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Enhancing groundnut (*Arachis hypogaea* L.) growth and yield using oil palm empty fruit bunch ash and urea fertilizer in Ultisols

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Abstract The results showed that a significant interaction affected the number of partially filled pods per plant, dry seed weight per plot, and 100-seed weight. Individually, oil palm empty fruit bunch (EFB) ash significantly affected plant height, flowering age, root nodules, leaf greenness, and pod yield parameters, while urea significantly influenced plant height, flowering age, root nodules, leaf greenness, and dry pod weight per plot. The optimal treatment combination was 50 kg ha^{-1} urea with 6 ton ha^{-1} oil palm EFB ash, producing the highest dry seed weight (269.60 g per plot). The most favorable single-factor responses were obtained at 4 ton ha^{-1} oil palm EFB ash for overall vegetative performance and at 50 kg ha^{-1} urea for nodulation and yield-related traits.

Keywords: Acidic soil, Nutrient management, Peanut, Root nodulation, Seed filling

Introduction

Groundnut (*Arachis hypogaea* L.) is an important food legume in Indonesia and many other countries because it provides both vegetable protein and oil. It is consumed in various processed forms and remains relevant for food and farming systems. However, actual field yields are often lower than the crop's genetic potential, especially when the crop is grown on suboptimal land (Boote *et al*., 2003; FAO, 2022).

Domestic production has not yet met national demand. Data from Pusat Data dan Sistem Informasi Pertanian (2023) show that peanut productivity in Indonesia has fluctuated in recent years, with a national average of 13.40 quintals ha^{-1} (approximately 1.34 tons ha^{-1}) in 2022. This figure remains below the yield potential of improved groundnut varieties, which can reach around 4 tons ha^{-1} or more under favorable conditions (Balai Penelitian Tanaman Aneka Kacang dan Umbi, 2023). Pressure on fertile land and continuing land conversion further strengthen the need to use marginal land more efficiently (BPS, 2023; Mulyani and Las, 2008).

Ultisols are among the major marginal soils in Indonesia. These acidic soils are widely distributed in regions such as Sumatra, Kalimantan, and Papua. Their main constraints include low pH, high Al and Fe toxicity, and low availability of essential nutrients such as nitrogen and phosphorus. These conditions can restrict root development, nodulation, and crop productivity (Subagyo *et al*., 2020; Von Uexküll and Mutert, 1995; Fageria and Baligar, 2005).

To address N limitations, farmers often depend on inorganic fertilizers like urea. Although effective, over-reliance on Urea has serious sustainability problems. Globally, N uptake efficiency by plants is often below 50%, meaning more than half of the N fertilizer is lost through leaching, volatilization, and denitrification, leading to water and air pollution (N_2O emissions) (Ladha *et al*., 2016). In Indonesia, this practice can also accelerate soil acidification and cause

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other nutrient imbalances (Purwanti *et al*., 2021). Therefore, the global sustainable agriculture paradigm encourages the integration of organic fertilizers to improve N efficiency and soil health (IPBES, 2018).

Oil palm empty fruit bunch (EFB) ash is a solid by-product of the palm oil industry and has potential as a soil amendment. Its alkaline nature helps reduce soil acidity, and it also supplies K, P, Ca, Mg, and several micronutrients (Noble *et al*., 2000; Rengel, 2003; Setiawan *et al*., 2022). Previous work on soybean also showed that oil palm EFB ash improved the root environment and supported yield formation (Sipayung *et al*., 2024). Therefore, combining oil palm EFB ash with urea was expected to improve nutrient availability and support groundnut growth in Ultisols.

This study aimed to evaluate the effect of oil palm EFB ash and urea, applied singly and in combination, on the growth and yield of groundnut in Ultisols.

Materials and methods

Research time and location

The experiment was conducted at the Agronomy Experimental Field, Department of Crop Production, University of Bengkulu, from July to October 2024. The site is located at 3.452060° S, 102.16180° E, at an altitude of about 10 m above sea level.

Materials and equipment

The materials used in this study were Talam 1 groundnut seeds, urea fertilizer, oil palm empty fruit bunch (EFB) ash, *Rhizobium* inoculant, TSP fertilizer, and pesticides. The equipment included hoes, measuring tapes, machetes, watering cans, labels, a SPAD meter, a knapsack sprayer, digital scales, a camera, and other supporting tools.

The study employed a factorial randomized complete block design, consisting of two treatment factors, i.e. Factor I was the dosage of oil palm empty fruit bunch (EFB) ash, comprising K0 = 0 ton ha^{-1} (control), K1 = 2 ton ha^{-1}, K2 = 4 ton ha^{-1}, and K3 = 6 ton ha^{-1} (Siringoringo, 2015), while Factor II was the dosage of single urea fertilizer, comprising N0 = 0 kg ha^{-1} (control), N1 = 25 kg ha^{-1}, N2 = 50 kg ha^{-1}, and N3 = 75 kg ha^{-1} (Kristina *et al.,* 2016); the two factors were combined to create 16 treatment combinations, each replicated 3 times, resulting in a total of 48 experimental plots, each plot measured 2.5 m × 2.0 m (5 m^2).

The research area was an open, flat field with optimal sunlight exposure. The soil was tilled and formed into plots, with 0.5 m spacing between plots and 1 m between blocks. Plants were spaced at 40 cm × 40 cm. Prior to the application of oil palm empty fruit bunch (EFB) ash, initial soil analysis was conducted by collecting composite soil samples from a depth of 0-20 cm at three different sites. These samples were analyzed for pH, organic-C, N, P, and K content. Simultaneously, a 300 g sample of the oil palm EFB ash was analyzed for its N, P, K content and pH.

As a treatment, the oil palm EFB ash was applied by evenly broadcasting it onto the planting rows within each plot, seven days prior to planting. Following this, basal fertilization was carried out by applying TSP fertilizer to the rows. Planting of the groundnut seeds was conducted three days after the application of the basal fertilizer.

Planting and crop management

The Talam 1 groundnut variety was sown along with Furadan insecticide followed by covering with soil, and at 7 Days After Planting (DAP), resowing was carried out to replace seeds that failed to grow. Urea fertilizer was applied in two split doses: half at 7 DAP and the remaining half at 21 DAP. The fertilizer was placed in furrows made between the plant rows to prevent losses from rain, irrigation, or volatilization.

Maintenance, observation, and harvest

Crop maintenance included manual weeding starting at 7 DAP with an interval every week. Irrigation was applied in the morning and evening during dry periods to maintain soil moisture at field capacity. Pest and disease control was implemented chemically using pesticides based on the kind of infested pests. Additionally, at 42 DAP, soil from between the rows was hilled around the plant base to provide space for gynophore development. Harvest was carried out when most leaves turned to yellow by carefully uprooting the plants to ensure that no pods were left behind in the soil.

A random sample of 5 plants per plot, excluding border plants, was selected for data collection. The observed variables in this study included plant height (cm), flowering age (days), number of root nodules, leaf greenness level (SPAD value), number of filled pods per plant, number of empty pods per plant, number of partially filled pods per plant, weight of filled pods per plant (g), dry pod weight per plot (g), dry seed weight per plot (g), and 100-seed weight (g). All data were analyzed by analysis of variance (ANOVA) using the SAS GLM procedure at the 5% level. When the F-test was significant, mean separation was performed using Duncan's Multiple Range Test (DMRT) at the same probability level. Climatic data and initial soil properties were also recorded to support interpretation of the results.

Results

This study showed that the integrated application of oil palm empty fruit bunch (EFB) ash and urea improved the growth and yield of groundnut cultivated on acidic Ultisols. Initial soil analysis revealed strongly acidic conditions (pH 4.18), low potassium (0.26 me/100 g), total nitrogen of 0.35%, and high organic carbon of 5.31%, indicating less favorable conditions for groundnut growth. Analysis of the oil palm EFB ash showed that it had high potassium (9.14%), phosphorus (0.97%), and an alkaline pH (10.2), indicating its potential as a soil amendment and nutrient source. Climatic conditions during the study period (July-October 2024) were also suboptimal, with rainfall averaging 106.1 mm month^{-1}, relative humidity of 83%, and mean temperature of 27.9°C. In this experiment, the soil was intentionally left unlimed to evaluate the effectiveness of oil palm EFB ash under acidic soil conditions.

Growth pattern of groundnut plants

Plant height was used to describe the growth pattern of groundnut during the vegetative phase. Plant height increased during early growth as a result of apical meristem activity in shoots and roots. Groundnut plant height continued to increase until the early generative phase. The treatment-specific plant height trend is presented in Figure 1.

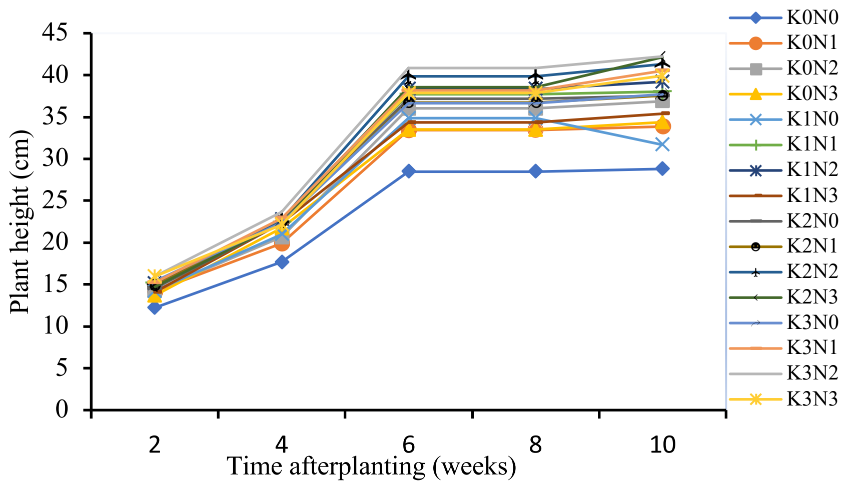

Figure 1. Plant height growth pattern of groundnut plants as influenced by the application of oil palm empty fruit bunch ash and urea doses

Note: K0 = 0 ton ha⁻¹, K1 = 2 ton ha⁻¹, K2 = 4 ton ha⁻¹, K3 = 6 ton ha⁻¹; N0 = 0 kg ha⁻¹, N1 = 25 kg ha⁻¹, N2 = 50 kg ha⁻¹, N3 = 75 kg ha⁻¹.

All treatment combinations exhibited a linear growth rate from week 2 to week 6, after which no further increase in plant height was observed after flowering began.

Root nodule growth pattern

Root nodules are found to be small swellings that form on the roots of plants, particularly legumes, as a result of infection by nitrogen-fixing bacteria. Observations of root nodules in groundnut plants were conducted at 2, 4, 6, and 8 weeks after planting (WAP), as illustrated in Figure 2.

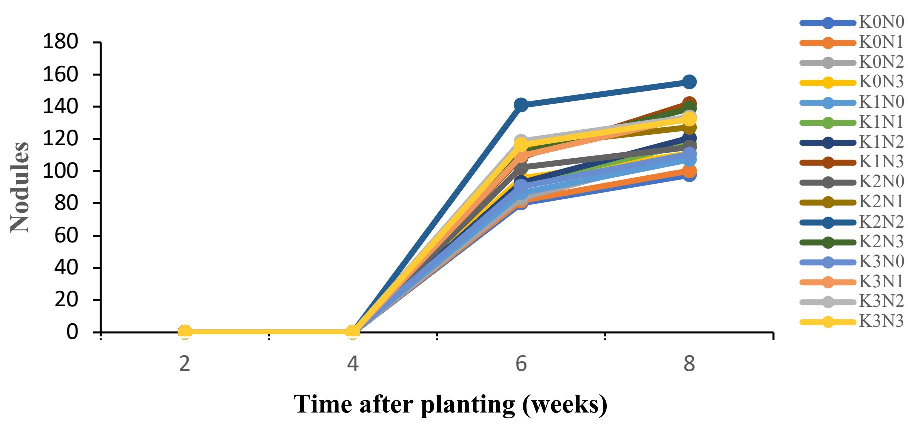

Figure 2. Formation of root nodules in groundnut plants on Ultisols soil under various doses of oil palm empty fruit bunch ash and urea fertilizer

Note: K0 = 0 ton ha⁻¹, K1 = 2 ton ha⁻¹, K2 = 4 ton ha⁻¹, K3 = 6 ton ha⁻¹; N0 = 0 kg ha⁻¹, N1 = 25 kg ha⁻¹, N2 = 50 kg ha⁻¹, N3 = 75 kg ha⁻¹.

Nodules were first observed at 6 weeks after planting in all treatments. From week 6 to week 8, nodule number continued to increase in all treatments. Their delayed appearance may be related to the initial acidity of the soil, while the subsequent increase suggests that the amended soil environment became more favorable for nodulation.

Analysis of variance

The results revealed significant independent effects of oil palm EFB ash and urea on most growth and yield parameters, while their interaction was significant only for the number of partially filled (cipo) pods, dry seed weight per plot, and 100-seed weight (Table 1).

Table 1. The effect of oil palm EFB Ash and urea fertilizer doses on the growth and yield of groundnut plants

Variables	F value						CV %
	EFB		Urea		Interaction		
Plant height	28.73	**	18.15	**	1.77	Ns	5.40
Flowering age	12.83	**	6.75	**	0.93	Ns	6.73
Number of root nodules	4.92	**	3.82	*	0.42	Ns	5.75T
Leaf greenness level	5.62	**	74.27	**	1.49	Ns	6.26
Number of filled pods per plant	4.50	*	2.07	Ns	1.02	Ns	25.05
Number of empty pods per plant	0.75	Ns	0.23	Ns	0.51	Ns	23.65T
Number of partially filled pods per plant	5.24	**	1.22	Ns	3.00	*	30.19
Weight of filled pods per plant	2.25	Ns	1.61	Ns	1.94	Ns	33.38
Dry pod weight per plot	17.12	**	9.13	**	0.57	Ns	20.07
Dry seed weight per plot	7.63	**	8.40	**	3.2	**	15.21T
100-seed weight	15.27	**	15.94	**	3.97	**	10.22

Note: (*) Significant at the 5% level, (**) Highly significant at the 1% level, (Ns) Not significant, (CV) Coefficient of variation (%), T = Data transformed using square root.

Interaction effects

Number of partially filled pods per plant

The mean comparison of the interaction effect between the dosage of oil palm EFB ash and urea fertilizer on the variable of number of partially filled (cipo) pods of groundnut is shown in Table 2.

Table 2. Mean comparison of the interaction effect between oil palm EFB ash and urea on the number of partially filled (cipo) pods of groundnut

EFB	Urea			
	0 kg ha^{-1}	25 kg ha^{-1}	50 kg ha^{-1}	75 kg ha^{-1}
0 ton ha^{-1}	7.07 b A	6.87 b A	5.80 b A	5.27 b A
2 ton ha^{-1}	8.33 ab AB	10.13 a AB	5.53 b B	6.93 ab B
4 ton ha^{-1}	10.80 a A	7.73 ab B	10.93 ab A	8.47 a AB
6 ton ha^{-1}	7.20 ab B	7.53 ab B	15.33 a A	9.27 a AB

Note: Lowercase letters are read vertically to compare values across oil palm empty fruit bunch (EFB) ash doses, while uppercase letters are read horizontally to compare values across urea fertilizer doses.

The interaction between oil palm EFB ash and urea significantly affected the number of partially filled (cipo) pods. The highest value (15.33) was recorded under the combination of 6 ton ha^{-1} oil palm EFB ash and 50 kg ha^{-1} urea. Lower values were observed in several other treatments, including K0N3 (5.27) and K1N2 (5.53). These results indicate that the response of cipo pods depended on the combination of both factors.

Dry seed weight per plot

The interaction between oil palm EFB ash and urea significantly affected dry seed weight per plot (Table 1). The response to each fertilizer was highly dependent on the dosage of the other, meaning their effects were not independent.

Table 3. Mean comparison of the interaction effect of oil palm EFB ash and urea on the dry seed weight per plot of groundnut

EFB	Urea			
	0 kg ha^{-1}	25 kg ha^{-1}	50 kg ha^{-1}	75 kg ha^{-1}
0 ton ha^{-1}	65.00 b B	88.33 b AB	104.26 b AB	149.26 ab A
2 ton ha^{-1}	101.16 a B	178.50 a A	154.76 b A	122.63 b A
4 ton ha^{-1}	113.36 a B	118.76 ab B	136.36 b B	216.76 a A
6 ton ha^{-1}	103.16 a B	143.36 ab BC	269.60 a A	201.60 ab B

Note: Lowercase letters are read vertically to compare values across oil palm empty fruit bunch (EFB) ash doses, while uppercase letters are read horizontally to compare values across urea fertilizer doses.

The highest dry seed weight, 269.60 g plot^{-1}, was obtained from the combination of 6 ton ha^{-1} oil palm EFB ash and 50 kg ha^{-1} urea. At the highest EFB level, dry seed weight increased up to 50 kg ha^{-1} urea and then declined at 75 kg ha^{-1}. In contrast, lower dry seed weights were generally found in the control and in several single-factor treatments. At 2 ton ha^{-1} oil palm EFB ash, dry seed weight declined from 178.50 g plot^{-1} at 25 kg ha^{-1} urea to 122.63 g plot^{-1} at 75 kg ha^{-1} urea. These results indicate that dry seed weight depended on a balanced combination of oil palm EFB ash and urea.

100-seed weight

Interaction between the two fertilizers also affected 100-seed weight, indicating that seed filling responded to the balance between soil amendment and nitrogen supply.

Table 4. Mean comparison of the interaction effect of oil palm EFB ash and urea on the 100-seed weight of groundnut

EFB	Urea			
	0 kg ha^{-1}	25 kg ha^{-1}	50 kg ha^{-1}	75 kg ha^{-1}
0 ton ha^{-1}	19.10 b B	30.00 b AB	31.73 b AB	37.63 a A
2 ton ha^{-1}	31.37 ab B	39.97 a A	37.37 b AB	36.73 a AB
4 ton ha^{-1}	35.20 a AB	37.70 ab AB	33.53 b B	41.00 a A
6 ton ha^{-1}	32.83 ab B	35.20 ab B	46.40 a A	42.00 a AB

Note: Lowercase letters are read vertically to compare values across oil palm empty fruit bunch (EFB) ash doses, while uppercase letters are read horizontally to compare values across urea fertilizer doses.

The highest 100-seed weight, 46.40 g, was obtained from the combination of 6 ton ha^{-1} oil palm EFB ash and 50 kg ha^{-1} urea (Table 4). This treatment outperformed most other combinations and suggests that seed filling was optimized when both inputs were applied at balanced levels. Increasing urea to 75 kg ha⁻¹ did not improve seed weight further at the highest EFB rate, indicating that a higher nitrogen dose was not always more effective.

Effect of oil palm empty fruit bunch ash dosage on the growth and yield of groundnut

Mean values for plant height, flowering age, number of nodules, and leaf greenness are presented in Table 5. Oil palm EFB ash significantly affected all four variables. In general, plant growth improved from 0 to 4 ton ha^{-1}, while the response at 6 ton ha^{-1} was smaller for some traits.

Table 5. The effect of EFB dosage on groundnut growth

EFB	PH (cm)	FA (days)	Nodules	LGL
0 ton ha^{-1}	33.48 c	32.87 b	105.00 c	31.40 b
2 ton ha^{-1}	36.08 b	36.32 a	121.75 b	33.60 a
4 ton ha^{-1}	39.64 a	38.07 a	134.16 a	33.81 a
6 ton ha^{-1}	40.08 a	38.40 a	128.08 a	34.79 a

Note: Means within a column followed by the same letter are not significantly different at the 5% level according to DMRT. PH = plant height; FA = flowering age; Nodules = number of root nodules; LGL = leaf greenness level.

Plant height increased from 33.48 cm in the control to 39.64 cm at 4 ton ha^{-1} and was not markedly higher at 6 ton ha^{-1}. Flowering was delayed in all EFB treatments relative to the control. The number of nodules increased up to 4 ton ha^{-1}, while leaf greenness improved in all amended treatments and remained high at 6 ton ha^{-1}. Overall, 4 ton ha^{-1} gave the most balanced response for vegetative growth.

The effect of oil palm EFB ash on groundnut yield

Oil palm EFB ash significantly affected several yield components of groundnut plants, including the number of filled pods, partially filled pods, dry pod weight per plot, dry seed weight per plot, and 100-seed weight (Table 6). The most effective EFB ash rates were generally observed at 4–6 ton ha^{-1}. The clearest responses were found in pod number, dry weight, and seed quality.

Table 6. The Effect of Oil Palm EFB dosage on the yield of groundnut

EFB	NFPP	NEPP	NPFPP	WFPP (g)	DPWP (g)	DSWP (g)	100-SW (g)
0 ton ha^{-1}	25.43 b	3.56	6.28 c	34.53	227.08 c	101.71 c	29.62 b
2 ton ha^{-1}	26.73 b	4.63	7.73 b	38.06	293.41 b	139.26 bc	36.36 a
4 ton ha^{-1}	33.83 a	4.51	9.53 ab	46.90	357.39 a	146.31 b	36.86 a
6 ton ha^{-1}	34.17 a	4.25	9.86 a	45.73	403.41 a	189.40 a	39.11 a

Note: Values within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% level. The abbreviations represent: Oil Palm Empty Fruit Bunch Ash (EFB), number of filled pods per plant (NFPP), number of empty pods per plant (NEPP), number of partially filled pods per plant (NPFPP), weight of filled pods per plant (WFPP), dry pod weight per plot (DPWP), dry seed weight per plot (DSWP), and 100-seed weight (100-SW).

Filled pods per plant increased from 25.43 in the control to 34.17 at 6 ton ha^{-1}. Dry pod weight per plot and dry seed weight per plot also increased, from 227.08 g and 101.71 g in the control to 403.41 g and 189.40 g, respectively, at 6 ton ha^{-1}. Although partially filled pods were also higher at the largest dose, seed weight and 100-seed weight still improved, indicating better overall yield performance. Empty pod number did not differ significantly among treatments. These results show that oil palm EFB ash improved yield formation on Ultisols, with the clearest gains occurring at 4-6 ton ha^{-1}.

The effect of urea on groundnut growth

Urea application significantly affected plant height, flowering age, root nodule number, and leaf greenness level of groundnut plants (Table 7). In general, plant growth improved up to 50 kg ha^{-1} urea, although the response at 75 kg ha^{-1} was not consistent for all variables.

Table 7. Effect of urea dosage on groundnut growth

Urea	PH(cm)	FA(days)	Nodules	LGL
0 kg ha^{-1}	33.94 c	34.30 c	107.0 c	26.37 c
25 kg ha^{-1}	38.11 b	36.52 b	119.6 b	32.68 b
50 kg ha^{-1}	39.89 a	38.77 a	130.27 a	36.51 a
75 kg ha^{-1}	37.97 b	36.07 bc	131.1 a	38.04 a

Note: Means within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% level. PH = plant height; FA = flowering age; Nodules = root nodule number; LGL = leaf greenness level.

Plant height increased from 33.94 cm in the control to 38.11 cm at 25 kg ha^{-1} urea and reached 39.89 cm at 50 kg ha^{-1}, then decreased slightly to 37.97 cm at 75 kg ha^{-1}. Flowering age also increased from 34.30 days in the control to 36.52 days at 25 kg ha^{-1} and 38.77 days at 50 kg ha^{-1}, before declining to 36.07 days at 75 kg ha^{-1}. Root nodule number increased from 107.0 in the control to 119.6 at 25 kg ha^{-1} and remained high at 50 and 75 kg ha^{-1}, with values of 130.27 and 131.1, respectively. Leaf greenness level also increased with urea application, from 26.37 in the control to 32.68, 36.51, and 38.04 at 25, 50, and 75 kg ha^{-1}, respectively. Overall, 50 kg ha^{-1} urea produced the most balanced response for the observed growth variables.

The effect of urea on groundnut yield

Urea application significantly affected dry pod weight per plot, dry seed weight per plot, and 100-seed weight of groundnut plants (Table 8). However, urea did not significantly affect the number of filled pods, empty pods, partially filled pods, or the weight of filled pods per plant.

Table 8. The effect of urea on the yield of groundnut

Urea	NFPP	NEPP	NPFPP	WFPP (g)	DPWP (g)	DSWP (g)	100-SW (g)
0 kg ha^{-1}	25.37	3.73	8.36	36.94	236.55 b	95.67 c	29.62 c
25 kg ha^{-1}	31.95	4.13	8.08	45.34	340.83 a	136.63 b	35.72 b
50 kg ha^{-1}	31.30	4.86	9.45	43.38	351.66 a	171.94 a	37.30 b
75 kg ha^{-1}	31.51	4.23	7.51	42.52	352.25 a	172.53 a	39.34 a

Note: Means within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% level. NFPP = number of filled pods per plant; NEPP = number of empty pods per plant; NPFPP = number of partially filled pods per plant; WFPP = weight of filled pods per plant; DPWP = dry pod weight per plot; DSWP = dry seed weight per plot; 100-SW = 100-seed weight.

The number of filled pods per plant increased from 25.37 in the control to 31.95 at 25 kg ha^{-1} urea and remained relatively similar at 50 and 75 kg ha^{-1}, with values of 31.30 and 31.51, respectively. The number of empty pods per plant ranged from 3.73 to 4.86, while the number of partially filled pods per plant ranged from 7.51 to 9.45. The weight of filled pods per plant ranged from 36.94 to 45.34 g. These variables did not show significant differences among urea treatments.

In contrast, dry pod weight per plot increased from 236.55 g in the control to 340.83 g at 25 kg ha^{-1} urea, 351.66 g at 50 kg ha^{-1}, and 352.25 g at 75 kg ha^{-1}.

Dry seed weight per plot also increased from 95.67 g in the control to 136.63 g, 171.94 g, and 172.53 g, respectively. Likewise, 100-seed weight increased progressively with urea dosage, from 29.62 g in the control to 35.72 g at 25 kg ha^{-1}, 37.30 g at 50 kg ha^{-1}, and 39.34 g at 75 kg ha^{-1}. Based on the overall response, 50 kg ha^{-1} urea gave a balanced improvement in yield, while 75 kg ha^{-1} produced the highest 100-seed weight.

Discussion

Plant height increased steadily from 2 to 6 weeks after planting and then tended to level off after flowering began. This pattern indicates that vegetative growth slowed when the plants entered the reproductive phase. Such a response is consistent with the growth habit of groundnut, in which assimilates are gradually redirected from stem elongation to pod and seed development (De Costa *et al*., 1997; Sutikarini *et al*., 2022; Delfin *et al*., 2021; Pasupuleti, 2023).

Root nodules were first observed at 6 weeks after planting and continued to increase up to 8 weeks after planting. These nodules reflect the symbiotic association between groundnut roots and nitrogen-fixing bacteria. Their development is important because effective nodules contribute to biological nitrogen fixation and support plant nitrogen supply during the reproductive stage. In legumes, active nodules are commonly associated with effective nitrogen fixation, whereas inactive nodules contribute less to plant nutrition (Imtiyaz & Octavia, 2023). The continued increase in nodulation up to the late vegetative stage in this study agrees with previous reports that root nodules play an essential role in supporting pod formation and seed development in legumes (Rafikasari *et al*., 2013; Delfin *et al*., 2021; Pasupuleti, 2023).

The interaction between Oil Palm Empty Fruit Bunch (EFB) ash and urea significantly affected the number of partially filled pods, dry seed weight per plot, and 100-seed weight. The combination of 6 ton ha^{-1} oil palm EFB ash and 50 kg ha^{-1} urea produced the highest dry seed weight and 100-seed weight. This result indicates that the combined use of both inputs improved yield formation more effectively than applying either factor alone. Oil palm EFB ash may improve soil conditions by reducing acidity and supplying several nutrients, while urea provides readily available nitrogen for plant growth and seed development (Setiawan *et al*., 2022; Boote *et al*., 2003). However, this same treatment combination also produced the highest number of partially filled pods. This result suggests that improved pod formation was not always followed by equally effective seed filling.

The increase in partially filled pods indicates that nutrient balance during seed filling may still have been suboptimal in some treatment combinations. This condition may be associated with uneven assimilate distribution or with limited availability of supporting micronutrients during reproductive development. Under such conditions, plants may form more pods, but some pods may not fill completely. Therefore, the combined application of oil palm EFB ash and urea increased productivity, but it also showed that seed filling remained sensitive to nutrient balance and growing conditions (Delfin *et al*., 2021; Pasupuleti, 2023).

As a single factor, oil palm EFB ash improved both growth and yield variables of groundnut grown on Ultisols. This result supports its role as a soil ameliorant in acidic soils. Oil palm EFB ash can increase soil pH and supply important nutrients such as potassium, calcium, and magnesium. The positive response observed in this study is in line with previous findings showing that oil palm EFB ash improved the chemical properties of Ultisols and supported crop production (Jatsiyah *et al*., 2024). Similar results were also reported by Setiawan *et al*. (2022), who showed that oil palm EFB ash reduced soil acidity and contributed essential nutrients for plant growth. In the present study, plant height, flowering age, root nodulation, and leaf greenness all responded positively to oil palm EFB ash application.

The delay in flowering observed in EFB-treated plants may indicate a longer vegetative phase before reproductive development became dominant. This response may have allowed greater biomass accumulation before the onset of pod filling. Similar responses have been reported in legumes grown under improved soil conditions or treated with alkaline organic amendments (Delfin *et al.*, 2021). In addition, the increase in leaf greenness and nodulation suggests that oil palm EFB ash improved the soil environment sufficiently to support both nutrient uptake and root activity.

Oil palm EFB ash also improved several yield components. The number of filled pods, dry pod weight per plot, dry seed weight per plot, and 100-seed weight all increased with oil palm EFB ash application. These responses indicate that oil palm EFB ash improved both yield quantity and seed quality. One likely explanation is that improved soil pH and nutrient availability enhanced assimilate production and translocation to the developing seeds. Potassium, in particular, plays an important role in carbohydrate transport and seed filling (Boote *et al.*, 2003). However, the increase in partially filled pods at higher EFB rates suggests that high ash application may still require better nutrient balance during pod filling, especially when reproductive demand increases (Pasupuleti, 2023).

Based on the overall response, oil palm EFB ash at 4-6 ton ha^{-1} gave the best performance. The 4 ton ha^{-1} dose supported balanced vegetative growth, especially nodulation, whereas the 6 ton ha^{-1} dose produced the highest dry seed weight and 100-seed weight. These results indicate that oil palm EFB ash was effective as a soil amendment for groundnut cultivation on acidic Ultisols. At the same time, the response pattern suggests that higher doses do not always result in proportional gains, so balanced application remains important.

Urea, as a single factor, also significantly affected both growth and yield variables. Plant height increased up to 50 kg ha^{-1} urea, then declined slightly at 75 kg ha^{-1}. This pattern suggests that moderate nitrogen application supported vegetative growth more effectively than the highest dose. Nitrogen is required for protein synthesis, cell division, and chlorophyll formation, so adequate urea application can enhance plant vigor during the early and middle stages of growth (Wang *et al.*, 2022). However, excessive nitrogen may reduce growth efficiency under certain soil conditions (Zhang *et al.*, 2023).

Urea application also delayed flowering and increased leaf greenness. These responses indicate that nitrogen promoted vegetative activity before reproductive growth became dominant. In this study, root nodulation also increased with urea application. This response suggests that, under nitrogen-deficient Ultisols, moderate nitrogen supply may improve early plant growth sufficiently to support nodulation rather than suppress it. Similar responses have been reported in legumes grown under nutrient-limited conditions, where moderate nitrogen input can stimulate early development without immediately inhibiting symbiotic nitrogen fixation (Duque *et al.*, 2021; Giller *et al.*, 2022).

For yield variables, urea increased dry pod weight per plot, dry seed weight per plot, and 100-seed weight. The strongest overall response was observed at 50 kg ha^{-1}, while the highest 100-seed weight occurred at 75 kg ha^{-1}. These results indicate that urea contributed substantially to seed filling and yield accumulation. Although filled pod number increased in all fertilized treatments, the differences among urea doses were not significant. This pattern suggests that nitrogen affected seed development more strongly than pod set. Previous studies also showed that nitrogen availability influences seed filling, biomass production, and final seed size in legumes (Boote *et al.*, 2003; Delfin *et al.*, 2021; Liu *et al.*, 2023*; Pasupuleti*, 2023).

Taken together, the findings of this study show that balanced nutrient management is important for improving groundnut productivity on acidic

Ultisols. The combination of 6 ton ha^{-1} oil palm EFB ash and 50 kg ha^{-1} urea gave the highest dry seed weight per plot and 100-seed weight, while oil palm EFB ash at 4-6 ton ha^{-1} and urea at 50 kg ha^{-1} produced the most favorable overall responses. These results indicate that oil palm EFB ash can function effectively as a local soil amendment, while moderate urea application can support growth and seed filling. In practical terms, this combination may improve crop performance while also supporting the agricultural use of oil palm waste as a useful input for marginal soils.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

Balai Penelitian Tanaman Aneka Kacang dan Umbi (2023). Performance Report 2022. Malang: Center for Food Crops Research and Development, Ministry of Agriculture of the Republic of Indonesia.

Boote, K. J., Jones, J. W., Batchelor, W. D., Nafziger, E. D. and Myers, O. (2003). Genetic coefficients in the CROPGRO-Soybean model: links to field performance and genomics. Agronomy Journal, 95:32-51. https://doi.org/10.2134/agronj2003.0032

BPS (2023). Agricultural land statistics 2023. Jakarta: BPS.

De Costa, W. A. J. M., Shanmugathasan, K. N. and Joseph, K. D. S. M. (1997). Physiology of yield determination of groundnut (*Arachis hypogaea* L.) under different irrigation regimes in a tropical environment. Experimental Agriculture, 33:323-343.

Delfin, E. F., Oraye, C. D. and Ocampo, E. T. M. (2021). Growth and development of groundnut (*Arachis hypogaea* L.): A review. Philippine Journal of Crop Science, 46:1-14.

Duque, L. O., Delatorre-Herrera, J. and Vega, I. (2021). Effect of nitrogen fertilization on nodulation, nitrogen fixation, and yield of common bean (*Phaseolus vulgaris* L.) grown in an acidic Ultisols. Journal of Plant Nutrition, 44:2549-2564.

Fageria, N. K. and Baligar, V. C. (2005). Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy, 88:97-185. https://doi.org/10.1016/S0065-2113(05)88004-6

FAO (2022). FAOSTAT: Crops and livestock products – Groundnuts, with shell. Rome: Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/faostat/en/#data/QCL

Giller, K. E., Delaune, T., Silva, J. V., Descheemaeker, K., van de Ven, G., Schut, A. G. T., van Wijk, M., Hammond, J., Hochman, Z., Taulya, G., Chikowo, R. and Narayanan, S. (2022). The role of nitrogen fixation in agricultural sustainability. Global Food Security, 32:100605.

Imtiyaz, M. and Octavia, N. L. (2023). The effectiveness of rhizobium inoculation on nodulation and nitrogen fixation of soybean (*Glycine max* L. Merrill) in acidic soil. Journal of Degraded and Mining Lands Management, 10:4417-4426.

IPBES (2018). The IPBES assessment report on land degradation and restoration. Bonn, Germany: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Jatsiyah, M., Fahmi, A. and Herviyanti, H. (2024). Application of empty fruit bunch (EFB) ash to improve chemical properties of ultisols soil and maize production. Jurnal Solum, 21:1-9.

Kristina, N., Muhsanati, and Padapotan, S. (2016). Effect of NT45 compost application frequency and urea dosage on the growth and yield of groundnut (*Arachis hypogaea* L.) in Ultisol. Agrotrop: Journal on Agriculture Science, 6:43-52.

Ladha, J. K., Tirol-Padre, A., Reddy, C. K., Cassman, K. G., Verma, S., Powlson, D. S. and Pathak, H. (2016). Global nitrogen budgets in cereals: A 50-year assessment for maize, rice, and wheat production systems. Scientific Reports, 6:1-9.

Liu, Y., Chen, W., Zhao, X., Zhang, F., Wang, L. and Hu, W. (2023). Optimizing nitrogen application for sustainable groundnut production and economic return. Agronomy Journal, 115:345-358.

Mulyani, A. and Las, I. (2008). Potential and availability of land resources to support food security. Jurnal Litbang Pertanian, 27:43-55.

Noble, A., Gillman, G. and Ruaysoongnern, S. (2000). A cation exchange index for assessing degradation of acid soils. Soil Research, 38:381-394.

Pasupuleti, J. (2023). The Groundnut Genome. In *Genome Designing for Climate-Smart Oilseed Crops*. Springer, Cham.

Purwanti, S., Marwoto, B. and Suryono, S. (2021). Impact of excessive inorganic fertilization on soil fertility and the environment. Jurnal Ilmu Lingkungan, 19:178-185.

Pusat Data dan Sistem Informasi Pertanian. (2023). *Agricultural Statistics Book 2023*. Jakarta: Ministry of Agriculture of the Republic of Indonesia.

Rafikasari, R., Hanafiah, D. S. and Sembiring, M. (2013). Growth and production response of groundnut (*Arachis hypogaea* L.) to organic fertilizer and nitrogen application. Jurnal Online Agroekoteknologi, 1:1-15.

Rengel, Z. (2003). Role of organic matter in alleviating soil acidity. Plant and Soil, 251:31-40.

Setiawan, A., Sudirja, R. and Nurmala, T. (2022). Potential of oil palm empty fruit bunch ash as an ameliorant and potassium source in acidic soil. Jurnal Ilmu Tanah dan Lingkungan, 24:23-30.

Sipayung, R., Simanjuntak, B. H. and Siregar, L. A. M. (2024). Growth and yield response of black soybean to oil palm empty fruit bunch ash application on Ultisols. Jurnal Agroteknos, 14:45-54.

Siringoringo, R. (2015). Study of several chemical properties of Ultisol and seed yield of Anjasmoro soybean due to the application of oil palm empty fruit bunch ash. Agroekoteknologi. (Unpublished). Repository Unja.

Subagyo, H., Suharta, N. and Siswanto, A. B. (2020). *Agricultural soils in Indonesia.* Bogor: Center for Soil and Agroclimate Research.

Sutikarini, Wisudawandinata, T. A. and Putra, A. M. (2022). Effect of pineapple peel bokashi on the growth and yield of yardlong bean on alluvial soil. Indonesian Journal of Agriculture and Environmental Analytics, 1:55-66. https://doi.org/10.55927/ijaea.v1i1.899

Von Uexküll, H. R. and Mutert, E. (1995). Global extent, development and economic impact of acid soils. Plant and Soil, 171:1-15. https://doi.org/10.1007/BF00009558

Wang, X., Feng, Z., Liu, X., Vance, C. P. and Wang, X. (2022). Sustainable nitrogen management strategies for legume-based cropping systems. Field Crops Research, 285:108591.

Zhang, Q., Li, Y., Zhu, B., Cheng, W. and Zhang, J. (2023). Mitigating ammonia volatilization from urea fertilization in acidic soils amended with biochar and organic wastes. Soil Science Society of America Journal, 87:456-468.

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