Jurnal Kultivasi Vol. 24 (2) Agustus 2025
ISSN: 1412-4718, eISSN: 2581-138x

Mulyani O · Sofyan ET · Citraresmini A · Joy B · Husen AY

Enhancing sustainable rice production through organic plus fertilizer in irrigated paddy fields

Abstract. Sustainable rice farming is increasingly threatened by declining soil fertility, excessive reliance on chemical fertilizers, and environmental degradation from intensive agricultural practices. There is an urgent need for innovative organic fertilizer products that combine organic materials with macro and micronutrient enhancements to restore soil health effectively. This research aimed to evaluate the effect of organic plus fertilizer (OPF) as a sustainable soil amendment to improve soil nutrient status, increase paddy productivity, and enhance overall soil health. The experiment was conducted using a Randomized Block Design (RBD) with nine treatments: one recommended OPF dose, six combinations of NPK (75 – 100%) and OPF (75 – 150%), one recommended conventional NPK dose, and one control. Variables observed included plant growth, yield, and yield components, total soil nitrogen, and plant uptake of N, P, and K. Results indicated that OPF combined with NPK significantly increased plant height (29.13 – 31.38%) and number of panicles (57.89%) compared to the control. Nutrient uptake improved for nitrogen (23.68%) and potassium (15.96 – 21.28%), although no significant improvement was observed for phosphorus. Yield parameters showed an 81.97%–118.50% increase over the control. The combinations of 75% NPK + 150% OPF, 100% NPK + 75% OPF, and 100% NPK + 100% OPF produced taller plants, higher yields, greater nutrient uptake, and lower residual nitrogen in the soil. For optimal rice yield and soil health, integrated application of OPF with either a full or 75% NPK dose is recommended.

Keywords: Environment · Fertilizer · Organic ·Residue · Soil health

Submitted: 4 July 2025, Accepted: 11 August 2025, Published: 14 August 2025
DOI: https://doi.org/10.24198/kultivasi.v24i2.64985

Mulyani O[1*] · Sofyan ET[1] · Citraresmini A[1] · Joy B[1] · Husen AY[2]
[1] Department of Soil Science and Land Resources Management, Faculty of Agriculture, Universitas Padjadjaran, Jatinangor, Sumedang, 45363, Indonesia
[2] Undergraduate Student of Agrotechnology Study Programme, Faculty of Agriculture, Universitas Padjadjaran, Jatinangor, Sumedang, 45363, Indonesia
*Correspondence: oviyanti.mulyani@unpad.ac.id

Mulyani O, Sofyan ET, Citraresmini A, Husen AY. 2025. Enhancing sustainable rice production through organic plus fertilizer in irrigated paddy fields. Jurnal Kultivasi, 24 (2): 206-219.

Introduction

Indonesia is one of the world's biggest rice producers, and it largely relies on paddy farming to maintain a safe food supply. In recent years, the application of chemical fertilizers, extensive monoculture practices, and a general disregard for the addition of organic materials have put at risk the future of rice farming (Bhattacharyya et al., 2015). These harmful practices have increased soil acidity, reduced organic carbon levels, decreased cation exchange capacity (CEC), and damaged essential microbial populations important to nutrient cycling (Anisuzzaman et al., 2021). Watering and flooding rice fields often also speed up the leaching of critical micronutrients like zinc (Zn) and iron (Fe), which makes the nutrient imbalances even worse (Nishimura & Itani, 2013). Organic fertilizers are popular because they are a long-term way to restore damaged soils and make rice harvests more productive. Organic fertilizers are made from decomposing plant and animal waste or organic compounds added to the soil. They enhance soil health by stabilizing pH levels, improving water retention, improving soil structure quality, and enhancing organic carbon content (Koorneef et al., 2024). Their slow-release nutrient composition makes sure that potassium (K), phosphorus (P), and nitrogen (N) are always available in paddy systems. This reduces the need for synthetic fertilizers and the loss of nutrients (Paramesh et al., 2023). Using organic fertilizers also helps to reach bigger agroecological goals. Research shows that adding organic matter to the soil makes it more diverse, helps plants absorb nutrients more effectively, and sometimes leads to higher yields (Paramesh et al., 2023). These benefits are achieved by the goals of agricultural systems that are good for the environment and can withstand climate change. These systems are vital for the future of farming in Indonesia. Using organic fertilizers on rice fields is not only a way to increase production, but it is also a vital step toward managing land in a way that is good for the environment and ensuring there is enough food for everyone. Adding organic fertilizer to rice fields, especially paddy fields, increases crop yields and follows ecological principles and food safety standards (Susanti et al., 2024). As worries about the environment and soil degradation grow, using organic fertilizer is an important way to make farming more sustainable and able to withstand climate change.

Despite the growing promotion of organic fertilizers as environmentally friendly substitutes for chemical inputs, many Indonesian commercial products still have several drawbacks. First, many organic formulations have relatively low nutrient content, especially in terms of potassium (K_2O), phosphorus (P_2O_5), and nitrogen (N), which frequently fall short of the nutritional requirements of staple crops like rice (Romadhon et al., 2024). According to Cao et al. (2021), many products also have an unbalanced C/N ratio, which can alter nitrogen dynamics by immobilizing or quickly mineralizing nitrogen in the soil. The existence of heavy metals, especially in fertilizers made from sludge or urban waste, is another serious issue that could endanger crop and soil safety in the long run (Su et al., 2025). Additionally, a public health concern is the presence of pathogenic microbes, like *Salmonella* or *Escherichia Coli*, due to insufficient composting (Xu et al., 2022).

Furthermore, many organic fertilizers currently on the market do not address micronutrient deficiencies like iron (Fe) and zinc (Zn), essential for rice metabolism and yield performance. The Organic Plus Fertilizer (OPF) formulation signifies an advance over traditional fertilization methods by synergizing organic and mineral nutrient sources. In contrast to conventional inorganic fertilizers that mainly provide immediately accessible nutrients while offering few benefits to long-term soil health, OPF integrates humic substances, agricultural products, and composted animal waste with specific macro and micronutrient enhancements. This dual strategy immediately provides vital nutrients, including potassium from ash or mineral deposits, phosphorus from natural phosphate rock, and nitrogen from targeted supplementation, while improving soil organic matter, microbial diversity, and nutrient cycling efficiency. The integration of humic compounds enhances nutrient chelation and accessibility, whereas composted manure offers slow-release nutrient savings, mitigating the risk of leaching and loss of nutrients. This formulation technique meets immediate crop nutrient requirements while ensuring long-term soil fertility, establishing OPF as an innovative solution that reconciles high-yield agriculture with ecological stewardship. Because of that, there is a growing need for organic fertilizer products that offer enhanced and consistent nutrient availability and contribute significantly to soil rehabilitation and

ISSN: 1412-4718, eISSN: 2581-138x

increased crop productivity sustainably. This research focuses on exploring the potential of organic fertilizer as a sustainable soil amendment solution for increasing soil nutrients, increasing paddy productivity, and supporting long-term soil fertility restoration and environmentally friendly rice cultivation.

Materials and Methods

Time, Place, and Methods of The Experiment. The research was conducted from February to July 2024 in the experimental field of the Soil Chemistry and Plant Nutrition Laboratory, Universitas Padjadjaran, Jatinangor. A randomized block design (RBD) was implemented in the experiment, consisting of nine treatments, namely one dose OPF recommendation, six combination dose NPK (75 – 100%) and dose OPF (75 – 150%), one recommended fertilizer dose (conventional), and one control treatment for comparison. Each treatment was given three replications, producing twenty-seven experimental plots. Plant growth data were observed every two weeks starting from 14 DAP to 56 DAP, yield components, content of total N in the soil during the maximum vegetative stage, sorption of macro elements (N, P, and K) by rice plants during the maximum vegetative stage, and initial soil analysis were observed. The data obtained from the results of laboratory and field analysis tested the difference in the average effect of treatment with the F test at the 5% significance level based on analysis of variance (ANOVA) to determine the effect of treatment on the observed parameters of each treatment given, and the difference in the average treatment continued with Duncan's multiple range test at the 5% significance level. The linear model equation for RBD is as follows (Gutpa et al., 2016). For analyzing the relationship between two continuous variables for all variables, the Pearson correlation coefficient was used, calculated by(Teng & Chen, 2024)**:**

$$r = \frac{\Sigma\,(X_i - X)(Y_i - Y)}{\sqrt{\Sigma(X_i - X)^2\,.\Sigma(Y_i - Y)^2}}$$

Which: r is Pearson correlation; X_i is the value of variable X at observation i, Y_i is the value of variable Y at observation i, X is the mean of X, Y is the mean of Y, and Σ is the summation symbol.

Sample Preparations. The plant sample includes components of unpolluted, healthy plants, including leaves and shoots. Thoroughly washing samples with distilled water eliminates dust or soil particles. To eliminate surface moisture, samples are initially rinsed with tap water and then dried gently with a paper towel or left to air dry. The organic material is placed in an oven at 65 – 70 °C for 48 to 72 hours, or until it starts to lose weight. A 0.5 mm sieve is employed to homogenize the ground dried plant tissue to ensure uniform particle size. Store ground samples in clean, sealed paper bags or containers. The sample information must be visible on the bags or containers (Balitan, 2005).

Samples of soil were collected at the Jatinangor region, 6° 55' 20,376" S dan 107° 46' 27,748" E as one of the Inceptisols soil type. The composite soil was collected from the area to reflect the local conditions. GPS (Garmin 585) was used to record the coordinates of each location point, and ArcGIS Desktop 10.2 software was used to plot the data on a map. Purposive sampling was used for the sampling process (Balitan, 2005).

Soil and Plant Analysis. Soil and plant analysis used reference materials (Balitan, 2005). Quantifying total nitrogen content in soil by converting all nitrogen in the sample into ammonium (NH_4^+), then liberating it as ammonia gas (NH_3), capturing it in a known amount of trapping solution, and determining the amount of nitrogen through acid–base titration. In plant sorption analysis, such as nitrogen sorption, all organic nitrogen in plant tissue is converted to ammonium sulfate through digestion with concentrated H_2SO_4 in the presence of a catalyst mixture (K_2SO_4 + $CuSO_4$ or selenium). The ammonium is released as NH_3 upon alkalization with NaOH, distilled, trapped in boric acid, and titrated with standardized H_2SO_4 or HCl. For phosphorus analysis, P in plant tissue is released by wet digestion. The orthophosphate reacts with ammonium molybdate under acidic conditions to form phosphomolybdic acid, which is reduced with ascorbic acid to produce a blue complex. Absorbance is measured at 882 nm using a spectrophotometer. K in plant tissue is released using the same digestion method as for P. The digested sample is aspirated into a flame photometer, where the excitation of potassium atoms produces light at 766.5 nm. The light intensity is proportional to the K concentration (Balitan, 2005).

Organic Fertilizer Formula. The first step in the formulation process is the selection of good quality of organic base materials, such as humic substances, agricultural residues, and composted livestock manure (20:20:60). These materials are supplemented with vital macro and micronutrients during or after maturation, such as potassium from ash or mineral sources, phosphorus from natural phosphate rock, and occasionally nitrogen. After enrichment, the mixture is made into granules using a pan or drum granulator and natural binders such as bentonite or molasses. This granulation, with particle sizes between 3 and 5 mm, yields an effective and homogeneous product that is easy to manage and utilize. Subsequently, the granules are desiccated to achieve less than 10% moisture content to enhance their structural integrity and longevity, and a selective coating procedure utilizing materials utilized to improve durability. The completed product is stored in dry, well-ventilated settings after being wrapped in moisture-resistant bags (Figure 1).

Figure 1. Morphological form of organic plus fertilizer (OPF)

Organic Fertilizer Analysis. For the quality of organic plus fertilizer, the present work follows the authorized Indonesian method for evaluating the safety and quality of solid organic fertilizers, as outlined in SNI 7763:2018. As part of this recommendation, the fertilizer's physical, chemical, and biological properties are thoroughly tested to ensure it is safe for crop use. To obtain uniform granules, the sample is then air-dried and sieved. Two crucial physical parameters examined are the moisture content, which cannot exceed 20%, and the particle size, which must be at least 80% able to pass through a 5 mm sieve. A minimum of 15% organic carbon (organic C) must be present in the product. Total nitrogen (N), phosphorus (P_2O_5), potassium (K_2O), pH, and the C/N ratio are all measured using standard laboratory techniques such as the Walkley-Black and Kjeldahl techniques. According to the guideline, levels of heavy metals such as chromium (Cr), lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) must remain below specific safety thresholds. Additionally, it states that testing for micronutrients like zinc and iron is necessary. Microbial safety is also crucial; no dangerous microorganisms, such as *Salmonella* species or *Escherichia Coli*, should be present in the fertilizer, referring to the regulations in force at the Ministry of Agriculture. When a product satisfies all the requirements, it can be certified and labeled, allowing it to be used in Indonesian agriculture without compromising crop nutrition, soil fertility, or the environment (National Standardization Agency, 2018).

Results and Discussion

Quality of Organic Fertilizer. Based on the analysis of the product of OPF (Table 1), the chemical content of the analysis followed SNI 7763:2018, the Indonesian National Standard for solid organic fertilizers. The product exhibited a high organic carbon (organic C) content of 23.22%, indicating a strong potential to improve soil organic matter and enhance microbial activity. The C/N ratio was measured at 21.30, within an ideal range to support balanced nitrogen mineralization and organic matter decomposition in the soil. The moisture content was relatively low at 8.80%, suggesting good storage stability and ease of handling. The fertilizer is enriched with both macro and micronutrients, featuring 1.09% total nitrogen (N), 4.90% phosphorus (P_2O_5), a notably high value that supports early root development, and 0.36% potassium (K_2O), essential for plant water regulation and stress tolerance.

Table 1. Chemical characteristics, macro- and micro-elements, heavy metals, and contaminant microorganisms in organic plus fertilizer

No.	Parameters	Unit	Result	Indonesian National Standard Criteria
1.	Organic C	%	23.22	meet the criteria
2.	C/N Ratio	-	21.30	meet the criteria
3.	By Products	%	-	
4.	Water Content	%	8.80	meet the criteria
5.	Macro Elements:			
	N	%	1.09	meet the criteria
	P_2O_5	%	4.90	meet the criteria
	K_2O	%	0.36	meet the criteria
6.	Micro Elements:			
	Total Fe	ppm	6938.89	meet the criteria
	Available Fe	ppm	6.55	meet the criteria
	Zn	ppm	403.14	meet the criteria
7.	pH	-	8.40	meet the criteria
8.	Heavy Metals:			
	As	ppm	0.00	meet the criteria
	Hg	ppm	0.00	meet the criteria
	Pb	ppm	9.71	meet the criteria
	Cd	ppm	0.62	meet the criteria
	Ni	ppm	44.28	meet the criteria
	Cr	ppm	104.05	meet the criteria
9.	Contaminant Microorganisms:			
	E. Coli	CFU/g	Negative	meet the criteria
	Salmonella sp.	CFU/g	Negative	meet the criteria
10.	Grain Size	%	89.42	meet the criteria

Micronutrient analysis indicated a substantial iron (Fe) concentration of 6938.89 ppm (total) and 6.55 ppm (available), with zinc (Zn) at 403.14 ppm, both of which are essential for enzymatic processes and photosynthesis in crops. This fertilizer, with a pH value of 8.40, is classified as moderately alkaline, making it appropriate for acidic soils by increasing the pH. Significantly, heavy metal analysis verified undetectable concentrations of arsenic (As) and mercury (Hg), with permissible levels of lead (Pb), cadmium (Cd), nickel (Ni), and chromium (Cr), all conforming to safe limits as per SNI 7763:2018 standards. Microbial safety was confirmed, with negative findings for *E. Coli* and *Salmonella sp.*, validating its hygiene and appropriateness for agricultural application as organic fertilizer. The product exhibited exceptional granule homogeneity, with 89.42% of particles meeting the specified size, facilitating uniform distribution during field application. This organic fertilizer plus product adheres to the rigorous quality and safety standards specified in the standard, rendering it a dependable resource for sustainable soil fertility and crop productivity improvement. This material serves not only as a soil conditioner but also as a nutrient source and booster of soil health. Its elevated phosphorus and micronutrient levels, acceptable heavy metal concentrations, and carbon-to-nitrogen ratio set it apart from traditional organic inputs, especially for intensive paddy rice farming.

Preliminary Soil Analysis. Table 2 comprehensively describes the physicochemical parameters of the soil sample used to conduct this study. The parameters being analyzed are critical indicators of soil health, fertility, and capacity to optimize crop growth, particularly for rice, which depends on pH and nutrient imbalances (Mulyani et al., 2019). The pH of this soil is slightly acidic, as is familiar with many tropical soils, which was classified as slightly acidic to moderately acidic (Tariq et al., 2020). While rice grows well in slightly acidic conditions, excessive acidity, as measured by the KCl reading, may inhibit the absorption of nutrients, especially phosphorus (P) and molybdenum (Mo) (McCauley et al., 2017).

ISSN: 1412-4718, eISSN: 2581-138x

Table 2. Physicochemical parameters in preliminary soil analysis

No.	Parameters	Value	Result	Criteria *
1.	pH (H_2O)	-	6.25	Slightly
	pH (KCl)		4.59	Acidic
2.	Organic C	%	2.35	Medium
3.	Total N	%	0.23	Medium
4.	C/N	-	10	Low
5.	P_2O_5 (HCl 25 %)	mg.100 g^{-1}	24.93	Medium
6.	P_2O_5 (Bray I)	ppm P	9.92	Medium
7.	K_2O (HCl 25 %)	mg.100 g^{-1}	23.88	Medium
8.	Cation Exchangeable Capacity (CEC)	cmol.kg^{-1}	17.87	Medium
9.	Cations:			
	Ca	cmol.kg^{-1}	4.50	Low
	Mg	cmol.kg^{-1}	1.77	Medium
	K	cmol.kg^{-1}	0.44	Medium
	Na	cmol.kg^{-1}	0.06	Low
10.	Base Saturation	%	37.92	Low
11.	Texture:			
	Clay	%	11	
	Dust	%	34	Clay
	Sand	%	55	

According to the soil research centre criteria, the soil's total nitrogen content is 0.23%, which falls into the medium category, and its organic carbon content is moderate at 2.35%. Enhancing soil structure, water retention, and microbial diversity depends heavily on organic matter. However, the low carbon-to-nitrogen ratio of 10 indicates fast mineralization, potentially leading to an immediate release of nutrients and a rapid depletion (Kumar et al., 2016). The phosphorus levels are in the medium range, at 9.92 ppm (Bray I) and 24.93 mg.100 g^{-1} (HCl 25%). These levels may be inadequate for later stages of rice development unless supplemented, despite being sufficient for early growth. The pH level significantly influences phosphorus availability; in acidic soils such as this, phosphorus combines with aluminium and iron, reducing its bioavailability (Akter et al., 2018). The measured potassium level of 23.88 mg.100 g^{-1} is also within the moderate fertility range. K is necessary for rice grain filling, disease resistance, and water regulation. Although K may not immediately limit at the level seen, supplementation would help guarantee steady uptake throughout the crop cycle (Ragel et al., 2019). The CEC value of 17.87 cmol.kg^{-1} indicates a moderate ability to retain and exchange nutrients. Soils that balance clay and organic matter tend to have a moderate CEC. The low base saturation of 37.92% suggests that acidic cations like Al^{3+} and H^{+} occupy a sizable portion of the exchange sites. Without fertilization, this exchange level indicates a reduced nutrient reserve that could impact plant growth (Silva & Uchida, 2000). The content of Ca is 4.5 cmol.kg^{-1} (low), Mg 1.77 cmol.kg^{-1} (moderate), K moderate, 0.44 cmol.kg^{-1}, and Na extremely low, 0.06 cmol.kg^{-1}, given the importance of calcium for root development and cell wall strength, low calcium and sodium levels point out the need for nutrient amendment. Although not necessary, high sodium can be a sign of salinity problems, so this matter must be paid close attention to (Shrivastava & Kumar, 2015).

The soil texture is sandy loam, with 55% sand, 34% silt, and 11% clay. Although this texture encourages excellent drainage and aeration, it may have a low capacity to hold water and nutrients, consistent with the noted mild CEC. Adding organic matter greatly enhances the structure and retention of these soils (Paramesh et al., 2023). The soil profile, which is sandy loam, moderately acidic, and medium in organic matter and nutrients, indicates that productivity can be increased by using organic fertilizers to increase microbial activity and nutrient retention. In particular, NPK supplementation addresses deficiencies in P and Ca. Using integrated nutrient management techniques, this approach balances short-term agricultural requirements with long-term soil health. This aligns with contemporary sustainable agriculture practices in tropical areas, where chemical dependence and soil degradation are significant issues (Massoukou Pamba et al., 2023).

Height of Plant. The results clearly show that using OPF alone or inorganic NPK fertilizer made the rice plants grow taller at every growth stage compared to the control (Table 3). Plant height is a standard metric for assessing rice plants' nutrient uptake and overall health throughout the initial stages of growth (Pandey et al., 2017). The stage of early growth is 14 days after planting (DAP). At 14 DAP, treatments with 100% dose of OPF through 100% NPK + 150% dose of OPF worked far better than the usual NPK treatment of standard NPK and the control.

ISSN: 1412-4718, eISSN: 2581-138x

Table 3. Effect of various combinations of organic plus fertilizer (OPF) on the plant height (cm)

Code	Treatments	Days After Planting (DAP)			
		14	28	42	56
A	Control	28.64 a	49.02 a	68.29 a	75.89 a
B	100% NPK Standard	35.79 b	61.36 b	76.19 ab	85.97 b
C	100% Dose of OPF	43.26 c	66.85 bc	78.79 b	86.51 b
D	75% NPK + 75% OPF	44.53 c	60.22 b	84.50 bc	86.56 b
E	75% NPK + 100% OPF	43.65 c	59.13 b	82.84 bc	86.54 b
F	75% NPK + 150% OPF	44.48 c	62.91 b	89.72 c	87.45 b
G	100% NPK + 75% OPF	42.90 c	62.23 b	88.24 c	87.12 b
H	100% NPK + 100% OPF	44.40 c	66.43 bc	88.18 c	87.09 b
I	100% NPK + 150% OPF	37.00 b	72.01 c	88.18 c	85.53 b

Note: Means followed by the same letter within the same column do not show significant differences based on Duncan's Multiple Range Test at the 5% significance level.

Treatments 75% NPK + 75% OPF and 75% NPK + 150% OPF showed the most notable early growth, indicating that OPF can support rapid early vegetative development even with lower NPK input. This could be because OPF has nutrients and beneficial microbial metabolites that are easy for plants to access and help grow roots (Iqbal et al., 2025). Compared to the control group, all the fertilized treatments at this time made the plants much taller. Treatment 100% NPK + 150% OPF had the tallest plants (72.01 cm), which suggests that a high dose of OPF and full NPK may work together to make plants grow taller. This backs up the findings of previous studies that show how organic matter improves the soil's ability to hold water, microbes, and nutrients, all of which help plants grow better (Iqbal et al., 2025; Mulyani et al., 2017). OPF is probably a slow-release nutrient source, especially in tropical soils with low amounts of organic matter. This reduces the possibility of nutrient leaching and enhances their availability to plants during the vegetative stage. Stages 42 and 56 of the late vegetative to reproductive cycle treatment 75% NPK + 150% OPF resulted in the tallest plants (89.72 cm) by 42 DAP.

Treatments 100% NPK combined with 75% OPF, 100% NPK with 100% OPF, and 100% NPK paired with 150% OPF followed closely behind. In these treatments, varying quantities of OPF were given with either complete or almost complete NPK. This outcome demonstrates the essential role of organic inputs in maintaining a consistent nutrition supply during crucial growth stages, particularly during panicle development and grain filling. The lack of notable variations between treatments that combined NPK with OPF and those utilizing OPF exclusively at 14, 28, and 56 DAP indicates that the nutrient provision from OPF was adequate to satisfy the plant's initial growth needs.

Organic plus fertilizer, comprising humic substances, composted manure, and enhanced macro- and micronutrients, offers immediately accessible nutrients and slow-release variants. During the initial growth stages (2 and 4 weeks), rice plants predominantly depend on the nitrogen reserves present in the soil and on the starting fertilizers. The mineralization of organic matter in OPF gradually releases nitrogen, phosphorus, and potassium, which can sustain optimal growth without the immediate requirement for more NPK. This aligns with the findings of Shu et al. (2025), which showed that well-balanced organic formulations can equal the efficacy of complete chemical fertilizers during the initial vegetative stages. At 8 weeks post-planting, the plant height measurements for both OPF-only and OPF with NPK treatments were statistically comparable, suggesting that the nutrient release from OPF consistently facilitated growth without acting as a limiting factor. This indicates that supplementary NPK inputs may not result in proportional growth enhancements when nutrient availability is sufficient, an effect commonly referred to as "diminishing returns" in fertilizer response.

Furthermore, the organic component in OPF enhances soil nutrient retention and the root-zone microenvironment, facilitating effective nutrient absorption. This can diminish reliance on elevated dosages of chemical NPK during the vegetative stage, using sustainable agriculture principles that seek to optimize rather than maximize fertilizer application. At 56 DAP, all fertilizer treatments significantly outperformed the control group. Nonetheless, treatments: One dose of OPF was given with one NPK, and one and a half doses of OPF exhibited no meaningful difference. This convergence indicates that the internal redistribution of nutrients becomes increasingly crucial as the plant matures. The prevailing trend remains in favor of OPF-enriched therapies. This indicates that they can offer a more consistent and enduring supply of nutrients throughout the crop's life cycle (Gamage et al., 2023).

Number of Tillers. Observation of the number of tillers (Table 4) showed interesting data to discuss, as each treatment can give different responses at different DAP. Because it directly affects the number of grains produced per plant, the number of tillers is essential to rice productivity. Important patterns about the effects of organic and inorganic fertilizer combinations on tiller growth can be seen in the data presented. In the early stage (14 and 28 DAP), the treatments did not differ significantly at 14 DAP.

All treatments, including the control, showed similar numbers of tillers (8 – 10), meaning that the tillers' growth had not fully reacted to the early fertilizer applications. The differences between the treatments were not statistically significant by 28 DAP, meaning the plants were still in the early stages of taking up nutrients and directing them to their reproductive parts. These findings are consistent with those of Huanhe et al. (2024), who found that vegetative biomass accumulation has a greater impact on early growth stages than reproductive. A more precise pattern appeared during growth from mid to late (42 and 56 DAP) at 42 DAP. In this situation, the treatments that used both NPK and OPF, especially at higher amounts (treatments 75% NPK + 150% OPF, 100% NPK + 75% OPF, 100% NPK + 100% OPF, and 100% NPK + 150% OPF), significantly raised the number of tillers compared to the control. The treatments 75%NPK + 150% OPF and 100% NPK + 75% OPF, 100% NPK + 100% OPF, and 100% NPK + 150% OPF (with full NPK and more OPF) had the highest number of tillers (30 tillers), which was much better than NPK only (21 tillers) and the control (19 tillers). The lack of notable differences between NPK with OPF combinations and OPF alone in weeks 2, 4, and 8 regarding the number of tillers likely arises from the notion that early tiller initiation is predominantly affected by the availability of balanced nutrients and the plant's physiological preparation rather than by excessive fertilizer application. The OPF comprises both macro and micronutrients in organic and mineral forms and humic compounds that enhance nutrient availability, soil microbial activity, and root health. When OPF sufficiently fulfils the crop's nutritional requirements, supplementary NPK may not result in a discernible alteration in yield components throughout that growth cycle. A further contributing element is that the number of panicles is established very early during tillering. However, nutrient absorption from OPF is gradual and persistent, enabling plants to achieve comparable tiller counts to those receiving combined NPK + OPF treatments. In inundated rice systems, nutrient losses by leaching or volatilization may diminish the advantages of additional NPK, rendering the efficacy of OPF-only treatments equivalent. This outcome demonstrates how chemical and organic fertilizers work in concert. Through slow-release mechanisms, organic amendments improve nutrient availability, microbial activity, and soil structure. These improvements help tillers' growth and development by encouraging better root growth and nutrient uptake. The trend persisted at 56 DAP. The number of tillers remained higher than the controls in all OPF treatments. The preservation of high values indicates that the beneficial effects of OPF are maintained throughout the reproductive stage, even though the increase in tiller numbers was less abrupt than at 42 DAP. Organic fertilizers are crucial not only for improving the physical and biological properties of soil but also for the long-term support of flowering and grain filling, according to claims (Wang et al., 2019).

Straw weight, Number of Panicles, and Panicle Length. The results indicate that adding OPF, either alone or in combination with NPK, improved straw weight, number of panicles per plant, and panicle length compared to the control. The analysis of yield components is shown in Table 5 below.

Table 4. Effect of various combinations of organic plus fertilizer (OPF) on the number of tillers

Code	Treatments	Days After Planting			
		14	28	42	56
A	Control	9 a	25 a	19 a	20 a
B	100% NPK Standard	9 a	23 a	21 a	22 b
C	100% Dose of OPF	8 a	23 a	22 ab	22 b
D	75% NPK + 75% OPF	9 a	25 a	24 bc	23 b
E	75% NPK + 100% OPF	10 a	24 a	27 cd	23 b
F	75% NPK + 150% OPF	10 a	23 a	28 d	24 b
G	100% NPK + 75% OPF	10 a	28 a	30 d	24 b
H	100% NPK + 100% OPF	10 a	27 a	30 d	22 b
I	100% NPK + 150% OPF	10 a	27 a	30 d	23 b

Note: Means followed by the same letter within the same column do not show significant differences based on Duncan's Multiple Range Test at the 5% significance level.

Table 5. Effect of various combinations of organic plus fertilizer (OPF) on straw weight, number of panicles, and panicle length

Code	Treatments	Straw Weight/plot (kg)	Number of panicles/plant	Panicle length (cm)
A	Control	10.27 a	12 a	23.74 a
B	100% NPK Standard	10.91 a	16 d	24.67 a
C	100% Dose of OPF	12.63 a	13 ab	24.31 a
D	75% NPK + 75% OPF	10.49 a	14 bc	25.17 ab
E	75% NPK + 100% OPF	11.50 a	14 bc	25.89 ab
F	75% NPK + 150% OPF	13.35 a	15 cd	26.00 ab
G	100% NPK + 75% OPF	13.79 a	17 d	26.49 ab
H	100% NPK + 100% OPF	15.96 a	17 d	27.69 b
I	100% NPK + 150% OPF	10.27 a	12 a	23.74 a

Note: Means followed by the same letter within the same column do not show significant differences based on Duncan's Multiple Range Test at the 5% significance level.

Based on data in Table 5, the statistical differences were insignificant ($p > 0.05$). The highest straw biomass was recorded in treatment 100% NPK + 100% OPF at 15.96 kg/plot, representing a 55.4% increase compared to the control (10.27 kg/plot). Treatments containing a higher proportion of OPF, such as 75% NPK + 150% OPF and 100% NPK + 75% OPF, also showed higher straw weights. This suggests that OPF contributes to enhanced vegetative growth, possibly through improved soil structure and nutrient retention, in line with previous findings by Liu et al. (2023) that organic amendments boost biomass accumulation. For the number of panicles/plant, the highest values (17 panicles) were obtained in treatments 100% NPK + 75% OPF and 100% NPK + 100% OPF, significantly higher than the control (12 panicles). This improvement of about 41.7% indicates that balanced nutrient availability from combined organic and inorganic sources can stimulate tiller development and reproductive branching (Khambalkar et.al, 2025). The longest panicles (27.69 cm) were recorded in 100% NPK + 100% OPF, significantly higher than the control (23.74 cm). Longer panicles are typically associated with higher grain-bearing capacity, suggesting potential yield advantages (IRRI, 2013). While some differences were not statistically significant for straw biomass, the trend shows that combining NPK with OPF at optimal doses (particularly 100% NPK + 100% OPF) produces the best results in yield component parameters. The likely mechanism involves synergistic effects: NPK provides immediate nutrient availability, and OPF enhances soil fertility, microbial activity, and nutrient release over time.

Sorption of N, P, and K in Plants. The analysis of macro elements such as N, P, and K sorption by plants is shown in Table 6.

Table 6. Effect of various combinations of organic plus fertilizer (OPF) on the sorption of plant

Code	Treatments	N	P	K
			%	
A	Control	1.14 a	0.69 a	0.94 ab
B	100% NPK Standard	1.34 b	0.85 a	1.08 bcd
C	100% Dose of OPF	1.47 b	0.78 a	0.88 a
D	75% NPK + 75% OPF	1.35 b	0.75 a	0.99 abc
E	75% NPK + 100% OPF	1.14 a	0.73 a	0.88 a
F	75% NPK + 150% OPF	1.46 b	0.80 a	0.99 abc
G	100% NPK + 75% OPF	1.41 b	1.00 a	1.09 cd
H	100% NPK + 100% OPF	1.41 b	0.92 a	1.14 d
I	100% NPK + 150% OPF	1.39 b	0.98 a	1.05 bcd

Note: Means followed by the same letter within the same column do not show significant differences based on Duncan's Multiple Range Test at the 5% significance level.

Table 7. Effect of various combinations of organic plus fertilizer (OPF) on soil N

Code	Treatments	Soil N (%)
A	Control	0.35 a
B	100% NPK Standard	0.38 a
C	100% Dose of OPF	0.40 ab
D	75% NPK + 75% OPF	0.44 ab
E	75% NPK + 100% OPF	0.40 a
F	75% NPK + 150% OPF	0.38 a
G	100% NPK + 75% OPF	0.51 b
H	100% NPK + 100% OPF	0.44 ab
I	100% NPK + 150% OPF	0.38 a

Note: Means followed by the same letter within the same column do not show significant differences based on Duncan's Multiple Range Test at the 5% significance level.

Nitrogen is necessary for the production of chlorophyll and for vegetative growth. While several treatments, such as 100% OPF, 75% NPK + 150% OPF, 100% NPK + 75% OPF, 100% NPK + 100% OPF, and 100% NPK + 150% OPF, recorded significantly higher levels (≥1.39%), suggesting effective nitrogen uptake, the data show that the control treatment had the lowest N content (1.14%). Treatments employing full OPF alone or in conjunction with NPK (75% NPK + 150% OPF and 100% NPK + 150% OPF) markedly increased the nitrogen content compared to control or NPK alone. This is in line with research by Eghball et al. (2002), which showed that in addition to providing a slow-release form of nitrogen, organic fertilizers also promote nutrient mineralization by increasing microbial activity and organic matter decomposition. Additionally, Ghosh et al. (2022) found that combining organic and inorganic sources improved nitrogen availability and uptake in rice systems.

Phosphorus is essential for root growth and energy transfer. This dataset showed no appreciable differences between treatments, ranging from 0.69% to 1.00%. Despite statistically similar P levels, the numerically higher P content in treatments 100% NPK + 75% OPF and 100% NPK + 150% OPF suggested a potential synergistic effect of combining NPK with organic inputs. Organic materials boost soil pH buffering and microbial activity, enhancing phosphorus uptake and solubilization (Suvendran et al., 2025). This corroborates the results of Mahmood et al. (2017), who found that organic manure increased P availability by releasing organic acids that mobilized the insoluble phosphates in the soil. Potassium is necessary for both water regulation and enzyme activation. The K content of treatment 100% NPK + 100% OPF was the highest at 1.14%, considerably higher than that of the control (0.94%) and OPF-only treatments. Treatments 100% NPK + 75% OPF and 100% NPK + 150% OPF also had relatively high K values. These findings support the notion that integrated nutrient management offers a long-term and immediate supply of K. Chemical fertilizers offer readily available K. However, organic amendments boost cation exchange capacity (CEC), ultimately enhancing K availability and retention (Morash et al., 2024).

Soil Analysis of Total N. Table 7 displays the effect of various combinations of organic fertilizer on N in soil, gives different results depending on the treatments.

Regarding applying nitrogen from OPF in one cultivation period, the nitrogen residue in the soil is still at a reasonable level. This is because organic fertilizer does not produce undesirable residue in the soil, as opposed to nitrogen derived

ISSN: 1412-4718, eISSN: 2581-138x

from inorganic materials. Enhancing soil organic matter (SOM) and microbial activity through organic fertilizers is essential for improving soil nitrogen retention. (Bingham & Cotrufo, 2016) claim that organic matter aids in binding nitrogen in more stable organic forms, minimizing leaching immediately, but gradually mineralizing over time. The higher N residue in treatment 100% NPK + 75% OPF can also be explained by (Govindasamy et al., 2023), who found that adding organic amendments to NPK improves nitrogen use efficiency (NUE) by improving soil structure, boosting microbial activity, and buffering nutrient release. It may have been best to apply OPF partially to prevent "microbial N immobilization", which stimulates microbial demand that can compete with plants for nitrogen, or excessive nitrogen immobilization. Furthermore, (Govindasamy et al., 2023) stressed that N loss is frequent in flooded paddy soils and that methods that enhance N retention, like incorporating organic inputs, can significantly enhance the sustainability of soil fertility. This is consistent with recent research showing that the best results were obtained when combining mineral and organic fertilizers.

In agronomic and practical consequences, the greater N conservation is indicated by treatment 100% NPK + 75% OPF, which has high residual N, which may encourage early growth in the following cropping season and lessen the need for initial fertilization. N residue may not always rise in treatments containing only OPF or high concentrations of OPF (75% NPK + 150% OPF, 100% NPK + 150% OPF). This could be because of increased microbial activity that consumes available N or because N release and plant demand are not sufficiently synchronized. It is crucial to maximize the proportion of inorganic to organic fertilizer. Better results might not always result from excessive organic input that is not balanced. A promising strategy for sustaining higher soil nitrogen levels after harvest is integrating 100% NPK + 75% OPF. This will improve soil fertility resilience and support sustainable nutrient management in rice-based systems. This approach aligns with the larger trend toward integrated nutrient management (INM), which recent studies have shown enhances soil health and productivity (Amanullah et al., 2023).

Yield Parameter. Parameters of the plant yield showed different responses for each treatment (Table 8). Several treatments with OPF combinations saw a significant increase in grain yield, with the treatment 100% NPK + 100% OPF having the highest yield at 9.33 kg, which was significantly higher than the control (4.27 kg).

Table 8. Effect of various combinations of organic plus fertilizer (OPF) on grain weight

Code	Treatments	Grain Weight/plot (kg)
A	Control	4.27 a
B	100% NPK Standard	6.46 ab
C	100% Dose of OPF	4.95 ab
D	75% NPK + 75% OPF	5.75 ab
E	75% NPK + 100% OPF	6.80 ab
F	75% NPK + 150% OPF	7.47 ab
G	100% NPK + 75% OPF	7.77 b
H	100% NPK + 100% OPF	9.33 b
I	100% NPK + 150% OPF	7.65 ab

Note: Means followed by the same letter within the same column do not show significant differences based on Duncan's Multiple Range Test at the 5% significance level.

Treatments 100% NPK + 75% OPF and 75% NPK + 150% OPF produced high grain yields (7.77 kg and 7.47 kg, respectively). This is consistent with previous studies by Zhao et al. (2016), which highlighted how combining organic and inorganic nutrients promotes balanced nutrient availability, enhancing grain filling and overall productivity. More straw biomass means better plant growth and photosynthesis, which are affected by more nutrients available (Rahman et al., 2020). The availability of potassium and nitrogen, which enhance vegetative growth, is frequently linked to straw yield. The pattern shows that mixtures enriched with OPF help keep strong plant growth, even though the results were similar across different treatments. Mulyani et al. (2017) stated that the application of OPF promotes the growth of additional shoots in plants by slowly supplying nutrients, which improves overall growth and the development of productive shoots. In systems combining organic and inorganic materials, the number of particles strongly influences nitrogen availability and how well it meets the plants' needs. Because micronutrients and organic matter support cellular development and hormone regulation, this trait is frequently improved when available (Rahman et al., 2020). Despite not being substantially different from most treatments, the steady rise across OPF-enriched treatments illustrates the compound's cumulative impact on plant physiology.

Conclusion

According to the study's findings, applying Organic Plus Fertilizer (OPF), especially when combined with inorganic NPK fertilizer, significantly enhances rice plant growth, nutrient uptake, soil fertility, and yield performance. Treatments that combined a full or partial dose of NPK with OPF consistently outperformed the control and NPK-only treatments in key agronomic parameters like plant height, panicle count, nutrient absorption, and grain production. The increase in nutrient uptake and improved nitrogen residue in the soil under OPF treatments further illustrate its role in improving soil health and nutrient efficiency. These findings show that integrated nutrient management, which uses organic and inorganic fertilizers, is a practical and effective way to increase rice yields while maintaining soil fertility. Also, a well-balanced mix of high-quality organic raw materials improves the organic fertilizer product. This synergy makes important nutrients more readily available right away and helps keep soil healthy in the long run by improving soil structure and keeping nutrient cycling going. These mixes provide both short-term and long-term benefits.

Acknowledgments

The authors are grateful to all Soil Chemistry and Plant Nutrition Laboratory members for their valuable suggestions, support, and encouragement, especially to the field assistance team, who have also contributed considerably to this paper.

References

Amanullah, Ondrasek G, Al-Tawaha AR. 2023. Editorial: Integrated nutrients management: an approach for sustainable crop production and food security in changing climates. Frontiers in Plant Science, 14: 1–4.

Anisuzzaman M, Rafii, MY, Jaafar NM, Ramlee SI, Ikbal MF, Haque MA. 2021. Effect of organic and inorganic fertilizer on the growth and yield components of traditional and improved rice (*Oryza sativa* L.) genotypes in malaysia. Agronomy, 11(9): 1–22.

National Standardization Agency 2018. Indonesian National Standard (SNI) 7763-2018 concerning Solid Organic Fertilizer. National Standardization Agency, 1–20.

Balitan B.D. 2005. Analisis Kimia Tanah, Tanaman, Air dan Pupuk. Analisis Kimia Tanah, Tanaman, Air dan Pupuk.

Bhattacharyya R, Ghosh B, Mishra P, Mandal B, Rao C, Sarkar D, Das K, Anil K, Lalitha M, Hati K, Franzluebbers A. 2015. Soil Degradation in India: Challenges and Potential Solutions. Sustainability, 7(4): 3528–3570.

Bingham, A.H. & Cotrufo, M.F. 2016. Organic nitrogen storage in mineral soil: Implications for policy and management. Science of the Total Environment, 551–552: 116–126.

Bremner J.M. 1965. Inorganic Forms of Nitrogen in Soil. (84): 1179–1237.

Cao Y, He Z, Zhu T, Zhao F. 2021. Organic-C quality as a key driver of microbial nitrogen immobilization in soil: A meta-analysis. Geoderma, 383: 114784.

Eghball B., Wienhold BJ, Gilley JE, Eigenberg RA. 2002. Mineralization of manure nutrients. Journal of Soil and Water Conservation, 57(6): 470–473.

Gamage A, Gangahagedara R, Gamage J, Jayasinghe N, Kodikara N., Suraweera P, Merah O. 2023. Role of organic farming for achieving sustainability in agriculture. Farming System, 1(1): 100005.

Ghosh D, Brahmachari K, Skalicky M, Roy D, Das A, Sarkar S, Moulick D, Brestic M, Hejnak V, Vachova, P, Hassan MM, Hossain A. 2022. The combination of organic and inorganic fertilizers influence the weed growth, productivity and soil fertility of monsoon rice. PLoS ONE, 17: 1–18.

Govindasamy P, Muthusamy SK, Bagavathiannan M, Mowrer J, Jagannadham PTK, Maity A, Halli HM, GKS, Vadivel R, TKD, Raj R, Pooniya V, Babu S, Rathore SSLM, Tiwari G. 2023. Nitrogen use efficiency—a key to enhance crop productivity under a changing climate. Frontiers in Plant Science, 14(3): 1–19.

Gutpa VK, Parsad R, Bhar LM, Mandal BN. 2016. Statistical Analysis of Agricultural Experiments Part I Single Factor Experiments (1). ICAR- Indian Agricultural Statistics Research Institute, 1: 1–414.

Huanhe W, Xiaoyu G, Xiang Z, Wang Z, Xubin Z, Yinglong C, Zhongyang H, Guisheng Z, Tianyao M, Qigen D. 2024. Grain Yield, Biomass Accumulation, and Leaf Photosynthetic Characteristics of Rice under Combined Salinity-Drought Stress. Rice Science, 31(1): 118–128.

Iqbal S, Begum F, Nguchu BA, Claver UP, Shaw P. 2025. The invisible architects: microbial communities and their transformative role in soil health and global climate changes. Environmental Microbiome, 20(1).

Joy B, Sudirja R, Sofyan ET, Harriyanto R, Mulyani O, Herdiansyah G. 2019. Evaluation of soil fertility status for rice, corn, soybean on suboptimal land in West Java Indonesia. IOP Conference Series: Earth and Environmental Science, 393(1).

Khambalkar PA, Agrawal S, Dhaliwal SS, Yadav SS, Sadawarti MJ, Singh A, Yadav IR, Shivans, Prasad D, Singh A, Afreen N. Sustainable nutrient management balancing soil health and food security for future generations. Applied Food Research 5 (2025) 101087.

Koorneef GJ, Pulleman MM, Comans RN, van Rijssel SQ, Barré P, Baudin F, de Goede RG. 2024. Assessing soil functioning: What is the added value of soil organic carbon quality measurements alongside total organic carbon content? Soil Biology and Biochemistry, 196.

Liu W, Yang Z, Te Q, Peng Z, Zhu S, Chen H, Liu D, Li Y, Deng L, Xhu X, Huang H. Positive Effects of Organic Amendments on Soil Microbes and Their Functionality in Agro-Ecosystems. Plants (Basel). 2023 Nov 7;12(22):3790. doi: 10.3390/plants12223790.

Massoukou Pamba R, Poirier V, Nguema Ndoutoumou P, Epule TE. 2023. How Can Plants Help Restore Degraded Tropical Soils? Land, 12(12): 1–18.

McCauley A, Jones C, Olson-Rutz, K. 2017. Soil pH and Organic Matter. Nutrient Management, (8): 16.

Morash J, Pamuru ST, Lea-Cox JD, Ristvey AG, Davis AP, Aydilek AH. 2024. Using organic amendments in disturbed soil to enhance soil organic matter, nutrient content and turfgrass establishment. Science of the Total Environment, 945: 174033.

Mulyani O, Sudirja R, Joy B, Hanandiva RA. 2019. The Effect of Organomineral on pH, Nitrogen Content, Organic-C Content and Yield of Upland Rice (*Oryza sativa* L.) on Inceptisols, West Java Indonesia. IOP Conference Series: Earth and Environmental Science, 334(1): 0–5.

Mulyani O, Trinurani E, Sudirja R, Joy B. 2017. The Effect of Bio-fertilizer on Soil Chemical Properties of Sugarcane in Purwadadi Subang. KnE Life Sciences, 2(6): 164.

Nishimura K, Itani, T. 2013. Leaching Behaviour of Nitrogen in Forage Rice Cultivation that Applied with Animal Manure. Journal of Tropical Soils, 18(3): 209–216.

Pandey R, Paul V, Das M, Meena M, Meena, R.C. 2017. Plant Growth Analysis Paper. ICAR.

Paramesh V, Kumar P, Bhagat T, Nath AJ, Manohara KK, Das B, Desai BF, Jha PK, Prasad PVV. 2023. Integrated Nutrient Management Enhances Yield, Improves Soil Quality, and Conserves Energy under the Lowland Rice–Rice Cropping System. Agronomy, 13(6).

Ragel P, Raddatz N, Leidi EO, Quintero FJ, Pardo JM. 2019. Regulation of K + nutrition in plants. Frontiers in Plant Science, 10.

Rahman R, Sofi J, Javeed I, Malik T, Nisar, S. 2020. Role of micronutrients in crop production (a review). Fert News., (11): 2265–2287.

Romadhon MR, Mujiyo M, Suntoro S, Dewi, WS, Syamsiyah J, Rahayu R, Widijanto H, Herdiansyah G, Herawati A, Anggita A, Hasanah K, Hardian T, Romadhon MR, Istiqomah NM, Irmawati V. 2024. Assessing the Quality of Organic Fertilizer Products Made from Cow Dung in Wonogiri Regency, Indonesia. Agroindustrial Journal, 10(2): 65.

Shrivastava P, Kumar, R. 2015. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi Journal of Biological Sciences, 22(2): 123–131.

Silva J, Uchida, R. 2000. Essential Nutrients for Plant Growth: Plant Nutrient Management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture.

Su, K., Zhang, Q., Chen, A., Wang, X., Zhan, L., Rao, Q., Wang, J. & Yang, H. 2025. Heavy metals concentrations in commercial organic fertilizers and the potential risk of fertilization into soils. Scientific Reports, 15(1): 1–10.

Susanti WI, Cholidah SN, Agus F. 2024. Agroecological Nutrient Management Strategy for Attaining Sustainable Rice Self-Sufficiency in Indonesia. Sustainability

(Switzerland), 16(2): 1–29.

Suvendran S, Acevedo MF, Smithers B, Walker SJ, XuP. 2025. Soil Fertility and Plant Growth Enhancement Through Compost Treatments Under Varied Irrigation Conditions. Agriculture (Switzerland), 15(7): 1–21.

Teng TP, Chen, W.J. 2024. Using Pearson correlation coefficient as a performance indicator in the compensation algorithm of asynchronous temperature-humidity sensor pair. Case Studies in Thermal Engineering, 5: 103924.

Wang H, Xu J, Liu X, Zhang D, Li L, Li W, Sheng, L. 2019. Effects of long-term application of organic fertilizer on improving organic matter content and retarding acidity in red soil from China. Soil and Tillage Research, 195: 104382.

Xu Y, Li H, Tan L, Li Q, Liu W, Zhang C, Gao Y, Wei X, Gong Q, Zheng X. 2022. What role does organic fertilizer actually play in the fate of antibiotic resistome and pathogenic bacteria in planting soil? Journal of Environmental Management, 317: 115382.

Yang J, Zhang J. 2010. Crop management techniques to enhance harvest index in rice. Journal of Experimental Botany, 61(12): 3177–3189.

Zhao J, Ni T, Li J, Lu Q, Fang Z, Huang Q, Zhang R, Li R, Shen B, Shen Q. 2016. Effects of organic-inorganic compound fertilizer with reduced chemical fertilizer application on crop yields, soil biological activity and bacterial community structure in a rice-wheat cropping system. Applied Soil Ecology, 99: 1–12.