Acta Solum 4, Number 3 (July 2026), 211–217. DOI: 10.20527/actasolum.v4i3.3741
http://jtam.ulm.ac.id/index.php/actasolum e-ISSN: 2987-5145

Combined Basal and Foliar NPK Fertilization Effects on Soil Properties and Rice Production

Shiamita Kusuma Dewi*, Winih Sekaringtyas Ramadhani, Naiya Aninda, Hery Novpriansyah, Afandi

Soil Science Department, Faculty of Agriculture, Lampung University, Bandar Lampung, Indonesia

*Correspondence author email: shiamita.kd@fp.unila.ac.id

Article Information

Received May 30th 2026
Accepted July 16th 2026
Published August 04th 2026
Online August 04th 2026

Keywords:

Paddy rice; Basal fertilizer; Foliar Fertilizer; Soil properties; Rice production

Abstract

Rice (*Oryza sativa* L.) productivity in intensively cultivated paddy systems is limited by soil fertility loss and low nutrient use efficiency of conventional NPK fertilization, which is prone to ammonia volatilization, leaching, and phosphorus fixation in tropical soils. Foliar NPK application is proposed to bypass soil nutrient losses and improve fertilizer efficiency, but its combined effects with basal fertilizer on soil properties and rice production in tropical paddy conditions are poorly understood. This study aimed to evaluate the effects of combined basal and foliar NPK fertilization on selected soil properties and rice production under tropical paddy conditions in Central Lampung. A field experiment was conducted using a Randomized Complete Block Design with 8 treatments and 4 replications, comprising combinations of basal and foliar NPK. Soil properties, including pH, soil dispersion ratio, and soil texture, alongside agronomic parameters, were associated with rice production. The results showed that combined basal and foliar NPK application significantly affected soil pH, with treatment H having a higher soil pH than the control and the standardized fertilizer. Combined application also significantly improved rice agronomic performance, with treatment H recording the highest rice production of 4.23 kg plot^{-1}, representing a 50% increase over the control treatment. These findings show that combining basal and foliar NPK fertilization can potentially manage nutrients to sustain soil fertility and enhance rice production in tropical paddy systems.

1. Introduction

Rice (*Oryza sativa* L.) is Indonesia's main staple for over 270 million people, crucial for food security and rural livelihoods. In 2025, paddy production reached 60.21 million tons GKG, up 13.29% from 2024's 54.14 million tons, on 11.32 million hectares with an average of 53.18 quintals per hectare (Badan Pusat Statistik, 2026). This recovery followed hydroclimatic normalization after the 2023–2024 El Niño, which disrupted planting and reduced harvested area, aided by government programs like land optimization, new paddy fields, infrastructure rehab, fertilizer subsidies, and climate-adaptive high-yield varieties such as Inpari 32 HDB and Inpari 42 Agritan GSR (Badan Pusat Statistik, 2026; Kementerian Pertanian, 2026).

Within Lampung Province, Central Lampung consistently recorded the highest paddy production, reaching 614,017 tons GKG in 2024 and achieving a productivity of 57.01 quintals per hectare, the highest among all regencies in the province (Badan Pusat Statistik, 2026). Despite these production gains at both the national and provincial levels, average rice productivity in Indonesia remains below its genetic yield potential. Soil fertility degradation, inefficient nutrient management, and suboptimal fertilization practices continue to constrain sustainable yield improvement, particularly in intensively cultivated paddy systems.

Soil fertility degradation and low nutrient use efficiency (NUE) limit sustainable rice yield in intensive paddy systems. Conventional NPK fertilization suffers from nutrient losses through volatilization, leaching, runoff, and phosphorus fixation, reducing effectiveness and productivity (Ladha et al., 2016; Liu et al., 2024). Foliar

fertilization offers a complementary approach, providing nutrients directly to leaves via stomata and cuticular absorption, bypassing soil losses (Balachandra et al., 2025). In rice, foliar NPK at tillering and panicle initiation improves chlorophyll, photosynthetic rate, and yield components, with combined basal and foliar application increasing yields by up to 50% (Tuiwong et al., 2024). However, responses are highly context-dependent, with variable efficacy based on timing, concentration, and soil conditions, limiting broader applicability.

Previous studies mostly examined basal and foliar NPK fertilization separately, focusing on yield rather than soil chemical properties like pH, organic matter, and available nutrients (Amoah and Tetteh, 2022; Tuiwong et al., 2024). This gap is crucial because soil properties under combined fertilization influence nutrient availability and sustainability in paddy soils (Xing et al., 2025). Limited research under tropical paddy conditions, especially in Central Lampung, Indonesia, limits the applicability of findings to local systems. The combined effects of basal and foliar NPK on soil properties and rice yield remain poorly understood, which this study aims to address.

2. Research Methods

2.1. Research Location

The research was conducted in Majapahit Village, Punggur, Central Lampung Regency. Initial soil analysis and rice production measurements were performed at the Soil Science Laboratory, Faculty of Agriculture, University of Lampung. The study took place from June to September 2025.

The materials used included low-fertility soil, Ngaos Mawar hybrid rice seeds, foliar fertilizers, and basic fertilizers such as urea and Phonska. The tools used in this experiment were a hand tractor, a knapsack sprayer, a measuring tape, plot markers, treatment labels, an analytical balance, and writing instruments.

2.2. Experimental Design

The experiment used a Randomized Complete Block Design. Eight treatments were tested, each replicated 4 times, for a total of 32 experimental plots. The basal fertilizer was applied at 10 DAP (days after planting) and 30 DAP. The foliar fertilizer composition is 6.82% nitrogen, 2.52% P_2O_5, and 2.21% K_2O. It was applied as a foliar spray, diluted with 1 liter of water, and sprayed directly onto the plant's leaves six times throughout the experiment (15 DAP, 25 DAP, 35 DAP, 45 DAP, 55 DAP, and 65 DAP). The treatment details are presented in Table 1.

Table 1. Treatment of the fertilizer used

Code	Treatment	Foliar Fertilizer (L ha^{-1})	Urea (kg ha^{-1})	Phonska (kg ha^{-1})
A	Control	0	0	0
B	Standard fertilized	0	100	300
C	¼ PK	0.63	25	75
D	½ PK	1.25	50	150
E	¾ PK	1.88	75	225
F	1 PK	2.5	100	300
G	1 ¼ PK	3.13	125	375
H	1 ½ PK	3.75	150	450

2.3. Soil Preparation and Rice Planting

Soil preparation was conducted twice to ensure an optimal planting medium. The first tillage was performed with a plow to a depth of 20 cm, followed by the repair of field embankments and the cleaning of irrigation channels surrounding the rice plots. Once the seedlings were ready for transplanting, a second tillage was carried out to further loosen and refine the soil structure.

Prior to planting, the field was sprayed with pesticides to control pests, particularly golden apple snails. The rice variety used in this study was Ngaos Mawar. Seedlings were transplanted 20 days after sowing, provided they showed healthy, vigorous growth. The planting spacing used was 27 cm × 27 cm. Crop management included weed control through both mechanical and chemical methods. Irrigation was supplied via a technical irrigation system connected to tertiary channels, ensuring adequate water availability throughout the growth period. Harvesting was conducted at 100 days after sowing.

2.4. Measured Parameters

Soil properties and yield components were the variables observed in this study. The observations included: (1) soil properties, consisting of dispersion ratio, microaggregate distribution, soil texture, and soil pH, (2) rice production. Soil texture was determined using the hydrometer method after chemical dispersion with sodium hexametaphosphate, yielding percentages of sand (0.05–2.0 mm), silt (0.002–0.05 mm), and clay (<0.002 mm). The dispersion ratio was measured by placing air-dried soil in distilled water without chemical dispersion, then

measuring the percentage of fine particles that naturally separated. Soil texture represents the inherent physical property, while dispersion ratio reflects the effective texture under natural wet conditions.

2.5. Statistical Analysis

The data were analyzed using ANOVA, and treatment means were further compared using the LSD (Least Significant Difference) test at the 95% confidence level.

3. Results and Discussion

3.1. Soil characteristics

The preliminary soil analysis conducted at the Soil Science Laboratory, Faculty of Agriculture, University of Lampung (Table 2) indicates that the soil at the study site contains 47.68% sand, 20% silt, and 32.32% clay, classifying it as a sandy clay loam. The soil pH was 4.34, indicating an acidic soil. The total N content (0.08%) was low, while exchangeable K at 0.17 me 100 g^{-1} and the cation exchange capacity (CEC) of 5 me 100 g^{-1} were both categorized as very low. Available P was 7.34 ppm, which falls within the low range according to the Soil and Fertilizer Instrument Standard Testing Center criteria. These results indicate that the experimental soil has low inherent fertility. Therefore, the application of appropriate fertilizers is necessary to improve soil fertility and enhance crop productivity.

Table 2. Soil characteristic

No.	Soil Properties	Unit	Result
1	pH H_2O		4.34
2	C-organic	%	2.43
3	N-total	%	0.08
4	Available-P (P_2O_5)	ppm	7.34
5	Exchangeable K	me 100 $gram^{-1}$	0.17
6	CEC	me 100 $gram^{-1}$	5
7	Soil texture		
	- Clay	%	32.32
	- Silt	%	20
	- Sand	%	47.68

3.2. The Effect of Combined Application of Basal and Foliar NPK Fertilizers on Soil Properties

Table 3 reveals that soil dispersion ratios across all treatments ranged from 52.66% to 95.21%, classifying the soils as highly dispersive according to (Afandi, 2019). Soil dispersion ratio is a critical indicator of structural stability, as highly dispersive soils are inherently prone to surface crusting, reduced infiltration, and accelerated erosion, collectively compromising root-zone aeration and nutrient availability for crop uptake. A consistent decline in the dispersion ratio was observed with increasing fertilizer application rates, suggesting a dose-dependent effect of fertilizer on soil structural stability. This pattern may be attributed to the synergistic action of combined basal and foliar NPK applications, which are known to stimulate root proliferation and enhance root exudate secretion, both of which play pivotal roles in promoting soil aggregate formation (Sekaringtyas Ramadhani et al., 2025). NPK indirectly improves aggregation through better root development, such as increased root density, which provides physical binding and chemical cementing, and through root exudates (sugars, amino acids, phenolics) that bind particles into microaggregates (Wang et al., 2017).

Soil pH measured at 100 days after planting (Table 4) increased progressively with fertilizer dose, with treatment H recording significantly higher pH than both the control and standard-fertilized treatment. This alkalinizing trend reflects the two-phase pH dynamics characteristic of submerged paddy soils. In the initial aerobic phase, ammonium-based fertilizers such as urea undergo hydrolysis, transiently raising pH, before stimulating ammonia-oxidizing bacteria that accelerate nitrification and release protons, causing a short-term depression in soil pH (Tong and Xu, 2012). However, as submergence is prolonged and anaerobic conditions become established, this acidification is progressively overridden: microbial reduction of Fe^{3+}, Mn^{4+}, and SO_4^{2-} consumes large quantities of protons, driving soil pH toward neutral values of 6.5–7.5 regardless of initial acidity (Ding et al., 2019; Theresa et al., 2025). The dose-dependent pH increase observed across treatments suggests that higher fertilizer inputs supplied additional organic carbon and nitrogen substrates, thereby intensifying anaerobic microbial activity, accelerating proton consumption, and amplifying the net alkalinizing effect measured at 100 days after planting.

Table 3. Effect of treatment on soil dispersion ratio

Code	Treatment	Soil Dispersion Ratio (%)
A	Control	95.21%
B	Standard fertilized	78.58%
C	¼ PK	93.04%
D	½ PK	89.34%
E	¾ PK	85.14%
F	1 PK	77.99%
G	1 ¼ PK	63.02%
H	1 ½ PK	52.66%

Table 4. Effect of treatment on soil pH

Code	Treatment	Soil pH
A	Control	5.31 b
B	Standard fertilized	5.29 b
C	¼ PK	5.16 c
D	½ PK	5.37 b
E	¾ PK	5.29 b
F	1 PK	5.32 b
G	1 ¼ PK	5.42 b
H	1 ½ PK	5.54 a

Note: Different lowercase letters indicate significant differences between treatments ($p < 0.05$).

Soil texture, as shown in Tables 5 and 6. Table 5 shows soil texture analysis without dispersion solution (water). Soil texture is a stable property that is not easily changed. According to Table 5, the G and H treatments shifted the soil texture class from sandy loam to loamy sand. This sand formation is a water-stable aggregate pseudosand, which does not mean the actual mineral particles (sand, silt, clay) have changed; rather, it explains why the measured or apparent texture shifts toward a coarser class when fertilizers promote stronger soil aggregation. Plant roots and rhizodeposits promote soil aggregation, and, in this regard, polysaccharides exuded by roots or microbes, and OM in general, are relevant binding agents in the formation of microaggregates. The effects of high exudate carbon addition rates are especially pronounced in subsoil, where C-poor conditions make exudate-driven aggregation particularly transformative (Baumert et al., 2018).

Table 6 presents soil texture classification following particle size analysis with sodium hexametaphosphate (NaHMP) as the dispersion agent, which works by increasing the negative surface charge of clay minerals being adsorbed as an anion, giving complexes with flocculant cations, and substituting cations in the electrical double layer of clay with Na^+ ions (Zimmermann and Horn, 2020). With chemical dispersion applied, treatments A, B, C, D, and F were classified as clay, and treatments E, G, and H as clay loam. The shift toward finer texture classes upon dispersion relative to undispersed measurements suggests that clay particles had been physically entrapped within stable microaggregates, as bonding substances such as organic matter, carbonates, and iron oxides, when not removed prior to particle size analysis, allow small and large microaggregates to remain intact and contribute to the silt- and sand-size fractions, while the proportion of the clay fraction is reduced (Zimmermann and Horn, 2020). These structures are potentially consistent with pseudosand-type microaggregates, whose genesis in Oxisols is attributed to: (i) residual accumulation of pedogenic Fe- and/or Al-(hydr)oxides that weld kaolinite particles; and (ii) linkages between Fe- and/or Al-(hydr)oxides, kaolinite, and organic matter, which increase cohesive forces among clay particles (Martinez and Souza, 2020). Without the dispersion solution, these aggregates behave as silt- or sand-sized units during sedimentation analysis, leading to an underestimation of silt and clay fractions in particle size distribution analysis and, thus, an overestimation of coarser fractions due to the continuous formation of microaggregates (Clunes et al., 2022), producing an apparent texture that deviates substantially from the true primary particle size distribution.

Table 5. Effect of treatment on soil texture (analyzed without dispersion solution)

Code	Treatment	% Clay	% Silt	%Sand	Soil Texture Class
A	Control	6.50	20.01	73.49	Sandy loam
B	Standard fertilized	6.11	18.76	75.13	Sandy loam
C	¼ PK	5.76	20.27	73.97	Sandy loam
D	½ PK	5.95	19.63	74.42	Sandy loam
E	¾ PK	6.50	19.62	73.87	Sandy loam
F	1 PK	8.95	16.27	74.77	Sandy loam
G	1 ¼ PK	6.83	15.72	77.45	Loamy sand
H	1 ½ PK	4.54	16.78	78.68	Loamy Sand

Table 6. Effect of treatment on soil texture (analyzed with dispersion solution)

Code	Treatment	% Clay	% Silt	%Sand	Soil Texture Class
A	Control	44.23	21.09	34.68	Clay
B	Standard fertilized	41.72	24.60	33.68	Clay
C	¼ PK	44.27	22.10	33.63	Clay
D	½ PK	47.31	23.10	29.59	Clay
E	¾ PK	39.78	23.58	36.64	Clay loam
F	1 PK	43.11	21.60	35.28	Clay
G	1 ¼ PK	37.11	27.10	35.79	Clay loam
H	1 ½ PK	29.68	31.88	38.45	Clay loam

3.3. The Effect of Combined Application of Basal and Liquid NPK Fertilizers on Rice Production

This study measured rice production, as shown in Table 7. The data indicate that treatments combining standard fertilization with foliar fertilizer at C, D, E, F, and G did not differ significantly from the standard fertilization alone. Only H treatments resulted in significantly higher rice production. Additionally, all combined basal and foliar treatments (C-H) significantly increased rice production compared with the control. Previous research has demonstrated that applying macro- and micronutrient foliar fertilizers can notably boost rice grain yield and total dry biomass, with yield increases of up to 11% over the control treatment (Hawrylak-Nowak et al., 2020). Furthermore, Ishfaq et al. (2022) mentioned that treatments combining basal soil-applied fertilizer with foliar fertilizer performed better than soil-applied fertilizer alone, improving growth and yield parameters. This dual approach triggers synergistic root-shoot interactions, in which foliar-applied minerals stimulate increased soil nutrient uptake by the roots. Additionally, it mitigates environmental stress by restoring photosynthetic activity and nutrient assimilation when metabolic energy for root absorption is low (Hasanuzzaman et al., 2021). Ultimately, this complementary strategy provides rapid, targeted nutrition during critical growth stages while maintaining soil availability, resulting in superior crop productivity and higher economic returns (Ishfaq et al., 2022).

Table 7. Effect of treatment on rice production

Code	Treatment	Rice Production (kg plot^{-1})
A	Control	2.81 c
B	Standard fertilized	3.55 b
C	¼ PK	3.55 b
D	½ PK	3.62 b
E	¾ PK	3.80 b
F	1 PK	3.88 ab
G	1 ¼ PK	3.73 b
H	1 ½ PK	4.23 a

Note: Different lowercase letters indicate significant differences between treatments ($p < 0.05$).

The results of this study show that rice production increased to 3.55 – 4.23 kg plot^{-1}, representing improvements of approximately 26-50% compared with the control. This increase is attributed to the rapid, direct absorption of nutrients through foliar application, which bypasses soil-related constraints such as nutrient fixation and low nutrient availability (Praba et al., 2018). This mechanism enables faster nutrient absorption and utilization by rice plants during critical growth stages, notably flowering and grain filling.

4. Conclusion

Combined basal and foliar NPK fertilization significantly affected soil pH and rice production and also improved the soil dispersion ratio. The highest fertilizer dose (treatment H) raised soil pH above both the control and the standard-rate treatment, while the progressive decline in the soil dispersion ratio with increasing doses indicates fertilization-driven improvement in aggregate stability. Furthermore, only the 1½ PK treatment produced a statistically significant increase in rice production compared with the standard fertilized treatment. Overall, rice production improved by 26–50% over the control, affirming the agronomic value of integrating basal and foliar NPK fertilization in tropical lowland paddy systems.

References

Afandi. 2019. Fisika Tanah. Anugrah Utama Raharja, Indonesia. (in Indonesia)

Amoah, A.A., Tetteh, C.K. 2022. Effect of soil-applied and foliar fertilizer on rice (*Oryza sativa*). African Journal of Agricultural Research 18(8), 657–663. https://doi.org/10.5897/ajar2022.16039

Badan Pusat Statistik. 2026. Luas Panen Padi pada Tahun 2025 (Berita Resmi Statistik No. 16/02/Th. XXIX). Retrieved from https://bps.go.id (in Indonesia)

Balachandra, Y., Tej, M.K., Raju, S.J., Reddy, B.J. 2025. Foliar fertilization for nutrient use efficiency. International Journal of Agriculture and Nutrition 7(9), 96-101. https://doi.org/10.33545/26646064.2025.v7.i9b.293

Baumert, V.L., Vasilyeva, N.A., Vladimirov, A.A., Meier, I.C., Kögel-Knabner, I., Mueller, C.W. 2018. Root exudates induce soil macroaggregation facilitated by fungi in subsoil. Frontiers in Environmental Science 6, 422975. https://doi.org/10.3389/fenvs.2018.00140/text

Clunes, J., Dõrner, J., Bravo, A., Jara, R., Zúñiga, F., Clunes, J., Dõrner, J., Bravo, A., Jara, R., Zúñiga, F. 2022. Did we underestimate silt and clay content in the textural analysis? Chilean Journal of Agricultural & Animal Sciences 38(1), 94–103. https://doi.org/10.29393/chjaas38-9dwjf50009

Ding, C., Du, S., Ma, Y., Li, X., Zhang, T., Wang, X. 2019. Changes in the pH of paddy soils after flooding and drainage: Modeling and validation. Geoderma 337, 511–513. https://doi.org/10.1016/j.geoderma.2018.10.012

Hasanuzzaman, M., Parvin, K., Bardhan, K., Nahar, K., Anee, T.I., Masud, A.A.C., Fotopoulos, V. 2021. Biostimulants for the regulation of reactive oxygen species metabolism in plants under abiotic stress. Cells 10(10), 2537. https://doi.org/10.3390/cells10102537

Hawrylak-Nowak, B., Mahmoodi, B., Moballeghi, M., Eftekhari, A., Neshaie-Mogadam, M. 2020. Effects of foliar application of liquid fertilizer on agronomical and physiological traits of rice (*Oryza sativa* L.). Acta Agrobotanica 73(3), 7332. https://doi.org/10.5586/aa.7332

Ishfaq, M., Kiran, A., ur Rehman, H., Farooq, M., Ijaz, N.H., Nadeem, F., Azeem, I., Li, X., Wakeel, A. 2022. Foliar nutrition: Potential and challenges under multifaceted agriculture. Environmental and Experimental Botany 200, 104909 https://doi.org/10.1016/j.envexpbot.2022.104909

Kementerian Pertanian. 2026. BPS Rilis Angka Tetap Produksi Beras 2025 Capai 34,69 Juta Ton, Naik 13,29 Persen. Retrieved from https://lahanirigasi.pertanian.go.id/post/berita/bps-rilis-angka-tetap-produksi-beras-2025-capai-3469-juta-ton-naik-1329-persen (in Indonesia)

Ladha, J.K., Tirol-Padre, A., Reddy, C.K., Cassman, K.G., Verma, S., Powlson, D.S., Van Kessel, C., De Richter, D.B., Chakraborty, D., Pathak, H. 2016. Global nitrogen budgets in cereals: A 50-year assessment for maize, rice and wheat production systems. Scientific Reports 6(1), 19355. https://doi.org/10.1038/srep19355

Liu, Y., Ding, W., He, P., Xu, X., Zhou, W. 2024. Estimating thresholds of nitrogen, phosphorus and potassium fertilizer rates for rice cropping systems in China. Frontiers in Plant Science 15, 1470774. https://doi.org/10.3389/fpls.2024.1470774/text

Martinez, P., Souza, I.F. 2020. Genesis of pseudo-sand structure in Oxisols from Brazil – A review. Geoderma Regional 22, e00292. https://doi.org/10.1016/j.geodrs.2020.e00292

Praba, H., Harjoko, D., Yunus, A. 2018. Aplikasi hara mikro dan lengkap melalui daun pada beberapa varietas padi hibrida China. Agrosains 20(1), 7–12. https://doi.org/10.20961/agsjpa.v20i1.26312 (in Indonesia)

Ramadhani, W.S., Faqina, S., Septiana, L.M., Novpriansyah, H. 2025. Aplikasi kombinasi pupuk kiserite dan pupuk NPK terhadap nisbah dispersi tanah pada pertanaman jagung (*Zea mays* L.), Bandar Lampung. Agrocentrum 3(2), 79–95 https://doi.org/10.33005/agrocentrum.v3i2.101

Theresa, K., Vijayakumar, S., Hena, J.V., Raja, V. 2025. Soil pH, salinity and nutrient release dynamics in paddy soil influenced by varied levels of NPK fertilizers: Anaerobic incubation study. Plant Science Today 12(2), 1-8. https://doi.org/10.14719/pst.7612

Tong, D., Xu, R. 2012. Effects of urea and $(NH_4)_2SO_4$ on nitrification and acidification of Ultisols from Southern China. Journal of Environmental Sciences (China) 24(4), 682–689. https://doi.org/10.1016/s1001-0742(11)60832-2

Tuiwong, P., Cho, H.K., Rouached, H., Prom-U-Thai, C. 2024. Synergistic effects of nitrogen and zinc foliar application on yield and nutrient accumulation in rice at various growth stages. Plants 13(23), 3274. https://doi.org/10.3390/plants13233274

Wang, Z.H., Fang, H., Chen, M. 2017. Effects of root exudates of woody species on the soil anti-erodibility in the rhizosphere in a karst region, China. PeerJ 5, e3029. https://doi.org/10.7717/peerj.3029

Xing, Y., Xie, Y., Wang, X. 2025. Enhancing soil health through balanced fertilization: a pathway to sustainable agriculture and food security. Frontiers in Microbiology 16, 1536524. https://doi.org/10.3389/fmicb.2025.1536524/full

Zimmermann, I., Horn, R. 2020. Impact of sample pretreatment on the results of texture analysis in different soils. Geoderma 371, 114379. https://doi.org/10.1016/j.geoderma.2020.114379