

The effect of NPK–Zeolite fertilizer on the growth of kopyor coconut and nutrient availability in ultisols of Tasikmalaya

Suwardi^{1*}, Aurellia Havifah Suryadi¹, Octaviana Randrikasari², Sri Malahayati Yusuf¹, Darmawan¹, and Putri Oktariani¹

¹Department of Soil Science, Faculty of Agriculture, IPB University, Bogor 16680, Indonesia

²Center for Mine Reclamation Studies, International Research Institute for Environment and Climate Change, IPB University, Bogor 16680, Indonesia

Abstract. Ultisols in the Tasikmalaya region have low fertility, limited cation exchange capacity, and high nutrient fixation, which cause nutrient loss and restrict the growth of kopyor coconut. This study evaluated the effects of NPK-Zeolite fertilizer on vegetative growth and soil nutrient availability across different land-slope conditions. The research was conducted at PT Cigula Bumi Mineral, Tasikmalaya, from August to December 2024 using a 2×4 factorial Randomized Complete Block Design with two factors: fertilizer type (NPK-Zeolite and Conventional NPK) and land-slope classes (0–8%, 8–15%, 15–25%, >25%). Each treatment was replicated three times, resulting in 24 experimental units receiving 300 g of fertilizer per plant every three months. Data on vegetative growth and soil chemical properties were analyzed using ANOVA followed by DMRT at 5% significance. NPK-Zeolite increased ammonium availability to 76.72 ppm and potassium availability to 88.46 ppm, reflecting the slow-release characteristics of zeolite that reduced nutrient loss. However, plant height, stem diameter, and leaf number did not differ significantly between fertilizer types. Low soil phosphorus availability was likely the main factor limiting growth. Overall, NPK-Zeolite improved nitrogen and potassium efficiency in Ultisols, but additional measures are needed to overcome phosphorus deficiency.

1 Introduction

Ultisols are widely distributed in humid tropical regions of Indonesia and are characterized by advanced weathering, low inherent fertility, low cation exchange capacity (CEC), and high nutrient fixation, particularly phosphorus by iron and aluminum oxides [1]. These constraints result in poor nutrient retention and high susceptibility to nutrient losses through leaching, especially under high rainfall conditions typical of West Java. In Tasikmalaya, Ultisols dominate plantation and marginal agricultural lands, creating significant challenges

* Corresponding author: suwardi-soil@apps.ipb.ac.id

for sustainable crop production due to rapid depletion of applied nutrients and persistent phosphorus deficiency [2].

The efficiency of conventional mineral fertilizers applied to Ultisols is generally low. Nitrogen is prone to leaching and volatilization, potassium is easily displaced from exchange sites due to low CEC, and phosphorus becomes rapidly immobilized through fixation reactions. Consequently, repeated applications of conventional NPK fertilizers often fail to proportionally improve soil nutrient availability or plant growth, while simultaneously increasing production costs and environmental risks [3]. These limitations highlight the need for fertilizer technologies that enhance nutrient retention and synchronize nutrient release with plant demand.

Zeolite-based fertilizers have gained increasing attention as an alternative approach to improve nutrient use efficiency in highly weathered tropical soils. Natural zeolites are crystalline aluminosilicate minerals with a high specific surface area and permanent negative charges, enabling strong adsorption of cationic nutrients such as NH_4^+ and K^+ [4]. When incorporated into NPK fertilizers, zeolite acts as a slow-release matrix, reducing nutrient leaching losses, improving soil moisture retention, and enhancing the availability of exchangeable nutrients over time [5]. Studies by Suwardi *et al.* demonstrated that NPK fertilizers enriched with zeolite and humic substances significantly increased soil ammonium and potassium availability compared with conventional formulations, although plant growth responses were sometimes constrained by other limiting factors such as phosphorus availability [6].

In plantation systems established on Ultisols, topography further influences soil nutrient dynamics. Increasing land slope accelerates surface runoff, erosion, and nutrient transport, thereby exacerbating nutrient losses and spatial variability in soil fertility [7]. Sloping Ultisol landscapes, such as those found in Tasikmalaya, therefore require fertilizer management strategies that are resilient to both chemical limitations and physical land characteristics. However, information on the interaction between fertilizer formulation and land-slope classes in Ultisol-based plantation systems remains limited.

Kopyor coconut (*Cocos nucifera* L.) is a high-value perennial crop whose early vegetative growth is strongly dependent on sustained nutrient availability [8]. Establishing kopyor coconut on Ultisols requires fertilizer strategies that can maintain nutrient supply during critical growth stages while minimizing losses under challenging soil and landscape conditions. Therefore, this study aimed to evaluate the effects of NPK–zeolite fertilizer compared with conventional NPK on vegetative growth and soil nutrient availability of kopyor coconut across different land-slope classes in Ultisols of Tasikmalaya. The results are expected to contribute to improved fertilizer efficiency strategies for perennial crops cultivated on marginal tropical soils.

2 Materials and methods

2.1 Study area and site characteristics

The study was conducted from August to December 2024 at the Kopyor Coconut Plantation of PT Cigula Bumi Mineral, Karangmekar Village, Karangnunggal Sub-district, Tasikmalaya Regency, West Java, Indonesia ($\approx 7^\circ 37' 46''$ S; $108^\circ 10' 00''$ E). The experimental area covered approximately 5,390 m² and was dominated by Ultisol soil, characterized by acidic reaction, low cation exchange capacity, and heterogeneous fertility associated with sloping terrain.

Soil and plant observations were conducted at the field site, while soil chemical analyses were performed at the Laboratory of Land Physical Resources Development and Soil Fertility Chemistry, Faculty of Agriculture, IPB University.

Geologically, the area is situated within a lithological transition zone between the Kalipucang Formation, composed mainly of coralline limestone, and the Jampang Formation, characterized by volcanic–clastic materials (Fig. 1). This contrast produces heterogeneous topography ranging from gentle slopes to steep hillsides, which strongly influences soil development, erosion processes, and nutrient distribution [9]. Soils derived from weathered volcanic materials exhibit acidic reactions, low base saturation, and high phosphorus fixation, typical of Ultisols.

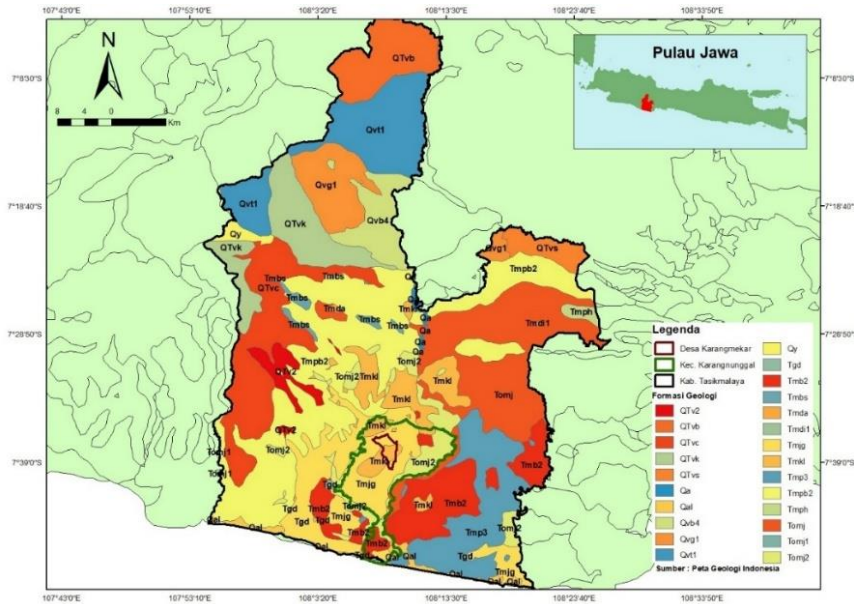


Fig. 1. Location and geological setting of the study area in Karangmekar Village, Karangnunggal Sub-district, Tasikmalaya Regency, West Java

2.2 Materials and equipment

The materials used in this study included an NPK–Zeolite fertilizer (6:6:12) formulated from urea, SP-36, and KCl, with natural zeolite as the carrier material and enriched with 1% humic substance. A conventional commercial NPK fertilizer (Phonska 15:15:15) was used as a comparison treatment. Pesticides were applied for routine crop protection during the experimental period, and disturbed soil samples were collected for soil chemical analysis.

Field equipment consisted of calipers and measuring tapes for plant growth measurements, soil augers, hoes, field knives, plastic bags, and labels. Laboratory analyses were conducted using standard soil chemical analysis instruments.

2.3 Experimental design

The plantation consisted of 110 ten-month-old dwarf kopyor coconut plants planted at a spacing of 7 × 7 m. From these population, 24 plants were selected as experimental units based on predefined criteria to ensure homogeneity and minimize bias. The selection criteria included good overall plant health, relatively uniform plant height and stem diameter, normal leaf colour and morphology, and absence of visible pest infection or disease symptoms. Plants showing mechanical damage, nutrient deficiency symptoms or abnormal growth were excluded. The selected plants were then grouped into four land-slope classes (0–8%, 8–15%,

15–25%, and >25%) to represent the variation in topographic conditions within the study area. The experiment employed a factorial Randomized Complete Block Design (RCBD) with two factors, as presented in Table 1.

Table 1. Experimental factors and treatment levels

Factor	Description	Treatment
A	Fertilizer type	Z = NPK–Zeolite (6:6:12)
		P = Conventional NPK (15:15:15)
B	Land-slope class (%)	L1 = 0–8%
		L2 = 8–15%
		L3 = 15–25%
		L4 = >25%

Each treatment combination was replicated three times, resulting in 24 experimental units. Land slope was determined in the field using a simple Abney level, based on elevation differences.

All treatments received 300 g plant⁻¹ of fertilizer, applied every three months intervals. The application rate was standardized on a mass basis to represent common field practice. Due to differences in formulation (NPK–zeolite 6:6:12 and Phonska 15:15:15), the resulting N, P, and K inputs were not nutritionally equivalent.

Nutrient contents were converted from oxide forms (P₂O₅ and K₂O) to elemental forms (P and K) using stoichiometric conversion to quantify actual nutrient supply. This design allowed evaluation of fertilizer performance under equal application weight, with particular emphasis on the potential role of zeolite in improving nutrient use efficiency and plant growth response.

2.3.1 Preparation of NPK–Zeolite Fertilizer

The NPK–Zeolite fertilizer (6:6:12) was produced by finely grinding urea, SP-36, and KCl to pass a 100-mesh sieve, followed by gradual mixing with natural zeolite (≈50% of total fertilizer mass) and 1% humic substance. The homogeneous mixture was granulated using a mechanical granulator.

The final nutrient composition slightly differed from the initial formulation (8:6:10) due to nitrogen losses during the granulation process, resulting in the applied formulation of 6:6:12.

2.3.2 Fertilizer application and crop management

Fertilizers were applied using a circular trench (ring placement) method at a radius of approximately 50–75 cm from the plant base, with a trench depth of 5–10 cm. Fertilizer granules were evenly distributed, then covered with soil to reduce nitrogen volatilization and surface runoff losses.

Weed control was conducted manually every two weeks to minimize nutrient competition. Preventive fungicide applications were applied weekly to control fungal diseases.

2.4 Plant growth observation

Vegetative growth was monitored every two weeks during the experiment. Measurements focused on plant height, stem diameter, and leaf number. Plant height was measured from the soil surface to the tip of the highest fully expanded leaf. Stem diameter was obtained by measuring stem circumference at 30 cm above ground level and converting it to diameter using the formula $D = C/\pi$. Leaf number was determined by counting fully expanded, healthy leaves, while old, drying leaves and unopened young leaves were not included.

2.5 Soil sampling and analysis

Disturbed soil samples were collected twice during the study: before fertilizer application to determine initial soil conditions and at the end of the experiment (week 13). Soil sampling was carried out at a depth of 0–20 cm using a composite sampling approach, in which soil from 10–15 sampling points within each land-slope class was combined.

The collected soil samples were air-dried, sieved, and then analyzed for their chemical properties using standard laboratory methods (Table 2).

Table 2. Soil chemical parameters and analytical method

Parameter	Method
NH ₄ ⁺ -N, NO ₃ ⁻ -N	Kjeldahl
Available P (P ₂ O ₅)	Bray-1
Available K	Bray-1
Exchangeable Ca, Mg, K, Na	NH ₄ OAc pH 7.0
Cation Exchange Capacity	NH ₄ OAc pH 7.0
Base saturation	Calculation
pH	H ₂ O (1:5)
Electrical conductivity	EC meter
Organic C	Walkley–Black

2.6 Statistical analysis

Data were analyzed using ANOVA at a 5% significance level. Prior to ANOVA, residuals were tested for normality (Shapiro–Wilk test) and homogeneity of variance (Levene’s test). When significant treatment effects were detected, Duncan’s Multiple Range Test (DMRT) at $\alpha = 0.05$ was applied to compare treatment means. The statistical model used was:

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \epsilon_{ijk}$$

where:

Y_{ijk} = observed response, μ = overall mean, A_i = effect of fertilizer type, B_j = effect of land slope, $(AB)_{ij}$ = interaction effect, ϵ_{ijk} = experimental error.

3 Results and discussion

3.1 Soil chemical characteristics before treatment

Before fertilizer application, the soil at the experimental site showed clear chemical limitations typical of Ultisols (Table 3). Soil pH was consistently acidic (pH 5.03–5.14), organic carbon content was low (2.01–2.72%), and available phosphorus was extremely low across all slope classes (approximately 4.0–4.3 ppm). These conditions indicate that phosphorus availability was already a major constraint prior to treatment.

Although the soil had a relatively high cation exchange capacity (27.37–28.30 cmol(+)/kg), exchangeable base cations such as Ca, Mg, and K were low. This suggests that most exchange sites were occupied by acidic cations rather than plant-available nutrients [10]. In practical terms, the soil had the *capacity* to retain nutrients, but the actual nutrient reserves were limited. These baseline conditions are important because they help explain why improvements in nutrient availability did not always translate into visible plant growth responses.

Table 3. Initial soil chemical properties before treatment

Soil Parameter	Value Range	Classification
Soil pH (H ₂ O)	5.03 – 5.14	Acidic
Organic Carbon (%)	2.0 – 2.7	Low
Available-K (ppm)	62 – 81	Low
Available-P (ppm)	4.06 – 4.25	Very Low
CEC cmol(+)/kg)	27.37 – 28.30	High
Exchangeable-Ca	4.34 – 5.44	Low
Exchangeable-Mg	0.25 – 0.36	Very Low
Exchangeable-K	0.20 – 0.25	Low

3.2 Vegetative growth response to fertilizer type and land slope

Fertilizer type did not significantly affect plant height, stem diameter, or leaf number during the 13-week observation period (Table 4). Although plants fertilized with P (15:15:15) tended to show slightly higher plant height at later observation weeks, while Z (6:6:12) showed marginally greater stem diameter, these differences were not statistically significant ($p \leq 0.05$). The relatively large standard deviations, particularly for plant height, indicate considerable variability among plants, which may have obscured treatment effects. Overall, both fertilizer types exhibited comparable performance during early vegetative growth of kopyor coconut.

Table 4. Effect of fertilizer type on growth of kopyor coconut at different weeks after fertilization

Plant height (cm)		
Weeks after fertilization	Z (6:6:12)	P (15:15:15)
5	248.63 ± 34.99 a	254.17 ± 35.31 a
7	255.83 ± 33.36 a	267.58 ± 37.92 a
9	261.00 ± 33.67 a	279.75 ± 37.87 a
11	270.89 ± 37.24 a	288.09 ± 39.53 a
13	281.06 ± 37.41 a	302.71 ± 33.44 a
Stem diameter (cm)		
Weeks after fertilization	Z (6:6:12)	P (15:15:15)
5	11.04 ± 0.57 a	10.85 ± 0.65 a
7	11.37 ± 0.53 a	11.01 ± 0.61 a
9	11.87 ± 0.56 a	11.42 ± 0.93 a
11	12.34 ± 0.49 a	11.65 ± 1.09 a
13	12.49 ± 0.48 a	11.66 ± 1.09 a
Number of leaves		
Weeks after fertilization	Z (6:6:12)	P (15:15:15)
5	6.67 ± 1.15 a	6.83 ± 1.11 a
7	7.33 ± 1.37 a	7.25 ± 1.06 a
9	7.33 ± 1.37 a	7.75 ± 1.06 a
11	8.17 ± 1.34 a	8.33 ± 1.23 a
13	8.33 ± 1.15 a	8.92 ± 1.51 a

Notes:

Values followed by the same letter within the same row indicate no significant difference between fertilizer types at the same observation time ($p \leq 0.05$).

Z = NPK–Zeolite fertilizer (6:6:12);

P = Phonska fertilizer (15:15:15).

Land slope significantly affected vegetative growth of kopyor coconut. Plant height decreased consistently with increasing slope [11], with the lowest values observed on steep land (>25%), likely due to increased runoff, reduced water infiltration, and nutrient losses (Table 5). In contrast, stem diameter was not significantly affected by slope, while leaf number was influenced only during the early observation period.

Table 5. Effect of land slope on plant height of kopyor coconut

Land slope class	Plant height (cm)				
	Weeks after fertilization				
	5	7	9	11	13
L1	276.00 a	283.00 a	293.00 a	302.50 a	311.92 a
L2	246.42 ab	259.00 ab	265.50 ab	273.33 ab	280.82 ab
L3	263.67 a	277.25 a	282.92 ab	296.75 a	312.28 a
L4	219.50 b	227.58 b	240.08 b	245.38 b	262.52 b

Notes:

Values followed by the same letter within the same column are not significantly different according to Duncan’s Multiple Range Test (DMRT) at $p \leq 0.05$.

L1 = land slope 0–8%; L2 = 8–15%; L3 = 15–25%; L4 = >25%.

A significant interaction between fertilizer type and land slope was observed for plant height, indicating that fertilizer performance depended on landscape position (Table 6). At 13 weeks after fertilization, the highest plant height was recorded under the Z fertilizer at the 8–15% slope (L2Z), whereas the lowest values were generally observed under P fertilizer at steeper slopes (L3P and L4P). These results indicate that fertilizer performance varied across slope classes, suggesting that nutrient response was influenced by landscape position.

Table 6. Interaction effect of fertilizer type and land slope on plant height of kopyor coconut

Treatments	Plant height (cm)				
	Weeks after fertilization				
	5	7	9	11	13
L1Z	260.00 ab	263.67 ab	269.00 ab	280.00 ab	292.17 ab
L2Z	292.00 a	302.33 a	317.00 a	325.00 a	331.67 a
L3Z	251.17 ab	254.67 ab	259.67 ab	271.00 ab	272.80 ab
L4Z	241.67 ab	263.33 ab	271.33 ab	275.67 ab	288.83 ab
L1P	260.67 ab	273.33 ab	278.50 ab	291.50 ab	304.67 ab
L2P	266.67 ab	281.17 ab	287.33 ab	302.00 ab	319.90 ab
L3P	222.67 b	231.67 b	236.83 b	241.07 b	254.60 b
L4P	216.33 b	223.50 b	243.33 b	249.70 b	270.43 ab

Notes:

Values followed by the same letter within the same column are not significantly different according to Duncan’s Multiple Range Test (DMRT) at $p \leq 0.05$.

3.3 Soil nutrient availability after fertilization

In contrast to plant growth responses, soil nutrient analysis displayed clear differences between fertilizer types (Fig. 2.). Despite receiving the same fertilizer dose (300 g plant⁻¹), soils treated with NPK–Zeolite contained significantly higher concentrations of ammonium and potassium at the end of the experiment (Table 7). Ammonium levels reached 76.72 ppm, and potassium reached 88.46 ppm, compared with 55.47 ppm NH₄⁺ and 69.11 ppm K under conventional NPK.

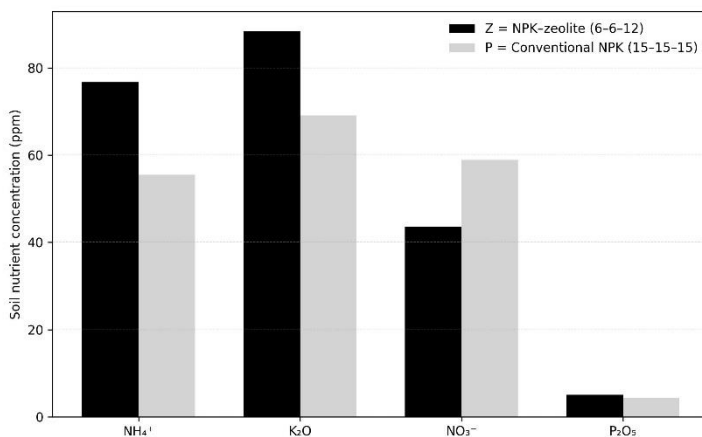


Fig. 2. Soil nutrient concentrations under NPK–zeolite (Z) and conventional NPK (P) treatments at the end of the experiment

These results demonstrate the ability of zeolite to retain cationic nutrients through its porous structure and high cation exchange capacity, of zeolite allow it to hold ammonium and potassium on exchange sites, protecting them from rapid leaching and releasing them gradually into the soil solution [12]. In contrast, nitrate and available phosphorus remained low and did not differ significantly between treatments. Nitrate is highly mobile and easily leached, while phosphorus in Ultisols is strongly fixed by iron and aluminum oxides [13]. Zeolite does not effectively bind anions, so it cannot overcome phosphorus fixation. This finding reinforces the conclusion that phosphorus availability remained the main limiting factor in this study.

Table 7. Effect of fertilizer type on soil nutrients after treatment

Treatments	NH ₄ ⁺ (ppm)	NO ₃ ⁻ (ppm)	P ₂ O ₅ (ppm)	K ₂ O (ppm)
Z (6:6:12)	76.72 a	43.55 a	5.05 a	88.46 a
P (15:15:15)	55.47 b	58.86 a	4.36 a	69.11 b

Notes:

Values followed by the same letter within the same row indicate no significant difference between fertilizer types at the same observation time ($p \leq 0.05$).

Z = NPK–Zeolite fertilizer (6:6:12);

P = Phonska fertilizer (15:15:15).

Land slope further influenced nutrient availability. Both ammonium and potassium decreased as slope increased (Table 8), reflecting higher risks of erosion and nutrient loss on steeper land. Importantly, NPK–Zeolite consistently maintained higher ammonium and potassium levels than conventional NPK across slope classes, suggesting that its benefits are especially relevant in sloping landscapes.

Table 8. Effect of land slope on soil nutrient contents after treatment

Land slope treatment	NH ₄ ⁺ (ppm)	NO ₃ ⁻ (ppm)	P ₂ O ₅ (ppm)	K ₂ O (ppm)
L1 (0–8)%	70.38 a	58.67 a	5.38 a	102.00 a
L2 (8–15)%	65.63 b	47.59 a	4.70 a	84.32 ab
L3 (15–25)%	67.67 ab	49.79 a	4.34 a	72.43 bc
L4 (>25)%	60.71 c	48.79 a	4.39 a	56.40 c

Notes:

Values followed by the same letter within the same column are not significantly different according to Duncan’s Multiple Range Test (DMRT) at $p \leq 0.05$.
 L1 = land slope 0–8%; L2 = 8–15%; L3 = 15–25%; L4 = >25%.

Overall, the results show that NPK–Zeolite is effective in improving nitrogen and potassium retention in Ultisols, but this improvement alone was not sufficient to enhance short-term vegetative growth of kopyor coconut. The consistently low phosphorus availability indicates that phosphorus was the dominant growth-limiting factor throughout the experiment.

In this context, the value of NPK–Zeolite lies not in rapid growth stimulation, but in building a more efficient and sustainable nutrient management system for perennial crops grown on highly weathered tropical soils.

4 Conclusion

NPK–Zeolite fertilizer significantly increased soil ammonium and potassium availability in Ultisols, but this improvement did not result in significant short-term vegetative growth of kopyor coconut. Land slope had a greater effect on plant height than fertilizer type, with growth decreasing markedly on steep slopes (>25%). Persistent low phosphorus availability remained the main growth-limiting factor, indicating that NPK–Zeolite should be combined with additional phosphorus management strategies to improve crop performance.

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