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# Growth Performance of Different Tree Species in Agroforestry Systems in IGNP Command Area in Western Rajasthan

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**Abstract:** Tree integration in agriculture lands is climate resilient land use system traditionally practiced for improved productivity in arid regions. It enhances land productivity and improves livelihoods of rural dwellers. Four agroforestry models that includes block plantations of *Prosopis cineraria* (Khejri), *Tecomella undulata* (Rohida), grafted *Zizyphus mauritiana* (Ber) and *Cordia myxa* (Gunda) and boundary plantations of *Dalbergia sissoo* (Shisham), *Carissa carandas* (Karonda) and *Cordia myxa* were assessed at two sites within 500 m distance involving two farmers. Seedlings were planted in September 2021. Different crops were cultivated during kharif and rabi seasons of 2021 and 2022. Plants were measured for height and collar diameter and crop yields recorded. After two years of establishment, *P. cineraria* and *T. undulata* seedlings exhibited 99.0% survival, whereas seedlings of *Z. mauritiana* and *C. myxa* showed survival of 93.0% and 95.0%, respectively. Survival was relatively greater under block plantation as compared to the boundary plantations. Height and collar diameter growth of *T. undulata* was greater ($p<0.05$) by 87.0% and 37.0% than *P. cineraria* seedlings in agri-silvi model. *Z. mauritiana* exhibited 30.0% greater height, whereas *C. myxa* showed 22.7% greater collar diameter in agri-horti system. In boundary plantation, survival and growth was greater ($p<0.05$) in *D. sissoo* than *C. carandas* and *C. myxa* seedlings. Yield of *Cyamopsis tetragonoloba* was lesser than *Plantago ovata* and it was higher in 2022-23 than in 2021-22. However, dry matter and grain yields of both *C. tetragonoloba* and *P. ovata* were almost similar ($p>0.05$) in control as well as tree integrated plots. This indicated least competitive effect of trees on crops during initial 2 years. Conclusively, *T. undulata* and *Z. mauritiana* in agroforestry and *D. sissoo* in boundary plantation appeared suitable in initial years. However, recording of data for long term is suggested for effectual conclusion and recommendation based on tree crop interaction.

**Key words**: Arid region, agroforestry, growth, survival, tree-crop interaction.

The construction of Indira Gandhi Nahar Pariyojna (IGNP) has increased water availability for drinking and cultivating agricultural crops in western Rajasthan. The total length of the main canal is about 460 km with about 10,000 km long distribution system that covers a command area of about 18.50 lakh ha (IWMI, 2007). This caters to the needs of about 17.5 million population of western Rajasthan. Increased availability of canal water has promoted intensive cultivation and enhanced agricultural production. However, over-exploitation of fragile ecosystems, harsh climatic conditions, and growing human pressure in the region contribute to land degradation (Varghese and Singh, 2016). Increased mechanization in agricultural activities also affects populations of naturally growing woody vegetation and their diversity. At the same time, tree-integrated farming systems are important concerning sustainability and livelihood in drought-prone dry regions (Harsh *et al*., 1992). The key benefits of integrating trees into farmlands include enhanced land productivity stemming from improved soil properties and fertility (Singh *et al*., 2000; Syano *et al*., 2023; Singh, 2020). Additionally, tree integration plays a crucial role in moderating soil carbon loss by controlling erosion and promoting carbon sequestration (Rizvi *et al*., 2019; Udawatta *et al*., 2023). It also facilitates nutrient cycling (Sileshi *et al*., 2020), enhances microbial populations (Yadav *et al*., 2008), and provides essential environmental services (Jose, 2009). In the Indian Desert region, species such as Prosopis cineraria, *Tecomella undulata*, *Acacia nilotica*, *Acacia senegal*, *Acacia tortilis*, and *Zizyphus mauritiana* are widely conserved and promoted within traditional agroforestry systems (Tewari *et al*., 2014). However, major drawbacks of these traditional agroforestry systems are random distribution and improper spacing and hence varying effects of trees on associated agricultural crops (Jodha, 1997; Singh *et al*., 2024).

On the other hand, the growth and development of the planted seedlings in farmland can significantly be affected by the existing environmental factors like air temperature, light intensity, soil water, and nutrient availability as well as competitive effects of the competing intercrops (Islam *et al*., 2024). The competition between trees and crops for the above- and below-ground resources is a major factor limiting the successful selection of an appropriate agroforestry model in dry regions (Ong *et al*., 1991; Upadhyaya *et al*., 2021). Initially planted tree seedlings face competition from the associated crops, whereas after establishment seedlings start competing with the crops mainly for soil water, nutrients, and light (Swieter *et al*., 2021). Crop yield reduction by 15-90% reported beneath tree canopy is because of varying levels of competitive interaction between tree and crop interaction that depended on tree species, age, soil type, rainfall and climatic factors (Singh, 2004; Kaushik *et al*., 2017; Singh, 2020). Tree competition with crops also depends upon root distribution patterns, crop types, and availability of resources (Toky and Bisht, 1992; Stahl *et al*., 2002; van Noordvijk *et al*., 2015). Such tree-crop interactions may be equally applicable to the crops grown in association with some important tree species grown in western Rajasthan. These include *Prosopis cineraria* (L.) Druce (Khejri), *Tecomella undulata* (Sm.) Seem (Rohida), *Dalbergia sissoo* Roxb. (Shisham), *Zizyphus mauritiana* Lamk. (Ber), and *Cordia myxa* L. (Gunda), etc. (Singh *et al*., 2014). The growth of these tree species may depend on the climate-growth responses of individuals (Primicia *et al*., 2015). There are limited studies on tree-crop interaction involving these tree species in agroforestry systems particularly under the irrigated condition of IGNP areas (Yadava *et al*., 2013; 2018). Thus, there is a need to assess different tree-crop combinations for adopting suitable agroforestry systems for the irrigated IGNP area of western Rajasthan to sustain ecological and socio-economic services in the region. Further, recognizing the growth patterns and trends of environmentally adaptive and economically important species is therefore crucial in increasing land productivity in the region.

Therefore, this study includes the performance of different silvi- and horti-species like *P. cineraria, T. undulata, D. sissoo, Z. mauritiana,* and *C. myxa* in terms of survival and growth and their effects on crop productivity in agroforestry system in IGNP command area of western Rajasthan.

## Materials and Methods

### *Site condition*

The study was conducted for two consecutive years (2021-2023) on two farmlands (sites) situated at 500 m distance in Indira Gandhi Nahar Pariyojana (IGNP) near Bandha, Ramgarh area of Jaisalmer (27º15′47.6″N, 70º16′58.0′′E and 27º14′51.8″N, 70º16′45.7′′E) district of Rajasthan, India. The climate of the region is tropical and characterized by hot and dry summer, warm autumn, and cool winter. The rainfall period is from mid-July to September. Annual rainfall at Ramgarh, Jaisalmer (nearest meteorological station) was 139 mm, 474 mm, and 295 mm in 2021, 2022, and 2023, respectively. The mean monthly maximum temperature was 39.0°C, 38.1°C, and 35.6°C, and the minimum temperature was 14.3°C, 16.8°C and 18.0°C, respectively in 2021, 2022 and 2023. The experimental area was flat with loamy sand soil having a Gypsum layer at 50-75 cm depth. The values of soil pH and organic carbon of the first experimental site (silvi species) were 8.96 and 0.065%, whereas at the second experimental site (horti species) these values were 8.73 and 0.079%, respectively.

*Plantation establishment*

Six months old seedlings of different species were planted in September 2021. Experimental site I, was planted with two silvi species viz. *P. cineraria* (Khejri) and *T. undulata* (Rohida) covering 2 ha area whereas experimental Site II comprised horticultural species, specifically grafted ber (*Zizyphus mauritiana*) and *Cordia myxa* (Gunda) covering 1.5 ha area. Three replicate plantations were done in a randomized block design and the spacing between the trees was 6 m × 6 m in both experiments. A basal dose of 5 kg FYM and 10 g anti-termite chemical (Forate) were mixed in each pit during the plantation. In addition, boundary plantation (300 running meters) of *D. sissoo* (Shisham) seedlings was done at 6 m spacing and *Carissa carandas* (Karonda) seedlings were planted in between the *D. sissoo* seedlings at experimental site I (50 plants of each species). At experimental site II, the boundary plants involved *D. sissoo* and *C. myxa* seedlings planted at 6 m spacing alternatively covering 550 running meters (45 plants of each species). Soil working was done at three-month intervals. Plants were irrigated weekly during the summer season in the first year. In the second year, irrigation was done at 15-day intervals during winter and 10-day intervals during the summer season, whereas in the third year, supplement irrigation was done at 15-day intervals during both winter and summer season. Mortality of plants was addressed in July 2022 by replacing the lost individuals to maintain the intended plant density. To protect the seedlings from termite attack, a 0.2% solution of Chlorpyrifos was applied in September, October, and April months or whenever required. During the rainy season of the third year, a second dose @ 3 kg FYM and 25 g DAP were applied to the plants.

***Crop yield recording*:** Cluster bean (*Cyamopsis tetragonoloba* (L.) Taub.) was the kharif season crop, whereas Ishabgol (*Plantago ovata* Forsk.) was the rabi season crop at experimental site I (Agri-Silvi model), whereas at experiment site II (Agri-Horti model), cluster bean (*C. tetragonoloba*) was the intercrop in the kharif season, and Mustard (*Brassica juncea (L.) Czern. & Coss.*) was sown as the rabi season in year 2021. In the year 2022, cluster bean and Isabgol were the kharif and rabi season crops respectively in both the experiment. In addition, there were three replicate control plots, which had pure crops without tree plantation at each site. Harvesting and yield recording of kharif and rabi seasons crops were done from 1× 1 $m^2$ size quadrates laid in each replicate plot of tree species as well as the control plots in both experiments. However, there were quadrates in planted area, i.e., one at 30 cm away from the plant root zone and the other was at the centre of four plants in each plot in block plantation. Thus, there were 15 quadrates (12 in plantation + 3 in control) at each experimental site. Agricultural crops were harvested in October and March (i.e., for kharif and rabi crops respectively) of each year from the above-mentioned quadrates. After air drying, the crops were threshed. Dry matter (straw) and grain of the crops were separated by winnowing, their yields were recorded by weighing using top loading balance and presented in Mega gram (tonnes) per hectare (Mg $ha^{-1}$). Due to the non-availability of irrigation water in the canal, the yield of Isabgol and mustard (sown during the rabi season of 2021) could not be recorded.

***Observations*:** The survival percentage of the planted seedlings was calculated from the ratio of the live seedlings and the initial number of seedlings planted. It was calculated on yearly basis. The height and collar diameter (10 cm above the ground level) of the planted seedlings were recorded at six-months intervals using measuring rods and Vernier calipers respectively. Grafted *Zizyphus mauritiana* (37 plants) and *Cordia myxa* (12 plants) started

*Table 1. Per cent survival of different species under different agroforestry systems in IGNP command area in western Rajasthan. Values are mean ± LSD of 3 replications*

| Model | Species | Replacement (%) in Aug 2022 | Survival (%) in October 2023 | ANOVA | |
|---|---|---|---|---|---|
| | | | | *F value* | *P value* |
| Agri-Silvi model (site-I) | | | | | |
| Block plantation | *P. cineraria* | 7.77 | 99±1.14 | 0.111 | NS |
| | *T. undulata* | 2.78 | 99±0.67 | | |
| Boundary plantation | *D. sissoo* | 33.33 | 96±1.11 | 5.991 | <0.05 |
| | *C. carandas* | 34.00 | 93±1.70 | | |
| Agri-Horti model (site-II) | | | | | |
| Block plantation | *Z. mauritiana* | 6.67 | 93±3.82 | 0.619 | NS |
| | *C. myxa* | 10.00 | 95±4.62 | | |
| Boundary plantation | *D. sissoo* | 11.33 | 95±2.23 | 0.920 | NS |
| | *C. myxa* | 12.47 | 94±1.81 | | |

NS - Non significant at p>0.05

fruiting in 2022-23; hence the fruit yields were also recorded in Agri-Horti system (Experiment II).

***Data analysis*:** Data collected in the studies were statistically analyzed using the SPSS statistical package. Survival, height and collar diameter of the planted seedlings were analyzed using a one-way ANOVA separately for both experiments and types of plantations (block plantation and boundary plantation). Type of tree species was the main factor. Yields of the dry matter as well as grain of the crops were also analyzed using one way ANOVA considering trees species and the control plots as the main factor. The least significant difference test was used to compare treatments at the $p$<0.05 levels. Pearson's correlation was also performed to find out relationship between plant growth/crop yield and annual rainfall.

## Results and Discussion

***Seedling survival*:** Per cent survival of the planted seedling at 2 years age did not differ significantly (p<0.05) between the species of both agroforestry models except boundary plantations in the Agri-Silvi system where survival of *D. sissoo* seedlings was significantly high (96%) in comparison of *C. carandas* (Table 1). However, survival percent ranged from 93 to 99 percent in Agri-Silvi model. It was relatively less under boundary plantation as compared to those in the block plantation. Among species, the survival was lowest for *C. carandas* and highest for *P. cineraria/T. undulata*. At the experimental site of the Agri-Horti model, survival percent ranged between 93% for *Z. mauritiana* and 95% for *C. myxa* and *D. sissoo*. Survival was almost similar in block and boundary plantations (Table 1).

***Seedling growth*:** At experimental site I, both height and collar diameter growth differed significantly (p<0.05) between the species. Incremental growth in height and collar diameter of *T. undulata* were 603% and 228% greater as compared to those for the *P. cineraria* seedlings under block plantation. At experiment site II, the height of the grafted *Z. mauritiana* was significantly (p<0.05) greater than the seedlings of *C. myxa* indicating a 383% and 146% enhancement in incremental growth in the height and collar diameter of *Z. mauritiana* seedlings.

In boundary plantations, the growth performance of *D. sissoo* seedling was significantly (p<0.05) better as compared to *C. carandas* and *C. myxa* seedlings. Increase in the height and collar diameter of *D. sissoo* seedlings were higher by 169.0% and 253.0% as compared to the respective growth variable for *C. carandas* at experimental site I. At the experimental site II, the growth of *D. sissoo* seedlings was 96% greater in height and 75% greater in collar diameter over the respective growth variable of *C. myxa* seedlings (Table 2).

Trends in periodic growth of height and collar diameter are presented in Fig. 1. The seedlings of *D. sissoo, T. undulata* and *Z. mauritiana* exhibited better height growth as compared to the seedlings of the other species. These seedlings showed better growth in second year as compared to that in the first

*Table 2. Growth of two-year-old seedling of different species in agroforestry in IGNP command area in western Rajasthan. Values are mean ± LSD of 3 replications*

| Models | Experimental site I | | | | |
|---|---|---|---|---|---|
| Agri-Silvi model | Growth parameter | *P. cineraria* | *T. undulata* | *F* value | *P* value |
| | Height (cm) | 118±5.95 | 221±4.94 | 65.39 | <0.001 |
| | Collar diameter (cm) | 3.24±0.19 | 4.43±0.18 | 18.79 | <0.001 |
| Boundary plantation | | *D. sissoo* | *C. carandas* | *P* value | *F* value |
| | Height (cm) | 167±14.15 | 62±4.66 | 18.09 | <0.001 |
| | Collar diameter (cm) | 3.74±0.21 | 1.06±0.12 | 15.22 | <0.001 |
| | Experimental site II | | | | |
| Agri-Horti model | | *Z. mauritiana* | *C. myxa* | *F* value | *P* value |
| | Height (cm) | 140±7.00 | 108±5.10 | 6.75 | <0.05 |
| | Collar diameter (cm) | 2.91±0.38 | 3.57±0.51 | 2.92 | NS |
| Boundary plantation | | D. sissoo | C. myxa | *P* value | *F* value |
| | Height (cm) | 225±24.29 | 4.54±0.58 | 20.11 | <0.001 |
| | Collar diameter (cm) | 5.54±2.49 | 3.17±0.09 | 11.46 | <0.001 |

NS - Non significant at P<0.05.

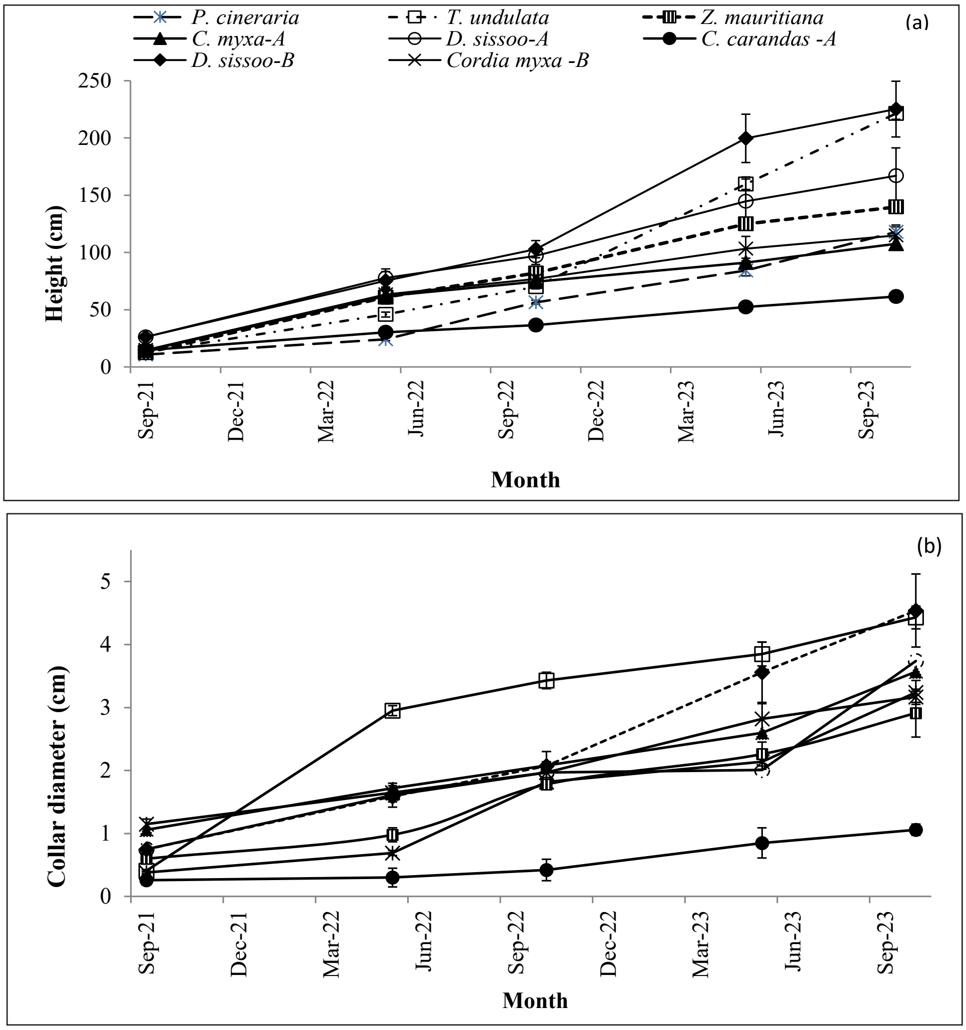


*Fig 1. Periodic growth in height (a) and collar diameter (b) of different species in various agroforestry systems in IGNP command area of Jaisalmer, Rajasthan.*

*Table 3. Crop yield (Mg ha$^{-1}$) in Agri-Silvi and Agri-Horti system in IGNP command area in western Rajasthan. Values are mean ± LSD of 3 replications*

| Experiment I (Agri-Silvi system) | | | | | | |
|---|---|---|---|---|---|---|
| Crop | | *P. cineraria* | *T. undulata* | Sole crop | *F* value | *P* value |
| 2021-22 | | | | | | |
| Cluster bean | Dry matter (Mg ha$^{-1}$) | 0.38±0.01 | 0.38±0.01 | 0.38±0.03 | 0.30 | NS |
| | Grain (Mg ha$^{-1}$) | 0.08±0.01 | 0.08±0.01 | 0.08±0.01 | 0.93 | NS |
| 2022-23 | | | | | | |
| Cluster bean | Dry matter (Mg ha$^{-1}$) | 1.55±0.04 | 1.58±0.07 | 1.59±0.06 | 1.25 | NS |
| | Grain (Mg ha$^{-1}$) | 0.49±0.04 | 0.51±0.05 | 0.53±0.41 | 2.08 | NS |
| Isabgol | Dry matter (Mg ha$^{-1}$) | 1.48±0.13 | 1.52±0.10 | 1.56±0.06 | 1.22 | NS |
| | Grain (Mg ha$^{-1}$) | 0.50±0.06 | 0.50±0.07 | 0.55±0.04 | 2.53 | NS |
| Experiment II (Agri-Horti system) | | | | | | |
| Crop | | Grafted *Z. mauritiana* | Grafted *C. myxa* | Sole crop | *F* value | *P* value |
| 2021-22 | | | | | | |
| Cluster bean | Dry matter (Mg ha$^{-1}$) | 0.70±0.01 | 0.71±0.01 | 0.72±0.01 | 1.24 | NS |
| | Grain (Mg ha$^{-1}$) | 0.23±0.01 | 0.23±0.02 | 0.24+0.01 | 1.06 | NS |
| 2022-23 | | | | | | |
| Cluster bean | Dry matter (Mg ha$^{-1}$) | 1.56±0.11 | 1.56±0.05 | 1.56±0.07 | 0.02 | NS |
| | Grain (Mg ha$^{-1}$) | 0.50±0.09 | 0.53±0.03 | 0.55±0.04 | 1.84 | NS |
| Isabgol | Dry matter (Mg ha$^{-1}$) | 1.82±0.15 | 1.83±0.10 | 1.91±0.09 | 1.48 | NS |
| | Grain (Mg ha$^{-1}$) | 0.60±0.06 | 0.59±0.05 | 0.62±0.04 | 0.67 | NS |

NS - Non significant at p<0.05.

year (Fig. 1a). Growth in collar diameter was also least in *C. carandas*. However, seedlings of *D. sissoo* and *T. undulata* showed better collar diameter growth as compared to the other species (Fig. 1b).

***Crops yield*: **Crop yield recorded in terms of dry matter (straw) and grain showed variations due to crop type. rabi crops of 2021 failed due to non-availability of supplemental irrigation from the canal and hence crop yield could not be recorded in 2021-22. During kharif seasons, dry matter and grain yields of clusterbean did not differ ($p$>0.05) between the tree integrated system and the control plots in both 2021-22 and 2022-23 (Table 3). Contribution of dry matter and grain yields in total yield was 82.6% and 17.4% in 2021-22 and 75.0% and 25.0% in 2022-23, respectively in agri-silvi system. The reduction in the yields of dry matter and grain in the tree integrated plots was insignificant as compared to those in the control plots in 2021-22. However, the reduction in dry matter and grain yield of cluster bean was by 2.5% and 7.6% in Khejri-based system, and by 0.63% and 3.77% in Rohida-based system respectively as compared to the yields in sole crop plot in 2022-23. Likewise, dry matter and grain yield of Isabgol showed a decrease by 5.1% and 9.1% in Khejri-based system, and by 1.6% and 9.1% in Rohida-based system.

In Agri-Horti system, dry matter and grain yields of clusterbean as well as Isabgol both did not differ significantly due to tree species and the control plots in both the years. Average yields of dry matter and grain of clusterbean were 0.71 Mg ha$^{-1}$ and 0.23 Mg ha$^{-1}$ with their contribution by 75.5% and 24.5% respectively in 2021-22. In 2022-23, dry matter and grain yields were higher ($p$<0.05) than those in 2021-22 and contribution of these components were 74.6% and 25.4% of the total yield respectively. Reduction in grain yields of clusterbean was 9.1% and 3.6% in grafted Ber and Gunda-based system than the yield in control plot in 2022-23. Contribution of dry matter and grain yields in total yield of Isabgol was 75.4% and 24.5% respectively in rabi season of 2022-23. Though not significant, but yield was relatively higher in the control plots than those in the tree integrated plots. The reduction in dry matter and grain yield were by 4.7% and 9.7% in grafted Ber system, and by 4.2% and 8.1%

in Gunda-based system, when compared with those in the sole crop plot (Table 3).

***Fruit yields of Ber and Gunda***: Fruit yield of grafted *Z. mauritiana* ranged between 0.60 kg plant$^{-1}$ to 2.5 kg plant$^{-1}$ in the second year (i.e. 2022-23) with an average yield of 1.45 kg plant$^{-1}$. In grafted *Cordia myxa*, the fruit yield was 0.78 kg plant$^{-1}$ that varied from 0.50 kg plant$^{-1}$to 1.50 kg plant$^{-1}$.

***Correlations***: Annual rainfall showed positive correlation with dry matter ($r^2$ = 0.99, $p$<0.01) and grain ($r^2$= 0.95, $p$<0.05) yields of Cluster bean in kharif season.

Harsh climatic conditions and low rainfall caused heat and water stresses and affected plant survival and establishment. It was further aggravated by reduced water availability in the nearest canal system disturbing supplemental irrigation to the plants as well as agricultural crops during rabi season. It was also substantiated by relatively low plant survival in boundary plantation, i.e. seedlings of *D. sissoo* and *C. carandas* as compared to the seedlings integrated in farmlands. Poor seedlings survival particularly in south-west side (direction) of the boundary plantation of Agri-Silvi system was because of sand blasting caused by wind-blown sand particles during summer season of the first year (Armbrust and Rett, 2000). Low soil water availability and resources appeared key driving factor influencing seedling survival and its establishment in the arid region (Singh and Singh, 2003; Masek *et al*., 2021). It was supported by low rainfall, i.e. 139 mm annual rainfall in 2021-22 and high temperature that induced water and heat stress and affected survival and growth of the integrated tree species.

Height and collar diameter growth of both silviculture and horticulture tree species increased with advancement in time in the present study. However, initial growth and development of tree species is generally poor owing to the poor soil resources and long dry spells despite of providing supplement irrigation to the planted seedlings (Bhadouria *et al*., 2016). Significantly *(*p<0.05*)* greater growth in height and collar diameter of *T. undulata* as compared to *P. cineraria* seedlings in Agri-Silvi model, Z. *mauritiana* as compared to *C. myxa* seedlings in Agri-Horti model, and *D. sissoo* as compared to *C. carandas* and *C. myxa* seedlings in boundary plantations was because of species characteristics and their responses to the available soil resources and climatic conditions (Cadotte *et al*., 2011; Tumber-Davila *et al*., 2022). We observed relatively greater growth in *T. undulata* seedling than *P. cineraria* seedlings in initial year under supplemental irrigation (limited by canal water availability), but contrasting result also observed on 5-year-old plants of *P. cineraria,* which showed marginally high growth in latter species under rainfed agroforestry system (Singh, 2004). Relatively greater height and collar diameter growth in *D. sissoo* seedlings as compared to the other tree species was similar to the existing literature (Kaushik *et al*., 2014). This enhanced growth of *D. sissoo* seedlings was because of efficient use of available soil resources like soil water and nutrient that makes this species effective in shelterbelt plantation on farm lands to check wind velocity and hence soil erosion (Mertia *et al*., 2006). Zhang *et al*. (2021) observed positive effects of water availability and growth form that greatly influenced shoot size and productivity in dry region. Lateral root systems in *D. sissoo* and *T. undulata* probably provided environment for enhanced resource use potential and hence plant growth as compared to *P. cineraria* and *Z. mauritiana* in irrigated condition (Gupta *et al*., 1995; Odhiambo *et al*., 1999; Singh *et al*., 2014; Upadhyaya *et al*., 1991).

Non-significant (p>0.05) differences in crop yield between tree integrated plots and the sole crop plots was because of insignificant competition between tree seedlings and the associated crops (Swieter *et al*., 2021). During early growth and development phase, young trees acquire soil water and nutrient from the upper soil layer (i.e., cropping zone), which may result in yield losses in drier environments (Luedeling *et al*., 2016). However, relatively greater difference in the dry matter and grain yields of the crops in control and tree integrated plots during both kharif and rabi seasons of 2022-23 was certainly due to increase in competitive stress for soil water and nutrient (Singh *et al*., 2014). However, differences due to reduced effective crop area due to tree integration cannot be ruled out. Frequency and amount of rainwater is major determining factor influencing crop yield and establishment of the planted seedlings. Only two rain days in monsoon season of 2021 resulting in 63 mm rain and 22 rain days with 451 mm rain during monsoon season of 2022 appeared strongest factor enhancing yield of Cluster bean in 2022-23 (Singh, 2010). It was also shown by positive correlation ($r^2$ = 0.99 and 0.95, $p<0.001$, respectively) between annual rainfall and dry matter and grain yield of Cluster bean. Furthermore, root architecture differs between tree species which influence competitive effects for soil resources between tree species and the companion crops owing to overlapping root systems and their associated rhizospheres (Livesley *et al*., 2000; Singh *et al*., 2014) and hence affects crop yield (Kaushik *et al*., 2017). However, non-significant difference indicates least competition between the planted seedlings and the associated agricultural crops during initial phase of plant establishment.

## Conclusion

Prevailing environmental conditions appears important factor influencing plant establishment and crop yields. Growth of the planted tree seedlings depended not only on the genetic characteristics of the species but also on the available soil resources. Integration of *T. undulata* in Agri-Silvi system and *Z. mauritiana* in Agri-Horti system appeared relatively better for irrigated agroforestry systems as compared to the other species in initial two years. Likewise, *D. sissoo* appeared better species for boundary plantation as compared to *C. carandas* and *C. myxa* and may be useful in erecting shelterbelt/boundary plantation in arid region of Rajasthan. However, further data recording and analysis will be more advantageous for effectual conclusion and recommendation.

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