of nutrients [9].

Soil fertility, agricultural yield production, and land management are closely related. Sustainable agricultural techniques include applying organic fertilizer to increase soil fertility. In organic farming, soil typically has better characteristics compared to conventional agriculture. Transitioning from traditional to organic farming systems can have long-term effects on nutrient availability or the physical state of soil, impacting land productivity. A study conducted by [10] showed that rice production using organic systems yielded higher results (6.92 tons/ha) than conventional systems (5.89 tons/ha). Similarly, investigation conducted by [11] in Girimarto rice field showed that converting conventional field to organic led to an increase in soil fertility index (SFI). Applying organic fertilizers in organic farming systems help maintain soil pH, thereby improving the adsorption and desorption mechanisms of P and enhancing the uptake by plants. Achieving pH conditions close to neutral is crucial for increasing both soil and plant P uptake [12]. On the other hand, conventional farming practices pose harmful effects on soil and plants. Chemical fertilization often lead to heavy metal accumulation and a decrease in soil organic matter (SOM) [13].

Paddy field has a strong adsorption capacity for soil phosphorus to retain and absorb phosphate ions (PO_4^{3-}), making the nutrient content unavailable to plant. However, in soil with high organic matter content, microbial activity, and neutral soil pH, P becomes readily available for plant absorption due to desorption. These conditions present the significance of proper land management in maintaining soil fertility and optimizing the use of P, thereby facilitating P uptake and maximizing production yields. It is necessary to assess SFI and P uptake in paddy crop across organic, semi-organic, and conventional farming systems to understand the impact of agricultural practices on soil fertility and rice production. The assessment is expected to help farmers and other stakeholders in selecting the most suitable rice field management system to enhance crop yields. The objectives of this study was to investigate the effect of various paddy field farming systems on SFI and P uptake of paddy crop in Girimarto District, providing management recommendations to improve rice production.

2. Materials and methods

2.1 Study area

Girimarto District is an area in Wonogiri Regency, Central Java, Indonesia, located at the coordinates 7°47'27.0 "S 111°06'47.3" E. Soil type map 1:50,000 showed that the district had 2 types of soil, namely Inceptisols and Alfisols. Inceptisols are characterized by the development of cambic B horizon, which has higher stability. In contrast, Alfisols have reddish brown to dark red color, high clay content, high base saturation of more than 35%, and an argillic horizon. Inceptisols, characterized by an ochric epipedon, have a relatively thick soil solum (1 to 2 meters depth), a black or gray to dark brown color, a low clay content of less than 8% at a 20-50 cm depth, and are supported by a cambic horizon.

Rice planted in the study area include *Menthik Wangi* variety, cultivated in both organic and semi-organic farming system, and Ciherang variety, grown in conventional farming system. Based on the information from local farmers, organic farming has been practiced for approximately 10 years, while conventional farming has been established for over 15 years. Organic rice field adopted a traditional manure input of 3 tons/ha during planting. Semi-organic rice field used inputs consisting of 1 ton/ha of organic fertilizer, 100 kg/ha of *Urea* fertilizer, and 80 kg/ha of NPK (*Phonska*) fertilizer. Conventional farming, on the other hand, relied on inputs including 300 kg/ha, 100 kg/ha, and 50 kg/ha of *Urea, Phonska*, and Ammonium Sulfate (*ZA*) fertilizers, respectively.

2.2 Soil and plant sampling and analysis

This study was conducted using descriptive explorative methods through a field survey, and was supported by laboratory analysis. Sampling points were determined by purposive sampling, and established in a working map known as land map unit (LMU), which consisted of overlaid landscape thematic maps, namely soil type, rainfall, slope, and land use (farming systems). LMU of the study area consisted of 6 sampling points, with each containing 4 replicate points, resulting in a total of 24 observation and sampling points. Annual rainfall of the sampling area was 2,105 mm per year, and the topography was approximately 15-40%. Soil types which include Inceptisols and Alfisols, were sampled at 0-30 cm depth and composited at each point. In addition, data was collected from plant samples and land management information by interviewing farmers who manage rice field at the study area. Soil observation indicators were determined using the disturbed soil sample method, while plant samples were obtained using a systematic random sampling method.

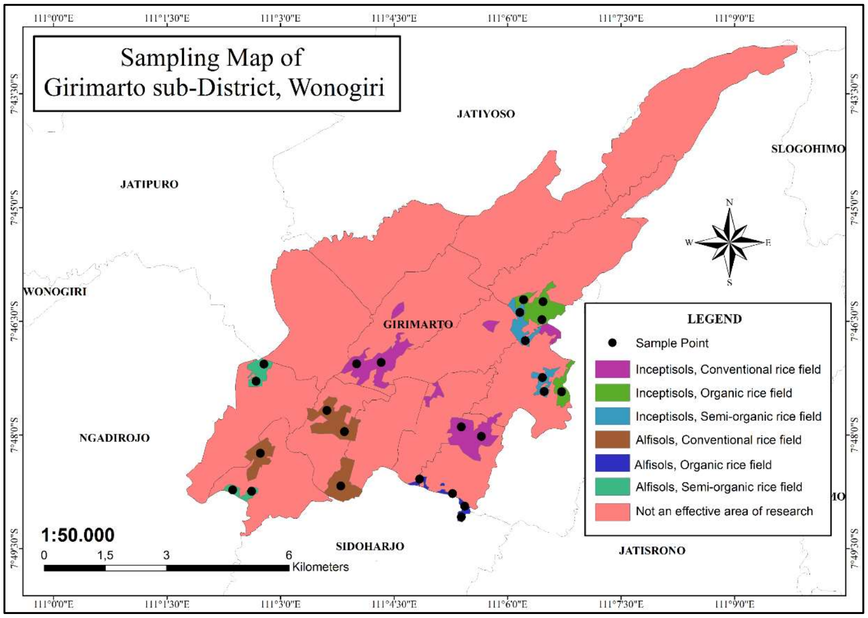

Figure 1 Sampling area.

Soil and plant samples were collected during the maximum vegetative phase. Parameters observed in soil samples [14] were soil pH and N-total, determined using Electrometric and Kjeldahl methods, respectively. P available, k available, Total P, Organic-C, Catching Exchange Capacity (CEC), Base Saturation (BS), Redox potential (Eh), C-Microbial biomass, and earthworms population, were evaluated using the Olsen, Ammonium acetate (NH_4Oac) 1 M pH 7 extraction, 25% Hydrogen Chloride (HCl) extraction, Walkey and Black, 1 N Ammonium Acetate extraction, NH_4OAc pH 7 extraction, Electrometric, fumigation, and Polyvinyl Chloride (PVC) ring methods, respectively.

Observations on plant samples included the number of tillers, root volume, root dry weight, the total rice crop yield, and P nutrient uptake. The number of tillers was calculated during paddy crop maximum vegetative phase. Measurements of root volume and dry weight were made during harvest. Meanwhile, rice crop yield was calculated after the maturation phase or at harvest using the 4-factor method, which entailed the multiplication of 4 production component factors, including the size of plant spacing, number of productive tillers per hill, number of grains per panicle, and weight per 1000 grains.

Figure 2 Sample of crop.

2.3 Data analysis

SFI serves as an assessment tool to measures soil fertility response to soil management. The results contain indicators that acts as a reference (determining factor) to help manage and increase crop cultivation. Determination of soil fertility status started with Principle Component Analysis (PCA) analysis on Statistical Program for Social Science (SPSS) Software. Subsequently, the results of PCA were scrutinized, focusing on principal component (PC) with eigenvalue ≥1. The indicator with the highest value in each PC were identified to establish Minimum Soil Fertility Index (MSFI). Following this, MSFI indicators were scored based on Soil Research Center assessment criteria [14]. Finally, SFI was calculated using formula number (1) according to [15].

Table 1 Scoring of soil fertility classes.

Parameters	Score				
	1	2	3	4	5
pH	<5,5 and>7,5	5,5-6,0	6,0-6,5	6,5-7,5	7,0-7,5
K-available (me/100 g)	<0,1	0,1-0,3	0,4-0,5	0,6-1,0	>1,0
Organic-C (%)	<1	1-2	2-3	3-5	>5
CEC (me/100g)	<5	5-16	17-24	25-40	>40
KB (%)	>20	20-40	41-60	61-80	<80
Total N (%)	<0,1	0,1-0,2	0,21-0,5	0,51-0,75	>0,75
Available P (mg/kg)	>5	5-10	11-15	16-20	>20
Redox Potential (mV)	0-100	101-200	201-300	301-400	>400 and <(-100)
Total Soil P	<15	15-20	21-40	41-60	>60
Microbial biomass C	<5	5-10	10-20	20-25	>25

Source: [4]

$$SFI = \left(\frac{SCi}{N}\right) x\ 10 \qquad (1)$$

Calculation details of formula (1):

$$SCi = Cj\ x\ pc$$
$$Cj = wi\ x\ si$$
$$pc = \frac{1}{nc}$$

Description

SFI : Soil Fertility Index
pc: Ranking value
SCi : Indicator score
nc : Number of hierarchies used
N : Number of MSFI indicators
wi : Weight index
cj : Total score weight
si : Scoring index

Table 2 SFI category.

Index	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

Source: [16]

Analysis of variance (ANOVA) statistical test was conducted to determine the effect of the source of diversity (various rice field management systems: organic, semi-organic, and conventional) on SFI and P uptake of paddy crop. Suppose the data had a significant result on SFI, Duncan's Multiple Range Test (DMRT) would be adopted at a significance level of 95% ($\alpha = 0.05$) to determine the most influential source of diversity. Furthermore, an unpaired T-test was conducted to identify the effect of soil type source of diversity. The relationship between SFI values with plant P uptake and rice yield was determined through Pearson correlation analysis.

3. Results and discussion

3.1 Soil characteristics

Soil fertility refers to the capacity of soil to provide nutrients in a readily available form and in amounts suitable for plant growth and reproduction [17]. PC with eigenvalue ≥1 were identified in PC1, PC2, and PC3, which has a cumulative presentation of 85.1% of the overall data, as shown in Table 3. The results of PCA obtained 7 out of 10 main indicators, representing the entire data set for determining soil fertility. Subsequently, MSFI indicators were scored based on the assessment criteria established by the Indonesian Soil Research Institute [14] .The next step include calculating SFI using the formulas by Mukashema ($SFI = \left(\frac{SCi}{N}\right) x\ 10$), necessitating the determination of weight index (wi) obtained from the division between proportion and cumulative values.

Table 3 PCA indicators.

Analysis of the Correlation Matrix			
Eigenvalue	5.6610	1.8494	1.0013
Proportion	0.566	0.185	0.100
Cumulative	0.566	0.751	0.851
Eigenvectors			
Variable	PC1	PC2	PC3
pH	-0.060	0.695*	0.218
Bio C-mic	0.403*	-0.093	0.068
Total N	0.298	-0.314	-0.268
P-Available	0.396*	-0.009	0.129
K-Available	0.370*	-0.157	0.180
CEC	0.411*	0.010	0.034
BS	-0.361	-0.023	0.054
Redox	-0.050	-0.276	0.850*
Organic-C	0.270	0.469*	0.219
P total	0.276	0.296	-0.227

Remark: Written letter by (*) remark as a principal component (PC) indicator.

The indicators with the highest values across PC1 to PC3 were C-microbial biomass (0.403), available P (0.396), available K (0.370), CEC (0.411), pH (0.695), Organic-C (0.469), and redox (0.850). Indicators in PC1 consist of C-microbial biomass, available P, available K, and CEC, with an eigenvalue of 5.6610, representing 56.6% of the data to determine soil fertility. Meanwhile, the analysis of pH and Organic-C in PC 2 accounts for 18.5% of the relevant dataset. PC3, mainly comprising Redox indicators, represented 10% of the data pertinent to soil fertility assessment. The cumulative contribution of the first to third principal components reached 85.1%.

PCA suggest that the 10 indicators can be reduced to 7 main, representing the entire data to determine soil fertility. The 7 indicators have been able to explain 85.1% of the total variability of the initial 10. These indicators, namely C-microbial biomass, available P, available Potassium (K), CEC, pH, Organic-C, and redox, served as pivotal parameters for developing MSFI, and were susceptible to soil fertility in the study area.

Table 4. The distribution of soil fertility.

Soil type	Farming system	LMU	Average value	Soil fertility category
Inceptisols	Organic	A1	0.79	High
	Semi-Organic	B1	0.64	Medium
	Conventional	C1	0.60	Medium
Alfisols	Organic	F1	0.77	High
	Semi-Organic	G1	0.65	Medium
	Conventional	H1	0.63	High

This study showed that organic farming on both soil types indicated a high category of soil fertility. In Inceptisols and Afisols, the highest values of SFI recorded was 0.79 and 0.77, respectively, as shown in Table 4. Semi-organic and conventional rice field had a moderate soil fertility class. SFI in semi-organic Inceptisols and Afisols, were 0.64 and 0.65, while in conventional Inceptisols and Alfidols, the values was recorded as 0.60 and 0.63.

Based on the results of ANOVA, farming systems significantly affect SFI in the study area (F-count= 150.741; Sig= 0.000; N=24). Organic fertilizers and continuous addition of organic matter were the most effective steps to improve soil fertility and microbial community [18]. This was followed by the results of SFI in Table 1, where organic farming soil had a higher SFI than semi-organic and conventional soil. The methods of organic farming return nutrients in the harvested residues to soil, making the levels of P and organic matter available in soil higher. The high organic carbon content crop residues will increase adsorption and CEC which affects the availability of nutrients [19].

In the study area, rice is grown using conventional, organic, and semi-organic paddy field farming systems. Based on the local information from the area, farmers in organic rice field have been managing for approximately 10 years, while conventional rice field has been cultivated for over a decade on average. Organic rice field used traditional manure input of 3 tons/ha during planting. Semi-organic rice field used inputs of 1 ton/ha of organic fertilizer, 100 kg/ha of *Urea* fertilizer, and 80 kg/ha of compound fertilizer containing nutrients of Nitrogen (N), P, and K called NPK fertilizer. Conventional farming incorporated inputs of 300 kg/ha, 100 kg/ha, and 50 kg/ha of *Urea*, NPK, and ammonium sulfate (*ZA*) fertilizers, respectively.

Organic rice field farming system showed higher soil fertility than conventional farming. The application of compost significantly affected the number of tillers. Quantity of productive tillers can increase the number of panicles in rice plants, each of which can form grains. The quantity of panicles formed from productive tillers is directly proportional to the grain harvested. In conventional rice field, a significant percentage of grain had suboptimal quality due to delayed growth of panicle compared to organic rice field, thereby affecting the grain filling.

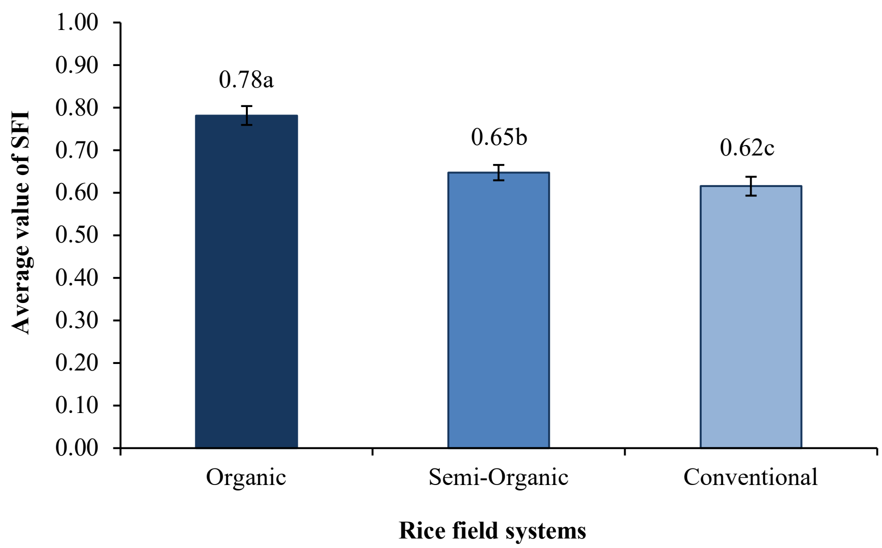

Figure 3. The distribution of soil fertility in various farming systems.
Note: Numbers followed by different letters in the same column indicate a significant difference in DMRT test at the 5% confidence level.

The various farming systems, including organic, semi-organic, or conventional, are significantly different in terms of average value of soil fertility. The highest SFI (0.78a) was in organic farming (Figure 3), followed by semi-organic (0.65b), and conventional (0.62c). Based on Table 3, organic agriculture showed a 14 to 19% increase compared to the conventional counterpart. In organic rice field, soil was tilled before planting, using organic fertilizer inputs to enrich soil organic material without resorting to chemical ingredients. Providing long-term inputs of manure and straw residue will increase the carbon organic content of soil [20]. The field studied under the three different farming systems had moderate organic carbon content of 2-3%. Organic matter was produced from the regular input of manure and crop residues, such as straw, left in rice field, with rice straw often applied as compost [8].Despite residue from burned straw being widely applied to restore nutrients to soil or reduce biotic pathogens, it lead to nutrient loss. Burning of banning straw to limit air pollution and global warming could increase human exposure to arsenic.

Regular fertilization and the return of crop residues to rice field results in higher soil P-available levels, with straw burning leading to loss of nutrients [21]. Combining straw and manure can increase total nitrogen, organic matter, available nitrogen, and potassium content [22]. However, burning of banning straw to limit air pollution and global warming could increase human exposure to arsenic [23]. Since most of the harvest is not returned into soil, organic matter decreases, adversely affecting soil P-availability. CEC greatly affects plant growth and the availability of nutrients in soil. Low CEC can lead to reduced soil fertility as it fails to retain nutrient cations such as calcium (Ca), magnesium (Mg), and potassium (K). Organic fertilizers also promote microbial diversity in soil, thereby enhancing nutrient availability for plants [24]. Microbial carbon biomass plays a crucial role in maintaining soil fertility by participating in soil nutrient cycle and the decomposition process of organic matter [18]. Microbes can decompose organic remains, such as fallen leaves or decaying roots, and release the nutrients into soil for plant uptake.

The use of plant pesticides had a significant influence on the presence of microorganisms. Conventional rice field management systems relies on chemical pesticides to control pests and plant diseases. Meanwhile, organic and semi-organic rice field management systems use natural pesticides, fostering proper microorganism activity and sustaining soil fertility. Organic rice field system adhered to organic farming methods, prioritizing natural materials and environmentally friendly cultivation methods without synthetic chemicals such as pesticides, herbicides, and synthetic fertilizers. In organic farming, natural fertilizers including compost and manure were used as a source of plant nutrients. Manure is one type of organic material that can be applied to soil to support plant growth in organic cultivation [25]. In comparation to chemical fertilizers, it has a slower reaction but provides better results in the long run. Furthermore, pest and disease control methods, such as natural predators, liquid organic fertilizers, and crop rotation, were conducted naturally. Organic rice field systems increase the population of natural enemies, thereby suppressing major rice pests including rice leafhoppers, stem borers, and apple snails [26].

Semi-organic rice field tends to have lower fertility levels than organic counterparts due to reliance on organic fertilizers. Farmers cultivating semi-organic agriculture in the study area mainly substitute organic and chemical fertilizer in a 50:50 ratio. The interest of conventional farmers in adopting 100% organic fertilizer remains limited, with majority expressing concerns about poor plant growth and crop productivity. In semi-organic farming systems, chemical fertilizers and pesticides were used alongside organic materials such as manure or compost. Cow manure, for instance, provide macronutrients, micronutrients, and growth hormones in the auxin and cytokinin groups, which can effectively repair damage to soil fertility [27].

3.2 Phosphorus uptake of crop yields

Nutrient uptake is the amount of nutrients absorbed by plant tissues. P uptake analysis was conducted at the maximum vegetative phase. Furthermore, adequate availability of P was essential for plants as the nutrient was insoluble and difficult for plants to absorb. This nutrient is a necessary nutrient for plant growth, and the availability in soil can affect productivity.

Table 5 Plant P uptake and rice yield under various rice field farming systems

Farming systems	Plant P uptake (%)	Number of productive tillers	Root dry weight (gram)	Root volume (mL)	Rice field (ton/ha)
Organic	2.21^{a}	22.88^{a}	47.63^{a}	172.5^{a}	8.49^{a}
Semi-Organic	1.57^{b}	17.38^{b}	36.13^{b}	86.5^{b}	6.34^{b}
Conventional	0.89^{c}	9.63^{c}	25.25^{c}	67.63^{b}	3.51^{c}

Note: Numbers followed by different letters in the same column indicate significant differences in DMRT test at the α = 5% level.

Organic matter applied by farmers in organic rice field includes compost. Additional composting of soil increased the availability of P nutrients for the decomposition of organic matter by producing organic acids that can improve solubility. Organic rice field farming system showed higher results in the number of tillers, root dry weight, and rice yield. Compost application significantly affected the number of tillers, and can increase the vegetative growth of paddy crop [28]. Manure, including compost, was used to provide sufficient nutrients for plant growth and development.

The large number of productive tillers can increase the number of panicles in paddy crop, each contributing to grain production. Conventional rice field often yields a percentage of grains of suboptimal quality due to slower panicle growth compared to organic rice field, leading to unfilled grains. Integrated rice management with organic rice field systems significantly increased the number of productive tillers and grain yield by 33.0% and 33.0%, respectively [29].

The higher weight of rice yield in organic field is attributed to the decomposition of applied manure over approximately 10 years, enriching soil with nutrients for paddy crop. The addition of manure increases the amount of nutrients in the growing medium. Cow manure, for instance, contains essential nutrients such as 26.2 kg/ton N, 4.5 kg/ton P, 13 kg/ton K, 5.3 - 16.28 kg/ton Ca, 3.5 - 12.8 kg/ton Mg, and 2.2 - 13.6 kg/ton S [30]. Rice requires N, P, and K macro-nutrients, particularly for tillering, which is crucial for increasing rice yield. Organic fertilizers have been recommended as an alternative to mineral fertilizers to enhance soil productivity, improve physical and chemical properties, and increase crop yields [31].

The most crucial role of P nutrient is to promote root growth, root system formation, and plant generative growth. Plant root development varies depending on P levels available in the growth medium [32]. Compost application has a very significant effect on root dry weight which serve as a crucial indicator of successful plant growth, representing the net photosynthetic products retained after water content is eliminated. The greater the biomass of a plant, the higher the nutrient content absorbed by the plant. Additionally, the ability of plants to absorb nutrients depends on the volume of the roots in a direct proportion [33]. Most of the elements needed by plants are sourced from soil solution, which is absorbed through the roots.

3.3 Relationship between soil fertility and plant phosphorus uptake

Using chemical fertilizers can make soil dependent on fertilizers and lead to the depletion of natural nutrients essential for soil health. Nutrient uptake serves as an indicator of nutrient sufficiency. Plants obtain P from soil through fertilization, or the decomposition of organic matter. Despite the substantial total P in soil, only a small portion is available to plants, typically ranging from 0.01-0.2 mg/kg soil [34].

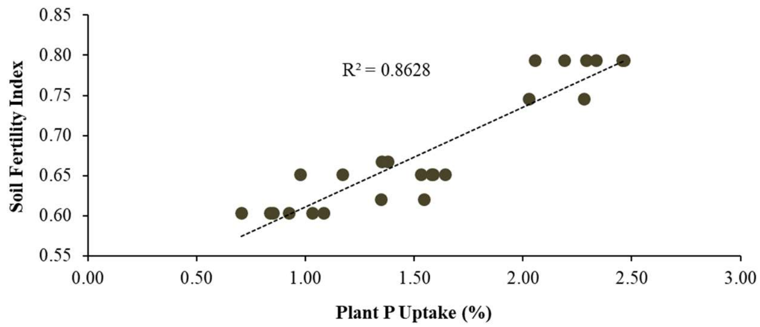

Figure 4 Correlation between plant P uptake and SFI.

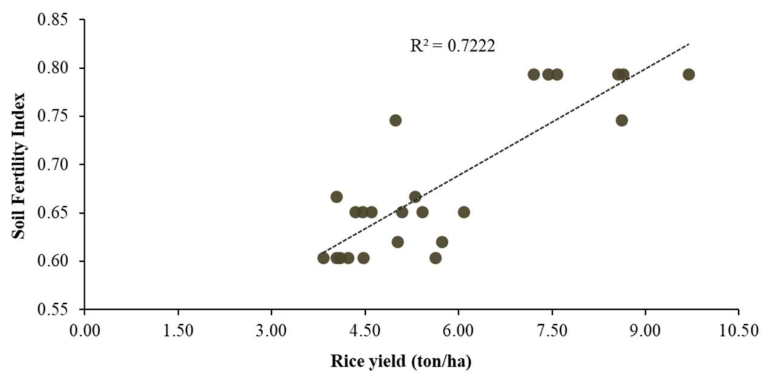

Figure 5 Correlation between rice yield and SFI.

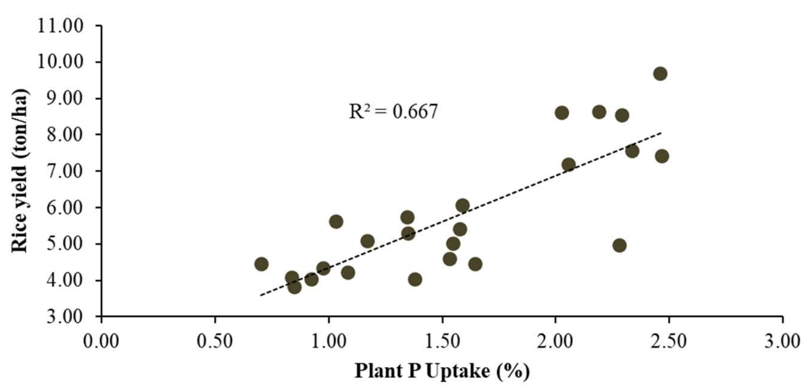

Figure 6. Correlation between plant P uptake and rice yield.

P nutrient uptake (Figure 4) and rice yield production (Figure 5) has been positively correlated to SFI vFalues, at 92,89%. The correlation between rice yield and SFI value is 84,98%, while the relationship between plant P uptake and rice yield is 81,67%. SFI value is directly proportional to the nutrients absorbed to increase rice yields. Applying organic fertilizers enhanced soil fertility by providing essential nutrients for plants, specifically macronutrients, which promote growth. Using organic matter such as manure and compost in soil increases the equilibrium concentration of P in soil solution, thereby elevating available P levels. The increased ability of plants to absorb the nutrient translates into an increase in P content in plant tissues [35].

Manure can replace mineral fertilizers to improve crop productivity, carbon sequestration, soil structure, and environmental pollution. It also improve the physical structure of soil to promote the storage of more water and nutrients, thereby increasing crop productivity and leaving a residual effect on subsequent crop. The main functions of organic fertilizer are nutrient source, supporting nutrient availability, and the life of soil microorganisms [36]. Organic matter that has decomposed entirely in soil could supply nutrients absorbable by plant. In addition, organic fertilizers provide macronutrients of N, P, K, Sodium (Na), Calcium (Ca), Magnesium (Mg), and Sulfur (S), as well as micronutrients of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B), and chlorine (Cl).

4. Conclusion

In conclusion, excessive chemical fertilizers damaged soil fertility, resulting in insufficient plant nutrients and negatively impacting reproductive ability, growth, and yield. Different rice field management systems affect SFI value and P uptake of paddy crop. The highest SFI value (0.78) and P uptake (2.21%) were observed in organic rice field management system. Applying organic fertilizer increased soil fertility by providing essential nutrients, specifically macronutrients, which promoted plant growth. Manure used for approximately 10 years had decomposed to offer nutrients to paddy crop. The higher the SFI value, the more nutrients the plants absorbed, resulting in abundant rice yields. Compost should be added to semi-organic or conventional rice field to preserve soil fertility and improve crop productivity. Additionally, farmers needed to add a variety of organic fertilizers, such as biological fertilizers with faster decomposition rate and rich microorganism sources.

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6. References

[1] Wahyuti I, Zulaika I, Supriyadi S, Tonabut W. Precise land evaluation implementation of the regional spatial plan in the sleman regency to maintain human health and food security. Agrihealth. J Agri-food Nutr Public Health. 2023;4(2):81-92.

[2] Zhou Z, Jin J, Liu J, Si Y. Covering rice demand in southern china under decreasing cropping intensities and considering multiple climate and population scenarios. Sustain Prod Consum J. 2023;40:13-29.

[3] Pambayun LPS, Purwanto, BH, Utami SNH. Carbon stock, carbon fraction and nitrogen fraction of soil under bamboo (*Dendrocalamus asper* Back.) and non-bamboo vegetation. Caraka Tani. J Sustain Agric 2023;38(2):404-420.

[4] Romadhon MR, Mujiyo M, Cahyono O, Maro'ah S, Istiqomah NM, Irmawati V. Potential soil degradation of paddy fields through observation approaches from various sources of environmental diversity. IOP Conf. Ser. : Earth Environ. Sci. 2023;1241(1):012013.

[5] Kurniawan ID, Kinasih I, Akbar RTM, Chaidir L, Iqbal S, Pamungkas B, Imanudin Z. Arthropod community structure indicating soil quality recovery in the organic agroecosystem of mount ciremai national park's buffer zone. Caraka Tani. J Sustain Agric. 2023;38(2):229-243.

[6] Haoyu L, Zhang Y, Sun Y, Liu P, Zhang Q, Wang X, et al. Long-term effects of optimized fertilization, tillage and crop rotation on soil fertility, crop yield and economic profit on the loess plateau. Eur J Agron. 2023;143:126731.

[7] Meilani RP, Putra ETS, Indradewa D. Macronutrient contents and yield of cocoa resulting from two different rejuvenation techniques. Caraka Tani. J Sustain Agric. 2023;38(2):387-403.

[8] Wu Q, Zhang S, Feng G, Zhu P, Huang S, Wang B, Xu M. Determining the optimum range of soil olsen P for high P use efficiency, crop yield, and soil fertility in three typical cropland soils. Pedosphere. 2020;30(6):832-843.

[9] Zhang J, Wen J, Zhang T, Zhang Y, Peng Z, Tang C, et al. Effects of five–year inorganic and organic fertilization on soil phosphorus availability and phosphorus resupply for plant P uptake during maize growth. Agriculture (Switzerland). 2023;13(4):858.

[10] Aisyah, Budianta D, Messalina L. Organic farming and its effect on soil chemical properties and rice production. Precision Agric. 2019;3(1):23-32.

[11] Kamalasari A. Comparison of soil fertility index in various rice field management systems in Girimarto District, Wonogiri Regency. Thesis. Sebelas Maret University; 2019.

[12] Penn CJ, Camberato JJ. A Critical review on soil chemical processes that control how soil pH affects phosphorus availability to plants. J Agric. 2019;9(6):120.

[13] Pahalvi HN, Rafiya L, Rashid S, Nisar B, Kamili AN. Chemical fertilizers and their impact on soil health. J Micro Biofertilizers. 2021;2:1-20.

[14] Indonesian Ministry of Agriculture. Technical manual 3rd edition: Chemical analysis of soil, aquatic plants and fertilizers. Soil And Fertilizer Instrument Standard Testing Center. Ministry of Agriculture: Bogor; 2023.

[15] Mukashema A. Mapping and modelling landscape-based soil fertility change in relation to human induction. Netherlands : International Institute for Geo-Information Science and Earth Observation; 2007.

[16] Bagherzadeh A, Gholizadeh A, Keshavarzi A. Assessment of soil fertility index for potato production using integrated fuzzy and AHP approaches, Northeast of Iran. Eurasian J Soil Sci. 2018;7(3):203-212.

[17] Syamsiyah J, Minardi S, Herdiansyah G, Cahyono O, Mentari FC. Physical properties of alfisols, growth and products of hybrid corn affected by organic and inorganic fertilizer. Caraka Tani. J Sustain Agric. 2023;38(1):99-112.

[18] Han J, Dong Y, Zhang M. Chemical fertilizer reduction with organic fertilizer effectively improve soil fertility and microbial community from newly cultivated land in the Loess Plateau of China. Appl Soil Ecol. 2021;165:103966.

[19] Prastiwi P, Sumani S, Slamet M, Suntoro S, Supriyadi S. The assessment of soil fertility index for evaluation of rice production in Karanganyar Regency. Mod Appl Sci. 2021;15(2):63-72.

[20] Chen S, Lin B, Yanqiang L, Sining Z. Spatial and temporal changes of soil property and soil fertility evaluation in a large grain-production area of Subtropical Plain, China. Geoderma. 2020;357:113937.

[21] Mishra AK, Chaundhari SK, Kumar P, Singh K, Rai P, Sharma DK. Consequences of straw burning on different carbon fractions and nutrient dynamics. Indian Farming. 2015;64(5):11-15.

[22] Li L, Dia L, Li Y, Wang Y, Ashraf U, Hamoud YA, et al. Deep fertilization combined with straw incorporation improved rice lodging resistance and soil properties of paddy fields. Eur J Agron. 2023;142:126659.

[23] Nguyen MN. Worldwide bans of rice straw burning could increase human arsenic exposure. Environ Sci Technol. 2020;54(7);3728-3729.

[24] Widhiyastuti A, Adjie E, Fauzan A, Supriyadi S. Sustainable food agricultural land preservation at Sleman Regency, Indonesia: an attempt to preserve food security. Agrihealth: J Agri-food, Nutr and Public Health. 2023;4(1):42-52.

[25] Rahayu R. Mujiyo M, Herdiansyah G, Herawati A, Sutarno S, Yang GM, et al. Utilization of local grass cynodon dactylon for football field rehabilitation and minimizing the incidence of injuries. AgriHealth: J Agri-food, Nutr Public Health. 2023;4(1):53-62.

[26] Lu QQ, Song YF, Pan KQ, Li Y, Tang MX, Zhong GH. et al. Improved crop protection and biodiversity of the agroecosystem by reduced tillage in rice paddy fields in Southern China. J Integr Agric. 2022;21(8):2345-2356.

[27] Purba ST, Damanik MMB, Lubis KS. Impact of TSP fertilizer and chicken manure on phosphorus availability and uptake as well as maize plant growth in Inceptisol Kwala Bekala soil. J Agroecotechnology. 2017;5(3):638-643.

[28] Dewi WS, Romadhon MR, Amalina DD, Aziz A. Paddy soil quality assessment to sustaining food security. IOP Conf. Ser.: Earth Environ. Sci. 2022;1107(1):1-9.

[29] Dong Y, Zeng F, Yuan J, Zhang G, Chen Y, Liu X, et al. Integrated rice management simultaneously improves rice yield and nitrogen use efficiency in various paddy fields. Pedosphere. 2020;30(6):863-873.

[30] Irawan TB, Soelaksini LD, Nusraisyah A. Analysis of organic matter content of Tenggarang, Bondowoso, Curahdami, Binakal And Pakem Subdistricts for assessment of fertility level of rice field soils in Bondowoso Regency. Scientific J Innov. 2021;21(2):73-85.

[31] Bilong EG, Angue MA, Ajebesone FN, Anaba BD, Madong BA, Nomo LB, et al. Improving soil physical properties and cassava productivity through organic manures management in the Southern Cameroon. Heliyon. 2022;8(6):e09570.

[32] Takahashi Y, Katoh M. Root Response and phosphorus root response and phosphorus uptake with enhancement in available phosphorus level in soil in the presence of water-soluble organic matter deriving from organic material. J Environ Manag. 2022;322:116038.

[33] Kurniawan ID, Kinasih I, Akbar RTM, Chaidir L, Iqbal S, Pamungkas B, et al. Arthropod community structure indicating soil quality recovery in the organic agroecosystem of Mount Ciremai National Park's Buffer Zone. Caraka Tani: J Sustain Agric. 2023;38(2):229-243.

[34] Yuniarti A, Solihin E, Putri ATA. Application of organic fertilizer and n, p, k on soil ph, p-available, p uptake, and yield of black rice (Oryza sativa L.) on inceptisol. J Cultivation. 2020;19(1):1040-1046.

[35] Siagian DR, Sjofjan J, Yoseva S. Mixture of palm oil empty bunch compost with LCC compost and p fertilizer on p uptake and production of sorghum (Sorghum bicolor L) plants. Doctoral dissertation. Riau University;2015.

[36] Setiawati MR, Herdiyantoro D, Damayani M, Suryatmana P. Analysis of soil C, N, C/N ratio and yield of rice treated with organic fertilizer and azolla-based biofertilizer in organic rice fields. Soilrens. 2018;16(2): 30-36.