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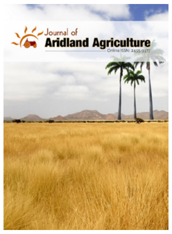
Research Article



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Potential of *Chromolaena odorata*, *Ipomoea carnea* and *Eichhornia crassipes* as green manures on soil fertility index and rice production on vertisols

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ABSTRACT

The organic farming system is an agricultural activity which aims to preserve soil fertility and create sustainable farming. The objective of this research is to evaluate the effects of the application of green manure on soil fertility index and rice production. The research was carried out in Weru District, Sukoharjo Regency, using an experiment method with a Randomized Complete Block Design (RCBD). The research included 10 treatments: T0 = Control, T1 = NPK fertilizer 0.2 ton/ha, T2 = rice straw 10 ton/ha, T3 = *Chromolaena odorata* 10 ton/ha, T4 = *Ipomoea carnea* 10 ton/ha, T5 = *Eichhornia crassipes* 10 ton/ha, T6 = NPK 0.1 ton/ha + rice straw 5 ton/ha, T7 = NPK 0.1 ton/ha + *C. odorata* 5 ton/ha, T8 = NPK 0.1 ton/ha + *I. carnea* 5 ton/ha, T9 = NPK 0.1 ton/h + *E. crassipes* 5 ton/ha, with three repetitions. The soil characteristics tested were pH, total N, available P, exchangeable K, exchangeable Ca, exchangeable Mg, Cation Exchange Capacity (CEC), Base Saturation (BS), and Soil Organic Carbon (SOC). The results show that *C. odorata*, *I. carnea*, and *E. crassipes* have potential as green manures, due to their high N content, of 3.38%, 3.54%, and 2.95% andthe ability to increase soil fertility and rice production. The soil fertility index increased from high to very high, neither within single applications nor combined with NPK fertilizer. The highest rice production was obtained with the use of *C. odorata*, which increased harvest dry weight by 2.24 ton/ha (67.67%) or an increase of 2.1 ton/ha (75%) in milled dry weight, followed by *I. carnea* and *E. crassipes*. There was a correlation between soil fertility index and rice production, shown by the higher SFI, the harvest dry weight and milled dry weight increases.

KEYWORDS: Soil Fertility Index, Green Manure, Macronutrients, Rice Production

INTRODUCTION

Rice is a primary food source which is consumed by approximately 50% of the world population, with a rise in consumption recorded in 2017 (Liu *et al*., 2021). The 7.9 million hectares of rice field land in Indonesia is forced to meet the food needs of 250 million people, and this will cause soil fatigue, leading to a decline in the level of sustainable production, amongst others marked by a decrease in soil organic matter. Most of the watershed areas in Indonesia have experienced soil degradation, including degradation in soil fertility as a result of the decrease in organic matter content (Maroeto *et al*., 2020). Meanwhile, Prusty *et al*. (2021) state that the goal of sustainable farming focuses on maintaining agricultural growth to meet food needs without draining basic resources. Numerous studies have shown that organic farming performs better than conventional farming, especially in terms of environmental aspects (Meng *et al*., 2017). Organic farming is a form of sustainable farming without external synthetic input (Soni *et al*., 2022). The development of organic farming helps sustainable practices by creating an agricultural production system with minimum environmental impact (Meng *et al*., 2017).

Organic fertilizer plays an important role in maintaining soil fertility levels, by helping to preserve soil fertility. One of the obstacles that are often encountered in the implementation of organic farming is the availability of local organic matter in farmland areas. The utilization of organic fertilizer that is found locally in the production area can increase yield by reducing the use of chemical fertilizer (Hafifah *et al.*, 2016). One source of organic fertilizer that can be used for this purpose is green manure that comes from plant materials. The application of green manure on farmland is useful for increasing organic matter and nutrition in the soil and improving the soil characteristics that have a positive impact on production. Green manure provides a source of plant nutrients, and can be used as an alternative to chemical fertilizers, which is extremely important in agricultural development (Pu *et al.*, 2023). One plant that can be found in abundance and grows well in highland areas is *C. odorata*, although its benefits in farming are not yet widely known (Ahmad *et al.*, 2022). Green manure plays a crucial role as an ameliorant, which not only increases the organic matter content of the soil to improve soil conditions but also adds nutrients that the plants need, through a process of decomposition, to be absorbed by the plants. One of the requirements of green manure is that it is easily decomposed, thereby making its nutrients more readily available for the plants. The use of green manure provides plants with nutrition and stimulates microbial activity in the soil. The organic matter supplied by green manure and plant residue affects the soil's moisture, temperature, and pH which trigger a short and medium-term response in the microbial population (Dong *et al.*, 2021).

Year by year, soil quality tends to decline as a result of soil acidification and an imbalance of soil nutrients and microbiomes, which ultimately affects plant growth, hinders cultivation, and leads to increased concern for the sustainability of the ecosystem (Kim *et al.*, 2023). Vertisols have high clay content and during the dry season are prone to develop wide cracks (Widijanto *et al.*, 2021). The results of research by Suntoro *et al*. (2020) show that organic matter content in rice fields on Vertisols, is one of the limiting factors for soil fertility. The presence of organic matter in the soil is an important factor for determining the soil fertility level and soil health. Soil organic carbon (SOC) is one of the important indicators of soil fertility and soil health. Green manuring is a practice that can help preserve soil fertility (Cheng *et al.*, 2023). Soil fertility is closely related to the nutrients contained in the soil. According to the research of Zhao *et al*. (2023), the soil fertility index is a method that is commonly used for making a comprehensive evaluation of soil fertility. Using fertilizer in correct proportions will increase crop production, and the foundation of organic farming lies in the health of the soil. Continued land use with a poor land management system (without the replenishment of organic matter or input of fertilizer) results in a decline in fertility.

The soil fertility index is an evaluation of fertility which serves to illustrate the condition of the soil. The most commonly measured soil fertility index indicators are pH, SOC, total N, available P, available K, CEC, and base saturation (BS) (Dewi *et al.*, 2022). Soil fertility is the soil's potential to make available sufficient nutrients in a form that is available for the plants (Prastiwi *et al.*, 2021). Green manure not only increases soil organic matter content but also increases the nutrients in the soil, thereby improving the physical, chemical, and biological properties of the soil, which in turn has a positive impact on soil production and helps to protect the soil from erosion. Soil microbes play an important role in altering the quality of the soil by improving the soil's structure, breaking down organic matter, and increasing soil fertility, as well as contributing to the preservation and production of the ecosystem by influencing soil quality and soil health (Seleem *et al.*, 2022). The objective of this research is to evaluate the effects of the application of local potential green manure on soil fertility index and rice production.

MATERIALS AND METHODS

Research Location

The research was conducted on rice field land in Tegalsari Village, Weru District, Sukoharjo Regency, Central Java, Indonesia. The chemical analysis of the soil was carried out in the Chemical Soil Laboratory in the Faculty of Agriculture, Universitas Sebelas Maret, Surakarta. The research was conducted from March to December 2023, the first stage is a survey of organic matter sources from plants or plant waste.

Local potential of green manure

The organic fertilizers used in this research were chosen based on the abundance of sources of organic matter from plants found at the research location. The potential local green manure was evaluated based on: the abundance of the plant biomass at the research location in Sukoharjo Regency; the rapid growth characteristics of the plants which enabled the rapid supply of a large biomass; the soft or succulent condition of the plants or leaves; the low C/N content, allowing the rapid decomposition and supply of nutrients. From the results of the survey, four sources of potential organic matter were found at the research location: (1) rice straw (agricultural waste with C/N 28), (2) green manure from land plants with rapid growth that were found in abundance at the location, namely *Chromolaena odorata* (local name *kirinyu*/siam weed) (N content 3.38% and C/N 11), and *Ipomoea carnea* (local name *kangkung pagar*/ morning glory) (N content 3.54% and C/N 10.24), and (4) the water plant *Eichhornia crassipes* (local name *enceng gondok*/ water hyacinth) (N content 2.95% and C/N 12.89).

Research design

This research uses an experiment method with a Randomized Complete Block Design (RCBD). A total of 10 treatments were used (Table 1) with three repetitions to obtain 30 treatment plots. Each plot measured 3 m x 2.5 m. The space between the rice plants was 25 cm x 25 cm.

Soil's Sampling Method and Analyis

The collection of composite soil samples was done at the start of the research and during the maximum vegetative phase (plant age 60 days). Soil samples were taken compositely from each treatment plot at a 1-30 cm depth. The application of green manure was done by chopping or cutting the plants and using a process of immersion 5 days before planting. Inorganic fertilizer was applied 14 days after planting (DAP). The plant maintenance included watering, weeding, and pest and disease control. The laboratory analysis included an analysis of the initial soil and samples of soils at the maximum vegetative stage from each treatment plot.

The soil indicators observed were pH (electrometric method), soil organic carbon (Walkey and Black), soil total nitrogen (Kjeldahl method), soil available phosphorus (Olshen), potassium, calcium, soil exchangeable magnesium (ammonium acetate extraction method), cation exchange capacity (CEC) (ammonium acetate extraction method), and base saturation (ammonium acetate extraction method).

Soil Fertility Index (SFI) Analysis

First, the soil fertility index was analyzed by selecting the indicators of soil fertility, or the minimum soil fertility index (MSFI), followed by testing with the Principal Component Analysis (PCA). The research used the Principal Component (PC) test with Minitab 18 software to obtain the correlation between the variables tested in the 30 soil samples analyzed. The recommendations for the preparation of land management were based on the parameters that correlated with the soil fertility index (SFI). The calculation of the soil fertility index values was done by adding the result of the division of the total weight with the number of MSFI indicators, as in the Equation 1 and soil fertility index classification in Table 2.

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

Description:

Sci = MSFI Weight amount

SFI = Soil Fertility Index

N = Number of MSFI used

Statistical Analysis

The data results of SFI and rice production were analyzed using an analysis of variance (ANOVA) and if there is any significant value will be continued by the Duncan Multiple Range Test (DMRT) with a 95% confidence level to determine the differences of SFI under different treatment, and a Pearson's correlation test to find the relationships between the selected variables.

RESULTS AND DISCUSSION

Characteristics of Soil

The soil at the research location belongs to the type of Vertisols. The soil in this area has a pH of 7.70 (somewhat alkaline), with a high cation exchange capacity (15.88 me/100 g soil), and a high level of exchangeable Ca (13.40 me/100 g soil) (Table 3). The high pH of the soil comes from the parent material of limestone ($CaCO_3$), and the high cation exchange capacity is due to the content of montmorillonite clay minerals in the Vertisols (Juita *et al.*, 2016).

Vertisols are black soils made up of various parent materials dominated by clay minerals, and can experience cracking during the dry season. Vertisols have a varied color matrix consisting of montmorillonite clay minerals (Mindari *et al.*, 2023). Vertisols contain dense clay which can expand, and the soil can also create deep, wide cracks during the dry season (Dotaniya *et al.*, 2022). In general, Vertisols have a pH in the range of 6.0-8.2. Based on their parent materials, Vertisols are rich in calcium carbonate, creating a calcareous soil that prevents the absorption of important nutrients by affecting the soil's physical, chemical, and biological properties (Sootahar *et al.*, 2020) (Table 4).

Soil Fertility Index (after Treatment)

The soil fertility index was measured using a statistical analysis, specifically the Principal Component Analysis (PCA), which

Table 1: Fertilizer Treatments and Fertilizer Doses

Code	Treatment	Doses	
		Green Manure (ton/ha)	Complex fertilizer NPK (ton/ha)
T0	Control	0	0
T1	NPK (mixed fertilizer)	0	0.200
T2	Rice straw	10	0
T3	*Chromolaena odorata* (siam weed)	10	0
T4	*Ipomoea carnea* (pink morning glory)	10	0
T5	*Eichhornia crassipes* (water hyacinth)	10	0
T6	Rice straw+NPK	5	0.1
T7	*Chromolaena odorata* (siam weed) + NPK	5	0.1
T8	*Ipomoea carnea* (pink morning glory) + NPK	5	0.1
T9	*Eichhornia crassipes* (water hyacinth) + NPK	5	0.1

Table 2: Soil Fertility Index Classification

Soil Fertility Index	Value
Very low	0.00-0.25
Low	0.25-0.50
Moderate	0.50-0.75
High	0.75-0.90
Very high	0.90-1.00

Table 3: Initial Soil Characteristics (before Treatment)

Indicator	Value	Category
pH	7.70	Slightly alkaline
SOC (%)	1.1	Low
CEC (me/100 g soil)	31.11	High
Total N (%)	0.10	Very low
Available P (ppm)	15.88	High
Exchangeable K (me/100 g soil)	0.40	Moderate
Base Saturation (%)	40.91	Low
Exchangeable Ca (me/100 g soil)	13.40	High
Exchangeable Mg (me/100 g soil)	0.90	Low

Table 4: Soil Chemical Characteristics after Treatment

Treatment	pH H_2O	SOC	CEC	Total N	Available P	Exchangeable K	Base Saturation	Exchangeable Ca	Exchangeable Mg
		(%)	(me/100 g)	(%)	(%)	(me/100 g)	(%)	(me/100 g)	(me/100 g)
T0	7.72	1.20	31.11	0.11	15.64	0.41	40.14	13.56	1.15
T1	7.64	1.32	34.73	0.22	22.40	0.46	45.62	14.00	1.05
T2	7.74	1.81	33.51	0.18	23.95	0.54	48.33	14.35	1.13
T3	7.85	1.92	35.82	0.21	21.86	0.58	43.04	13.69	1.12
T4	7.82	1.45	38.34	0.20	23.56	0.56	44.89	14.48	1.04
T5	7.72	1.30	36.26	0.21	21.33	0.45	48.51	14.06	1.14
T6	7.68	1.34	35.93	0.20	22.94	0.44	40.42	14.78	0.92
T7	7.66	1.46	40.37	0.25	24.57	0.52	44.34	14.06	1.07
T8	7.68	1.63	41.01	0.23	24.50	0.55	42.05	14.71	0.98
T9	7.71	1.39	42.47	0.22	23.07	0.52	40.57	14.14	0.85

Description: T0 = Control; T1 = NPK (Complex Fertilizer), T2 = Rice straw, T3 = *Chromolaena*, T4 = *Ipomoea*, T5 = *Eichhornia*, T6 = Rice straw+NPK, T7 = *Chromolaena*+NPK, T8 = *Ipomoea* +NPK, *dan* T9 = *Eichhorni*+NPK

Table 5: Results of Analysis of Soil Chemical Properties in Treatment Plots

	pH	CEC	SOC	Available P	Exchangeable K	Total N	BS	Exchangeable Ca	Exchangeable Mg
pH	1								
CEC	-0.132	1							
SOC	**0.486****	0.039	1						
P	0.006	**0.550****	**0.375***	1					
K	**0.491****	**0.390***	**0.720****	**0.470****	1				
N	-0.266	**0.646****	0.282	**0.751****	**0.448***	1			
BS	0.075	-0.200	**0.367***	0.273	0.164	0.183	1		
Ca	-0.239	0.256	0.068	0.148	-0.032	-0.114	-0.0011	1	
Mg	0.292	**-0.605****	0.238	**-0.400***	-0.002	**-0.390***	**0.521****	-0.242	1

Remark: the values written in bold have significant correlation results

produced data known as the PC (primary components). The result of the PC analysis produced the Minimum Soil Fertility Index (MSFI), the collection of the minimum data representing all the soil fertility indicator values used. From each PC, one of the indicators was selected by taking the highest value. The PCA was conducted to find the primary component (PC) data, and the PC data was used to determine the Minimum Data Set (MDS). The PC data selected had an eigenvalue ≥ 1 or a cumulative value of 60%. The primary components with an eigenvalue of 1 or a cumulative percentage >60 = were PC1, PC2, and PC3. The indicators with the highest values obtained from PC1, PC2, and PC3 were SOC, total N, available P, exchangeable K, CEC, Ca, and Mg. PC1 consisted of total N, available P, and exchangeable K. PC2 consisted of SOC, and PC3 consisted of BS. In PC1, CEC, available P, and total N had an eigenvalue of 3.095, proportion and cumulative with a value of 0.344. In PC2, the selected indicators were SOC and Mg which had an eigenvalue of 2.438, proportion with a value of 0.271 and cumulative with a value of 0.615. In PC3, the exchangeable K and Ca indicators had an eigenvalue of 1.327, proportion with a value of 0.148, and cumulative with 0.762 (Table 6). These seven indicators were the indicators that were included in the Minimum Soil Fertility Index (MSFI).

The results of the correlation analysis (Table 5) show that SOC correlates with pH. Available P correlates strongly with CEC and SOC. Exchangeable K correlates closely with pH, CEC, SOC, and available P. In line with the statement of Abdullahi *et al.* (2020), that the element P is obtained from and affected by the input of organic matter into the soil. Total N correlates with CEC, available P, and exchangeable K, BS correlates with SOC.

Table 6: Results of Principal Component Analysis

Eigen Value	3.095	2.438	1.327
Proporsion	0.344	0.271	0.148
Cumulative	0.344	0.615	0.762
Eigen vector Variables	**PC1**	**PC2**	**PC3**
pH	0.037	0.422	0.545
SOC	0.314	**0.454**	0.082
CEC	**0.413**	-0.313	0.213
Available P	**0.496**	-0.036	-0.219
Exchangeable K	0.418	0.283	**0.319**
Total N	**0.488**	-0.133	-0.234
Exchangeable Ca	0.062	0.19	**-0.462**
Exchangeable Mg	-0.237	**0.486**	-0.131
BS	0.102	0.384	-0.465

This research used seven parameters of soil fertility: SOC, available P, exchangeable K, total N, Ca, Mg, and CEC (Table 7). Nutrients that are available sufficiently for plants will influence the soil fertility level. The addition of soil organic matter in the form of straw and green manure, by undergoing a process of decomposition and mineralization, can provide macronutrients for the process of plant metabolism in the formation of protein in the plant (Wood *et al.*, 2018).

The results of the analysis of the soil fertility index show that the application of rice straw and the green manures *Chromolaena*, *Ipomea*, and *Eichhornia* can increase the soil fertility index, both with single applications and in combination with NPK fertilizer. The application of green manure increases the content of soil organic matter and the availability of N, P, and K nutrients which are the main components of the SFI (Dewi *et* *al.*, 2022). Similarly, adding NPK fertilizer will directly provide the availability of the nutrients N, P, and K in the soil. Based on the results of the SFI analysis, the highest value was found in treatment T7, *Chromolaena* + NPK, with a score of 0.975. This is in line with the statement of (Azu *et al.*, 2018) that *Chromolaena* is used as a soil improver because it has a high biomass, which can play a role in soil fertility. The highest SFI value was obtained with the treatment of *Chromolaena* + NPK, followed by a combination of NPK fertilizer and *Ipomea*, with a value of 0.973. The treatment with a combination of NPK fertilizer was seen to increase the effectiveness of the availability of soil nutrients, especially N, P, and K. This is because the addition of green manure also increases the availability of N, P, and K nutrients, and the addition of organic matter leads to an increase in NPK.

The essence of soil fertility is the ability of the soil to provide sufficient nutrition for plants without creating a toxic effect. The results of the SFI in Figure 1 show the values of the soil fertility index with the category or criteria of high to very high. The conditions of the land strongly influence the production of rice yields. The plants cannot produce maximum yield with the presence of limiting factors such as a low soil fertility level, 1000 grain weight and productive offspring are used as parameters for obtaining the results of plant production.

Effects of Treatments on Rice Production

The results of the variant analysis show that the fertilizer application treatments significantly increase the soil fertility index, from high to very high. It can be seen from the Duncan Multiple Range Test (DMRT), which shows a significant influence of fertilizer treatments on productive offspring, harvest dry weight, milled dry weight, and 1000 grain weight (Table 8).

The results of the DMRT analysis show that the use of *C. odorata* fertilizer produces the highest result, with the production of 5.55 ton/ha harvest dry weight or 4.89 ton/ha milled dry weight. Compared with the control, this is an increase of 2.24 ton/ha (67.67%) of harvest dry weight or an increase of 2.1 ton/ha (75%) of milled dry weight. This is in line with the research of Aboyeji (2019), which shows that green plants can increase plant production by increasing the availability of soil N. The *C. odorata* plant, which is often known as a weed, has the potential to be used as a source of organic matter and a source of nutrients, especially N and K. The research of Puli *et al.* (2017) explains that management involving organic matter, inorganic substances, and cut-off residue can increase soil nutrition and production and the system can be sustainable. From the research, adding a combination of organic fertilizer and NPK is found to produce a better result. The treatment which produced the lowest production value was the plot without treatment, or the control plot. Parameter P can also influence the result of plant production because P plays a role in various activities of plant metabolism. The level of P content is also influenced by applying fertilizer at the start of cultivation (Supriyadi *et al.*, 2017). An increase in the availability of P occurs due to an increase in soil pH due to the application of organic matter (Syofiani & Islami, 2021).

Table 7: Calculation of Minimum Soil Fertility Index (MSFI)

MDS	Proportion	Cumulative	Wi
CEC	0.344	0.762	0.150
Available P	0.344	0.762	0.150
Total N	0.344	0.762	0.150
SOC	0.271	0.762	0.177
Exchangeable Mg	0.271	0.762	0.177
Exchangeable K	0.148	0.762	0.097
Exchangeable Ca	0.148	0.762	0.097

Table 8: The Distribution of Rice Yield Production under different Treatment

Treatment	Productive Offspring	Harvest Dry Weight	Milled Dry Weight	1000 Grain Weight
T0	12.26^{a}	3.31^{a}	2.79^{a}	23.04^{a}
T1	17.47^{f}	5.60^{de}	4.73^{e}	25.51^{ab}
T2	14.47^{c}	4.13^{b}	3.54^{c}	23.78^{a}
T3	17.53^{f}	5.55^{e}	4.89^{e}	25.65^{ab}
T4	16.13^{e}	5.09^{de}	4.42^{d}	25.47^{a}
T5	15.33^{d}	4.37^{bc}	3.73^{c}	23.31^{ab}
T6	13.80^{b}	4.33^{bc}	3.19^{b}	24.56^{ab}
T7	16.06^{e}	5.29^{c}	4.44^{d}	27.65^{b}
T8	15.73^{de}	4.89^{c}	3.25^{b}	25.63^{ab}
T9	15.60^{de}	5.09^{d}	4.25^{d}	24.88^{ab}

Description: T0 = Control; T1 = NPK (Complex Fertilizer), T2 = Rice straw, T3 = *Chromolaena,* T4 = *Ipomoea,* T5 = *Eichhornia,* T6 = Rice straw + NPK, T7 = *Chromolaena* + NPK, T8 = *Ipomoea* + NPK, *dan* T9 = *Eichhorni* + NPK. Numbers followed by different letters have different significant values

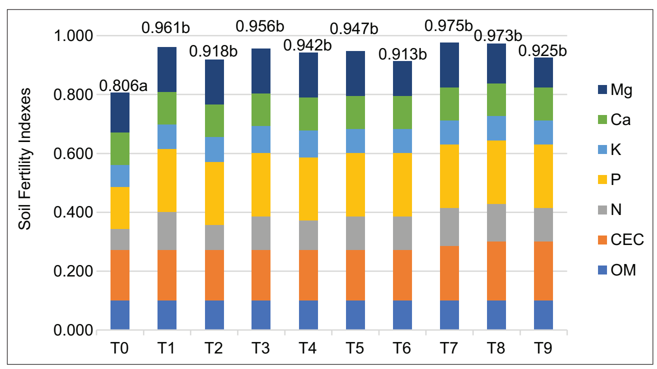

Figure 1: Soil Fertility Index (Description: T0 = Control; T1 = NPK (Complex Fertilizer), T2 = Rice straw, T3 = *Chromolaena,* T4 = *Ipomoea,* T5 = *Eichhornia,* T6 = Rice straw + NPK, T7 = *Chromolaena* + NPK, T8 = *Ipomoea* + NPK, *dan* T9 = *Eichhorni* + NPK; numbers followed by different letters have different significant values)

Based on the results of the DMRT analysis shown in Figure 2, it can be seen that there is a significant difference between treatments on the number of productive offspring, with the highest result found in the treatment of *C. odorata* green manure with a dose of 10 ton/ha. In addition, the effects of treatments on the quality of yield, shown by 1000 grain weight, show the highest result with the treatment of *Chromolaena* green manure combined with the addition of NPK-complex fertilizer.

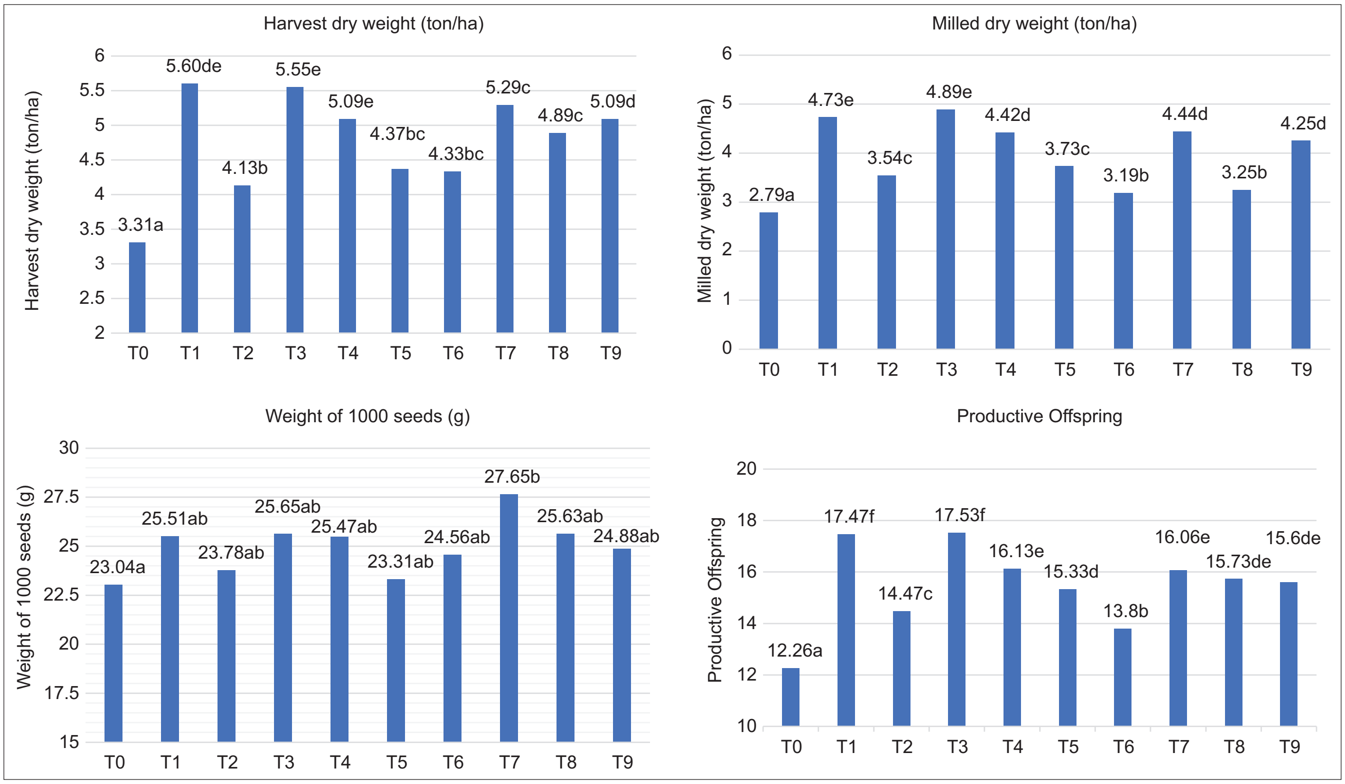

Figure 2: Effects of various treatments on SFI, harvest dry weight, milled dry weight, and 1000 grain weight (Description: T0 = Control; T1 = NPK (Complex Fertilizer), T2 = Rice straw, T3 = *Chromolaena,* T4 = *Ipomoea,* T5 = *Eichhornia,* T6 = Rice straw + NPK, T7 = *Chromolaena* + NPK, T8 = *Ipomoea* + NPK, *dan* T9 = *Eichhornia* + NPK. Numbers followed by different letters have different significant values)

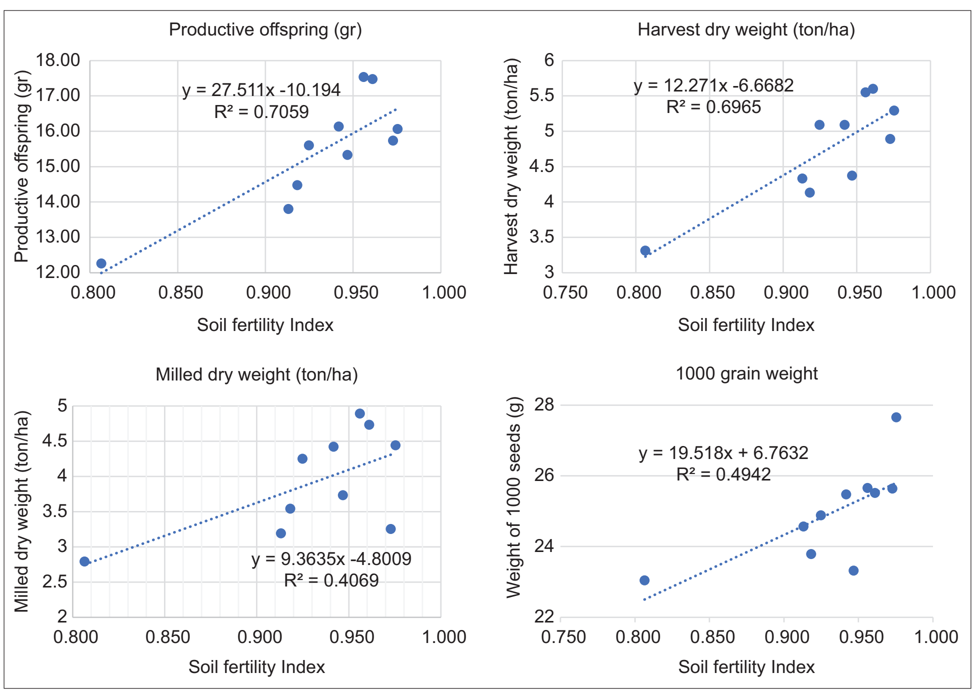

Figure 3: Relationship between SFI and harvest dry weight and milled dry weight (ton/ha)

Relationship between SFI and rice production

The correlation test results indicate a positive relationship between SFI and rice productivity (Figure 3). Soil fertility index influences production because fertile soil with sufficient availability of nutrients for the plant will influence the growth/production of the plant itself. The use of organic matter is important for plant production because it can maintain the continuity of soil health

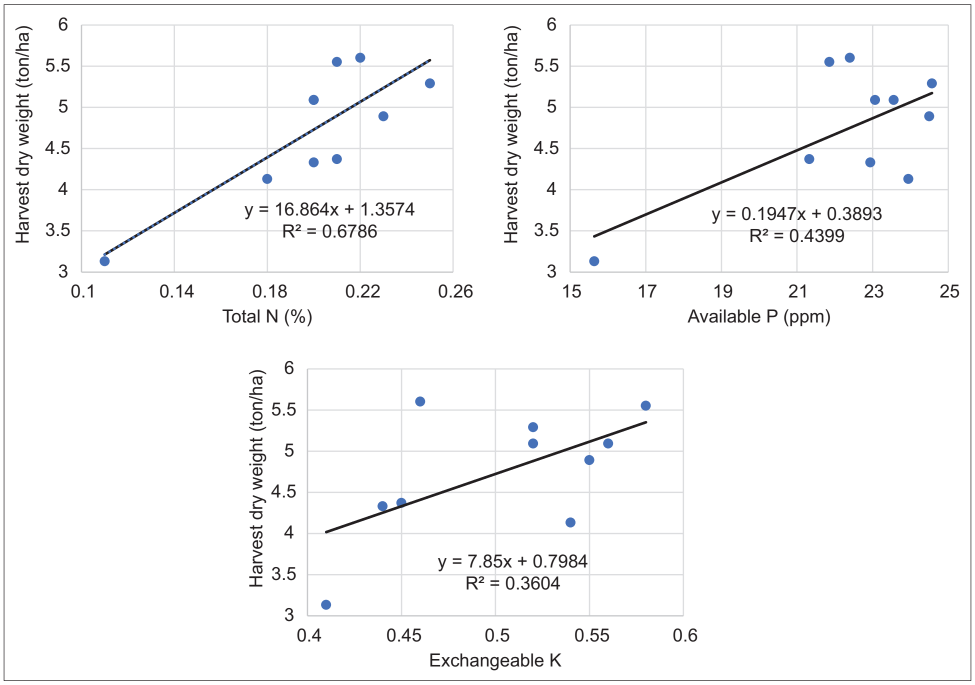

Figure 4: Relationship of total N, available P, and soil exchangeable K on production (ton/ha)

Table 9: The correlation (r) of selected soil fertility indicators and rice yield indicator

Indicators	Productive offspring	Harvest dry weight	Milled dry weight	1000 Grain weight
SFI	0.477**	0.732**	0.548**	0.692**
Total N	0.654**	0.756**	0.514**	0.427**
Available P	0.460**	0.587**	0.365*	0.367*
Exchangeable K	0.588**	0.532**	0.490**	0.302^{ns}
SOC	0.401*	0.314*	0.283^{ns}	0.096^{ns}

Description: *= Significant, **= Very Significant, ^{ns} = No significant

and play an important role as a source of nutrient supply (Singh *et al.*, 2022). The use of organic fertilizer is more environmentally friendly as it can align the supply of nutrients, especially N, P, and K, with the needs of the plant. These conditions will facilitate better plant growth and development at all stages of growth, and also increase plant yield (Moe *et al.*, 2019).

In the generative phase, the optimal availability of nutrients for the rice plant is crucial. The addition of the N nutrient will increase the number of productive offspring, which will influence production because it will lead to an increase in the number of grains/panicles. Nutrition from N plays an important role in the formation of protein which the plant will utilize to increase the number of panicles/clusters. The application of green matter which is quick to decompose and has a high N content can provide an effective source of N for the plant. The application of organic fertilizer can cause an increase in the total N of the soil (Zhang *et al.*, 2022).

The application of green manure or NPK fertilizer shows a positive result (Table 9). According to a study by Akhmad *et al.* (2018), the application of NPK fertilizer has a positive response on the availability of nutrients and the production of dry grain. Unlike inorganic fertilizer, the proper application of green manure in rice cultivation is still a challenge, as it requires time for mineralization and must therefore be applied before planting. Plants can only utilize N that has been mineralized. The percentage of N that can be mineralized in organic fertilizer depends on the total N content (Moe *et al.*, 2019). From the analysis of the green manures used in this study, *C. odorata* has an N content of 3.38%, *I. carnea* has an N content of 3.54%, and *E. crassipes* has an N content of 2.95%, meaning that they are easily mineralized.

Relationship of total N, available P, and soil exchangeable K on harvest dry weight

Based on Figure 4, soil fertility is influenced by several parameters, such as SOC, total N, available P, and exchangeable K. These parameters influence the parameters of rice yield such as harvest dry weight and milled dry weight. One of the components of rice yield is the number of grains per panicle. NPK fertilizer can influence rice yield. NPK fertilization can increase the availability of nitrogen for generative growth, including the number of grains per panicle. Soil fertility influences the result of rice production because the addition of organic matter such as green manure to the soil will cause an increase in soil organic matter content, soil pH, and soil total N, and will increase soil production (Suntoro *et al.*, 2020).

Figure 4 shows a correlation between the availability of N, P, and K nutrients and harvest dry weight. In rice plants, N, P, and K nutrients are the three essential nutrients that are much needed during the growth and development stages of the rice plants. The N nutrient influences organ construction, physiological properties, and the synthesis and distribution of substances in the plant. All three nutrients affect the yield and quality of the rice (Ye *et al.*, 2019). The P nutrient is important for forming cell membranes and plays a role in metabolism, as well as encouraging growth of the rice plant and physiological metabolism. The K nutrient is an activator of several enzymes and plays an important role in the transportation of carbohydrates in the rice plant as well as benefitting the plant metabolism and resistance to stress (Ye *et al.*, 2019).

CONCLUSION

The research results show that 5 selected parameters determine the soil fertility index in the research area, namely total N, available P, exchangeable K, base saturation (BS), and soil organic carbon (SOC). The green manures *C. odorata*, *I. carnea*, and *E. crassipes* have the potential to be used as green manures, not only because of their high N content, 3.38% N, 3.54% N, and 2.95% N respectively but also because they are proven to increase the soil fertility index and rice production. The soil fertility index increases from moderate to high, both with single applications and in combination with NPK fertilizer. The highest result was found with the treatment of *Chromolaena* + NPK with a value of 0.975. Treatment with NPK + *I. carnea* also increased the fertility index to 0.973. In addition to increasing the soil fertility index, the use of green manure was found to have a significant effect on grain yield. The highest result of grain production was found with the treatment of *C. odorata*, neither with a yield of 5.55 ton/ha harvest dry weight, nor an increase of 2.24 ton/ha (67.67%) in harvest dry weight, and an increase of 2.1 ton/ha (75%) in milled dry weight, as well as an increase in the quality of yield (1000 grain weight). A correlation between soil fertility index, and availability of N, P, and K nutrients and rice production in shown by the increase in harvest dry weight and milled dry weight.

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