Indian Journal of Agroforestry 28(1): 44-51 (2026)

Performance of agricultural crops under *Eucalyptus tereticornis* based agroforestry system in semi-arid ecosystem of Haryana

Chhavi Sirohi[1]*, Parvinder Kumar[1], R.S. Dhillon[1], K.K. Bhardwaj[2], K.S. Ahlawat[1], A.K. Handa[3], A. Arunachalam[3] and Sushil Kumari[1]

ABSTRACT: *A field experiment was carried out during 2019-20 and 2020-21 to evaluate the crop productivity and light availability under Eucalyptus tereticornis based agrisilviculture system in semi-arid region of Haryana. Clonal eucalypts was established at 8 × 2 m spacing in October 2016, with initial plant height and basal diameter of 48.9 cm and 3.81 mm, respectively. After 3 and 4 years, the trees attained an average height of 16.5 m and 17.8 m, and diameter at breast height (dbh) of 15.5 cm and 17.1 cm, respectively. The experiment was laid out in a randomized block design with three replications, incorporating two Kharif crops (moong and cowpea) and three Rabi crops (wheat, mustard, and berseem) grown in interspaces. Results revealed a significant decline in yield of all intercrops under eucalypts based agroforestry system compared to sole cropping. After attaining the age of three years, the maximum yield reduction was recorded in mustard (27.8%) and cowpea (27.7%), followed by moong (22.8%), wheat (17.3%), and berseem (15.8%). However, the reduction was more pronounced at the age of four years plantation, with cowpea showing the highest decline (36.3%), followed by mustard (32.4%), moong (31.0%), wheat (29.2%), and berseem (25.4%). The decrease in crop productivity was mainly attributed to reduced solar radiation and increased competition for moisture and nutrients. Light measurements indicated a substantial reduction (54.9-61.9%) in available light intensity under eucalypts canopy compared to open conditions, with the highest reduction observed during the Kharif season. The findings suggest that while Eucalyptus tereticornis based agroforestry systems significantly affect intercrop yields due to shading and resource competition, they remain a viable land-use option if appropriate management practices are adopted.*

Research Article

ARTICLE INFO

Received: 06.12.2025

Accepted: 15.03.2026

Keywords:
Agroforestry,
Eucalyptus tereticornis,
Green fodder yield,
Grain yield,
Light intensity

1. INTRODUCTION

Agroforestry, a sustainable land-use system integrating trees with agricultural crops, has gained global recognition as an effective strategy for improving productivity, environmental sustainability, and resilience under changing climatic conditions. In India, agroforestry plays a vital role in addressing challenges such as land degradation, declining soil fertility, and increasing pressure on natural resources. Haryana, being one of the agriculturally advanced states, has emerged as a significant hub for agroforestry adoption, where farmers have extensively integrated fast-growing tree species with traditional cropping systems to enhance farm income and ecological stability. Among various tree species, eucalypts has become one of the most widely planted species due to its rapid growth, high biomass yield, short rotation, and strong market demand for pulpwood and timber. In India, the supply of raw materials for the pulp and paper industry stands at 2.76 million tonnes, while the demand is 5.04 million tonnes, resulting in a shortfall of about 45% (Ramesh *et al.,* 2023).

Eucalypts is widely favored for planting along the edges or bunds of agricultural fields and has become well integrated and widely accepted within agroforestry systems in India. Rising population pressure has led to the overexploitation of natural resources, creating a significant gap between the demand and supply of wood products. The shortage of industrial roundwood has hindered the modernization, growth, and expansion of wood-based industries in India, leading to increased imports of timber, paper, and other wood products. Under these conditions, agroforestry has re-emerged as a highly suitable land-use option. They promote efficient use and management of natural resources by adhering to the principle of sustained yield, while also enhancing overall production and land productivity.

Chhavi Sirohi
chhavisirohi22dec@gmail.com

[1] Department of Forestry, CCS Haryana Agricultural University, Hisar, Haryana-125004

[2] Department of Soil Science, CCS Haryana Agricultural University, Hisar, Haryana-125004

[3] ICAR- Central Agroforestry Research Institute, Jhansi-284003, U.P.

Agroforestry systems designed for pulpwood production involve cultivating commercial timber species within agricultural fields using inputs such as irrigation, fertilizers, and improved plant management practices, typically over a harvest cycle of 4-7 years. Beyond integrating forestry and agriculture, these systems enhance the efficient use of both above and belowground resources, a feature that has consistently attracted significant attention (Huang *et al.,* 2022). Combining agricultural crops with eucalypts trees for pulpwood production can yield higher returns than cultivating either separately. In intercropping systems, it is essential to identify crops that can be grown profitably under clonal tree plantations, while also considering their impact on tree growth and soil fertility, to achieve improved overall productivity.

The widespread adoption of eucalypts in Haryana is primarily attributed to its economic viability and adaptability to semi-arid conditions. Studies have shown that eucalypts plantations contribute significantly to biomass accumulation and carbon sequestration, thereby playing an important role in climate change mitigation. Kumar *et al.* (2019) reported substantial biomass production and carbon storage in eucalyptus plantations, with total carbon stocks reaching up to 122.6 Mg ha^{-1} in six-year-old plantations, indicating its potential as a carbon sink. In addition, agroforestry systems involving eucalypts provide multiple ecosystem services such as soil improvement, wind protection, and diversification of farm income, making them an integral component of sustainable agriculture in semi-arid ecosystems.

However, its integration with agricultural crops has generated considerable debate due to its competitive nature. Studies indicate that while eucalypts contributes significantly to biomass production, carbon sequestration, and farm income, it also exerts strong competitive effects on associated crops, particularly under semi-arid conditions where water availability is limited. The performance of crops under eucalypts based agroforestry systems varies depending on crop type, management practices, and environmental conditions. Cereal crops such as wheat and barley are highly sensitive to shading and moisture stress, leading to substantial yield reductions. Oilseed crops such as mustard exhibit even greater sensitivity due to their high light requirement.

Wheat grown under eucalypts plantations showed significant reductions in grain and straw yield due to competition for soil moisture and nutrients (Deswal *et al.*, 2013). Similarly, Dahiya *et al.* (2023) observed that nutrient uptake and yield of crops declined under agroforestry systems compared to sole cropping, emphasizing that competition for resources is a major constraint in eucalypts based agroforestry systems. These studies collectively indicate that resource competition is the primary factor influencing crop productivity under eucalypts plantations. The performance of cereal crops such as wheat and barley under eucalypts based systems has been widely studied. Sirohi *et al.* (2021) evaluated the productivity of barley under eucalypts clones in semi-arid Haryana and reported a reduction of 14% in grain yield and 30.1% in straw yield compared to sole cropping. In addition to cereals, pulses and oilseed crops also show significant yield reductions under eucalypts based agroforestry systems.

Mustard, being highly sensitive to shading, exhibits substantial decline in yield when grown under tree canopy. Studies have shown that yield reduction is more pronounced near the tree line due to higher competition for light and soil moisture. Despite the negative effects on crop yield, eucalypts based agroforestry systems offer several long-term benefits. These include carbon sequestration, improvement in soil structure, enhancement of biodiversity, and diversification of farm income. Agroforestry systems have significant potential for carbon sequestration and climate change mitigation, making them an important component of sustainable agriculture.

Therefore, the overall productivity of the system should be evaluated not only in terms of crop yield but also in terms of total system output and ecosystem services. The performance of agricultural crops under eucalypts based agroforestry systems in semi-arid regions is influenced by a complex interplay of ecological and management factors. Therefore, optimizing agroforestry designs through appropriate spacing, pruning, irrigation, and selection of compatible crops is essential to enhance system productivity and sustainability. Continued research is needed to develop site-specific models that balance economic returns with ecological benefits, ensuring the long-term viability of eucalypts based agroforestry systems.

2. MATERIALS AND METHODS

A field experiment was carried out at the research farm of the Department of Forestry, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana during *Kharif* and *Rabi* season of 2020-21. The experimental site is situated in the north-western arid region of India at 29°09′ N latitude and 75°43′ E longitude with an elevation of 215.2 m above mean sea level.

During the two-year study period, the rainfall pattern was found to be below normal and erratically distributed, which significantly influenced crop performance. A total rainfall of 397.8 mm was recorded during July-April in 2019-20 against the long-term mean of 561.7 mm, whereas 317.5 mm rainfall was received during July-March in 2020-21 compared to the long-term mean of 410.6 mm, indicating a substantial rainfall deficit in both years. During *Kharif* season (July-October), the total rainfall received was 249.0 mm in 2019-20 and 274.4 mm in 2020-21. Although relatively higher rainfall was observed during the months of July and September in both the years, the overall distribution was highly uneven. The months of June and August, which were critical for crop establishment and vegetative growth, received comparatively low rainfall (200.2 mm in 2019-20 and 113.6 mm in 2020-21), leading to moisture stress conditions. Consequently, the productivity of *Kharif* crops was adversely affected during both years.

During winter (*Rabi*) season, only limited rainfall was received due to occasional western disturbances, which provided some supplementary moisture but was insufficient to meet the crop water requirements. The climatic conditions of the region were characterized by extremes, with very hot summers where maximum temperatures ranged between 39.0-40.5°C during May-June, while December and January remained the coldest months of the year. Overall, the two-year analysis indicates that deficient and poorly distributed rainfall coupled with extreme temperature conditions played a crucial role in reducing crop productivity, particularly during the *Kharif* season under semi-arid conditions.

Clonal eucalypts was planted at 8×2 m spacing from October 29-30, 2016. At the time of transplantation, the average plant height and basal diameter was 48.9 cm and 3.81mm, respectively. The experiment was laid out in a randomized block design with three replications. During the years 2019-20 and 2020-21, two *Kharif* crops (moong and cowpea) and three *Rabi* crops, namely berseem (HB-1), wheat (WH-1105) and mustard (RH-30), were cultivated in the interspaces of 3- and 4-year-old eucalyptus plantations established at a spacing of 8 × 2 m. Observations on growth and yield parameters of all *Kharif* and *Rabi* crops were recorded under both the eucalypts based agroforestry system and the control (sole cropping) conditions. The data thus obtained were subjected to appropriate statistical analysis for interpretation of the results.

3. RESULTS AND DISCUSSION

Growth of eucalyptus

The growth performance of clonal *Eucalyptus tereticornis* (clone P-21) planted at a spacing of 8 × 2 m was evaluated over two consecutive years. At the time of transplantation (October 29-30, 2016), the clone exhibited uniform growth with an average plant height of 48.9 cm and basal diameter of 3.81 mm, indicating healthy and vigorous planting stock. After three years of plantation, the trees attained an average height of 16.5 m and diameter at breast height (dbh) of 15.5 cm. Further growth assessment during the fourth year showed that the average tree height increased to 17.8 m, while dbh reached 17.1 cm. This reflects an increment of 1.3 m in height and 1.6 cm in dbh over one year, indicating rapid growth and good adaptability of eucalypts under semi-arid conditions. The steady increase in both height and diameter suggests that the species maintained a high growth rate even after canopy development, which has implications for resource competition with intercrops. The observed rapid growth of Eucalypts is consistent with its well-known fast-growing nature and high biomass accumulation potential under agroforestry systems. The significant increase in height and diameter from the third to fourth year reflects the fast-growing nature and high productivity potential of *Eucalyptus tereticornis*. These findings are in close agreement with the results of Sirohi et al. (2021), who reported that eucalypts clones attained heights up to 14.2 m within three years under agri-silviculture systems in Haryana. The relatively higher growth observed in the present study may be attributed to better clonal performance, site-specific management practices, and favorable environmental conditions

Similar findings were reported by Tripathi *et al.* (2020) who observed that 3.4-4.4 year-old eucalypts trees attained heights of 12.8-13.9 m and dbh of 12.41-13.88 cm under semi-arid conditions, with substantial annual increments in both parameters. Compared to these findings, the present study recorded relatively higher growth, which may be attributed to favorable management practices, site conditions, and clone performance.

The continuous increase in height and dbh from the third to fourth year indicates that eucalyptus trees remain in an active growth phase during early rotation, contributing significantly to biomass production. This is in agreement with the findings of Nirmal *et al.* (2021) who reported that clonal eucalypts exhibits high productivity and can produce significantly greater biomass compared to seedling-origin plantations due to superior genetic potential and coppicing ability. Tree age and canopy development play a crucial role in determining the extent of tree-crop interaction. For instance, research on eucalyptus-based agroforestry systems demonstrated that crop yield reductions become more pronounced as tree age increases due to increased shading and competition (Ramesh *et al.,* 2023).

Availability of light intensity during *Kharif* and *Rabi* season under eucalypts based agroforestry system

The availability of light intensity under Eucalypts plantation (8×2 m spacing) was assessed at different times of the day from July 2020 to April 2021 and compared with open (sole crop) conditions (Table 1). The data revealed a substantial reduction in incident solar radiation under the eucalypts canopy across both *Kharif* and *Rabi* seasons. During *Kharif* season (July-October 2020), the mean reduction in light intensity ranged from 56.3% (August) to 61.9% (July), with the maximum reduction (61.9%) observed in July. Across different times of the day, the reduction was consistently high, exceeding 60% during most hours, particularly in the afternoon (1 PM to 5 PM), indicating strong canopy interference with solar radiation. In the *Rabi* season (November 2020-April 2021), the mean reduction in light intensity varied between 54.9% (February) and 59.9% (April). Although slightly lower than *Kharif*, the reduction remained substantial throughout the season. The lowest reduction was observed during February (54.9%), possibly due to partial leaf shedding and lower canopy density, whereas higher reductions in March and April may be attributed to renewed canopy development. Overall, the results clearly indicate that light availability under eucalypts plantation was reduced by approximately 55-62% throughout the year, and the light intensity received under sole cropping conditions remained significantly higher during all months and time intervals.

The marked reduction in light intensity under eucalypts based agroforestry systems observed in the present study is primarily due to canopy development, leaf area expansion, and tree architecture, which intercept and absorb a large proportion of incoming solar radiation. These findings are in close agreement with Sirohi *et al.* (2021), who reported significant shading effects of eucalypts plantations on understory crops in semi-arid regions of Haryana, leading to reduced light availability and crop productivity. The higher reduction in light intensity during *Kharif* season, particularly in July (61.9%), may be attributed to peak vegetative growth and maximum canopy cover during the monsoon period. Similar observations were reported by Chavan *et al.* (2024), who noted that canopy expansion in eucalypts based systems leads to maximum radiation interception during the rainy season, thereby limiting light penetration to the understory crops. The relatively lower light reduction during February (54.9%) suggests a seasonal variation in canopy density, possibly due to partial leaf fall or reduced leaf area index during winter. This seasonal fluctuation in light transmission has also been reported by Ramesh *et al.* (2023), who observed that light interception in agroforestry systems varies with phenological stages of trees and significantly affects crop growth and yield.

Furthermore, the diurnal variation indicates that light reduction was consistently high throughout the day, with slightly greater reductions during midday and afternoon hours (1 PM-5 PM). This is critical because these hours correspond to peak photosynthetically active radiation (PAR), and reduced light during this period can severely affect photosynthesis and biomass accumulation of intercrops. Similar findings were

Table 1: Per cent reduction in available sun light in eucalypts based agroforestry system over control during *Kharif* and *Rabi* seasons

Time	July, 2020	August, 2020	September, 2020	October, 2020	November, 2020
7 A.M.	61.2	63.8	60.9	62.0	55.0
9 A.M.	55.9	51.1	55.6	65.2	60.2
11 A.M.	62.4	58.0	62.1	58.5	56.3
1 P.M.	63.6	52.3	63.3	56.1	54.1
3 P.M.	63.9	54.9	63.6	59.0	53.0
5 P.M.	64.3	57.6	64.0	62.4	54.4
Mean	61.9	56.3	61.6	60.5	55.5
	December, 2020	**January, 2021**	**February, 2021**	**March, 2021**	**April, 2021**
7 A.M.	59.4	52.4	61.9	58.9	60.2
9 A.M.	53.3	62.0	52.1	53.6	63.2
11 A.M.	57.1	58.2	56.1	60.1	58.5
1 P.M.	57.8	55.1	50.4	61.3	56.1
3 P.M.	57.9	52.4	53.0	61.6	59.0
5 P.M.	59.6	56.3	55.7	62.0	62.4
Mean	57.5	56.1	54.9	59.6	59.9

reported by Kumar *et al.* (2021), who emphasized that reduced PAR under eucalypts canopy significantly limits crop growth due to shading effects. The overall reduction of more than 50% light intensity observed in the present study clearly indicates that light becomes a major limiting factor in eucalypts based agroforestry systems. This reduced light availability directly affects photosynthesis, dry matter accumulation, and ultimately crop yield.

Crop performance under eucalypts based agroforestry system

Grain and Stover yield (t/ha) of moong

The data presented in Table 2 revealed that the yield of moong crop was significantly influenced by eucalypts based agroforestry system as compared to sole cropping. The grain yield of moong under eucalypts plantation (8×2 m spacing) was recorded as 0.68 and 0.58 t ha^{-1} during 2019-20 and 2020-21, respectively, whereas the corresponding grain yield under sole cropping (control) was higher, *i.e.*, 0.88 and 0.84 t ha^{-1}. This indicates a reduction of about 22.7% and 30.9% in grain yield under agroforestry system during the respective years. Similarly, stover yield was also reduced under eucalypts based agroforestry system (1.48 and 1.28 t ha^{-1}) as compared to sole cropping (1.81 and 1.78 t ha^{-1}). The reduction in yield under eucalypts based agroforestry system can be attributed to competition for essential growth resources such as light, moisture, and nutrients. The shading effect of tree canopy reduces the availability of photosynthetically active radiation (PAR), thereby limiting photosynthesis and biomass accumulation in understory crops. Similar findings were reported by Kumar *et al.* (2022) where significant reduction in yield of intercrops including pulses under eucalypts plantations was observed due to reduced light interception. Likewise, Newaj *et al.* (2020) reported that grain yield of blackgram decreased under eucalypts based agri-silviculture system compared to sole cropping, with higher reduction at closer spacing due to increased competition.

The comparatively higher reduction observed during 2020-21 might be due to increased canopy development of eucalypts trees with age, leading to greater shading and resource competition. Earlier studies have also shown that yield reduction tends to increase with tree age and canopy expansion (Dhiman and Gandhi, 2020). Overall, the results clearly indicate that although eucalypts based agroforestry systems provide additional benefits such as timber and ecological services, they significantly reduce the productivity of moong crop.

Green fodder yield (t/ha) of cowpea

The data presented in Table 3 indicated that green fodder yield of cowpea was markedly influenced by eucalypts based agroforestry system. The green fodder yield under eucalypts plantation (8×2 m spacing) was recorded as 15.64 t ha^{-1} in 2019-20 and 12.84 t ha^{-1} in 2020-21, whereas significantly higher yields of 21.62 and 20.15 t ha^{-1} were obtained under sole cropping (control). This reflects a reduction of about 27.7% and 36.3% in green fodder yield under eucalypts during the respective years. The reduction in green fodder yield under eucalypts based system can be primarily attributed to interspecific competition for light, soil moisture, and nutrients. The shading effect of eucalyptus canopy reduces light availability, which directly affects photosynthesis and vegetative biomass production, particularly in fodder crops like cowpea that depend on rapid vegetative growth. These findings are strongly supported by the work of Sirohi *et al.* (2022a) on fodder crops under poplar based agroforestry systems with different spacings. Their study revealed that fodder yield increased with increase in tree spacing and was maximum under wider spacing (8×3 m), while significantly lower yields were recorded under closer spacings (3×3 m). They further reported that fodder crops such as cowpea, sorghum and berseem produced significantly higher biomass in open conditions (control) compared to poplar based systems due to reduced competition.

Table 2: Yield (t/ha) of moong under eucalypts based agroforestry system

Treatments	Grain yield (t/ha)		Stover yield (t/ha)	
	2019-20	2020-21	2019-20	2020-21
Eucalypts at 8 × 2	0.68	0.58	1.48	1.28
Control (sole crops)	0.88	0.84	1.81	1.78
CD at 5%	0.13	0.107	0.24	0.20

Table 3: Green fodder yield (t/ha) of cowpea under eucalypts based agroforestry system

Treatments	Green fodder yield (t/ha)	
	2019-20	2020-21
Eucalypts at 8 × 2	15.64	12.84
Control (sole crops)	21.62	20.15
CD at 5%	4.22	2.95

Similar findings were reported by Kumar and Nandal (2004) who observed that all intercrops grown under eucalypts exhibited reduced plant vigour and yield compared to open conditions, with reductions depending on crop type and intensity of competition. The greater reduction in fodder yield during 2020-21 compared to 2019-20 may be attributed to increased canopy development and root expansion of eucalypts trees over time, leading to higher competition for light and below-ground resources. This trend is consistent with findings of Newaj *et al.* (2020), who reported increased yield reduction of intercrops with advancing age of eucalypts plantations as competition intensifies with tree growth. Overall, the results clearly demonstrate that although eucalypts based agroforestry systems provide long-term economic and ecological benefits, they significantly reduce the green fodder yield of cowpea.

Yield (t/ha) of wheat, mustard and berseem (green fodder yield) during Rabi season

The data revealed that wheat yield was significantly influenced by eucalypts based agroforestry system (Table 4-6). The grain yield under eucalypts (8×2 m spacing) was recorded as 3.80 and 3.27 t ha^{-1} during 2019-20 and 2020-21, respectively, which was considerably lower than the sole crop yield (4.59 and 4.62 t ha^{-1}). Similarly, straw yield was also reduced under eucalypts (4.05 and 3.58 t ha^{-1}) compared to control (5.59 and 5.60 t ha^{-1}). The reduction in grain yield ranged from about 17-29%, while straw yield decreased by about 27-36%. This reduction is mainly attributed to competition for light, moisture, and nutrients between trees and crops. Shading by eucalypts canopy reduces photosynthetically active radiation, thereby lowering biomass production. Similar findings were reported by Sirohi *et al.* (2021) where grain and straw yield of barley under eucalypts decreased by 14-30% due to resource competition. Likewise, Kumar and Nandal (2004) reported that wheat yield under eucalypts decreased up to 62.3% compared to sole cropping due to reduced plant vigour and resource competition. Similarly, Panozzo *et al.* (2026) reviewed global agroforestry systems and reported that cereal crops like wheat generally experience yield reductions under tree-based systems unless appropriate management practices such as pruning, wider spacing, and selection of compatible crop varieties are adopted. Scordia *et al.* (2023) reported that wheat productivity showed positive responses to tree cover only under particular conditions-specifically in certain years or at sites experiencing high temperatures and elevated potential evapotranspiration (PET). Ong *et al.* (2015) working on tree-crop interactions in tropical agroforestry systems, concluded that competition for light is the primary factor limiting cereal crop productivity under tree canopies. They emphasized that reduction in photosynthetically active radiation significantly affects wheat growth and yield components. The results are in close conformity with the findings of Sirohi *et al.* (2022b) where wheat grown under poplar boundary plantation exhibited a noticeable decline in grain yield compared to open conditions. The study reported that wheat yield reduction was more pronounced near the tree line and gradually improved with increasing distance from the trees. This spatial variation was mainly attributed to differential shading and root competition. The findings of the present study

Table 4: Yield (t/ha) of wheat under eucalypts based agroforestry system

Treatments	Grain yield (t/ha)		Straw yield (t/ha)	
	2019-20	2020-21	2019-20	2020-21
Eucalypts at 8 × 2	3.80	3.27	4.05	3.58
Control (sole crops)	4.59	4.62	5.59	5.60
CD at 5%	0.64	0.55	0.73	0.82

Table 5: Yield (t/ha) of mustard under eucalypts based agroforestry system

Treatments	Grain yield (t/ha)		Stover yield (t/ha)	
	2019-20	2020-21	2019-20	2020-21
Eucalypts at 8 × 2	1.3	1.15	2.1	1.86
Control (sole crops)	1.8	1.70	2.4	2.30
CD at 5%	0.26	0.22	0.35	0.17

Table 6: Green fodder yield (t/ha) of berseem under eucalypts based agroforestry system

Treatments	Green fodder yield (t/ha)	
	2019-20	2020-21
Eucalypts at 8 × 2	40.8	35.21
Control (sole crops)	48.4	47.2
CD at 5%	5.5	4.85

are in conformity with the results of Ahlawat *et al.* (2024), who reported significant reductions in growth, physiological parameters, and yield of sorghum and barley under kadam-based agroforestry systems compared to sole cropping. They observed yield reductions of 21.16% in sorghum and 43.43% in barley, mainly due to shading and competition for moisture and nutrients. This supports the present results, indicating that tree-crop competition in agroforestry systems adversely affects intercrop productivity.

The yield of mustard was also significantly reduced under eucalypts based system. Grain yield under eucalypts was 1.30 and 1.15 t ha^{-1} during 2019-20 and 2020-21, respectively, compared to 1.80 and 1.70 t ha^{-1} under sole cropping. Similarly, stover yield was reduced from 2.40-2.30 t ha^{-1} in control to 2.10-1.86 t ha^{-1} under eucalypts. The reduction in grain yield ranged from about 28-32%, while stover yield declined by about 12-19%. The reduction in mustard yield is due to strong interspecific competition, particularly for soil moisture and nutrients, as mustard is highly sensitive to competition under limited resource conditions. Similar observations were reported by Kumar and Nandal (2004) where mustard yield declined up to 82.4% under eucalypts plantations due to severe competition effects. The decline in yield was more pronounced in the second year (2020-21), which may be due to increased canopy development and root proliferation of eucalypts trees, leading to intensified competition. The greater reduction in mustard yield observed during 2020-21 in the present study is consistent with earlier findings, as competition tends to intensify with increasing tree age due to canopy expansion and root proliferation.

The green fodder yield of berseem was significantly influenced by eucalypts based agroforestry system. The fodder yield under eucalypts was 40.8 and 35.21 t ha^{-1} during 2019-20 and 2020-21, respectively, whereas the control recorded higher yields of 48.4 and 47.2 t ha^{-1}. This indicates a reduction of about 15.7% and 25.4% under eucalypts system. The reduction in fodder yield is mainly due to reduced light availability and competition for nutrients and soil moisture. Fodder crops like berseem require high light intensity for rapid vegetative growth, and shading under eucalypts canopy restricts biomass accumulation. The results of the present study are in close agreement with the findings of Kombra *et al.* (2021), who reported significantly higher growth parameters and fodder yield of berseem and oat under sole cropping compared to eucalypts-based systems due to reduced competition for light, moisture, and nutrients. However, despite lower yields under trees, the eucalypts + berseem system provided higher economic returns, indicating that agroforestry systems can remain economically viable even with some yield reduction in intercrops. Further, Sirohi *et al.* (2022a), who reported that fodder crops grown under tree based agroforestry systems recorded significantly lower yields than open (control) conditions, with yield improving as spacing increased. Their study showed that maximum fodder yield was obtained in wider spacing (8×3 m), while closer spacing resulted in substantial yield reduction, clearly indicating the role of tree competition.

4. CONCLUSION

The study demonstrates that eucalypts plantation performs exceptionally well under semi-arid conditions, showing rapid growth and substantial biomass production, which highlights its suitability and high productivity in agrisilviculture systems. The consistent increase in tree height and diameter from the third to fourth year confirms that the trees remain in an active growth stage, enhancing timber yield while simultaneously increasing competition with associated crops. As a result, all intercrops experienced notable yield reductions under eucalypts based agroforestry system compared to sole cropping. This decline became more pronounced with increasing plantation age, indicating intensified competition for light, water, and nutrients due to expanding canopy and root systems. Among the crops, cowpea and mustard were the most adversely affected, whereas berseem showed relatively greater tolerance. Although eucalypts based agroforestry systems lead to reduced intercrop yields due to shading and resource competition, they remain a sustainable and economically viable land-use option because of their high tree growth and biomass potential. Implementing suitable management practices such as wider spacing and the use of shade-tolerant and less competitive crops can help improve overall system productivity and sustainability.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Indian Council of Agricultural Research (ICAR), New Delhi, and the ICAR-Central Agroforestry Research Institute, Jhansi, for providing financial support through the All India Coordinated Research Project on Agroforestry (AICRP-AF) for conducting this study.

References

Ahlawat, K.S., Kumari, A., Bishnoi, D.K., Chaudhary, K., Sirohi, C., Satpal, Dalal, V. and Poonia, P.K. 2024. Performance of sorghum and barley intercropped with kadam based agroforestry system in semi-arid ecosystem of Haryana. *Forage Research*, 49(4): 461-466.

Chavan, S.B., Dhillon, R.S., Sirohi, C., Saleh, I.A., Uthappa, A.R., Keerthika, A., Jinger, D., Halli, H.M., Pradhan, A., Kakade, V., Morade, A., Chichaghare, A.R., Rawale, G.B., Okla, M.K., Alaraidh, I.A., AbdElgawad, H., Fahad, S., Nandgude, S. and Singh, R. 2024. Optimizing planting geometries in eucalyptus-based food production systems for enhanced yield and carbon sequestration. *Frontiers in Sustainable Food Systems*, 8: 1386035.

Dahiya, G., Dahiya, G., Bhardwaj, K., Devi, S., Ahlawat, I., Singh, C. and Dhillon, R. 2023. Influence of different agroforestry systems on yield and nutrient uptake in semi-arid region of Haryana. *Indian Journal of Agroforestry*, 24(2).

Deswal, A.K., Nandal, D.P.S., Dhindwal, A.S., Garg, R.K. and Kumar, R. 2013. Yield and nutrient uptake pattern of wheat in eucalyptus system. *Indian Journal of Forestry*, 36(3): 344-348.

Dhiman, R. and Gandhi, J. 2020. Comparative performance of poplar, melia and eucalyptus based agroforestry systems. *Indian Journal of Agroforestry*, 19(2).

Huang, C., Wang, Z., Ren, X., Ma, X., Zhou, M., Ge, X., Liu, H. and Fu, S. 2022. Evaluation of soil quality in a composite pecan orchard agroforestry system based on the smallest data set. *Sustainability*, 14: 10665.

Kombra, S., Ahlawat, K.S., Dhillon, R.S., Sirohi, C., Hooda, V.S., Yadav, S. and Dalal, V. 2021. Growth performance of fodder crops under eucalyptus based silvipasture system in semi-arid region of India. *Forage Research*, 47(3): 344-349.

Kumar, A. and Nandal, D.P.S. 2004. Performance of winter crops under *Eucalyptus tereticornis* based agrisilviculture system. *Indian Journal of Agroforestry*, 6(2).

Kumar, A., Kumar, M., Poonia, P.K., Dhillon, R.S., Daneva, V. and Dagar, H. 2022. Performance of field crops under eucalyptus system. *Biological Forum-An International Journal*, 14(3): 1030-1035.

Kumar, P., Mishra, A.K., Kumar, Chaudhari, M., Singh, S.K., Singh, K., Rai, P. and Sharma, D.K. 2019. Biomass production and carbon sequestration of Eucalyptus tereticornis plantation in reclaimed sodic soils of north-west India. *Indian Journal of Agricultural Sciences*, 89(7): 1091-1095.

Kumar, P., Sirohi, C., Dhillon, R.S., Kumari, S., Bhardwaj, K.K., Kumar, M., Chaudhary, K. and Nanda, K. 2021. Effect of bund planted eucalyptus on crop yield and soil properties in semi-arid region of Haryana. *Journal of Plant Development Sciences*, 13(2): 155-160.

Newaj, R., Handa, A. and Chaturvedi, O. 2020. Performance of intercrops with various clones of eucalyptus planted under agrisilviculture system. *Indian Journal of Agroforestry*, 15(1).

Nirmal, Ajit and Handa, A. 2021. Biomass and volume models for clonal *Eucalyptus tereticornis* coppice under agroforestry systems in central India. *Indian Journal of Agroforestry*, 23(1).

Ong, C.K., Black, C.R. and Wilson, J. 2015. Tree–crop interactions: Manipulation of water use and root function. In: Jackson, L.E. (Ed.), *Agroforestry-The Future of Global Land Use*. Springer, pp. 145-174.

Panozzo, A., Quataert, P., De Swaef, T., Pardon, P., Vamerali, T., Verheyen, K. and Reubens, B. 2026. A meta-analysis on the impact of trees on yield of intercrops in alley-cropping systems of temperate climates. *Agricultural Systems*, 232: 104578.

Ramesh, K.R., Deshmukh, H.K., Sivakumar, K., Guleria, V., Umedsinh, R.D., Krishnakumar, N., Thangamalar, A., Suganya, K., Kiruba, M., Selvan, T., Balasubramanian, P., Ushamalini, C., Thiyagarajan, G., Vincent, S., Rajeswari, P., Bavish, S., Riaz, A. and Senthil, K. 2023. Influence of eucalyptus agroforestry on crop yields, soil properties and system economics in southern regions of India. *Sustainability*, 15(4): 3797.

Scordia, D., Corinzia, S.A., Coello, J., Vilaplana Ventura, R., Jim´enez-De-Santiago, D.E., Singla Just, B. and Testa, G., 2023. Are agroforestry systems more productive than monocultures in Mediterranean countries? A meta-analysis. *Agronomy for Sustainable Development*, 43: 73. https://doi.org/10.1007/s13593-023-00927-3.

Sirohi, C., Bangarwa, K.S., Dhillon, R.S., Chavan, S.B. and Handa, A.K. 2022b. Productivity of wheat (*Triticum aestivum* L.) and soil fertility with poplar (*Populus deltoides*) agroforestry system in the semi-arid ecosystem of Haryana, India. *Current Science*, 122(9): 1072-1080.

Sirohi, C., Dhillon, R.S., Chavan, S.B., Handa, A.K., Balyan, P., Bhardwaj, K.K., Kumari, S. and Ahlawat, K.S. 2022a. Development of poplar-based alley crop system for fodder production and soil improvements in semi-arid tropics. *Agroforestry Systems*, 96: 731-745.

Sirohi, C., Kumar, P., Dhillon, R.S., Handa, A.K., Bhardwaj, K.K., Kumari, S. and Ahlawat, K.S. 2021. Productivity of barley and growth of eucalyptus clones under agrisilviculture system in semi-arid ecosystem of Haryana, India. *Indian Journal of Agroforestry*, 23(1): 18-22.

Tripathi, V.D., Venkatesh, A., Prasad, R., Shukla, A., Alam, B. and Chaturvedi, O.P. 2020. Tree-crop interaction in eucalyptus based agrisilviculture in semi-arid region of Central India. *Indian Journal of Agroforestry*, 22(2): 39-46.