Performance Of Okra Under Pulpwood-Based Multifunctional Agroforestry: A Study From The Sylvan Surroundings Of Western Ghats, India

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Abstract
Crop diversification through the agroforestry system is gaining significance and vegetable-based agroforestry is one of the means, but studies on the performance of vegetable crops under the agroforestry system are mere hence, the present research was carried out to study the performance of Okra under one-year-old pulpwood-based agroforestry. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications and six treatments. The Sowing of Okra under each pulpwood tree species is treated as a different treatment and in open areas is treated as a control treatment. Six treatments consist of Okra under open area (T0), *Neolomarckia cadamba* (T_1), *Dalbergia sissoo* (T_2), Acacia hybrid (T_3), *Gmelina arborea* (T_4), and *Melia dubia* (T_5). The results revealed that the maximum growth and yield of Okra was observed in T0 and under pulpwood tree species highest growth was recorded under T_4 and yield was decreased in the order of $T_5 > T_2 > T_3 > T_1$. The growth and yield performance of Okra were influenced by crown spread and light intensity of pulpwood tress species.

Keyword: Pulpwood Species, Agroforestry, Crown spread, light intensity, Okra

Introduction

India is an agriculture-intensive country, comprising 2.4 % of the total geographical area of the world and supporting 16.8 % of the global population. The area under agriculture consists of 197.32 million ha which supports 58% of the population and contributed 18.3% to the GDP of the country (Agristat 2022). Before 1990 India was food starving country but after the green revolution, the adaption of new technologies and the increase in crop productivity per hectare area led India into a food surplus country. In the last decades, an increase in population, decline in agricultural land, land degradation, loss of soil fertility due to excessive use of chemical fertilizer, vagaries of monsoon, climate change, and continued degradation of ecosystem resources due to intensive cultivation led to the practice of alternate land use system for sustainable production (Kadam et al., 2020).

Agroforestry is a sustainable land-use system in which trees and crops are integrated into the same unit of land (Nair et al., 2021). Agroforestry emerged as one of the alternate land use systems for crop diversification, assured income, diversified products and sustainable production (Bhardwaj et al., 2021; Banoo et al., 2021; Parthiban et al., 2021a). Agroforestry has been considered an important land use system to achieve sustainable goals like poverty reduction (SDG1), hunger alleviation (SDG2), climate action (SDG13), and biodiversity conservation (SDG 15) (Sharma et al., 2022). With the enactment of the Forest Conservation Act 1980, the country's forests were managed for conservation rather than production and the subsequent enunciation of the 1988 forest policy clearly states that all wood-based industry should meet their raw material requirement from outside the forest, which paved the way for the expansion of tree-based land use systems like agroforestry for sustainable raw material production.

Agroforestry is an age-old land use system practiced by 1.2 billion people worldwide and occupies 10% of all agricultural land. In India area under agroforestry estimated is 8.65% (25.43mha) of the total geographical area of the country (Arunachalam et al., 2022). Agroforestry is extensively practiced for higher economic profit but it faces a wide range of challenges from production to consumption system (Parthiban et al., 2021). Lack of suitable technologies (quality planting material, improved genetic resources, low productivity), small land holding, poor adoption and absence of sustainable agroforestry model, and increasing demand for wood and wood products have necessitated the design and development of new innovative multifunctional agroforestry models not only to meet the raw material demand of wood-based industries but also to suit the requirement of the small farmers for sustainable development (Keerthika and Parthiban, 2022).

The multifunctional pulpwood-based Agroforestry Model (MPAF) has been designed to suit small landholders by integrating superior genetic resources. In India, the estimated demand for pulpwood is 12.5 million m^3, (ITTO 2022) and per capita, paper consumption increased from 9 kg in 2015 to 13 kg in 2022. The higher demands have raised the need for higher production, which can potentially be fulfilled by integrating high-yielding short rotation .pulpwood tree species (HYSR clones) in the agroforestry model that would ensure the supply with maximum remuneration to farmers. Hence the concept of MPAF emerged as a significant land-use system in which superior pulpwood tree species integrated with perennial and seasonal crops for multifarious benefits, sustainable raw material supply and improving the livelihood of the farmers.

One of the important vegetable crops of the Malvaceae family is Okra or lady finger (*Abelmoschus esculentus* L.Moench.) originated in Africa or Asia and has been growing predominantly in India as a lucrative vegetable crop. India is the world's largest producer of okra with a contribution of more than 72% (6 million tonnes), which is grown on 0.5 million hectares of land (NHB, 2020). A number of agricultural crops can be grown with trees for continuous supplementary income generation. The usual agroforestry consists of one or two tree species with agricultural crops like, Okra with *Melia composita* and *Melia dubia* have been studied (Jilariya et al., 2017; Mohanty et al., 2017; Thakur et al., 2018). However, the performance of Okra under different pulpwood species has not been studied. With this background present study was carried out to evaluate the growth and yield of okra under Multifunctional pulpwood-based agroforestry (MPAF) and to study the productivity of the whole landscape.

Material and Methods Study site

The field experiment was conducted at Forest College and Research Institute, Mettupalayam, Tamil Nadu, India (Figure 1), located at the foothills of Niligiri, Western Ghats (11°19′27″N latitude, 76°56′19″E longitude) at an altitude of 309 m above mean sea level during *kharif* season (June-September 2022). The climate is tropical with a hot year-round, the dry season is humid, and the monsoon is overcast and oppressive and receives an average rainfall of 242-369 mm contributed mainly by the southwest monsoon. Mettupalayam falls under the western zone of agro-climatic zones of Tamil Nadu with red calcareous soil type. The maximum temperature recorded is 36°C, minimum of 33°C during summer, and 20-22°C in winter (November-January).

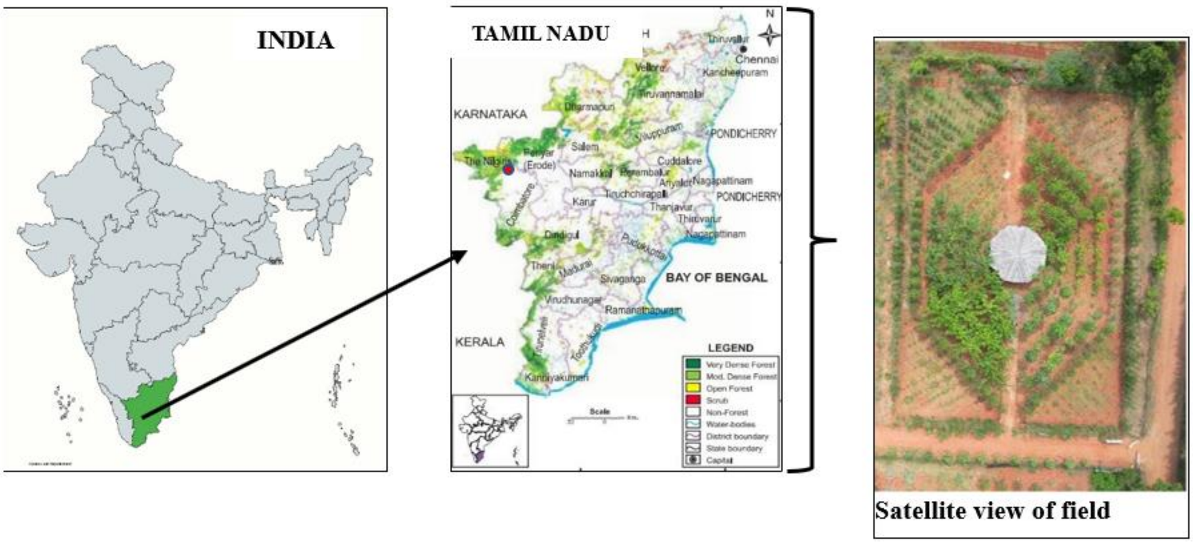

Figure 1. Map and Aerial view of the Experimental Study

Experiment details

The experiment was performed under the one-year-old pulpwood tree species. MPAF is a hexagonal shape covering an area of 0.60 acres, established in the year 2021. The MPAF system consists of 7 superior genetic pulpwood tree species, and 4 perennial intercrops. The outer boundary of the field consists of casuarina (windbreak-196 trees) with a spacing of 1×1m, outer boundary of the hexagonal is planted with eucalyptus (2×2m, 66 trees). The whole hexagonal area is divided into 6 sections, with one pulpwood species in each section with a spacing of 3×2 m (24 trees- each species) and one section is left blank (control). At four corners of the field is planted with four perennial crops viz., Jasmine flower, Sesbania, hybrid lemon, and Morinda fruits (Figure 2).

Experimental design and treatments

Okra was planted during *kharif* season between the rows of each tree species with a plot size of 2.5×5 m plot as given in Figure 2. The experiment was laid out in RCBD design with 6 treatments with 3 replication. The treatment consists of cultivating Okra under open area (T0), *Neolomarckia cadamba* (T1), *Dalbergia sissoo* (T2), Acacia hybrid (T3), *Gmelina arborea* (T4), *Melia dubia* (T5).

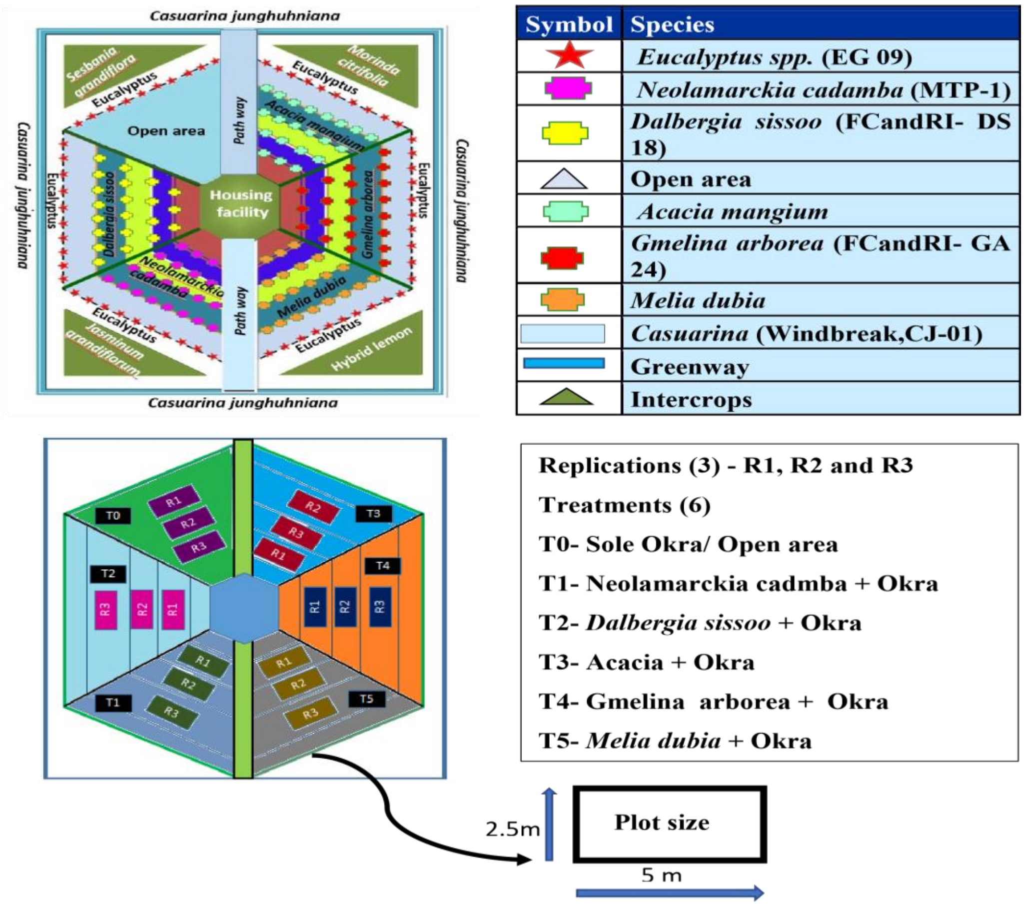

Figure 2. Experimental design and layout of the field

Data collection and analysis

Meteorological observations

Meteorological observations were taken under pulpwood trees and in an open area. Air temperature and air humidity were recorded with the help of a microclimatic sensor kit and light intensity was recorded with a lux meter beneath the canopy of each pulpwood tree species. The observation was recorded at 1 m above the ground level twice a day (morning 10 am- and noon 2 pm) during the cropping season.

Growth parameters of the pulpwood tree species

Tree growth parameters viz., Height and GBH are recorded with help of Ravi altimeter and measuring tape respectively

c. Crown spread (m^2)

The crown spread was measured in meters from tree trunk in horizontal (E-W) and vertical (N-S) direction with the help of measuring tape beneath the canopy tree.

$$\text{Widest diameter } (D) = \frac{D1 + D2}{2}$$

$$CS = \Pi D^2/4$$

Where, CS = crown spread
D1 = Crown spread in north-south direction (m)
D2 = Crown spread in east-west direction (m)

Growth and yield of Okra

In order to evaluate the performance of Okra under the MPAF system, the growth parameters like the height (cm) of the plant, number of branches, leaves, and number of flowers were recorded and yield parameters like the number of fruits per plant, fruit length, girth and yield (kg) per plot under each pulpwood species and in open area were recorded. The recorded data were subjected to analysis of variance as given by Gomez and Gomez (1984)

Incident solar radiation (%)

It is estimated by the given formula:

$$ISR = \frac{Total\ incident\ radaition\ recieved\ under\ agroforestry\ system}{Total\ incident\ solar\ radiation\ recieved\ by\ sole\ crop\ (control)}$$

Correlation

Pearson correlation coefficients were measured using the SPSS version and the level of significance was taken as P = 0.01

Results Climatic parameter

The relative humidity and temperature variation were recorded under cropping systems (pulpwood trees + Okra and sole okra) for 2022- 23. During the *Kharif* season (June – September), relative humidity beneath the pulpwood tree species ranges from 77.55 -78.13 % which is the maximum then open area (74.51-75.49%). The maximum temperature recorded was lower beneath the canopy of pulpwood trees (33.46-32.90°C) than in an open area. Under pulpwood tree canopy minimum temperature varied from 21.18 to 20.61°C, whereas it is higher under open conditions ranging from 21.55 – 20.98° C.

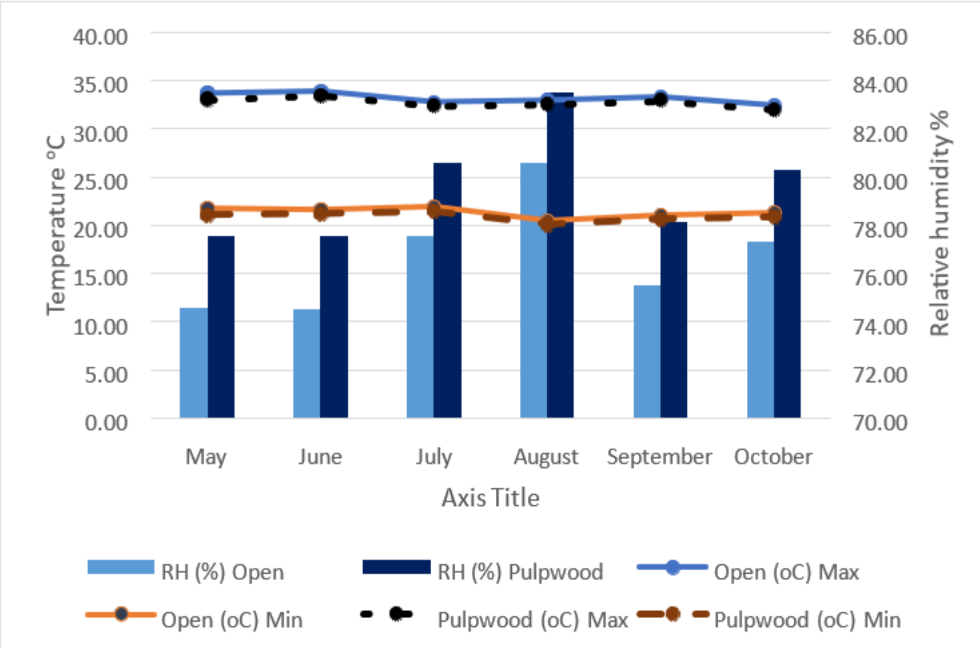

Figure 2. Temperature and relative humidity as influenced by pulpwood tree species Light Intensity

The variation in light intensity was observed beneath a canopy of different pulpwood trees and in the open area. During the growth period of okra (kharif season), the average light intensity was higher in the open area and ranged from 53755.58 lux to 81911.2804 lux (June – September 2022). It is observed that there is considerable variation in light intensity under the canopy of the pulpwood tree species. Among the pulpwood tree species higher light intensity was observed under the *Gmelina arborea* followed by *Melia dubia, Dalbergia sissoo,* and Acacia hybrid and lowest under the canopy of *Neolamarckia cadamba.*

Table. 1 Total light intensity (lux) and ISR (%) under pulpwood based Agroforestry system during the Kharif cropping season

	June		July		August		September	
Treatments	**Total L.I (lux)**	**ISR (%)**	**Total L.I (lux)**	**ISR (%)**	**Total L.I (lux)**	**ISR (%)**	**Total L.I (lux)**	**ISR (%)**
Open (T0)	81755.58	-	80911.28	-	80554.38	-	80911.28	-
Kadam + Okra (T_1)	25902.92	31.68	24037.98	29.71	24109.27	29.93	24987.98	30.88
Acacia + Okra (T_3)	30924.42	37.83	25857.35	31.96	25847.14	32.09	27707.35	34.24
Sissoo+ Okra (T_2)	32906.75	40.25	30093.98	37.19	30410.49	37.75	31843.98	39.36
Melia+ Okra (T_5)	32942.17	40.29	31062.29	38.39	31050.77	38.55	31912.29	39.44
Gmelina+ Okra (T_4)	34937.67	42.73	32028.88	39.59	32543.90	40.40	33478.88	41.38

Incident solar radiation (%)

The variation in the incident solar radiation observed beneath the canopy of pulpwood tree species is given in Figure 3. The highest incident solar radiation was observed under *Gmelina arborea* (T4) in the month of June (42.73%) and the lowest was observed in the month of July (39.59%) while the minimum incident solar radiation was observed under *Neolamarckia cadamba* (T1) in the month of July (29.71%).

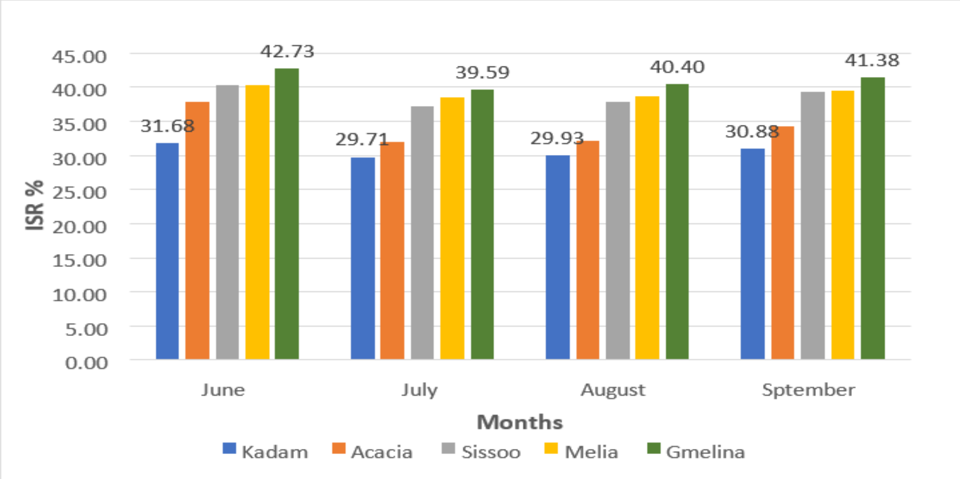

Figure 3. Incident solar radiation (%) under pulpwood tree species

Tree growth parameter

Height, girth at breast height and crown width of pulp wood tree species recorded during the cropping season and given in table 2. The maximum height and minimum GBH was recorded by *Casuarina junghuhniana* at 6.21 m and 6.89 cm respectively, while *Gmelina arborea* recorded minimum height and crown spread (1.81 m^2).

Table 2. Height, girth at breast height and crown spread of pulpwood species

Species	Height m	GBH (cm)	Crown spread (m^2)
Eucalyptus urograndis	4.35 ± 0.42	15.14 ± 0.16	2.10 ± 0.32
Neolamarckia cadamba	4.79 ± 0.31	15.62 ± 0.14	5.35 ± 0.41
Dalbergia sissoo	3.73 ± 0.20	14.51 ± 0.21	3.24 ± 0.32
Melia dubia	5.28 ± 0.19	18.58 ± 0.20	3.14 ± 0.52
Gmelina arborea	2.12 ± 0.16	7.78 ± 0.18	1.81 ± 0.41
Acacia mangium	5.57 ± 0.25	15.32 ± 0.15	4.51 ± 0.31
Casuarina junghuhniana	6.21 ± 0.30	6.89 ± 0.19	1.940 ± 0.34

Values given are means ± SE

Correlation between light intensity and crown spread

Correlation analysis showed that there strong negative correlation between crown spread and light intensity with a correlation coefficient of -0.974 (Table 3). It shows that an increase in crown spread results decrease in light intensity and vice versa.

Table 3. Correlations between crown spread and light intensity

	Crown spread	**Light Intensity**
Crown spread	1	-.974**
Light Intensity	-.974**	1

**. Correlation is significant at the 0.01 level (2-tailed).

Plant Height

A significant difference in Okra plant height was observed between open area (T_0-sole crop) and under-pulpwood tree species. The maximum height was obtained in sole crop T_0 (open area) with 40 cm, 75.17 cm and 103.53 cm at 30 DAS, 60 DAS and 90 DAS respectively. The plant height of Okra was significantly influenced by the overstorey of all pulpwood tree species. Among all the pulpwood tree species maximum height was recorded under *Gmelina arborea* (T_4) with 33.44cm, 54.44 cm and 95.80 cm at 30 DAS, 60 DAS and 90 DAS respectively followed by *Melia dubia* (T_5) and *Dalbergia sissoo* (T_2). The Minimum plant height of Okra at 30 DAS, 60 DAS and 90 DAS was recorded as 21.13cm, 34.44cm and 66.08cm respectively under Kadamb (T_1) followed by Acacia (T_3).

Number of branches

The number of branches per plant was also found significantly different under pulpwood trees and open areas (sole crop). A significantly higher no of branches was observed under the sole crop (T0) with an average no of branches of 5.27, 9.67 and 11.31 at 30 DAS, 60 DAS and 90 DAS respectively. Under the pulpwood tree species maximum number of average branches of Okra at 30 DAS, 60 DAS and 90 DAS was recorded 3.13, 8.22, and 9.63 respectively under *Gmelina arborea* (T_4) followed by *Melia dubia* (T_5) and *Dalbergia sissoo* (T_2). The minimum number of average branches was observed under Kadamb (T_1) followed by Acacia (T_3).

Number of leaves

The influence of the overstorey of pulpwood tree species on the number of leaves per plant was almost similar to the number of branches Table. The highest no of leaves per plant (5.53, 10.20 and 12.98 at 30 DAS, 60 DAS and 90 DAS respectively) were recorded in sole cropping Okra (T_0). Beneath the canopy of pulpwood tree species highest number of leaves were found under the *Gmelina arborea* (T_4) followed by *Melia dubia* (T_5) and *Dalbergia sissoo* (T_2). A significant reduction in the number of leaves was observed in the Kadamb (T_1) followed by Acacia (T_3) due to its wide canopy.

Number of Flowers

Sole crop (T_0) recorded significantly greater number of flowers per plant (3.40, 4.13 and 5.53 at at 30 DAS, 60 DAS and 90 DAS respectively. Under the pulpwood tree species higher number of flowers was observed in *Gmelina arborea* (T_4) followed by *Dalbergia sissoo* (T_2) and *Melia dubia* (T_5). Under Kadamb (T_1) and Acacia (T_3) significant minimum no of flowers were recorded.

Number of fruits

The *kharif* Okra planted as sole crop (T0) recorded a significantly higher number of fruits per plant (7.97) than intercrop under pulpwood tree species Table . However, under intercropping system significantly maximum number of fruits was obtained in *Gmelina arborea* (T_4-5.90) followed by *Melia dubia* (T_5-5.63) and *Dalbergia sissoo* (T_2-5.23). A significant reduction in the number of fruits was observed in the Kadamb (T_1- 4.37) followed by Acacia (T_3-4.50).

Fruit length

The fruit length of Okra was significantly influenced by intercropping under pulpwood tree species and open space. Maximum fruit length was observed in sole cropping (T0-13.47 cm) than under intercropping. Further in intercropping maximum fruit length was observed under *Gmelina arborea* (T_4-12.30 cm). The minimum length was observed under the Kadamb (T_1- 4.37 cm) followed by Acacia (T_3-4.50 cm).

Fruit girth

Higher fruit girth was recorded in the sole crop with 5.83 cm and under the intercropping system, maximum fruit girth was obtained in *Gmelina arborea* (T_4-15.57 cm) followed by *Dalbergia sissoo* (T_2) and *Melia dubia* (T_5). The minimum fruit girth was observed under the Kadamb (T_1- 4.08 cm) followed by Acacia (T_3-4.12 cm).

Yield Contributing Parameters of Okra

The yield of okra was significantly influenced by the cropping system viz., sole crop and intercrop (Table 5). Sole crop(T0) recorded significantly higher single fruit weight (17.87g), fruit weight/ plant (142.34 g), yield per plot (8.54 kg), and yield t/ha (5.59 t/ha). Whereas yield under intercropping system ranged from 3.66-2.66 t/ha. However, under the intercropping system, significant differences in yield among pulpwood tree species were observed. Among all, Okra under *Gmelina arborea* (T_4) recorded significantly higher single fruit weight (16.36 g), fruit weight/ plant (96.51 g), yield per plot (5.79 kg), and yield t/ha (3.85 t/ha) than others but statistical at par with *Dalbergia sissoo* (T_2-16.28 g) single fruit weight. Under the *Melia dubia* (T_5) intercropping system Okra performance was significantly higher after *Gmelina arborea* (T_4) with single fruit weight (16.07 g), fruit weight/ plant (90.51 g) and yield per plot (5.43 kg), but recorded yield t/ha (3.66 t/ha) was statistically at par with an Okra yield under *Dalbergia sissoo* (T_2- 3.30 t/ha). Okra yield performance under Kadamb (T_1) showed a significant reduction in single fruit weight (15.20 g), fruit weight/ plant (66.36 g), and yield per plot (3.98 kg) and yield t/ha (2.66t/ha) followed by Acacia (T_3).

Table 4. Growth attributes of okra as influenced by different pulpwood tree species and sole cropping

Treatments	Height			No of branches			No of leaves			No of Flowers		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T0	40.00a	75.17a	103.53a	5.27a	9.67a	11.31a	5.53a	10.20a	12.98a	3.40a	4.13a	5.53a
T1	21.13f	34.44f	66.08f	2.83d	5.27f	7.30e	2.53d	5.23e	7.17e	1.57f	2.17d	2.23e
T2	28.53d	48.93cd	82.00d	3.13b	6.23cd	8.30cd	3.23bc	5.93d	8.50cd	2.33c	2.80bc	3.23c
T3	23.49e	37.12e	70.20e	2.87d	5.73e	7.50de	2.47d	5.20e	7.40de	1.83e	2.17d	2.50e
T4	33.44b	54.44b	95.80b	3.13b	8.22b	9.63b	3.27b	7.80b	9.00b	2.73b	2.93b	4.00b
T5	30.37c	49.70c	85.17c	3.10bc	6.67c	8.90bc	3.13c	6.53c	8.83bc	2.13d	2.80bc	3.20cd
CD (5%)	1.18	1.63	2.69	0.17	0.23	0.80	0.11	0.32	0.48	0.15	0.11	0.42
CV	2.21%	1.79 %	1.76 %	2.73%	1.79%	4.97%	1.86%	2.61%	2.95%	2.30%	3.30%	6.74%

Table 5. Yield attributes of okra under as influenced by different pulpwood tree species and sole cropping

Treatment	No of fruits	Fruit length (cm)	Fruit girth (cm)	Single fruit weight (g)	Fruit weight/Plant (g)	Yield per plot(kg)	Yield t/ha
T0	7.97a	13.47a	5.83a	17.87a	142.34a	8.54a	5.59a
T1	4.37d	10.53f	4.08	15.20e	66.36d	3.98f	2.66e
T2	5.23c	11.13d	4.78	16.28b	85.18d	5.11d	3.30cd
T3	4.50d	10.77e	4.12	15.38d	69.22d	4.15e	2.76e
T4	5.90b	12.30b	5.57b	16.36 b	96.51b	5.79b	3.85b
T5	5.63bc	11.53c	5.06c	16.07c	90.56c	5.43c	3.66bc
SD	0.17	0.12	0.14	0.14	3.10	0.19	0.43
CV	1.63%	0.58%	1.53%	0.48%	1.86%	1.86%	6.51%

Discussion

The growth and yield attributes mainly depend on the genetic makeup, crop management practices and environmental conditions. The plant height of Okra was found significantly higher in sole cropping (T0) compared to intercropping system. It is due to the less availability of light beneath the canopy of pulpwood tree species compared to open field conditions, which resulted in lower plant height under tree species. A similar trend was observed by Rani et al., (2015) under poplar-based agroforestry, Hasan et al., (2012) study on Indian spinach (*Basella alba*) and okra (*Abelmoschus esculentus*) performance under Lombu (Swietenia hybrid) and Rajalingam et al., (2016) in Ailanthus excelsa with vegetable, Under intercropping system plant height was recorded in the order of T_4>T_5>T_2>T_1>T_3 it is because the increase in canopy cover lead to decrease in the availability of light which was also reported by Hanif et al., (2010) in okra with litchi based agroforestry and Bhusara et al. (2018) evaluated the performance of *A. esculentus* under different spacing of *M. composite.*

The number of branches was significantly recorded higher in sole cropping compared to intercropping and further, a significant reduction in the number of branches was observed with an increase in canopy cover of the pulpwood tree species and a reduction in the light availability. The lower number of branches under the shaded area is due to the production of higher auxin which resulted in the suppression of lateral branches. A similar result was observed in Spinach and Okra under *Swietenia hybrid*-based agroforestry system (Hasan *et al*., 2012) and Bhusara et al (2018) also reported a higher number of branches of Okra in the open area and a decrease in the number with the decrease in spacing.

The number of leaves increased gradually with an increase in the availability of light hence the sole cropping recorded a higher number of leaves compared to intercropping and the minimum was recorded under maximum canopy cover (T_1). The reason is a higher photosynthetic activity under more light conditions for a longer period in the open area compared to beneath the canopy of trees (Miah et al., 1999). Ummah (2012) also reported a reduction in the number of leaves of Bottle Gourd in the Crop Field having boundary plantation of Mahogany.

Number of flowers is one of the important yield contributing character and is dependent on environmental conditions and crop management practices hence in current study revealed that maximum number of flowers in open conditions because of maximum light availability, no competition for nutrients and moisture. Similar results were observed by Bhusara et al., (2018) and Kumar et al 2017 study on Teak –Ocimum based agroforestry.

The number of fruits per plant is an important factor contributing to the yield which is influenced by light conditions, nutrients and moisture. The maximum number was observed under open conditions compared to the intercropping system. Similar results were reported by Basak et al., (2009) the study showed that the yield contributing characters of the vegetables increased gradually with the increase in light intensity and decrease in the nutrient competition of planting distance from the tree. Rahman (2006) also reported a higher number of fruits per plant of eggplant in open fields and Khatun et al., (2009) showed similar results.

Light, nutrients and moisture are important environmental factors contributing growth and development of plants. The limit in one of these factors results in a reduction in the growth and yield attributes of the plant. In the present study maximum growth and yield was observed in open condition or sole cropping and in intercropping yield was significantly reduced in the order of T_4 >T_5>T_3>T_4>T_1 due to reduced light and competition for nutrient and moisture. The present study results were in accordance with Ankita et al 2021 Onion under Poplar block plantation; Raziya et al 2022 cucurbit spp. under poplar block plantation; Babu (2012) and

Singh et al., (1997) study on the performance of vegetables under Eucalyptus tree rows; Vanlalhluna et al., (2014) in maize under multipurpose tree species and Thakur et al., (2011).

Conclusion

Agroforestry is considered as one of the sustainable land use systems for higher productivity, crop diversification and higher economic income. Under Agroforestry productivity of crop was influenced by microclimatic variations and tree crop interaction. The higher productivity of system depends on combination of suitable tree species with crops. In the present study the best combination was Gmeilina + Okra, which recorded higher yield compared with other pulpwood species.

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