Optimizing Radish Yield and Soil Fertility in Medicinal Tree–Based Agroforestry Systems of Bangladesh

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Abstract: Agroforestry integrates crop production with ecological benefits. This study evaluated growth, yield, land equivalent ratio (LER), and soil fertility of radish (*Raphanus sativus* L.) under medicinal tree–based agroforestry systems in Bangladesh. Radish was cultivated with Amloki (*Phyllanthus emblica*), Haritoki (*Terminalia chebula*), and Bohera (*Terminalia bellirica*) at three distances from tree bases (0–68 cm, 69–136 cm, and 137–204 cm), alongside an open-field control. Growth and yield were significantly influenced ($p < 0.05$) by tree species and distance. The highest yield was obtained in open fields (48.02 t/ha), followed by radish with *Amloki* at ≥137 cm (42.31 t/ha). The lowest yield was recorded under *Bohera* at 0–68 cm (24.45 t/ha). Yields improved with distance from tree bases, reaching levels statistically similar to open-field conditions at ≥137 cm. Land Equivalent Ratio (LER) values were consistently greater than 1.0, ranging from 1.64 (Bohera) to 1.73 (Amloki), indicating superior land-use efficiency compared to monocropping. Soil fertility also improved under agroforestry: the highest organic carbon (1.25%) and nitrogen (0.125%) were recorded in Radish–Amloki systems, while the lowest values were found in Radish–Haritoki (1.10% and 0.118%, respectively). Available phosphorus ranged from 7.43 ppm (Haritoki) to 7.72 ppm (Bohera). Overall, medicinal tree–based agroforestry, particularly with Amloki, enhanced land productivity and soil fertility, while mitigating yield losses near tree bases.

Keywords: Agroforestry, Medicinal trees, Radish yield, Land Equivalent Ratio (LER), Soil fertility, Sustainable agriculture

Introduction

Agroforestry, the deliberate integration of trees with crops and/or livestock within the same land unit, is increasingly recognized as a sustainable land management system (Nair et al., 2021). By combining complementary species, agroforestry enhances ecological functions such as soil fertility improvement, carbon sequestration, biodiversity conservation, and microclimate regulation, while also contributing to livelihood resilience and food security (Pantera et al., 2021). Globally, agroforestry occupies nearly 1 billion hectares, representing about 43% of agricultural land, and supports the livelihoods of more than 560 million people in developing countries (Kala et al., 2025). It is widely regarded as a practical solution to challenges such as land degradation, reduced crop productivity, and climate change impacts (Duffy et al., 2021; Bishaw et al., 2022). In Bangladesh, where arable land is shrinking and floods and droughts increasingly threaten crop production, agroforestry has been promoted as an integrated adaptation strategy that balances agricultural productivity with ecological sustainability (Kausar et al., 2024).

Medicinal trees within agroforestry systems add a unique dimension by providing health-related, ecological, and economic benefits. They supply raw materials for pharmaceutical industries while simultaneously contributing to soil fertility, nutrient cycling, and biodiversity conservation (Sahel et al., 2018). In Bangladesh, species such as Amloki (*Phyllanthus emblica*), Bohera (*Terminalia bellirica*), and Haritoki (*Terminalia chebula*) are especially significant. Together, they form the well-known Ayurvedic preparation "Triphala," valued for its therapeutic properties including antioxidant, digestive, and detoxifying effects (District et al., 2010). *Amloki* is renowned for its high vitamin C and polyphenol content, *Bohera* is traditionally used in treating digestive and respiratory ailments, while Haritoki is regarded in Ayurveda as a multipurpose "panacea" for its detoxifying and nutritive properties (Sahel et al., 2018).

However, these species face increasing threats from overexploitation, habitat destruction, and land degradation. Their inclusion in agroforestry systems offers opportunities for both conservation and sustainable utilization, while diversifying income sources for farmers.

Radish (*Raphanus sativus* L.) is an important winter vegetable in Bangladesh, locally known as Mula. It is widely consumed for its edible roots and leaves and is rich in nutrients such as calcium, potassium, phosphorus, and vitamin C (Dulal et al., 2021). Nationally, it is cultivated on about 76,943 acres, producing nearly 469,204 metric tons annually (BBS, 2023). Radish is adaptable to tree-based systems, although its growth and yield are influenced by tree species, shading, and soil nutrient availability. Previous research shows that radish achieves optimal performance in open fields but can also yield satisfactorily in agroforestry when planted at appropriate distances from tree bases (Ferdous et al., 2022). For example, Hossain et al. (2014) observed that proximity to *Akashmoni* trees suppressed radish growth due to competition, particularly near tree bases. Nonetheless, tree–crop systems often provide higher land equivalent ratios (LER) and better economic returns compared to monocropping, making them advantageous from a systems perspective (Karlıdağ et al., 2022).

Tree–crop interactions also contribute significantly to soil fertility restoration. Trees enrich soils through litter fall, root turnover, and enhanced microbial activity, thereby increasing organic carbon, nitrogen, and phosphorus availability (Mesele et al., 2025). Al-Jawahry and Almoussaw (2025) reported that agroforestry systems improve soil nitrogen by 15–20%, phosphorus by 10–15%, potassium by 15–20%, and crop yield by 20–25% compared with monocropping. Similarly, systems with diverse tree species have been shown to increase soil organic matter, improve pH balance, and aid pest control (Grandez-Alberca et al., 2025). These ecological benefits make agroforestry both a productive and restorative farming approach.

Despite extensive work on radish cultivation with fruit trees such as aonla, guava, and carambola (Ahmed et al., 2018; Ferdous et al., 2022), little is known about radish performance under medicinal tree-based agroforestry in Bangladesh. In particular, the effect of distance from tree bases on radish growth and yield has not been systematically evaluated for Amloki, Bohera, and Haritoki. Understanding these interactions is essential because radish provides immediate food and income, while medicinal trees contribute long-term ecological and medicinal benefits. Identifying optimal planting distances could help minimize competition, maximize yield, and simultaneously support conservation of medicinal trees.

The present study was therefore undertaken to evaluate radish performance under medicinal tree-based agroforestry systems in Bangladesh. Specifically, the objectives were to (i) examine the suitability of radish cultivation with Amloki, Bohera, and Haritoki at different planting distance from these tree species, (ii) determine the influence of tree species and planting distance on radish growth and yield, and (iii) assess soil fertility and land equivalent ratio under these systems. The findings are expected to generate scientific insights into tree–vegetable interactions, promote sustainable land management, and demonstrate how integrating radish with medicinal trees can simultaneously enhance farm productivity, conserve valuable medicinal species, and improve soil health.

Materials and Methods

Research Site and Experimental Period

The experiment was conducted from July 2024 to June 2025 at the Agroforestry field, Bangladesh Agricultural University (BAU), Mymensingh, located in the Old Brahmaputra Floodplain (AEZ-9). The soils are non-calcareous dark grey floodplain types with medium–high fertility (Brammer, 1996). The climate is subtropical with hot summers, monsoon rains, and mild winters (BMD, 2023).

Experimental Design and Treatments

Radish was intercropped with three medicinal trees—Amloki, Bohera, and Haritoki. Trees were planted in 2018 at 3.25 × 3.25 m spacing.

The experiment followed a two-factor factorial RCBD with four replications:

- **Factor A (Tree species):** T_0 = Sole radish, T_1 = Amloki, T_2 = Bohera, T_3 = Haritoki

- **Factor B (Distance from tree base):** D_1 = 0–68 cm, D_2 = 69–136 cm, D_3 = 137–204 cm

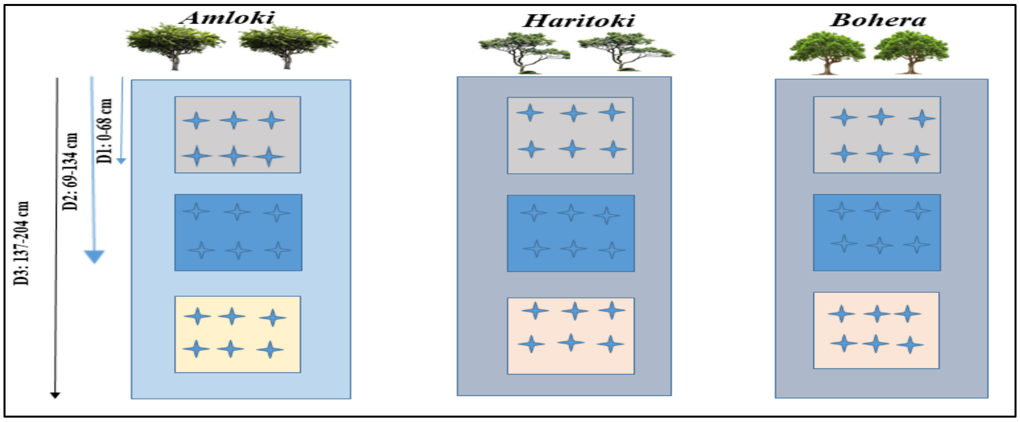

Figure 1. Experimental Layout of Radish Cultivation under Three Medicinal Tree Species at Varying Distances from Tree Base in an Agroforestry System

Crop Establishment and Management

Radish was grown following BARI (2021) recommendations. Standard practices (weeding, gap filling, irrigation, pest control) and recommended fertilizer doses were applied. No additional fertilizers were given to trees.

Data Collection

Data on radish growth and yield performance were recorded at harvest. The parameters measured included plant height (cm), number of leaves per plant, root length (cm), root diameter (cm), individual root weight (g), and total yield (t ha^{-1}).

The reduction in radish yield under tree-based systems relative to sole cropping was estimated using the formula suggested by Willey (1979):

$$\text{Yield reduction (\%)} = \frac{\text{Ys} - \text{Yi}}{\text{Ys}} \times 100 \qquad (1)$$

where,
Y_s = yield of sole radish crop, Y_i = yield of radish intercropped with medicinal trees.

The **Land Equivalent Ratio (LER)** was calculated to evaluate land-use efficiency using the equation (Mead & Willey, 1980):

$$\text{LER} = \frac{\text{Yri}}{\text{Yrs}} + \frac{\text{Yti}}{\text{Yts}} \qquad (2)$$

where,
Y_{ri} = yield of radish in agroforestry, Y_{rs} = yield of radish in sole cropping, Y_{ti} = yield of trees in agroforestry, Y_{ts} = yield of trees in sole stand. An LER value greater than 1 indicates a land-use advantage of the agroforestry system over mono-cropping.

Soil Sampling and Analysis

Composite soil samples (0–15 cm) were collected before sowing and after harvest. Analyses included pH (glass electrode), organic C (Walkley & Black, 1934), total N (Kjeldahl; Bremner & Mulvaney, 1982), available P (Olsen et al., 1954), exchangeable K (flame photometer), and available S (Page et al., 1982).

Statistical Analysis

Data were analyzed using STATISTICS 10. A two-way ANOVA tested the effects of tree species, distance, and their interaction.

Significant differences were separated by Duncan's Multiple Range Test (DMRT) and LSD at the 5% level (Gomez & Gomez, 1984).

Results and Discussion

Growth Performance of Radish under Different Medicinal Tree Species

The growth and yield attributes of radish varied significantly under different medicinal tree species (**Table 1**). The control treatment (T_0) recorded the highest plant height (24.80 cm), leaf number per plant (13.76), root length (18.78 cm), root girth (23.50 cm), and root weight (326.91 g). Among the tree species, *Amloki* (T_1) produced comparatively higher values of all parameters than Haritoki (T_3) and Bohera (T_2). Bohera (T_2) generally resulted in the lowest plant height (13.74 cm), number of leaves (7.62), root girth (13.02 cm), and root weight (181.13 g). The coefficients of variation ranged from 9.12 to 12.44%, indicating reliable experimental precision. All growth characteristics differed significantly among treatments at $P \leq 0.05$ according to Duncan's Multiple Range Test (DMRT). These findings clearly demonstrate the influence of medicinal tree species on radish growth. Similar trends have been reported in previous studies, where radish and other winter vegetables achieved higher growth and yield under open-field conditions compared with tree-based agroforestry systems (Hossain et al., 2014). Ferdous et al. (2022) likewise reported that the radish variety 'Rocky 45' attained its maximum root yield (39.47 t ha^{-1}) under sole cropping, although some agroforestry combinations (e.g., aonla + carambola) enhanced leaf production. The observed decline in radish performance under tree canopies in the present study can be attributed to interspecific competition for essential resources such as light, water, and nutrients. Ahmed et al. (2018) similarly found substantial yield reductions in summer vegetables grown near guava trees, and Karlıdağ et al. (2022) noted that vegetable growth often declines under fruit trees in agroforestry systems despite the broader benefits of diversified land use. However, Sahel et al. (2018) reported minimal differences in root vegetable performance under medicinal tree-based systems, suggesting that careful spatial planning can mitigate competitive effects.

Table 1. Effect of medicinal tree species on the growth characteristics of Radish

Tree species (A)	Plant height (cm)	Leaves /plant	Root length (cm)	Root girth (cm)	Weight/Root (g)
T_0	24.80 a	13.76 a	18.78 a	23.50 a	326.91 a
T_1	17.22 b	9.55 b	15.88 b	16.32 b	227.91 b
T_2	13.74 d	7.62 d	14.08 d	13.02 d	181.13 d
T_3	15.29 c	8.49 c	12.88 c	14.50 c	201.62 c
CV (%)	12.19	11.59	10.86	12.44	9.12
Level of sign.	**	**	**	**	**

Means in column followed by the different letters are significantly different by DMRT at $P \leq 0.05$; T_0 = Control, T_1 = Amloki, T_2 = Bohera, T_3 = Haritoki

Radish growth also varied significantly with distance from the tree base (**Table 2**). Plants nearest to the tree trunks (D_1) exhibited the lowest plant height (15.53 cm), leaf number (8.62), root length (10.00 cm), root girth (14.71 cm), and root weight (204.76 g). Growth improved at an intermediate distance (D_2), while the farthest distance (D_2) produced the highest values (plant height 20.03 cm, leaves per plant 11.11, root length 14.33 cm, root girth 18.98 cm, and root weight 264.01 g). This gradient indicates progressively reduced competition for light, water, and nutrients with increasing distance from tree bases. These results align closely with findings from previous agroforestry studies. Ahmed *et al*. (2018) observed that summer vegetables grown near guava trees suffered significant yield reductions, with the sharpest decline (32.16%) occurring within 0–60 cm of the tree base compared with open-field cultivation. Similarly, Hossain et al. (2014) reported that radish plants grown near Akashmoni trees had reduced plant height, leaf number, root length, and root weight, while those in open fields showed more vigorous growth. Comparable evidence has been reported for other crops as well. Khatun et al. (2010) documented growth suppression in medicinal plants under multilayered agroforestry systems, attributing the decline to resource competition. Sahel et al. (2018) noted that yield differences of root vegetables grown under trees were often not statistically significant, but crops closest to tree bases consistently performed 2–5% worse. Taken together, the present study confirms that Radish yield declines near tree bases but improves with distance, highlighting the need for proper spacing in agroforestry systems.

Table 2. Effect of distance from tree base on the growth characteristics of Radish

Distance (B)	Plant height (cm)	Leaves /plant	Root length (cm)	Root girth (cm)	Weight/Root (g)
D_1	15.53 c	8.62 c	10.00 c	14.71 c	204.76 c
D_2	17.73 b	9.84 b	12.14 b	16.80 b	233.66 b
D_3	20.03 a	11.11 a	14.33 a	18.98 a	264.01 a
CV (%)	12.19	11.59	10.86	12.44	9.12
Level of sign.	**	**	**	**	**

Means in column followed by the different letters are significantly different by DMRT at $P \leq 0.05$; D_1 = 0 - 68 cm, D_2 = 69 - 136 cm, D_3 = 137-204 cm distance from different medicinal plants.

The combined influence of tree species and distance from the tree base (A × B) on radish growth was highly significant for all measured parameters (**Table 3**). Across plant height, leaf number per plant, root length, root girth, and root weight, clear interaction patterns emerged: radish performance improved with increasing distance from tree bases and was consistently highest under the control (T_0, no trees). Radish grown in the open-field control plots (T_0) exhibited the highest values for all growth attributes—plant height (24.80 cm), leaves per plant (13.76), root length (18.78 cm), root girth (23.50 cm), and root weight (326.91 g)—confirming the advantages of sole cropping. In contrast, the lowest growth values were recorded for radish planted closest to the Bohera tree base ($D_1 \times T_2$): plant height 10.99 cm, leaves per plant 6.10, root length 10.66 cm, root girth 10.41 cm, and root weight 144.93 g. Intermediate performance was observed at mid-distances (D_2), while the highest values among tree-associated treatments consistently occurred at the farthest distance (D_3), especially under *Amloki* ($D_3 \times T_1$: plant height 20.35 cm; leaves per plant 11.29; root length 15.49 cm; root girth 19.29 cm; root weight 268.22 g). Based on overall performance, the relative suitability of radish cultivation in these agroforestry systems can be ranked as: Amloki > Haritoki > Bohera. These findings are consistent with earlier studies. Ahmed et al. (2018) reported that summer vegetable yields were lowest within 60 cm of guava tree bases but comparable to open-field levels beyond 120 cm. Hossain et al. (2014) also observed reduced radish growth (plant height, leaf number, root length, and root weight) under Akashmoni trees, with growth recovery evident at increasing distances. Ferdous et al. (2022) reported maximum radish yield in open fields, with significant declines in aonla + carambola systems due to shading. In contrast, Sahel et al. (2018) observed only modest yield reductions (2–5%) near tree bases, while Karlıdağ et al. (2022) noted higher overall productivity in agroforestry despite lower individual yields. The present study similarly shows that maintaining ≥137 cm distance reduces competition, with *Amloki* most compatible and *Bohera* least suitable for radish.

Table 3. Interaction (tree × distance) effects on the growth characteristics of Radish

Interaction (A × B)	Plant height (cm)	Leaves /plant	Root length (cm)	Root girth (cm)	Weight/Root (g)
Control – T_0	24.80 a	13.76 a	18.78 a	23.50 a	326.91 a
$D_1 \times T_1$	13.97 g	7.76 g	12.20 f	13.25 f	184.17 g
$D_1 \times T_2$	10.99 i	6.10 i	10.66 h	10.41 e	144.93 i
$D_1 \times T_3$	12.36 h	6.86 h	11.37 g	11.71 g	163.03 h
$D_2 \times T_1$	17.34 d	9.61 d	13.94 d	16.43 d	228.37 d
$D_2 \times T_2$	13.57 g	7.53 g	12.00 f	12.86 f	178.94 g
$D_2 \times T_3$	15.51 f	8.45 f	13.84 e	14.41 e	200.42 f
$D_3 \times T_1$	20.35 b	11.29 b	15.49 b	19.29 b	268.22 b
$D_3 \times T_2$	16.65 e	9.24 e	13.58 d	15.78 d	219.53 e
$D_3 \times T_3$	18.31 c	10.16 c	14.44 c	17.36 c	241.40 c
CV (%)	12.19	11.59	10.86	12.44	9.12
Level of sign.	**	**	**	**	**

Means in column followed by the different letters are significantly different by DMRT at $P \leq 0.05$; T_0 = Control, T_1 = *Amloki*, T_2 = *Bohera*, T_3 = *Haritoki*, and D_1 = 0 - 68 cm, D_2 = 69 - 136 cm, D_3 = 137-204 cm distance from different medicinal plants.

Yield of Radish in Association with Medicinal Tree Species

Figure 2. Radish with medicinal tree species in different growth stage

Radish yield was significantly influenced by both tree association and planting distance from the tree base (**Figure 3**). The highest yield (48.02 t ha^{-1}) was obtained in the open-field control (without tree association), which reflects the absence of competition for light, nutrients, and water. In contrast, yields declined progressively with proximity to tree bases across all medicinal tree species, highlighting the dual influence of shading (reduced solar radiation and photosynthetic activity) and belowground competition for resources. Among the medicinal trees, *Amloki* supported the highest average yield (36.82 t ha^{-1}), followed by Haritoki (34.13 t ha^{-1}) and Bohera (32.07 t ha^{-1}). A clear distance gradient was observed under Amloki: 30.42 t ha^{-1} at 0–68 cm, 37.73 t ha^{-1} at 69–136 cm, and 42.31 t ha^{-1} at 137–204 cm. This trend demonstrates that competitive effects are strongest near tree bases but diminish as distance increases. Variations among species may be linked to differences in canopy density (phyllotaxy) and root system architecture, both of which influence shading intensity and resource competition. Based on yield performance, the relative compatibility of radish cultivation can be ranked as Amloki > Haritoki > Bohera.

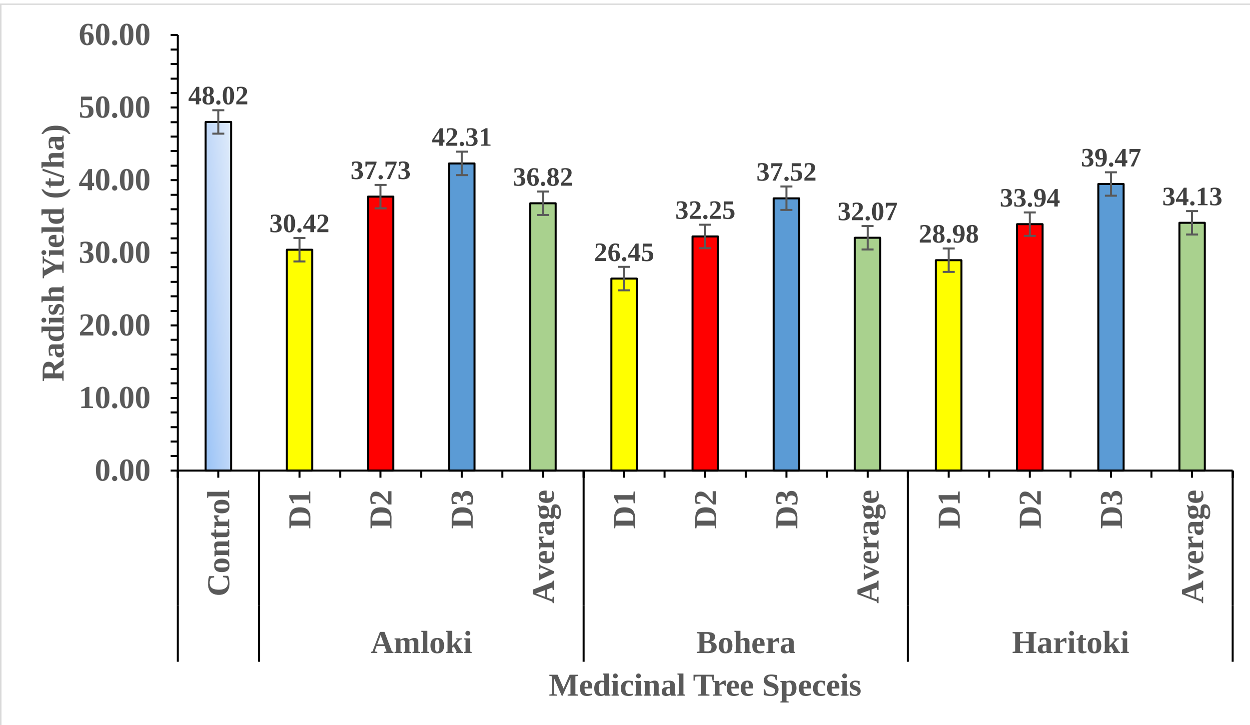

Figure 3. Yield of Radish with different medicinal tree species

The percentage yield reduction of radish relative to the open-field control decreased progressively with increasing distance from medicinal tree bases (**Table 4**). At the closest distance (D_1), yield losses were highest, ranging from 36.65% under Amloki**,** to 44.93% under Bohera**,** and 39.65% under Haritoki**.** At the intermediate distance (D_2), yield reductions fell to 21.42%, 32.84%, and 29.31%, respectively. The lowest reductions were observed at the farthest distance (D_3), with only 11.88% yield loss under Amloki, 21.87% under Bohera, and 17.80% under Haritoki. Averaged across distances, Bohera caused the greatest overall yield reduction (33.22%), followed by Haritoki (28.93%) and Amloki (23.32%). This clear gradient demonstrates that both tree species and distance from the tree base strongly influence radish yield. The effect was most pronounced under Bohera, which consistently produced the largest reductions, while Amloki showed the smallest yield losses at all distances.

Table 4. Yield reduction (%) of Radish with medicinal tree species

Distance	Yield Reduction (%)		
	Radish with Amloki	Radish with Bohera	Radish with Haritoki
D_1	36.65	44.93	39.65
D_2	21.42	32.84	29.31
D_3	11.88	21.87	17.80
Average	23.32	33.22	28.93

D_1 = 0 - 68 cm, D_2 = 69 - 136 cm, and D_3 = 137-204 cm distance from different medicinal plants

These results align with earlier studies. Ahmed et al. (2018) reported up to 32% yield loss in vegetables near guava trees, and Hossain et al. (2014) found radish and other winter crops performed better in open fields than under Akashmoni due to resource competition. Ferdous et al. (2022) also noted the highest radish yield (39.47 t ha^{-1}) in open-field cultivation. While open fields maximize yield, agroforestry offers advantages in land-use efficiency and returns. Sahel et al. (2018) observed minimal yield loss in root vegetables near medicinal trees, particularly in early tree stages, supporting coexistence. In the present study, yields above 30 t ha^{-1} were obtained even close to *Amloki* trees, showing their compatibility. Organic inputs can further improve performance; Aboyeji et al. (2019) demonstrated that *Tithonia diversifolia* manure matched inorganic fertilizers in radish. Overall, sole cropping ensures maximum yield, but *Amloki*-based agroforestry balances productivity, economic benefits, and sustainability.

Yield and yield attributes of medicinal tree species

Table 5 shows that tree yield attributes were only slightly affected by radish intercropping. In Amloki, fruit length and girth were marginally higher under agroforestry, though fruit weight per tree and yield were slightly lower (18.55 kg, 21.67 t ha^{-1}) than in sole-tree systems (19.69 kg, 22.47 t ha^{-1}). *Haritoki* showed negligible changes in fruit size but a small yield reduction (35.56 vs. 37.25 t ha^{-1}). *Bohera* recorded slight declines in both fruit size and yield (13.35 vs. 13.75 t ha^{-1}). Overall, radish intercropping caused minor yield reductions without affecting fruit quality, indicating that medicinal trees can be effectively integrated with vegetables while sustaining productivity.

Table 5. Yield and yield attributes of medicinal tree species with or without radish vegetables

Tree species	Parameters		With Radish	Without Radish
Amloki	Fruit size	Length (cm)	2.63	2.51
		Girth (cm)	3.95	3.88
	Fruit weight $tree^{-1}$ (kg)		18.55	19.69
	Yield (t ha^{-1})		21.67	22.47
Haritoki	Fruit size	Length (cm)	3.49	3.52
		Girth (cm)	6.28	6.29
	Fruit weight $tree^{-1}$ (kg)		47.67	51.25
	Yield (t ha^{-1})		35.56	37.25
Bohera	Fruit size	Length (cm)	4.95	5.03
		Girth (cm)	8.45	8.59
	Fruit weight $tree^{-1}$ (g)		23.57	25.15
	Yield (t ha^{-1})		13.35	13.75

Land Equivalent Ratio (LER)

The Land Equivalent Ratio (LER) assessed the productivity of radish–tree systems versus monocultures (**Table 6**). All combinations recorded LER > 1.0, confirming land-use advantages. Radish–Amloki achieved the highest efficiency (1.73), followed by Radish–Haritoki (1.66) and Radish–Bohera (1.64), indicating 64–73% greater output than monocropping. This ranking aligns with yield results, highlighting Amloki as the most compatible tree for radish intercropping. The LER values in this study (1.64–1.73) align with the 1.36–2.00 range reported by Seserman (2018) and support the view of Lehmann et al. (2020) that values above 1.0 confirm agroforestry's efficiency. Similar findings were noted by Karlıdağ et al. (2022), who reported higher productivity and profitability despite reduced vegetable yields (LER: 1.86–1.97), and by Solanki (2018), who showed medicinal plant–based systems outperform monocultures. Gruenewald et al. (2007) also observed no negative effects of hedgerows on intercrops when measured through LER. Overall, this study confirms that radish–tree agroforestry enhances land-use efficiency, with Amloki–radish combinations proving most compatible and sustainable.

Table 6. Land Equivalent Ratio (LER) of Medicinal trees and Radish-based agroforestry practices

	Relative yield		LER (a + b)
	Medicinal trees (a)	Radish (b)	
Amloki - Radish	0.96	0.77	1.73
Bohera - Radish	0.97	0.67	1.64
Haritoki - Radish	0.95	0.71	1.66

Soil Fertility Improvement

Soil fertility improved across all tree–radish systems after one cultivation cycle (**Table 7**). Organic carbon and total nitrogen increased, with the highest gains in the Radish–*Amloki* system, consistent with findings by Mesele et al. (2025) and Al-Jawahry & Almoussaw (2025). Available phosphorus, potassium, and sulphur also rose slightly, again most in *Amloki* plots, while pH remained stable within the optimal range for radish growth, reflecting the buffering effect of tree–soil interactions (Wariyo, 2025). These improvements align with reports of enhanced nutrient cycling and soil enrichment in diverse agroforestry systems (Mesele et al., 2025; Grandez-Alberca et al., 2025; Mahadik et al., 2025). Overall, the results confirm that medicinal tree–radish agroforestry, especially with *Amloki*, enhances soil quality while maintaining balanced conditions for crop production.

Table 7. Soil fertility status of different Agroforestry practices before and after the experimental study

Soil parameters	Time	Agroforestry Practices		
		Amloki tree-based	*Haritoki* tree-based	*Bohera* tree-based
pH	Before	5.95	5.97	6.00
	After	6.05	5.95	6.05
Org. C (%)	Before	1.20	1.12	1.17
	After	1.25	1.10	1.15
Total-N (%)	Before	0.123	0.118	0.119
	After	0.125	0.120	0.121
P (ppm)	Before	7.59	7.43	7.72
	After	7.63	7.46	7.68
K (mg/100g)	Before	0.154	0.145	0.147
	After	0.155	0.144	0.149
S (ppm)	Before	8.72	8.45	8.30
	After	8.75	8.48	8.28

Conclusion

Radish cultivation under medicinal tree–based agroforestry systems revealed a clear trade-off: although the highest yield was obtained in open fields (48.02 t/ha), substantial production was sustained under tree associations, particularly with *Amloki* (36.82 t/ha). Importantly, these systems demonstrated high land-use efficiency (LER: 1.64–1.73) and significantly enhanced soil fertility through increased organic carbon, nitrogen, and phosphorus levels relative to pre-establishment conditions. Among the tree species studied, the Radish–*Amloki* combination emerged as the most productive and sustainable option. Overall, despite some reduction in individual crop yield, medicinal tree–based agroforestry systems provided superior total productivity, improved soil health, and greater long-term sustainability compared to monocropping.

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Declaration of Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

References

Aboyeji, C.M., Adekiya, A.O. and Dunsin, O. (2019). Growth, yield and vitamin C content of radish (*Raphanus sativus* L.) as affected by green biomass of *Parkia biglobosa* and *Tithonia diversifolia*. *Agroforest Systems*, 93:803–812. https://doi.org/10.1007/s10457-017-0174-6

Ahmed, F., Monika, A. U. H., Hossain, M. A., Wadud, M. A., and Rahman, G. M. M. (2018). Performance of guava fruit tree-based agroforestry practice during summer season in charland and plainland ecosystems. *Journal of Agroforestry and Environment*, 12(1):1-8.

Al-Jawahry, H. M., and Almoussaw, Z. A. (2025). Exploring the potential of agroforestry to improve soil fertility and crop yields. In *SHS Web of Conferences* (Vol. 216, p. 01050). EDP Sciences.

Bangladesh Bureau of Statistics (BBS). (2023). *Yearbook of Agricultural Statistics 2023*. Dhaka, Bangladesh: Statistics and Informatics Division, Ministry of Planning.

BARI. (2021). Annual Report 2020–21. Bangladesh Agricultural Research Institute, Joydebpur, Gazipur.

Bishaw, B., Soolanayakanahally, R., Karki, U. and Hagan, E. (2022). Agroforestry for sustainable production and resilient landscapes. Agroforestry Systems, 96(3):447-451.

BMD. (2023). Climate Data Summary, Mymensingh Station. Bangladesh Meteorological Department

Brammer, H. (1996). The Geography of the Soils of Bangladesh (revised and updated ed.). Dhaka: University Press Limited

Bremner, J. M. and Mulvaney, C. S. (1982). Nitrogen–Total. In A. L. Page (Ed.), Methods of Soil Analysis, Part 2. ASA and SSSA, Madison, WI.

District, B., Rani Chowdhury, A., Israt Jahan, F., Seraj, S., Khatun, Z., Jamal, F., Ahsan, S., Jahan, R., Ahmad, I., Chowdhury, M. H. and Rahmatullah, M. (2010). A survey of medicinal plants used by Kavirajes of Barisal town in Barisal district, Bangladesh. *Journal of Sustainable Agriculture*, 4(2):237–246.

Duffy, C., Toth, G.G., Hagan, R.P., McKeown, P.C., Rahman, S.A., Widyaningsih, Y., Sunderland, T.C. and Spillane, C. (2021). Agroforestry contributions to smallholder farmer food security in Indonesia. *Agroforestry Systems*, *95*(6): 1109-1124.

Dulal, D., Baral, D., Poudel, A., Kafle, K. and Shrestha, B. (2021). Effect of different doses of vermicompost on growth, yield, and quality of radish (*Raphanus sativus* L. cv. Mino Early).

Archives of Agriculture and Environmental Science, 6(3):354–359. https://doi.org/10.26832/24566632.2021.0603014

Ferdous, J., Ahamed, T., Miah, M. M. U. and Rahman, M. M. (2022). Performance of radish in aonla based multistoried agroforestry system. *European Journal of Agriculture and Food Sciences*, 4(3):9-16.

Gomez, K. A. and Gomez, A. A. (1984). Statistical Procedures for Agricultural Research (2nd ed.). John Wiley & Sons.

Grandez-Alberca, M.A., Cotrina-Sanchez, A., Haro, N., Zabaleta-Santisteban, J.A., Silva-Melendez, T.B., Sanchez-Vega, J.A., Medina-Medina, A.J., Tuesta-Trauco, K.M., Rivera-Fernandez, A.S., Granda-Santos, M. and Oliva-Cruz, M. (2025). Agronomic and Economic Sustainability Perspectives in Coffee-Based Agroforestry System (*Coffea arabica* L.) in Rodríguez de Mendoza, Amazonas, Peru. *Trees, Forests and People*, 21:1-11.

Gruenewald, H., Brandt, B. K., Schneider, B. U., Bens, O., Kendzia, G. and Hüttl, R. F. (2007). Agroforestry systems for the production of woody biomass for energy transformation purposes. *Ecological engineering*, 29(4):319-328.

Hossain, M. I., Akter, A., Wadud, M. A. and Rahman, G. M. M. (2014). Winter vegetables cultivation in charland-based farming system under Akashmoni tree. *Journal of Agroforestry and Environment*, 8(2):35–38.

Kala, C. P. (2025). Agroforestry in a changing climate: Challenges, opportunities and solutions. *Ecological Frontiers*, 45(2):269–276.

Karlıdağ, H., Kutsal, İ. K., Karaat, F. E., Küçük, R. and Kan, T. (2022). Evaluation of an intercropping system: Lettuce and radish growing in fruit sapling production. *Bangladesh Society of Journal of Agriculture*, 5(3):220–226.

Kausar, D. R., Ehsan, M. S., Jilani, D. G. and Nain, Q. (2024). The agroforestry potential and analysis of growth and yield of different vegetables grown under olive orchard to mitigate climate change effects. *International Journal of Innovations in Science & Technology*, 6(6): 685–700.

Khatun, M. U. S., Rahim, M. A., Wadud, M. A. and Rahman, G. M. M. (2010). Performance of medicinal plants grown under multilayered Agroforestry system. *Journal of Agroforestry and Environment*, 4(2): 201-204.

Lehmann, L.M., Smith, J., Westaway, S., Pisanelli, A., Russo, G., Borek, R., Sandor, M., Gliga, A., Smith, L. and Ghaley, B.B. (2020). Productivity and economic evaluation of agroforestry systems for sustainable production of food and non-food products. *Sustainability*, 12(13):5429.

Mahadik, S. P., Dalvi, V. V. and Meshram, N. A. (2025). Soil fertility under Asana (Bridelia retusa) based agroforestry systems in lateritic soil of Konkan. *Indian Journal of Agroforestry*, 27(2):109-113.

Mead, R. and Willey, R. W. (1980). The concept of a 'Land Equivalent Ratio' and advantages in yields from intercropping. Experimental Agriculture, 16(3):217–228.

Mesele, S. A., Adelana, F. O. and Mechri, M. (2025). Soil fertility improvement in agroforestry after 30 years of silvopasture on ferric lixisols within the Guinea Savanna ecology of Nigeria. *Trees, Forests and People*, 20:1-9.

Nair, P. K. R., Kumar, B. M. and Nair, V. D. (2021). Definition and concepts of agroforestry. In *An Introduction to Agroforestry*. Springer, Cham. https://doi.org/10.1007/978-3-030-75358-0

Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A. (1954). Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. USDA Circular 939.

Page, A. L., Miller, R. H., and Keeney, D. R. (1982). Methods of Soil Analysis, Part 2. ASA and SSSA, Madison, WI.

Pantera, A., Mosquera-Losada, M. R., Herzog, F. and Den Herder, M. (2021). Agroforestry and the environment. *Agroforestry Systems*, 95(5):767–774.

Sahel, M. O. R., Noman, M. A. A., Ahmed, F., Wadud, M. A. and Rahman, G. M. M. (2018). Performance of root vegetables in association with medicinal trees under charland ecosystem. *Journal of Agroforestry and Environment*, 12(1):47-52.

Seserman, D. M. (2018). Benefits of agroforestry systems for land equivalent ratio-case studies in Brandenburg and Lower Saxony, Germany. In *European Agroforestry Conference-Agroforestry as Sustainable Land Use, 4th. EURAF*.

Solanki, V. K. (2018). Economic and Land Equivalent Ratio performance of herbal medicinal crops under three-tier agroforestry system. *International Journal of Current Microbiology and Applied Sciences,* 7:2458-2463.

Walkley, A. and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter. *Soil Science*, 37:29–38.

Wariyo, D. Z. (2025). Agroforestry practices: a necessity for improving agricultural productivity and soil fertility in different agroecological zones of Ethiopia. *Journal of the Selva Andina Biosphere,* 13(1):41-52.

Willey, R. W. (1979). Intercropping – Its importance and research needs. *Field Crop Abstracts*, 32(1):1–10.