



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(9): 250-257
Received: 01-07-2026
Accepted: 30-07-2026
Publish Date: 01-08-2026

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Sustainable land use system option for rice growth and yield enhancement resources in indo-Gangetic plain region of Uttar Pradesh, India

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i9Sc.6352>

Abstract

Rice-based agroforestry is a promising option for diversifying the traditional rice (*Oryza sativa* L.) monoculture while maintaining resource use efficiency and productivity. A field experiment was conducted to evaluate the performance of two rice varieties viz. Sarjoo-52 and NDR-359 grown at three tree trunk distances (0.5-1.50 m, 1.50-2.50 m and 2.50-3.50 m) under three agroforestry systems viz. Shisham (*Dalbergia sissoo*), Casuarina (*Casuarina equisetifolia*) and Eucalyptus (*Eucalyptus* spp.) during kharif season. Growth attributes, yield attributes and yield performance of rice varieties were recorded under different agroforestry systems. The rice variety grown at 2.50-3.50 m tree proximity recorded significantly higher growth attributes, yield attributes, grain yield, straw yield, biological yield and harvest index over the tree trunk distances of 0.5-1.50 m and 1.50-2.50 m. Significantly higher growth attributes, yield attributes, grain yield, straw yield, biological yield and harvest index were recorded in Casuarina based agroforestry system over the Shisham and Eucalyptus based agroforestry systems. Significantly higher growth attributes, yield attributes, grain yield, straw yield, biological yield and harvest index were recorded in Sarjoo-52 variety over NDR-359 variety. Highest grain yield was recorded in 2.50-3.50 m tree proximity while lowest productivity was observed in 0.5-1.50 m tree proximity from the tree trunk. All the interactions were found non-significant for grain yield, straw yield, biological yield and harvest index. Based on the study it may be concluded that selection of suitable agroforestry species, proper tree-crop distance and suitable rice variety are very crucial to minimize competition and increase productivity of rice. Thus, for good productivity of rice-based agroforestry systems, Sarjoo-52 variety grown at 2.50-3.50 m tree proximity under Casuarina species may be proved a suitable option.

Keywords: Agroforestry, biological yield, casuarina, grain yield, harvest index, tree proximity

Introduction

Cultivation of rice is one of the most important contributors to agricultural economy and food security in Eastern Plain Zone of Uttar Pradesh. Rice is the dominant kharif crop of the plain zone and the most important livelihood for millions of farming households. However, rice-based monocultures are now under threat from loss of soil fertility, inefficient production system, groundwater depletion, climate change, and biodiversity loss (Datta *et al.*, 2026) [2]. The agro-climatic conditions of the Eastern Plain Zone, fertile alluvial soil and diverse ecological conditions, provide a good opportunity to assess the performance of rice varieties. By estimating production performance and economic efficiency of rice varieties in different agroforestry systems, it will help to develop sustainable production systems for enhancing yield and economic benefits (Nayak *et al.*, 2019) [14].

Rice (*Oryza sativa* L.), is the most important cereal crop of the kharif season. It is the staple food for more than half the world's population and is central to food security and nutrition in many developing countries. Rice is successfully cultivated in tropical and subtropical regions as well as in temperate areas. It grows from sea level up to an altitude of 2500-3000m (Malik *et al.*, 2017) [12]. In the country, India is the largest producer of rice in terms of area and the second-largest producer after China in terms of production. Similarly, it is the largest producer of rice in the state of Uttar Pradesh. Adopting improved crop varieties of rice along with site-specific

nutrient management and proper crop management is one of the best options to increase yield and ensure sustainable production of rice (Singh *et al.*, 2024) ^[19, 23].

Rice grains provide dietary energy and are a good source of food. Starch content is about 78-80%, protein 6-8%, fat 0.5-1.0%, and mineral matter 0.5-1.5%. Besides, they contain B-complex vitamins like thiamine, riboflavin, niacin, and minerals. Milled rice provides about 345-365 kcal energy per 100 edible grams. It makes rice one of the most important sources of energy-rich food. Even though rice has lower protein content compared to wheat, rice proteins have high biological value and are easily digested (Juliano, 1993; FAO, 1993) ^[9].

Agroforestry, the intentional integration of trees with agricultural crops and/or animals, is a viable option for sustainable land-use systems. It promotes agricultural production while conserving natural resources (Nair, 1998; Singh *et al.*, 2025) ^[24]. Trees improve the quality of agricultural produce, support higher yields of crops, soil organic matter, nutrient cycling, and retention, conserve water and moisture, and improve microclimate, reduce soil erosion, and increase biodiversity (Fahad *et al.*, 2022; Singh *et al.*, 2024) ^[4, 19, 23]. Tree-based agroforestry practices benefit rice agro-ecosystems by enhancing productivity, profitability, and the provision of environmental services. It also increases income from trees through timber, fuelwood, fodder, and other products and reduces risks to rice cropping from climate change and other factors (Bhandari and Upadhyaya 2025).

Agroforestry is a climate-smart land-use practice that promotes carbon sequestration, biodiversity, and sustainable land-use, while also building resilience to climate change. Trees provide multiple goods and services on farms, facilitating the transformation of agro-ecosystems into multi-functional agricultural systems. In India, agroforestry has gained significant attention as a sustainable production system while balancing conservation and production needs, and contributing to livelihood security (Ntawuruhunga *et al.*, 2023) ^[15].

Despite the potential of agroforestry systems for diversifying traditional rice monoculture, little is known about the performance of different rice varieties in varying planting densities near tree trunks. A better understanding of the tree-crop interactions that influence rice production is vital for developing improved agroforestry systems and practices. Tree-crop competition occurs for light, water, nutrients, and space. It becomes intense depending on the species and the distance between the rows of trees and crops. Thus, the identification of suitable rice variety and planting proximity to the tree row is essential in agroforestry tree-crop systems for enhancing yield, resource use efficiency, and profitability.

In view of the foregoing facts, the present study was carried out to evaluate the performance of different rice varieties under various agroforestry land-use systems to identify the best-performing rice variety, and the appropriate planting distance from the tree trunk for maximizing grain yield, resource use efficiency and economic benefits.

Materials and Methods

Study location and climatic conditions

A field experiment was conducted at the Main Experimental Station of Agroforestry, Department of Silviculture & Agroforestry, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya, U.P., India (26°33'45"N, 81°50'58"E and 125m MSL) during kharif season 2022-23. The study area falls under the agro-climatic zone (UP-9) which is a semi-arid and sub-tropical Indo-Gangatic eastern plain zone.

The meteorological observations for the study period were: the minimum and maximum temperature recorded for the whole period were 18.20-39.60°C, Relative humidity 68.3-83.9% with total rainfall of 956 mm received during the experimental period from sowing to harvesting i.e. during the month of May-November 2025 (Climatic data 2025-23).

Soil characteristics

The soil physical and chemical properties of the experimental site were found to be: The analysis done at 0-20 depth layer showed that bulk density ranged from 0.33-0.35 and organic carbon ranged from 0.279-0.336 which might be the reason that lower bulk density was recorded in Shisham based agri-silvi system having comparatively higher organic carbon content 0.336 %. The pH of the experimental site found to be moderately alkaline ranged from (8.08-8.80). The range of available nitrogen, available phosphorus and available potassium were (151.25-162.24 kg ha⁻¹), (15.80-18.06 kg ha⁻¹) and (178.33-193.90 kg ha⁻¹) in various land used systems respectively.

Experiment setup and crop management

A set of 18 treatment combinations comprising of three agroforestry systems viz. S1 (*Casuarina equisetifolia*), S2 (*Dalbergia sissoo*), and S3 (*Eucalyptus globules*) based agroforestry systems were assigned to first factor and three tree proximity viz. D1 (0.50-1.50m), D2 (1.50-2.50m), and D3 (2.50-3.50m) were allocated to Second factor and Rice variety V1 (Sarjoo-52) and V2 (NDR-359) tested following a Factorial RCBD with three replications. Rice (*Oryza sativa*) was transplanting manually with a row to plant spacing of 20x20 cm during the second week of July. Plant protection measure was applied as there was attack of insect-pests and diseases during crop growth period. The crop was harvested when rice panicle matures and dried but prior to shattering.

Sampling procedure and observations

The observation of growth attributes viz. plant height (cm), number of tillers per row meter length, dry matter accumulation (g per row meter length), length of panicle (cm), weight of panicle (g) and yield attributes viz. no. of grain per panicle, test weight (g), grain yield (kg ha⁻¹), straw yield (kg ha⁻¹), biological yield (kg ha⁻¹), and harvesting index (%) was recorded at harvest stage. The growth attributes were measured by averaging the data of five randomly selected plants from net plot area. The plant height was measured from ground level to the tip of the shoot. For dry matter accumulation, the sundried plants were oven dried at 70°C for 24 hours and weighed on weighing balance. The number of panicle plant⁻¹, length of panicles, number of grains panicles⁻¹ were also recorded by taking measurements from five randomly selected plants from net plot area. The test weight was recorded by weighing one thousand seeds and expressed in grams. The grain yield (weight of sun-dried grains), straw yield (sun dried plant material after harvesting plant), and biological yield (weight of grains + weight of straw) was recorded from net plot area and converted to express per hectare. The ratio of economic yield to biological yield expressed as a percentage constitutes the harvesting index. The experiment was subjected to economic analysis using cost of cultivation, gross returns, net return and benefit-cost ratio.

Statistical analysis

analysis was performed by using analysis of variance technique for Factorial Randomized Complete Block Design (F-RCBD) to

find out the significant difference between treatment by using doebioresearch Package. Shapiro-wilk test was used for testing assumptions of normality, and Bartlett's test was used for testing homogeneity of error variances. For comparison of treatment means LSD (Least Significant Difference) was used. All the statistical analysis was performed using R-software version, 4.3.0.

Results and discussion

Growth parameters and yield attributes

The results presented in Table 1 revealed that the growth parameters of rice were significantly influenced by agroforestry systems, tree proximity and rice variety. The Casuarina based agroforestry system (S_2) produced significantly higher plant height (101.28 cm), number of tillers per row meter (63.91), dry matter accumulation ($199.73 \text{ g row}^{-1} \text{ m}^{-1}$) followed by Shisham and Eucalyptus based agroforestry systems. However, the Shisham based agroforestry system (S_1) remained statistically at par with Casuarina for plant height. The lowest values for all the growth parameters were recorded in Eucalyptus based agroforestry system (S_3) with plant height, number of tillers per row meter and dry matter accumulation were 95.05 cm, 55.10 and $180.63 \text{ g row}^{-1} \text{ m}^{-1}$ respectively. Tree proximity significantly influenced the growth parameters of rice. The 2.50–3.50 m distance (D_3) from tree trunk recorded the highest plant height (100.64 cm), number of tillers per row meter (63.58), and dry matter accumulation ($196.76 \text{ g row}^{-1} \text{ m}^{-1}$) which were significantly higher than values recorded at 1.50–2.50m (D_2) and 0.50–1.50 m (D_1). However, plant height at D_3 remained statistically at par with D_2 . The lowest values for all the growth parameters were observed at closest distance (D_1) from tree trunk. The rice variety Sarjoo-52 (V_1) recorded significantly higher plant height (99.39 cm), number of tillers per row meter length (61.81) and dry matter accumulation ($193.92 \text{ g row}^{-1} \text{ m}^{-1}$) as compared with NDR-359 (V_2) variety which recorded (97.19 cm), (57.96) and ($184.63 \text{ g row}^{-1} \text{ m}^{-1}$) respectively. The interaction effects of agroforestry system (S) $\times$ tree proximity (D) was significant only for number of tillers per row meter length while $S \times V$ interaction was significant only for the number of tillers per row meter length. Similarly, the $D \times V$ interaction significantly influenced the number of grains per panicle and all other interactions were found to be non-significant. The three-way interaction ($S \times D \times V$) was found to be non-significant for all the growth parameters.

The yield attributes of rice were also significantly influenced by agroforestry systems, tree proximity and rice variety. The Casuarina based agroforestry system (S_2) recorded the highest panicle length (21.82 cm), panicle weight (2.77 g), number of grains per panicle (49.10) and test weight (22.69 g) followed by Shisham and Eucalyptus based agroforestry systems. However, the Eucalyptus based agroforestry system (S_3) recorded lowest values for panicle length (19.92 cm), panicle weight (2.55 g), number of grains per panicle (42.30) and test weight (21.13 g). Tree proximity significantly influenced all the yield attributes of rice. The treatment combination at 2.50–3.50 m (D_3) recorded the highest panicle length (21.69 cm), panicle weight (2.74 g), number of grains per panicle (49.03) and test weight (22.93 g) which were found to be significantly higher over the other distances i.e. 1.50–2.50m (D_2) and 0.50–1.50 m (D_1). The lowest values for all the yield attributes were recorded at closest distance (D_1) from the tree trunk. The rice variety Sarjoo-52 (V_1) recorded significantly higher panicle length (22.35 cm), panicle weight (2.70 g), number of grains per panicle (46.60) and test weight (22.49 g) than the variety NDR-359 (V_2) which recorded

panicle length, panicle weight, number of grains per panicle and test weight as 19.12 cm, 2.59 g, 44.34 and 21.26 g respectively. The interaction effect of $D \times V$ was significant only for number of grains per panicle while other interactions were found to be non-significant.

Yield parameters

The yield parameters of rice were significantly influenced by agroforestry systems, tree proximity and rice variety (Table 2). The Casuarina based agroforestry system (S_2) recorded the highest grain yield (27.33 q ha^{-1}), straw yield (46.90 q ha^{-1}) and biological yield (74.24 q ha^{-1}) followed by Shisham and Eucalyptus based agroforestry systems. However, the harvest index recorded under Casuarina (35.00%) remained statistically at par with Shisham based agroforestry system (34.77%). The lowest values of grain yield (24.60 q ha^{-1}), straw yield (44.17 q ha^{-1}), biological yield (68.78 q ha^{-1}) and harvest index (33.83%) were recorded in Eucalyptus based agroforestry system (S_3). Tree proximity significantly influenced all the yield parameters of rice. The treatment combination at 2.50–3.50 m (D_3) recorded the highest grain yield (28.25 q ha^{-1}), straw yield (49.05 q ha^{-1}), biological yield (77.30 q ha^{-1}) and harvest index (35.42%) which were significantly higher than the other distances i.e. 1.50–2.50m (D_2) and 0.50–1.50 m (D_1). However, the lowest values of grain yield (23.04 q ha^{-1}), straw yield (40.10 q ha^{-1}), biological yield (63.14 q ha^{-1}) and harvest index (33.53%) were recorded at closest distance (D_1) from the tree trunk. The rice variety Sarjoo-52 (V_1) recorded significantly higher grain yield (27.52 q ha^{-1}), straw yield (47.60 q ha^{-1}), biological yield (75.12 q ha^{-1}) and harvest index (35.00%) than the variety NDR-359 (V_2) which recorded corresponding values of 24.45 q ha^{-1} , 43.24 q ha^{-1} , 67.70 q ha^{-1} and 34.06%. The interaction effect of $S \times D$ was significant for grain yield, straw yield, and biological yield while for harvest index it was found to be non-significant. All other interactions ($S \times V$, $D \times V$, and $S \times D \times V$) were non-significant for all the yield parameters.

Discussion

Growth and yield attributes

The variation in growth and yield parameters of rice cultivated under various tree systems clearly demonstrates the effect of species on crop performance. Rice recorded higher growth and yield under Casuarina than Eucalyptus based treatment which implies that the former treatment created a more favorable environment for crop production than the latter (Doddabasawa & Chittapur, 2023) [3]. Differences in the performance of tree species could be due to variation in their canopy structure, rooting pattern, phenology, and water and nutrient use regimes, thus altering belowground and aboveground resources for the associated crop (Doddabasawa & Chittapur, 2023; Ruscena *et al.*, 2021) [3]. Tree-crop associations are therefore, species- and site-specific, and the net outcome of tree-crop interactions on the growth and yield of crops depends on the complementarity and competition of species (Ruscena *et al.*, 2021; Singh *et al.*, 2020) [18].

The higher growth and yield of rice under Casuarina species may be related to less competitive dominance in the crop growth zone since there was lower competition in terms of radiation, root proliferation, and soil water and nutrients (Ruscena *et al.*, 2021) [18]. Partitioning of the above and belowground resources is usually important in agroforestry since tree canopies modify the quantity and quality of radiation reaching the crop stand while their rooting patterns influence the availability of water and nutrients (Jose, 2021) [7, 8]. The balance between competition

and complementation determines the extent to which trees influence the productivity and performance of associated crops (Ruscena *et al.*, 2021; Jose, 2021) ^[7, 8, 18]. Global studies on rice agroforestry further indicate that the yield response of rice varied with the treatment, configuration, and species used with substantial yield reduction recorded where competition occurred (Rodenburg *et al.*, 2022) ^[17].

The relatively poor growth and yield recorded in the Eucalyptus treatment could be due to intense competition for radiation, soil moisture, and nutrients. Compared to other species, Eucalyptus is more competitive in terms of biomass production and resource use which could explain the poor performance of rice recorded in this treatment. However, the competition between Eucalyptus and rice for water and nutrients should be interpreted with caution since the study did not evaluate root distribution, soil moisture, and radiation use by the two species. The competition between trees and rice further depends on species and the stand density, tree age, size, canopy structure, rooting patterns, and soil and climatic conditions (Doddabasawa & Chittapur, 2023; Ruscena *et al.*, 2021) ^[3, 18]. It is also important to note that trees do not necessarily have a negative effect on the productivity of the associated crops since the response of crops to trees depends partly on the degree of complementarity and competition between species (Zhu *et al.*, 2020; Kuyah *et al.*, 2021) ^[11, 22].

The gradual rise in growth and yield parameters with an increase in distance from the tree trunk further demonstrates the effect of tree proximity on crop performance. The decline in crop performance under the close tree proximity and subsequent rise at further distances suggests that competition between trees and rice was intense but decreased with an increase in distance from the tree trunk (Doddabasawa and Chittapur 2023) ^[3]. This observation agrees with previous research that demonstrated that tree-crop competition was usually strongest at the tree line and declined progressively with distance (Doddabasawa and Chittapur 2023) ^[3]. This difference in tree-crop competition may probably be related to the proximity of tree rows, tree species, and crop type (Thaware *et al.*, 2020) ^[21]. Direct evidence supporting this relationship comes from research carried out on tree-based agrisilviculture. For example, the study by (Thaware *et al.*, 2020) ^[21] on agroforestry systems showed that tree proximity reduced rice yield attributes, grain, and straw yield. The yield of rice also decreased linearly as the planting distance from the tree increased. This further confirms the need to consider tree position when designing agroforestry systems since the relative spacing between tree rows usually determines their competitive influence on the growth and productivity of associated crops.

The decrease in crop performance with an increase in distance from the tree trunk could also be related to changes in available radiation under the tree cover. Tree canopies create large spatial variations in incident radiation with shading being most intense under the tree crown. Reduced irradiance has been demonstrated to affect the photosynthesis, biomass production, and yield of rice (Chen *et al.*, 2019; Ganguly *et al.*, 2020) ^[1, 6]. Shading by tree canopies has further been reported to reduce the grain yield of rice by affecting the number of panicles per plant, grains per panicle, and weight per thousand grains (Chen *et al.*, 2019; Ganguly *et al.*, 2020) ^[1, 6]. As a result, it is likely that the higher grain yields recorded in plots located further from the tree trunk were related to improved radiation receipt as compared to plots located closer to the tree trunk. In addition to differences in available radiation, competition for belowground resources by trees and rice could also explain the trends recorded in this study. However, further research is required to establish the

relationship between tree proximity and radiation since irradiance was not measured in this study. Overall, the differences in growth and yield parameters of rice recorded in this study were probably due to competition for soil moisture and nutrients as well as changes in incident solar irradiance caused by the tree cover.

Compared to NDR-359, Sarjoo-52 variety of rice recorded higher growth and yield parameters which suggests that genetic potential plays an important role in rice production under agroforestry. Differences in growth and yield performance of rice genotypes may be explained by the wide variation in growth and yield characters of rice cultivars grown under reduced solar irradiance in agroforestry systems. Differences in genetic potential may therefore partially explain the superior performance of Sarjoo-52 variety recorded in this study compared to NDR-359 variety. Ganguly *et al.* (2020) ^[6] reported that wide genetic variation among rice genotypes was apparent for most of the parameters measured under a low-light environment. Their study further demonstrated that radiation levels affected the panicle number, grains per panicle, and thousand-grain weight which were lowest for treatments subjected to reduced irradiance. Panda *et al.* (2025) ^[16] further reported that rice genotypes differed in terms of shade tolerance as demonstrated by differences in canopy structure, photosynthesis, biomass, and radiation-use efficiency. These differences in shade tolerance can be used to explain the superior performance of Sarjoo-52 variety recorded in this study. The observed varietal difference is probably related to the ability of the Sarjoo-52 variety to maintain tillering, leaf production, and assimilation under reduced irradiance as compared to the NDR-359 variety (Doddabasawa & Chittapur, 2023) ^[3]. However, direct evidence supporting this claim is required since this study did not determine photosynthesis, leaf area, radiation-use efficiency, and leaf carbohydrate content.

It is also important to note that tree-crop systems do not provide uniform irradiance but instead modify the light regime of rice cultivation. The differences in solar irradiance recorded under tree cover create favorable conditions for the superior genotype to outperform the inferior ones. Observations on rice production under reduced irradiance further indicate that shade during critical growth stages reduces grain yield, spikelet fertility, and thousand-grain weight while the response of different rice genotypes to reduced irradiance levels varies (Paez & Rebolledo, 2020). As a result, the superior performance of Sarjoo-52 variety recorded in this study could be related to its ability to tolerate shade better than the NDR-359 variety despite the reduced irradiance levels recorded under tree canopies. The observed varietal difference further emphasizes the importance of selecting high-yielding varieties capable of tolerating reduced irradiance levels for use in tree-based agroforestry systems.

The predominantly non-significant interaction effects among the various factors analyzed in this study demonstrate that the relative performance of the two rice varieties remained stable across the different agroforestry treatments and tree distances. In other words, the effects of the various factors analyzed were not dependent on the levels of the other factors since no significant two-way interactions were recorded for most parameters. Stability in the ranking of rice varieties across the different levels of the various factors is important in agroforestry since genotype-environment interactions often influence crop performance and productivity (Doddabasawa & Chittapur, 2023) ^[3]. However, it is critical to note that the lack of significant interaction effects does not imply that the factors analyzed were independent. On the contrary, significant two-way interactions

would be expected if the effect of one factor on the response variables was dependent on the levels of the other factors. Overall, the observed stability in the performance of the two rice varieties was probably due to their ability to produce more assimilates and maintain a relatively high photosynthetic rate despite the reduced solar irradiance.

Yield attributes and yield parameters of rice

The yield attributes and parameters of rice were significantly affected by the agroforestry, tree proximity and varietal effects indicating the significance of reducing resource competition in agroforestry. The increase in grain, straw, and biological yields recorded under the Casuarina treatment can be attributed to the favorable canopy structure created by the species. This implies that this species recorded less competition for moisture and nutrients and favored improved vegetative growth which in turn increased the assimilate available for grain production. These results further support the findings of Rodenburg *et al.*, (2022) [17] who emphasized the importance of designing improved rice agroforestry systems so that competition for resources between the component crops and trees is minimized.

The decrease in grain, straw, and biological yields recorded under the Eucalyptus treatment further confirms the competitive nature of this species as reported by previous researchers (Doddabasawa & Chittapur, 2023; Ruscena *et al.*, 2021) [3, 18]. Compared to other species, Eucalyptus has been reported to have extensive rooting systems and compete intensely with crops for moisture and nutrients thus reducing crop productivity. Similar evidence also suggests that Eucalyptus plantations exhibit reduced soil water availability and canopy interception of radiation which limits biomass production and grain yields of rice. Therefore, the observed reduction in rice yields under this treatment can be attributed to reduced water availability and increased competition for nutrients and radiation as reported by previous studies (Jose, 2021; Doddabasawa & Chittapur, 2023)

[3, 7, 8]. The gradual increase in grain, straw, and biological yields with an increase in distance from the tree trunk further suggests that competition for resources decreased as the distance from the tree increased. Increased solar radiation, moisture availability, and reduced root competition at further distances from the tree trunk probably favored increased photosynthesis and dry matter production which subsequently improved the yields of rice. These findings agree with those of previous researchers who demonstrated that tree-crop spacing significantly influenced the productivity of agroforestry systems by determining the extent to which competition between the component crops and trees occurred (Rodenburg *et al.*, 2022; Thaware *et al.*, 2020; Doddabasawa & Chittapur, 2023) [3, 17, 21]. Similar distance-dependent responses of rice grain yield and biomass to agroforestry have been demonstrated by other researchers indicating that rice crop growth and yield generally increased linearly with an increase in distance from the tree row (Thaware *et al.*, 2020; Sinha & Prajapati, 2022) [20, 21].

The higher productivity of Sarjoo-52 compared with NDR-359 demonstrates the importance of genotype selection for agroforestry-based rice production. Superior genetic potential, efficient assimilate partitioning, and better adaptation to altered light environments may have contributed to its enhanced performance (Ganguly *et al.*, 2020; Panda *et al.*, 2025) [6, 16]. Although the interaction between agroforestry system and tree distance significantly affected grain, straw, and biological yields, the absence of significant varietal interactions suggests that varietal ranking remained relatively consistent across different agroforestry environments. These findings indicate that appropriate tree species selection, optimum tree-crop spacing, and the use of well-adapted rice cultivars are essential for maximizing productivity and ensuring the sustainability of rice-based agroforestry systems (Rodenburg *et al.*, 2022; Doddabasawa & Chittapur, 2023) [3, 17].

Table 1: Growth and yield attributes of Rice varieties as influenced by various agroforestry system and tree proximity at harvest

Treatment	Growth attributes			Yield attributes			
	Plant height (cm)	No. of tillers per row meter length	Dry matter accumulation (g) row per meter length	Panicle length (cm)	Panicle weight (g)	No. of grain per Panicle	Test weight (g)
Agroforestry Systems (S)							
S ₁ (Shisham)	98.55 ^b	60.64 ^b	187.46 ^b	20.48 ^b	2.62 ^b	45.01 ^b	21.81 ^b
S ₂ (Casuarina)	101.28 ^a	63.91 ^a	199.73 ^a	21.82 ^a	2.77 ^a	49.10 ^a	22.69 ^a
S ₃ (Eucalyptus)	95.05 ^c	55.10 ^c	180.63 ^c	19.92 ^c	2.55 ^c	42.30 ^c	21.13 ^c
LSD _{0.05}	1.67	1.18	2.30	0.40	0.03	1.05	0.34
Tree trunk distance (D)							
D ₁ (0.5-1.50m)	95.25 ^b	56.51 ^c	180.10 ^c	19.81 ^c	2.55 ^c	41.76 ^c	20.62 ^c
D ₂ (1.50-2.50m)	98.99 ^a	59.55 ^b	190.95 ^b	20.72 ^b	2.65 ^b	45.63 ^b	22.08 ^b
D ₃ (2.50-3.50m)	100.64 ^a	63.58 ^a	196.76 ^a	21.69 ^a	2.74 ^a	49.03 ^a	22.93 ^a
LSD _{0.05}	1.67	1.18	2.30	0.40	0.03	1.05	0.34
Varieties (V)							
V ₁ (Sarjoo-52)	99.39 ^a	61.81 ^a	193.92 ^a	22.35 ^a	2.70 ^a	46.60 ^a	22.49 ^a
V ₂ (NDR-359)	97.19 ^b	57.96 ^b	184.63 ^b	19.12 ^b	2.59 ^b	44.34 ^b	21.26 ^b
LSD _{0.05}	1.36	0.97	1.88	0.32	0.032	0.86	0.27
S×D	NS	NS	NS	NS	NS	NS	NS
S×V	NS	NS	NS	NS	NS	NS	NS
D×V	NS	NS	NS	NS	NS	NS	NS
S×D×V	NS	NS	NS	NS	NS	NS	NS

Values given are means within column followed by different letters are significantly different

Table 2: Yield of Rice varieties as influenced by different agroforestry systems and tree trunk distance

Treatment	Grain yield (Q/HA)	Straw yield (Q/HA)	Biological yield (Q/HA)	Harvest index (%)
Agroforestry Systems (S)				
S ₁ (Shisham)	26.10 ^b	45.18 ^b	71.20 ^b	34.77 ^a
S ₂ (Casuarina)	27.33 ^a	46.90 ^a	74.24 ^a	35.00 ^a
S ₃ (Eucalyptus)	24.60 ^c	44.17 ^c	68.78 ^c	33.83 ^b
LSD _{0.05}	0.81	0.90	1.57	0.48
Tree trunk distance (D)				
D ₁ (0.5-1.50m)	23.04 ^c	40.10 ^c	63.14 ^c	33.53 ^c
D ₂ (1.50-2.50m)	26.67 ^b	47.10 ^b	73.79 ^b	34.65 ^b
D ₃ (2.50-3.50m)	28.25 ^a	49.05 ^a	77.30 ^a	35.42 ^a
LSD _{0.05}	0.81	0.90	1.57	0.48
Varieties (V)				
V ₁ (Sarjoo-52)	27.52 ^b	47.60 ^a	75.12 ^a	35.0 ^a
V ₂ (NDR-359)	24.45 ^b	43.24 ^b	67.70 ^b	34.06 ^b
LSD _{0.05}	0.66	0.74	1.28	0.39
S×D	NS	NS	NS	NS
S×V	NS	NS	NS	NS
D×V	NS	NS	NS	NS
S×D×V	NS	NS	NS	NS

Values given are means within column followed by different letters are significantly different

Conclusion

Agroforestry provides a mechanism for improving agricultural production while conserving natural resources through efficient use and diversification of rice-based agroforestry systems. This study clearly demonstrates the effect of agroforestry on the productivity of rice cultivars. The changes in microclimatic conditions brought about by agroforestry significantly influenced the growth, yield attributes and productivity of rice varieties. This study observed that rice varieties cultivated under various agroforestry systems were significantly affected by the agroforestry system used, distance from the tree, and varietal effects. Based on the findings recorded in this study, the Casuarina species recorded the best performance among the agroforestry systems used followed by the Shisham system while the Eucalyptus system had the least effect on rice performance. The increase in distance from the tree trunk improved the yield and growth of rice. Among the tree proximity treatments, the 2.50-3.50 m distance recorded the highest grain, straw, and biological yields probably due to minimal competition for moisture, nutrients, and solar irradiance. Sarjoo-52 variety recorded higher growth, yield attributes, grain yield, straw yield, biological yield, and harvest index compared to the NDR-359 variety which implies that it was more tolerant to the modified environmental conditions created by agroforestry. Therefore, the use of Sarjoo-52 variety intercropped with trees at a distance of 2.5-3.5 m is the best option for increasing rice productivity.

Reference

- Chen H, Li QP, Zeng YL, Deng F, Ren WJ, *et al.* Effect of different shading materials on grain yield and quality of rice. *Sci Rep.* 2019; 9:9992.
- Datta A, Pradhan A, Yadav AK, Das A, Nayak HS, Mandal S, *et al.* Navigating challenges and unlocking future opportunities in cereal-based cropping systems in India. *Crop Environ.* 2026;100137.
- Doddabasawa D, Chittapur BM. Tree-crop interaction: a sustainability issue in agroforestry a review. *Indian J Agrofor.* 2023;25(1).
- Fahad S, Chavan SB, Chichaghare AR, Uthappa AR, Kumar M, Kakade V, *et al.* Agroforestry systems for soil health improvement and maintenance. *Sustainability.* 2022;14(22):14877.
- Food and Agriculture Organization of the United Nations. Rice in human nutrition. Rome: FAO; 1993.
- Ganguly S, Saha S, Vanguru S, Purkayastha S, Das D, Saha AK, *et al.* Identification and analysis of low light tolerant rice genotypes in field conditions and their SSR-based diversity in various abiotic stress tolerant lines. *Physiol Mol Biol Plants.* 2020; 26:2447–2460. DOI:10.1007/s12298-020-00900-6.
- Jose S. Agroforestry for the provision of ecosystem services. *Agrofor Syst.* 2021; 95:1–6.
- Jose S. Tree-crop interactions in temperate agroforestry. In: *Agroforestry: enhancing resilience and sustainability in temperate agricultural systems.* Wiley; 2021.
- Juliano BO. Rice in human nutrition. Rome: Food and Agriculture Organization of the United Nations and International Rice Research Institute; 1993.
- Kumar BM, Nair PKR, Nair VD. An introduction to agroforestry: four decades of scientific developments. Cham: Springer; 2021. DOI:10.1007/978-3-030-75358-0.
- Kuyah S, Whitney C, Jonsson M, Sileshi GW, Öborn I, Muthuri CW, *et al.* Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa: a meta-analysis. *Agron Sustain Dev.* 2021;41.
- Malik TH, Baba A, Haji SA, Mir SD, Dar SA. Rice (*Oryza sativa*) cultivation in temperate areas of India. *IJF.* 2017; 11:47–56.
- Nair PKR. An introduction to agroforestry. Dordrecht: Kluwer Academic Publishers; 1993.
- Nayak AK, Shahid M, Nayak AD, Dhal B, Moharana KC, Mondal B, *et al.* Assessment of ecosystem services of rice farms in eastern India. *Ecol Process.* 2019;8(1):35.
- Ntawuruhunga D, Ngowi EE, Mangi HO, Salanga RJ, Shikuku KM. Climate-smart agroforestry systems and practices: a systematic review of what works, what doesn't work, and why. *For Policy Econ.* 2023; 150:102937.
- Panda D, Mohanty S, Das S, Mishra B. Shade tolerance is associated with foliar adaptations, improved radiation use efficiency, and photosynthetic rate in rice. *Sci Rep.* 2025; 15:40835. DOI:10.1038/s41598-025-24504-8.
- Rodenburg J, Mollee E, Coe R, Sinclair F. Global analysis of yield benefits and risks from integrating trees with rice and implications for agroforestry research in Africa. *Field Crops Res.* 2022; 281:108504.

DOI:10.1016/j.fcr.2022.108504.

18. Ruscena RPW, Wiederholt R, Grote R. Tree–crop ecological and physiological interactions within climate change contexts: a mini-review. *Front Ecol Evol.* 2021;9:661978. DOI:10.3389/fevo.2021.661978.
19. Singh S, Kumar V, *et al.* Future climate change impacts on rice in Uttar Pradesh, India's most populous agrarian state. *Earths Future.* 2024;12(4):e2023EF004009. DOI:10.1029/2023EF004009.
20. Sinha S, Prajapati RK. Performance of rice crop in association with Eucalyptus based bund agro forestry system in plains of Chhattisgarh. *J Pharmacogn Phytochem.* 2022;11(2):188–191.
21. Thaware BL, Bhagat SB, Khadtar BS, Jadhav BB, Dhonukshe BL, Jambhale ND. Effect of tree species on growth and yield of rice (*Oryza sativa* L.) in Konkan region. *Indian J Agrofor.* 2020;6(2).
22. Zhu X, Liu W, Chen J, Bruijnzeel LA, *et al.* Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: a review of evidence and processes. *Plant Soil.* 2020;453:45–86. DOI:10.1007/s11104-019-04377-3.
23. Singh AK, Shukla S, Singh MK, Singh A, Singh R, Singh BK. Urban forests: importance, challenges and opportunities. In: *Urban forests, climate change and environmental pollution: physio-biochemical and molecular perspectives to enhance urban resilience.* 2024. p. 23–45.
24. Singh AK, Shukla S, Dey A, Singh A, Tantuway G. Agroforestry: climate-smart agriculture technique for semi-arid climate. In: *Sustainable agriculture management in semi-arid climates.* Vol. 1. Cham: Springer Nature Switzerland; 2025. p. 51–68.