© IIJP 2026 | Volume 2, Issue 3, pp. 1397-1407| ISSN: 2636-4484

EVALUATION OF NEEM LEAF AND WOOD ASH EXTRACT ON SOIL PROPERTIES, GROWTH AND YIELD OF PEPPER (*Capsicum annuum* L.)

Prof Adekola Olabisi Fatima[1], Muftau Azeezat Pekan[2], *Nurudeen Khadijat[3] & Atanda Afusat Omolabake[4]

[1,3,4]Department of Agronomy, University of Ilorin, Ilorin.

[2] Crop Production Departments, Kwara State University, Malete.

****Corresponding Author**: nurudeenkhadijat16@gmail.com*

ARTICLE INFO
Article No.: 0520
Accepted Date: 10/08/2026
Published Date: 28/08/2026
Type: Research

ABSTRACT

High cost and environmental impacts of inorganic fertilizers necessitate sustainable, locally available nutrient alternatives, while the interactive effects of organic liquid amendments, application time and rate on soil health and pepper productivity data is limited. This study evaluated the effects of neem leaf and wood ash extracts, application time and rate on soil chemical properties, growth and yield of pepper (*Capsicum annuum* L.) in Ilorin, Nigeria. A pot experiment was conducted at the University of Ilorin, Nigeria, during the 2025 rainy season using 90 experimental sacks, each containing 10 kg of sandy loam soil, arranged in a split-split-plot design with three replications. Treatments comprised two bio - fertiliser (neem leaf and wood ash extract), three application time (2 weeks before transplanting 2WBT, at transplanting AT and 2 weeks after transplanting 2WAT), and five application rates (0, 25000, 50000, 75000 and 100000 L ha^{-1}). Data were subjected to analysis of variance, and treatment means were separated using LSD test at 5% probability level. The pre-planting soil was sandy loam with low available phosphorus. Both bio-fertilisers maintained favourable soil pH after harvest and slightly increased exchangeable cations and organic carbon. Bio-fertiliser did not significantly affect fruit yield, however, application time and rate significantly ($P \leq 0.05$) influenced productivity. Application at 2 WBT produced the highest fruit yield (1.86 t ha^{-1}), whereas 75,000 L ha^{-1} recorded the highest fruit yield (2.66 t ha^{-1}) and fresh fruit weight (0.0133 kg plant^{-1}). Application of either extract at 75,000 L ha^{-1}, particularly 2 WBT, therefore shows potential for improving pepper productivity while maintaining favourable soil chemical properties and may provide a low - cost nutrient management option for smallholder production.

Keywords: Bio-fertiliser, *Capsicum annuum*, Neem leaf extract, Wood ash extract, Pepper yield.

Introduction

Pepper (*Capsicum* spp.) ranks among the oldest cultivated plant species in America and is currently one of the most valuable vegetable and spice crops within the *Solanaceae* family. Archaeological findings, together with genomic analyses, suggest that chilli peppers were first domesticated in Mesoamerica thousands of years ago (Russo, 2012). Current genomic evidence recognizes five domesticated *Capsicum* species, of which *Capsicum annuum* is the dominant species in global cultivation (Chiou et al., 2024). Peppers are widely consumed in both fresh and processed forms because of their diverse culinary applications, attractive fruit colour, pungency, and nutritional benefits. In addition, pepper fruit is an important source of vitamin C, provitamin A carotenoids, phenolic compounds, and other antioxidants, making them valuable for human nutrition as well as food processing industries (Al Kafi et al., 2025).

Despite its importance, sustainable pepper production is increasingly constrained by high cost and uncertain availability of conventional inputs. Cross-country evidence from Sub-Saharan Africa shows that inorganic fertiliser prices have risen since 2020, forcing many smallholders to reduce application rates or fertilise smaller areas, with likely consequences for crop productivity (Amankwah et al., 2024). At the same time, pest pressure in chilli-based systems frequently encourages repeated pesticide use, while recent farm and monitoring studies continue to report extensive pesticide use and residue detection in chilli peppers, raising concerns for food safety, environmental quality and long-term system resilience (Amekawa et al., 2023). These pressures justify renewed attention to low-cost, locally available alternatives that can support both crop nutrition and safer pest management.

Neem (*Azadirachta indica*) has emerged as one of the most promising botanical resources for this purpose. Reviews published in the last few years describe neem as an effective plant-derived biocide with relatively low toxicity and multiple modes of action against insect pests and plant pathogens, while pepper studies indicate that response depends strongly on dose and application regime (Tobing et al., 2023). For example, neem extract improved chilli growth and reduced pest severity at moderate concentration in Malaysia, whereas repeated neem leaf extract applications in red chilli were more effective in suppressing aphid attack and improving plant development than infrequent use (Che Soh et al., 2021; Tobing et al., 2023). These findings suggest that neem can contribute both protective and growth related benefits, but also that optimum concentration and timing require crop specific evaluation.

Wood ash is likewise attracting interest as a recycled soil amendment because of its liming potential and its supply of potassium, calcium, magnesium and phosphorus. Recent reviews and field studies show that wood ash can improve soil pH, nutrient availability, cation exchange capacity and, in some cases, crop yield, although its performance varies with feedstock, combustion conditions and application rate (Manirakiza et al., 2025). In pepper, moderate concentrations of wood ash liquid fertiliser have recently been shown to improve growth, fruit number and fruit nutritional quality, while longer term studies indicate that ash can leave measurable residual effects on soil chemical properties after cropping (Ojewumi et al., 2025; Javed, 2021). However, evidence directly integrating neem leaf and wood ash extracts in pepper remains limited. Therefore, the objective of this study was to determine the optimum rate and time of application of neem leaf and wood ash extract on the growth and yield of pepper, while also assessing their residual effects on soil physical and chemical properties after planting.

Materials and Methods

The experiment was carried out during the onset of the early rainy season in 2025 at the nursery pavilion of the Department of Agronomy, Faculty of Agriculture, University of Ilorin,

Ilorin, Kwara State, Nigeria (8.47°N, 4.54°E). The soil used in this study is sandy loam topsoil described as low in fertility. Treatments were arranged in a split-split-plot design with three replicates. Two bio-fertiliser source (Neem leaf extract and Wood ash extract) constituted the main plot factor, three time of application (2 weeks before transplanting, at transplanting, and 2 weeks after transplanting) was assigned to subplots and five application rate (0, 25,000, 50,000, 75,000 and 100,000 L ha^{-1}) was assigned to sub-subplots, each plot consist of 15 sacks which makes a total of 90 sacks altogether and spacing of 0.5m between and within each plot for pathway. Hybrid pepper seed was obtained from mature fruits harvested at the University of Ilorin Agronomy nursery. Fresh neem leaves were collected within the Faculty of Agriculture, while wood ash was sourced from Tanke, Ilorin. The preparation of the aqueous botanical inputs followed procedures consistent with recent work on neem and ash-based fertiliser materials for crop production (Kabir et al., 2024).

Neem leaf extract was prepared by chopping 3 kg of fresh leaves and soaking them in 15 L of water for 7 days, after which the mixture was filtered and the extract diluted 1:1 with water. Wood ash extract was prepared by mixing 3 kg of sieved wood ash with 15 L of water, stirring the suspension at 3-day intervals for 7 days, decanting and filtering the liquid phase, and diluting the filtrate 1:1 with water. Pepper seedlings were raised for 4 weeks in seed trays filled with cocopeat amended with poultry manure, kept under shade, and irrigated morning and evening. Thereafter, uniform seedlings were transplanted into pots containing 10 kg of sandy loam soil. The extracts were applied according to treatment, watering was carried out twice daily, hand weeding was done as required and insect pests were controlled with acetamiprid. The amount of bio-fertilizer extract applied per pot was calculated as thus:

Using the standard conversion basis where 1ha of soil = 2,000,000kg

$$\text{Application rate (ml/plot)} = \frac{\text{weight of soil per pot (kg)} \times \text{Recommended rate (L/ ha)}}{\text{Weight of soil per hectare (kg)}} \times 1000 \text{ ml/L}$$

Data collection commenced at 2 weeks after transplanting and continued until 5 weeks after transplanting. Vegetative parameters recorded were plant height, number of leaves, stem girth, leaf area, and fresh leaf weight. Yield parameters included fruit length, number of fruits per plant, and fruit weight per plant. Soil samples were analysed for textural class, pH, organic carbon, available phosphorus, exchangeable acidity, and total nitrogen. Soil pH was determined in water and 1 M KCl suspension, organic carbon was determined by the Walkley - Black wet oxidation method, available phosphorus by the Bray I procedure with spectrophotometric determination, exchangeable acidity by 1 M KCl extraction followed by NaOH titration and total nitrogen by the micro-Kjeldahl method (Latimer, 2023). Data were subjected to analysis of variance using SAS, and treatment means were separated by least significant difference at 5% probability level (SAS Institute Inc., 2023).

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Results

Table 1a: Physical and chemical properties of the experimental soil before planting and chemical constituents of Neem leaves and Wood ash aqueous extract.

Physical properties	**Soil**	**Wood ash**	**Neem leaves**
Clay (%)	10.61		
Silt (%)	8.00		
sand (0/6)	81.36		
Textural class	Sandy loam		
Chemical properties			
pH (H2O)	8.10	7.93	8.14
pH (Kcl)	7.16	7.71	7.60
Available P (mg/kg)	0.18	0.89	0.85
Total N (mg/g)	1.43	1.74	3.20
Organic carbon (%)	1.12	5.2	4.4
Organic matter (%)			
Exchangeable H+ (Cmol/Kg)	0.20	0.29	0.37
ca+ (Cmol/kg)	4.33	2.80	2.75
Mg+ (Cmol/Kg)	12.36	13.19	11.04
Na+ (Cmol/Kg)	2.26	2.34	1.85
K+ (Cmol/Kg)	1.65	1.50	1.35
Electrical conductivity (µS/cm)	264	359	1141

Table 1b: Chemical properties of the soil after harvesting

Properties	**Wood Ash**			**Neem**		
	2 WBP	**2 AP**	**2WAP**	**2 WBP**	**2 AP**	**2 WAP**
pH	7.75	7.62	7.55	7.60	7.53	7.59
K (mg/L)	1.15	1.18	1.20	1.35	1.41	1.42
Ca (mg/L)	1.34	1.38	1.34	1.26	1.42	1.48
Mg (mg/L)	1.90	1.87	1.87	2.01	2.08	2.03
Na(mg/L)	0.75	0.74	0.74	0.67	0.70	0.66
Organic Carbon (%)	5.05	5.93	6.23	8.80	10.78	11.40
Electrical Conductivity(µS/cm)	295.00	195.00	217.00	336.00	128.00	231.00
Available Phosphorus (mg/kg)	0.06	0.07	0.05	0.08	0.09	0.03

WAP- weeks After Planting, AT- At Planting, WBP-weeks Before Planting

The initial and post-harvest soil physical and chemical properties under the different wood ash and neem leaf extract treatments are presented in Table 1a and 1b. The initial soil was sandy loam, comprising 81.36% sand, 8.00% silt and 10.61% clay. The soil pH was 8.10 in water, while organic carbon (OC) was 1.12%. The available phosphorus (P) concentration was 0.18 mg kg^{-1}. The chemical characteristics of the amendments differed between bio-fertilizer sources. Neem leaf extract contained 3.20 mg g^{-1} total nitrogen and had an electrical conductivity (EC) of

1,141 µS cm⁻¹, whereas wood ash contained 1.74 mg g^{-1} total nitrogen and had an EC of 359 µS cm^{-1}. Available P was 0.85 mg kg^{-1} in neem leaf extract and 0.89 mg kg^{-1} in wood ash.

Post-harvest soil analysis showed soil pH ranged from 7.53 to 7.75 across the treatment combinations. Soil OC increased relative to the initial value of 1.12%, with values varying among the bio-fertilizer types, application times and application rates. The highest OC value of 11.40% was recorded with neem leaf extract applied at 2 weeks after planting (2 WAP). Application at 2 WAP also resulted in comparatively high OC values under both bio-fertilizer sources. Available P after harvest ranged from 0.03 to 0.09 mg kg^{-1}, compared with the initial value of 0.18 mg kg^{-1}. Residual exchangeable K, Ca and Mg also varied among the bio-fertilizer treatments, with neem leaf extract generally recorded higher values than wood ash.

Effect of bio-fertilizer type, application time and rate on pepper vegetative growth

Table 2: Effect of Application Time and Rate of Bio-Fertilizer on Plant Height, Stem Girth, Number of Leaves and Leaf Area Growth of Pepper

Bio-fertilizer (B)	Plant Height (cm)	Stem Girth (cm)	Number of Leaves	Leaf Area (cm²)
Wood ash	32.55	1.38	62.00	11.04
Neem	30.49	1.26	52.00	9.83
LSD(0.05)	3.93	0.07	5.49	0.88
Application time (T)				
2 WBP	30.64	1.35	61.00	11.73
AP	32.44	1.31	65.00	10.39
2WAP	31.48	1.29	45.00	9.19
LSD(0.05)	Ns	Ns	11.49	0.86
Application Rate (R)				
0 L/ha	29.99	1.27	43.00	9.66
25000L/ha	31.04	1.28	51.00	9.43
50000L/ha	31.99	1.41	69.00	11.25
75000L/ha	33.87	1.36	67.00	11.27
I00000L/ha	30.71	1.27	56.00	10.57
LSD (0.05)	Ns	0.1	10.54	1.15
Interactions				
BxT	Ns	Ns	Ns	Ns
BxR	Ns	Ns	Ns	Ns
TxR	Ns	Ns	Ns	*
BxTxR	Ns	*	Ns	*

WAP- weeks After Planting, AT- At Planting, WBP-weeks Before Planting, NS- not significant, * - significant

The effects of bio-fertilizer type, application time and application rate on pepper plant height, stem girth, leaf number and leaf area are presented in Table 2. Bio-fertilizer type significantly affected ($p \leq 0.05$) all measured vegetative growth parameters. Wood ash produced higher plant height (32.55 cm), stem girth (1.38 cm), leaf number (62.00) and leaf area (11.04 cm²) than neem leaf extract, which recorded 30.49 cm, 1.26 cm, 52.00 leaves and 9.83 cm², respectively.

Application time did not significantly affect plant height or stem girth but significantly affected leaf number and leaf area ($p \leq 0.05$). Application at planting (AP) produced the highest leaf number (65.00), which was statistically comparable with application at 2 weeks before planting (2 WBP; 61.00) but significantly higher than application at 2 WAP (45.00). The greatest leaf area (11.73 cm²) was recorded with application at 2 WBP, compared with 10.39 cm² at AP and 9.19 cm² at 2 WAP. Application rate significantly affected stem girth, leaf number and leaf area but did not significantly affect plant height. The 50000L/ha rate produced the greatest stem girth (1.41 cm) and leaf number (69.00), while the 75000L/ha rate recorded 1.36 cm and 67.00 leaves, respectively. The two rates were statistically comparable for these parameters. Leaf area was highest at 75000L/ha (11.27 cm²) and 50000L/ha (11.25 cm²), whereas the 100000L/ha rate produced lower values. The bio-fertilizer type × application time (B × T) and bio-fertilizer type × application rate (B × R) interactions were not significant for the measured growth parameters. However, the application time × application rate (T × R) interaction significantly affected leaf area, while the B × T × R interaction significantly affected stem girth and leaf area ($p \leq 0.05$).

Effect of bio-fertilizer type, application time and rate on pepper yield

Table 3: Effect of application time and rate of bio - fertilizers on yield of pepper

Bio - fertilizer (B)	Number of Fruit per Plant	Fresh Fruit Weight per Plant (kg)	Yield (ton/ plant)
Wood ash	2.71	0.0085	1.69
Neem	2.20	0.0063	1.26
LSD(0.05)	Ns	Ns	Ns
Application Time(T)			
2WBP	3.13	0.0093	1.86
At Planting	2.70	0.0087	1.73
2WAP	1.53	0.0042	0.84
LSD(0.05)	0.47	0.0020	0.91
Application Rate(R)			
0L/ha	0.94	0.0030	0.60
25000L/ha	2.56	0.0067	1.34
50000L/ha	2.56	0.0072	1.43
75000L/ha	3.83	0.0133	2.66
100000L/ha	2.39	0.0068	1.36
LSD(0.05)	0.58	0.0019	0.77
Interactions			
BxT	Ns	Ns	Ns
BxR	Ns	Ns	Ns
T x R	Ns	Ns	Ns
BxTxR	Ns	Ns	Ns

WAP- weeks After Planting, AT- At Planting, WBP-weeks Before Planting, NS- not significant

The effects of bio-fertilizer type, application time and application rate on number of fruits per plant, fresh fruit weight per plant and yield are presented in Table 3. Bio-fertilizer type did not significantly affect any of the yield parameters ($p > 0.05$). Wood ash recorded 2.71 fruits plant^{-1}, 0.0085 kg plant^{-1} fresh fruit weight and 1.69 t ha^{-1} yield, while neem leaf extract recorded 2.20 fruits plant^{-1}, 0.0063 kg plant^{-1} and 1.26 t ha^{-1}, respectively. Application time significantly affected all yield parameters ($p \leq 0.05$). Application at 2 WBP produced the highest number of fruits (3.13 fruits plant^{-1}), fresh fruit weight (0.0093 kg plant^{-1}) and yield (1.86 t ha^{-1}). These values were statistically comparable with those obtained at AP, which recorded 2.70 fruits plant^{-1}, 0.0087 kg plant^{-1} and 1.73 t ha^{-1}, respectively. Application at 2 WAP produced the lowest values, with 1.53 fruits plant^{-1}, 0.0042 kg plant^{-1} and 0.84 t ha^{-1}.

Application rate significantly affected number of fruits per plant, fresh fruit weight per plant and yield ($p \leq 0.05$). The highest values were obtained at 75000L/ha, with 3.83 fruits plant^{-1}, 0.0133 kg plant^{-1} and 2.66 t ha^{-1}, respectively. Increasing the rate to 100000L/ha resulted in lower values than those obtained at 75000L/ha. The control recorded the lowest values for all yield parameters. No significant B × T, B × R, T × R or B × T × R interactions were detected for any of the measured yield parameters ($p > 0.05$).

Discussion

The sandy loam texture of the experimental soil indicates a relatively coarse-textured soil, while the low initial available P and OC indicate limited fertility status for sustained crop production. The decline in soil pH from 8.10 before planting to 7.53–7.75 after harvest suggests that the alkaline condition of the soil was moderated during the cropping period. This change may be associated with crop nutrient uptake, leaching and biological processes occurring during crop growth. The observation is noteworthy because wood ash commonly has an alkalising effect and is generally used as a liming material, particularly in acidic soils. Jian et al., (2025) similarly demonstrated that wood ash can alter soil pH and contribute to soil nutrient status, although the magnitude and direction of the response depend on the properties of the ash and the receiving soil.

Increase in OC following amendment application, particularly under neem leaf extract, indicates an increased input of carbon-containing material into the soil. The particularly high OC recorded with neem application at 2 WAP suggests that application timing influenced the amount of amendment extract carbon retained in the soil. The greater residual K, Ca and Mg associated with neem leaf extract is consistent with findings reported by Sriraj et al., (2022), who found that neem leaf extract increased soil concentrations of P, K, Ca and Mg relative to an untreated soil. The study therefore provides direct support for the capacity of neem-extract materials to modify soil nutrient availability.

The reduce in available P from 0.18 mg kg^{-1} before planting to 0.03 - 0.09 mg kg^{-1} after harvest indicates a reduction in readily available P during the cropping period. Crop uptake is a plausible explanation, particularly because P is required for root development, energy transfer and reproductive development. However, P dynamics are controlled by several simultaneous processes, including sorption, precipitation, mineralisation and plant uptake. This is particularly relevant in the initially alkaline soil because soil pH strongly regulates P solubility and availability. Penn & Camberato (2019) identified soil pH as a major control of P availability through its influence on P sorption and precipitation reactions. Thus, the observed decline should not be attributed solely to crop removal.

The significantly greater plant height, stem girth, leaf number and leaf area recorded under wood ash indicate that this amendment provided a more favourable nutrient environment for vegetative development than neem leaf extract under the conditions of the experiment. Wood ash commonly contains appreciable quantities of base-forming elements, particularly Ca, K and Mg, and can therefore contribute to plant nutrient supply as well as modify soil chemical conditions. The response observed in the present study agrees with the findings of Ojewumi et al. (2023), who reported positive responses of *Capsicum annuum* to wood-ash liquid fertiliser.

The stronger vegetative response to wood ash did not translate into a statistically significant advantage in yield. This distinction is important because vegetative growth and reproductive productivity do not always respond proportionally to a particular nutrient source.

The present findings suggest that wood ash was more effective in promoting vegetative development, whereas both amendments provided broadly comparable reproductive responses. The significant effects of application timing on leaf number and leaf area indicate that the availability of nutrients during crop establishment and canopy development was important. Application at planting produced the greatest leaf number, whereas application at 2 WBP produced the greatest leaf area. These responses suggest that nutrient availability before or at crop establishment allowed plants to develop a larger photosynthetic surface during the vegetative phase. Conversely, the lower leaf number and leaf area following application at 2 WAP indicate that delaying amendment application reduced the opportunity for the crop to benefit from the supplied nutrients during early canopy formation.

The significant effect of application rate on stem girth, leaf number and leaf area, with the strongest responses generally occurring at 50000 - 75000L/ha, indicates that increasing the amendment rate did not produce a proportional increase in vegetative growth. The poorer performance at 100000L/ha suggests that the optimum response was reached before the highest application rate. Such a response is agronomically plausible because nutrient additions generally exhibit diminishing returns once the crop's nutritional requirements are adequately met. In the case of alkaline materials such as wood ash, excessive application can additionally alter soil chemical conditions and nutrient balance. Manirakiza et al (2025) similarly emphasised the importance of appropriate wood-ash application in managing soil chemical responses. The significant T × R interaction for leaf area and B × T × R interaction for stem girth and leaf area further demonstrate that vegetative responses were dependent on the combination of amendment source, application timing and application rate. This indicates that the agronomic value of these amendments cannot be evaluated solely on the basis of amendment type or application rate in isolation.

The absence of a significant effect of bio-fertilizer type on number of fruits per plant, fresh fruit weight and yield indicates that the two amendments produced statistically similar reproductive performance, despite the superior vegetative growth recorded with wood ash. The numerical advantage of wood ash in all three yield variables should therefore be regarded as a trend rather than evidence of a statistically superior treatment. This result is consistent with the principle that greater vegetative biomass does not necessarily result in a corresponding increase in reproductive yield. Yield formation in pepper depends on nutrient availability, assimilate partitioning, flowering, fruit set and subsequent fruit development. Thus, the significant vegetative advantage of wood ash may have been insufficient to produce a statistically detectable yield advantage over neem leaf extract.

Application time had a pronounced effect on yield. The highest fruit number, fresh fruit weight and yield were obtained when the amendment was applied 2 WBP, while application at 2 WAP resulted in the lowest values. The superior response to pre-planting application suggests that the amendment had sufficient time to interact with the soil and release nutrients before the crop reached periods of rapid nutrient demand. Early nutrient availability may consequently have supported establishment, canopy development and subsequent reproductive growth. Similar evidence from pepper production demonstrates that nutrient - source management can substantially influence growth and yield responses. For example, Aliyu (2000) reported differential responses of pepper to organic and mineral nutrient sources, demonstrating the importance of nutrient supply in determining pepper productivity.

The significant effect of application rate on all yield variables, with 75000L/ha producing the highest fruit number, fresh fruit weight and yield, indicates that this rate provided the most favourable nutrient supply among the rates evaluated. The decline at 50ml/pot suggests that increasing the quantity beyond the optimum did not enhance productivity. Instead, the response indicates a rate-dependent optimum, beyond which additional amendment may provide little benefit or may disturb nutrient balance. This is particularly relevant for wood ash because of its alkaline nature and its capacity to modify soil chemical conditions when applied excessively.

The yield obtained in the present study also demonstrates the importance of considering application timing and rate together with amendment source. Although no interaction among the experimental factors was significant for yield, the independent effects of application time and rate were clear. Thus, under the conditions of this experiment, application at 2 WBP and a rate of 75000L/ha represented the most favourable treatment combination based on the individual main effects, while wood ash was particularly effective for vegetative growth.

The results also compare favourably with previous work demonstrating beneficial responses of pepper to organic nutrient sources. Ike et al., (2023) reported that organic soil amendments affected the soil properties, growth and yield of yellow pepper in Nigeria, supporting the broader observation that organic nutrient inputs can improve pepper performance when appropriately selected and managed. Similarly, Iren et al., (2017) showed that organic amendments altered soil nutrient status and improved pepper growth and yield in an Ultisol of southeastern Nigeria. However, differences between those studies and the present experiment are expected because amendment composition, soil type, crop genotype, climatic conditions, application rate and method of application differed.

Conclusion

The study showed that the performance of pepper was influenced more by the time and rate of bio-fertiliser application than by the bio-fertiliser source. Both neem leaf and wood ash extracts maintained favourable soil pH and slightly improved soil organic carbon and exchangeable cations after harvest, although available phosphorus remained low. Wood ash significantly enhanced vegetative growth, while bio-fertiliser source had no significant effect on yield. Applying the bio-fertiliser two weeks before planting resulted in the highest fruit number, fresh fruit weight and yield, indicating better synchronisation between nutrient release and crop demand. Likewise, the 75000L/ha application rate produced the best overall growth and yield performance. These findings suggest that early application of bio-fertiliser at an optimum rate is an effective strategy for improving pepper productivity while maintaining favourable soil chemical properties.

Recommendation

Based on the findings of this study, Apply bio-fertiliser two weeks before planting and at 75000L/ha to maximise pepper growth and yield. Supplement with phosphorus fertiliser where soil phosphorus is deficient. Further studies should evaluate combined neem extract and wood ash applications and assess their long - term effects on soil fertility and pepper productivity under different agroecological conditions.

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