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Evaluation of *Azadirachta indica* Seed Extracts as Silvicultural Amendments for Enhancing Growth and Productivity of *Moringa oleifera*

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Abstract

The study evaluated the potential of *Azadirachta indica* (neem) seed extract as a natural amendment for improving the early growth and biomass production of *Moringa oleifera*. A randomized complete block design was used with four replications and four treatment conditions: untreated control, neem seed extract, synthetic fertilizer (NPK 20:20:20), and a combination of neem seed extract and synthetic fertilizer. Plant height and leaf number were assessed at 12, 32, and 52 days after planting, while root length, fresh weight, and dry weight were assessed at 52 days. The combined treatment produced the highest values for plant height (70.2 cm), leaf number (28.2), root length (40.5 cm), fresh weight (28.5 g), and dry weight (9.2 g). Synthetic fertilizer alone produced intermediate values (62.5 cm, 25.5 leaves, 35.2 cm, 24.2 g, and 7.8 g, respectively), while neem seed extract alone produced 55.8 cm, 22.8 leaves, 30.2 cm, 20.5 g, and 6.2 g. The untreated control recorded the lowest values (45.2 cm, 18.5 leaves, 25.5 cm, 15.2 g, and 4.5 g). The findings indicate that neem seed extract can contribute to improved *M. oleifera* seedling performance and may complement mineral fertilization. However, the treatment-rate descriptions in the source study are internally inconsistent and should be verified before submission to a journal.

Keywords: *Azadirachta indica; Moringa oleifera*; neem seed extract; organic amendment; synthetic fertilizer; seedling growth; biomass

Introduction

Declining soil fertility and the environmental consequences associated with excessive dependence on synthetic fertilizers have increased interest in sustainable nutrient-management

options. Long-term and excessive fertilizer use has been associated with soil degradation, nutrient imbalance, water contamination, and changes in soil microbial communities (Akinmoladun *et al*., 2019; Gupta & Pandey, 2022; Ochieng & Mwangi, 2021). Natural amendments derived from plant materials may provide an alternative or complementary approach because they can contribute organic matter and biologically active compounds while reducing dependence on external chemical inputs (Akintoye *et al*., 2020; Akinmoladun *et al*., 2021).

Azadirachta indica is widely recognized for its agricultural importance. Neem tissues contain bioactive compounds, including azadirachtin and related limonoids, that have been associated with pest-management activity and other biological effects relevant to crop production (Ademola *et al*., 2021a; Moyo *et al*., 2020; Ghaffari *et al*., 2021). Neem-derived materials have also been investigated for their potential contribution to soil fertility, nutrient cycling, and plant growth (Ademola *et al*., 2021b; Akinmoladun *et al*., 2020, 2022; Ogunyemi *et al*., 2022).

Moringa oleifera is a fast-growing multipurpose tree of substantial nutritional and economic importance. Its leaves, seeds, and pods are widely utilized, and its nutritional composition has encouraged increased cultivation in tropical and subtropical regions (Adedeji & Omotayo, 2022; Mbithi *et al*., 2021). Improving early seedling establishment is therefore important for productive *M. oleifera* cultivation. Previous work cited in the source study indicates that neem-based amendments and combinations of organic and mineral inputs can improve plant growth, but information specific to neem seed extract and *M. oleifera* seedlings remains limited (Okafor & Adebayo, 2021).

This study therefore evaluated the response of *M. oleifera* seedlings to neem seed extract, synthetic fertilizer, and their combination, using plant height, leaf number, root length, and biomass as indicators of early growth performance.

Study Area

The experiment was conducted at the Federal Polytechnic, Bauchi, Bauchi State, Nigeria. The study area is located approximately 6–7 km southwest of Bauchi city, around latitude 10.3333° N and longitude 9.8333° E. The area lies within a savanna environment and is characterized by seasonal rainfall. The source document reports annual rainfall of approximately 700–1,300 mm and describes the area as having marked wet and dry seasons (Bauchi State of Nigeria, 2022).

Experimental Design and Treatments

The experiment employed a randomized complete block design (RCBD) with four replications. Four treatment conditions were evaluated: (i) untreated control; (ii) neem seed extract; (iii) NPK 20:20:20 synthetic fertilizer; and (iv) neem seed extract combined with NPK fertilizer. Individual plants were randomized within blocks to reduce the influence of environmental heterogeneity.

Plant Materials and Soil

Moringa oleifera seeds were obtained from a local nursery. Neem seeds were obtained from a local market, dried, and processed for extraction. The experimental soil was described as sandy loam with a pH of 6.5 and was air-dried and assessed for baseline nutrient status before use.

Preparation and Application of Neem Seed Extract

Neem seeds were dried in a hot-air oven at 50 °C for 24 h and ground to increase the surface area available for extraction. The ground material was mixed with water at a 1:10 ratio and extracted using a Soxhlet apparatus. The extract was filtered using a Büchner funnel and concentrated with a rotary evaporator before storage in sterile containers until application.

Neem extract was applied as a foliar spray using a hand sprayer, with applications conducted in the morning or evening. NPK 20:20:20 was incorporated into the soil as the synthetic fertilizer treatment. Plants were watered regularly throughout the experimental period.

Data Collection

Plant height and leaf number were recorded at 12, 32, and 52 days after planting. Plant height was measured from the soil surface to the apex using a metre rule, while leaves were counted manually. At 52 days, seedlings were harvested for determination of root length, fresh weight, and dry weight. Root length was measured from the root collar to the terminal root, while biomass was determined from fresh and oven-dried plant material.

Statistical Analysis

The data were subjected to analysis of variance (ANOVA), followed by Duncan's multiple range test, with statistical significance set at $p < 0.05$.

Plant height

Plant height increased progressively with time in all treatments. At 52 days, the neem-plus-synthetic-fertilizer treatment recorded the greatest mean height (70.2 cm), followed by synthetic fertilizer (62.5 cm), neem seed extract (55.8 cm), and the control (45.2 cm).

Table 1. Mean plant height of *Moringa oleifera* seedlings at different assessment periods.

Treatment	12 days (cm)	32 days (cm)	52 days (cm)
Control	10.0	30.5	45.2
Neem seed extract	12.5	37.5	55.8
Synthetic fertilizer	14.8	42.2	62.5
Neem + synthetic fertilizer	16.5	55.8	70.2

Leaf production

Leaf number also increased over time. At 52 days, the combined neem and synthetic fertilizer treatment produced the highest mean leaf number (28.2), followed by synthetic fertilizer (25.5), neem seed extract (22.8), and the control (18.5).

Table 2. Mean leaf number of *Moringa oleifera* seedlings at different assessment periods.

Treatment	12 days	32 days	52 days
Control	5.2	12.2	18.5
Neem seed extract	6.8	15.5	22.8
Synthetic fertilizer	7.7	17.2	25.5
Neem + synthetic fertilizer	8.2	19.5	28.2

Root length and biomass

At 52 days, the combined treatment produced the greatest root length (40.5 cm), fresh weight (28.5 g), and dry weight (9.2 g). The corresponding values for synthetic fertilizer were 35.2 cm, 24.2 g, and 7.8 g; neem seed extract produced 30.2 cm, 20.5 g, and 6.2 g; and the control recorded 25.5 cm, 15.2 g, and 4.5 g.

Table 3. Root length, fresh weight, and dry weight of *Moringa oleifera* seedlings at 52 days.

Treatment	Root length (cm)	Fresh weight (g)	Dry weight (g)
Control	25.5	15.2	4.5
Neem seed extract	30.2	20.5	6.2
Synthetic fertilizer	35.2	24.2	7.8
Neem + synthetic fertilizer	40.5	28.5	9.2

Discussion

The observed increase in plant height and leaf production following application of neem seed extract is consistent with the proposed role of neem-derived materials in improving plant growth and nutrient-use processes. Neem contains biologically active compounds and has been investigated as a plant-growth and soil-management input (Ademola *et al*., 2021a; Ghaffari *et al*., 2021). The higher values recorded under the combined treatment suggest that neem extract may complement the readily available nutrients supplied by synthetic fertilizer.

The pattern observed for root length and biomass is also consistent with the general importance of adequate nutrient availability for root development and biomass accumulation (Adebayo *et al*., 2021). The combined treatment recorded the greatest root length, fresh weight, and dry weight, followed by synthetic fertilizer, neem extract, and the control. Similar benefits of combining organic or biological amendments with mineral fertilizers have been reported in the literature cited in the source manuscript (Akinmoladun *et al*., 2021; Culman & Snapp, 2018).

Neem may additionally contribute indirectly to plant performance through its reported pesticidal and antimicrobial properties. Neem-based products have been investigated for suppression of insect pests and soil-borne organisms and for their potential effects on soil biological processes (Adedokun *et al*., 2021; Olayiwola *et al*., 2021; Oluwaseun *et al*., 2022). The findings provide preliminary evidence that neem seed extract can be used alongside mineral fertilizer to improve early *M. oleifera* growth.

Conclusion

Neem seed extract was associated with improved early growth of Moringa oleifera relative to the untreated control. The combined neem seed extract and synthetic fertilizer treatment recorded the highest observed values for plant height, leaf number, root length, fresh weight, and dry weight at the reported assessment periods.

Recommendations for Further Research

Future experiments should evaluate multiple neem extract concentrations and application frequencies, include appropriate mineral-fertilizer rates, characterize the chemical composition of the extract, measure soil nutrient and microbial responses, and report complete inferential statistics. Longer-duration trials under nursery and field conditions are also needed to determine whether the early growth responses observed here translate into improved survival, yield, and soil fertility.

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