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Research article

Early tree growth and crop yields under *Prosopis cineraria* and *Ailanthus excelsa* based agroforestry system in north western India

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Abstract
A field experiment was initiated in 2017 to evaluate the effect of tree species and tree spacing on intercrop productivity and tree growth with advancing age of *Prosopis cineraria* and *Ailanthus excelsa* in an agroforestry system at Bikaner, Rajasthan. Both *P. cineraria* and *A. excelsa* were planted at three spacings: 4m × 4m, 6m × 6m and 8m × 8m; and *Cyamopsis tetragonoloba* L. Taub. (Cluster bean) was grown as intercrop during the *kharif* seasons of 2018 and 2019. At 24 months after planting (MAP), *A. excelsa* trees were significantly taller and thicker in wider spacings of 6m × 6m and 8m × 8m compared to closer spacing of 4m × 4m; while in *P. cineraria*, different spacings did not significantly affect tree height and collar diameter. In this period, collar diameter and height of *A. excelsa* increased by 10.9 and 6.9-fold in 6m × 6m and 9.9 and 6.8-fold in 8m × 8m spacing, respectively. Percent increment in tree growth parameters were higher during initial growth period (6-12 MAP), and decreased in the subsequent months for both *A. excelsa and P. cineraria*. Among the different spacings, higher percent increment in collar diameter in both the species at 24 MAP was recorded in 6m × 6m spacing. The intercrop yield in both the years was not significantly affected by different tree species and spacings. The study indicated that *A. excelsa* could be established and grown faster in arid region at wider spacings to get maximum tree growth.

Keywords: Agroforestry, *Ailanthus*, Cluster bean, *Prosopis*, Spacing

Introduction
Western Rajasthan accounts for 61 percent of total hot arid region of the country (Tewari *et al.,* 2017). Agroforestry plays a vital role in the economy of arid regions due to the high risk involved with arable farming, which is also affected by the scanty and erratic rainfall, low soil fertility, recurring droughts, and also by wind erosion. Integration of trees in farmlands is considered a promising approach to improving livelihood security (Glover *et al.,* 2012; Subbulakshmi *et al.,* 2017), because trees are reported to improve soil health, aid in the recycling of nutrients, control soil erosion, conserve soil moisture, and therefore, improve crop production. Agroforestry systems provide resilience to vulnerable arid farming systems by ensuring supply of outputs such as wood, fuelwood, fodder, and edible products. In addition, trees sequester carbon in wood and soil, which can help mitigate climate change impacts (Chaturvedi *et al.,* 2016). Selection of suitable tree species, optimum tree spacing and intercropping are important aspects of agroforestry practices. In drier parts of Rajasthan, farmers traditionally grow trees, *viz*., *Prosopis cineraria* (L.) and *Ziziphus nummularia* (L.), which sustain farmers' income and livelihood during unforeseen crop failures.

Prosopis cineraria (L.) Druce is a commonly grown perennial tree in the Indian desert (Garg *et al.,* 2004). It is a moderate sized, leguminous, evergreen, thorny, perennial tree and an important tree species in traditional agroforestry practices of Thar Desert (Jatasra and Paroda, 1981) due to its multiple uses *viz*., vegetable pods, shade, fodder value, and sand dune stabilization ability. The role of *P. cineraria* in sustainable agriculture production in arid zones is immense (Singh and Bishnoi, 2013). *Ailanthus* *excelsa* Roxb. belongs to the family Simaroubaceae and is a fast growing, deciduous tree native to India. Under irrigated conditions, 50-75 tons ha^{-1} of wood was obtained at a rotation of 5-6 years in Tamil Nadu (Rajasugunasekar, 2014). When it comes to digestibility, flavour, and nutritional value, *A. excelsa* leaves are one of the best among all the fodder trees, with green leaves comprising 19.87% crude protein. (Jat *et al.,* 2011). Realizing the multiple uses of *A. excelsa*, its cultivation is extended in various agroforestry systems as a profitable venture. Cluster bean (*Cyamopsis tetragonoloba* L. Taub.) is commonly known as gaur is a drought tolerant legume crop grown for gum purpose in arid regions of India. Rajasthan is the major producer of cluster bean in India, followed by Haryana (Bhatt *et al.,* 2017).

There was a need to find out the growth of *A. excelsa* and *P. cineraria* with increasing tree age in the initial years for successful establishment of agroforestry plantation, especially in arid conditions. Due to the inclusion of perennial trees, interactions in agroforestry systems are more complicated and extensive than those in annual intercropping, and these interactions rely on the traits and nature of trees, their density, age, and layout (Rao *et al*., 1998). Indeed, there was also a need to evaluate the possibility of growing intercrops, with the different tree species and spacing, during the initial years of establishment to increase overall productivity of farmland. Keeping these points in view, this study was formulated with the objectives of determining the effect of different spacings of *A. excelsa* and *P. cineraria* with advancing age on tree growth and intercrop productivity for integrating these trees in agroforestry systems for higher profitability.

Materials and Methods

Site description: The experiment was initiated at the farm of ICAR-Central Arid Zone Research Institute, Regional Research Station, Bikaner, Rajasthan situated in north western India (located at 11° 19′ N latitude and 77° 56′ E longitude and an altitude of 300 m above mean sea level). Mean annual rainfall of the region is 255 mm and has very high mean evaporation of 1255 mm $year^{-1}$. The mean maximum and minimum temperatures are 49°C and 5°C, respectively with less relative humidity. The soil of this region is sandy loam with an average pH of 8.5 (Yadava *et al.,* 2019).

Tree establishment: *P. cineraria* and *A. excelsa* seedlings were established at three different spacings *viz*., 4m × 4m, 6m × 6m and 8m × 8m with four replications per treatment. The field selected for this study was not under cultivation during the previous seasons. They were plowed twice using a disc harrow and leveled. Pits of 0.30 × 0.30 × 0.30 m size were dug with tractor mounted augur and 3 kg of FYM was added to each pit and the soil thoroughly mixed. 30 cm tall seedlings of *A. excelsa* and *P. cineraria* were transplanted in pits in October 2017. Immediately after transplanting, each pit was irrigated to prevent seedling mortality. Any seedling that died was replanted within 30 days of planting. Since the study was to monitor the effect of tree spacing on tree growth and associated agricultural crop, no control as tree only plot was taken.

Intercrops and their management: Cluster bean was raised as an intercrop under rainfed condition in *kharif* seasons (August to October) of 2018 and 2019. Cluster bean was sown at the recommended seed rate using tractor mounted seed drill, in rows spaced at 40 cm. The seedlings were thinned to maintain an intra-row spacing of 10 cm between plants after germination. The crop was fertilized with the recommended rate of 10 kg N ha^{-1} and 20 kg P ha^{-1} through urea and diammonium phosphate. Weeds were controlled manually by inter row cultivation. Sole cluster bean without trees was also established for comparison.

Observations: Each treatment was replicated four times. In each replication, three trees were randomly marked and the same trees were measured at six month intervals, *i.e*., at 6, 12, 18, and 24 months after planting (MAP), for height and collar diameter. The height of trees was recorded from the base of the tree to the growing tip with the help of a measuring stick. The diameter was measured at 15 cm above the ground level using a vernier caliper. Height and collar diameter increments were calculated every six months to monitor the effect of different tree spacing and intercrop cultivation on tree growth.

Growth increment (%) = [(Growth variable in a particular year - Growth variable in a previous year)/ Growth variable in a previous year] × 100

The regression model $M= a(pD^2H)^b$ was used to estimate the above ground biomass (AGB) of *A. excelsa*; where M= dry biomass of tree (kg), D = diameter at breast height (cm), H = height of the tree (m), p = wood specific gravity, a = regression constant, b = regression coefficient. Below ground biomass (BGB) was estimated by multiplying AGB with a factor of 0.26 (Chave *et al*., 2014). Crop yields were recorded by harvesting the crops from one square meter from the centre of the crop row in each treatment. The yield parameters were measured on hectare basis.

Statistical analysis: Tree height and collar diameter were analyzed using a one-way ANOVA with growth parameters as the dependent variables. The variations in intercrop yield due to tree spacing and tree species were tested using a two way ANOVA model. To compare treatments, the least significant difference test was used at the P<0.05 levels.

Results and Discussion

Tree survival and growth: The tree survival at early stages in both the tree species were not significantly affected by tree spacing. The survival was 75 % in 4m × 4m, 89 % in 6m × 6m, 94 % in 8m × 8m in *A. excelsa*, and 94 % in 4m × 4m, 88 % in 6m × 6m, 81 % in 8m × 8m in *P. cineraria*. Closer spacing did not induce any extra mortality. Reddy *et al.* (2000) reported the survival of perennial legumes (*Sesbania grandiflora, Leucaena leucocephala* and *Gliricidia sepium*) was not affected by row spacing (4, 8, or 12 m).

In *A. excelsa,* the effect of tree spacing on collar diameter was significant (P<0.05) at 24 months after planting (MAP), whereas height was significantly influenced at 12 MAP and 24 MAP (Table 1). At one year of age (12 MAP), tree height was significantly higher at 8m × 8m compared to 4m × 4m, but on par with 6m x 6m. At 2 years of age (24 MAP), trees were significantly taller and thicker in 6m × 6m and 8m x 8m spacing compared with 4m × 4m. Lower tree density and the consequent greater availability of soil water and nutrients might explain the resulting greater thickness and height of trees in wider spacings compared with closer spacing. The results were in agreement with those reported by Subbulakshmi *et al.* (2019) who observed a significantly higher height of *Jatropha curcas* at wider spacing of 4m × 3m at the age of four years, compared with those grown at 4m × 2m and 3m × 3m spacing. Similarly, Deswal *et al.* (2021) reported higher plant height and DBH in *A. excelsa* at 20m × 10m spacing compared to closer spacings of 10m × 10m, 10m × 6.5m and 10m × 5m. More space available at both above and below ground level under wider spacing probably decreased the competition for resources like water, light and nutrients among the trees. The increase in collar diameter over the base data of 6 MAP was 10.9-fold in 6m × 6m and 9.9-fold in 8m × 8m spacings. The corresponding increase in height was 6.9-fold in 6m × 6m and 6.8-fold in 8m × 8m spacing (Table 1). The collar diameter was positively correlated with tree height (r = 0.98, P<0.01).

In *P. cineraria,* there was no significant difference observed in growth parameters irrespective of tree spacing. However, among the three spacing, the maximum of 2.8-fold increase in collar diameter and 2.7-fold increase in height over the base data of 6 MAP were observed at 6m × 6m spacing (Table 2). This might be due to slower growth rate of *P. cineraria*. Francois *et al.* (2016) observed non-significant effect of spacing on tree height in *Pinus banksiana* trees. Similarly, in olive trees, tree spacing had no significant effects on tree diameter and height in the initial four years (Gomez *et al.,* 2017).

Tree growth increment percent: Percent increment in collar diameter during initial growth period was observed to be higher and to decrease in the subsequent months in *A. excelsa*. Significantly higher increment in collar diameter was observed during 6-12 months, followed by 12-18 months. However, the increment was found on par at all three spacings. During 18-24 months collar diameter increment was found significantly lower at 4m × 4m spacing over 6m ×

Table 1. Growth of *Ailanthus excelsa* as influenced by tree spacing and the associated crop

Tree spacing	6 MAP	12 MAP	18 MAP	24 MAP
Collar diameter (mm)				
4m × 4m	8.8	25.8	52.3	76.3^{b}
6m × 6m	10.2	29.1	57.2	110.7^{a}
8m × 8m	10.6	30.8	60.8	104.5^{a}
CD (P<0.05)	NS	NS	NS	6.80
Height (cm)				
4m × 4m	40.7	98.7^{b}	155.0	265.7^{b}
6m × 6m	49.5	109.8^{ab}	174.4	343.7^{a}
8m × 8m	49.5	116.9^{a}	180.0	335.4^{a}
CD (P<0.05)	NS	11.15	NS	42.85

*P-values are result of a one-way ANOVA; Values within columns followed by different letters differed significantly at P<0.05; NS: Non-significant

6m, but it was at par with 8m × 8m. Contrary to our finding, Meena *et al.* (2005) found maximum increment in growth parameters *viz.* plant height, collar diameter, and canopy diameter in *A. excelsa* at wider spacing (20m × 20m) compared to closer spacings (20m × 10m, 13.3m × 10m and 10m × 10m). There was also no significant difference in height increment between the three spacings during 6-12 months, but comparatively lower growth increment in 6m × 6m. The height increment during 12-18 and 18-24 months was at par with all the three spacings (Fig 1).

In *P. cineraria,* percent increments in collar diameter and height were highest in 6-12 months and then it decreased in the subsequent months. Singh *et al.* (2007) observed a similar trend in *P. cineraria* agroforestry system in the initial year of tree growth. The percent increment in collar diameter was found significantly higher in initial 6-12 MAP at 4m × 4m spacing, compared to later growth. This might be due to more competition between trees at 4m × 4m spacing as the age increases. During 12-18 and 18-24 months, collar diameter increment was higher at 6m × 6m spacing; however, it was statistically at par with collar diameter at other spacings. The highest increment in height was found at 4m × 4m during 6-12 months. It was statistically higher than at 8m × 8m, but on par with increment at 6m × 6m. There was no significant difference in height at all three spacings during 12-18 and 18-24 months (Fig 2).

Biomass: Biomass production of Ailanthus excelsa at 24 MAP was significantly higher in medium spacing (6m × 6m) than at closer and wider spacings. At this spacing, the total biomass produced was 1.9 t ha^{-1}, of which the above ground biomass comprised 1.51 t ha^{-1} and the below ground biomass comprised 0.39 t ha^{-1}. Lesser tree growth at closer spacing and less number

Table 2. Growth of *Prosopis cineraria* as influenced by tree spacing and the associated crop

Tree spacings	6 MAP	12 MAP	18 MAP	24 MAP
Collar diameter (mm)				
4m × 4m	2.06	4.2	5.71	6.31
6m × 6m	2.27	3.45	4.91	6.35
8m × 8m	2.27	3.78	4.63	5.37
CD (P<0.05)	NS	NS	NS	NS
Height (cm)				
4m × 4m	15.58	27.53	35.00	41.08
6m × 6m	16.70	25.98	38.05	44.38
8m × 8m	16.63	25.15	33.68	39.88
CD (P<0.05)	NS	NS	NS	NS

*P-values are result of a one-way ANOVA; Values within columns followed by different letters differed significantly at P<0.05; NS: Non-significant

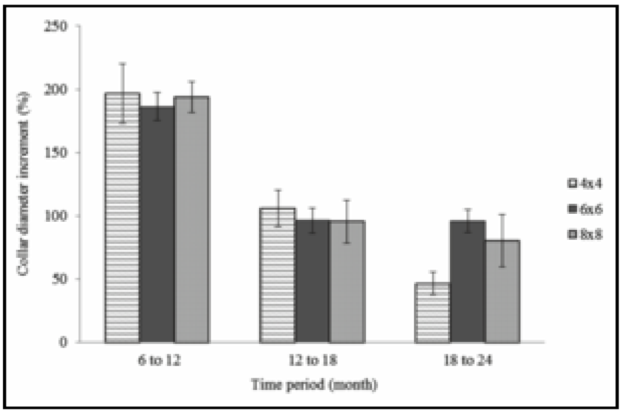

Fig 1(a). Effect of tree spacing on percent growth increment in collar diameter of *Ailanthus excelsa* trees; Error bars are ±SE of four replicates; Columns within month interval denoted by different letters differed significantly at P<0.05

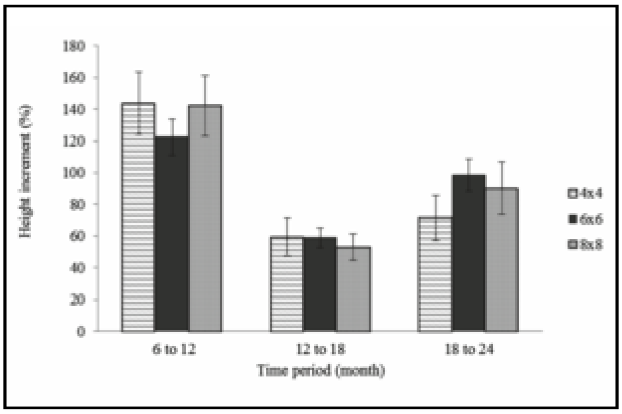

Fig 1(b). Effect of tree spacing on percent growth increment in height of *Ailanthus excelsa* trees; Error bars are ±SE of four replicates; Columns within month interval denoted by different letters differed significantly at P<0.05

of trees at wider spacing, compared to the optimum tree growth and tree stock at medium spacing might have contributed for more biomass production at 6m × 6m spacing (Table 3). The results were consistent with previous studies in which stand biomass production was significantly higher at intermediate spacing compared to narrow and wider spacings in Cunninghamia lanceolata (Farooq et al., 2019). Similarly Abeje Eshete et al. (2022) reported significantly higher dry leaf biomass in medium spacing (1m × 1m) compared to wider spacing of 2m × 2m in Moringa stenopetala.

Table 3. Tree biomass of *Ailanthus excelsa* influenced by tree spacing and the associated crop at 24 MAP

Tree spacing	Above ground biomass (t ha^{-1})	Below ground biomass (t ha^{-1})
4m × 4m	0.92b	0.24b
6m × 6m	1.51a	0.39a
8m × 8m	0.72b	0.19b
CD (P<0.05)	0.45	0.11

*P-values are result of a one-way ANOVA; Values within columns followed by different letters differed significantly at P<0.05

Crop production: Intercrop yields were not significantly affected by tree species at any of the spacings, during the initial two cropping seasons after tree planting (*i.e*., 2018 and 2019). However, higher intercrop yield was recorded when cluster bean was grown with *P. cineraria* during 2018 at 4m × 4m and 6m × 6m spacing, whereas it was higher with *A. excelsa* during 2019 at all spacing (Table 4). Similar results were reported by Prasad *et al.* (2010) in *Eucalyptus tereticornis* based agroforestry system in the first year. Patil *et al.* (2012) reported that during the first year of tree establishment, the grain yield of intercropped soybean remained unaffected under different spacing of *Melia azedarach;* however, soybean grain yield was reduced with the advancement of tree age. In another study, during the initial years of establishment, the average yields of arable crops were at par with those obtained from different silvi-horticultural systems (Kaushik *et al.,* 2011; 2014). This was probably due to the availability of sufficient moisture and solar radiation in the initial years as the trees are short and had less lateral spread to intercept light and compete with the crop for moisture. Interaction among different spacing and tree species was also found non-significant. Similar results were observed in *Eucalyptus camaldulensis* and *Melia azedarach* based agroforestry systems with wheat crop (Satyawali *et al.,* 2018).

In both the years of cropping, average crop yields were slightly higher when grown as an intercrop compared to yield under sole cropping. Average intercrop yield was higher with *P. cineraria* and lower with *A. excelsa* during 2018, though it was much higher than that of sole cluster bean. During 2019, average crop yield was higher with *A. excelsa* compared to sole cluster bean. Similarly, Kaushik and Kumar (2003) reported better growth and yield of crops under *P. cineraria* than sole cropping. Whereas Shanker *et al.* (2005) recorded low yield of *Brassica compestris* when intercropped with *H. binata* trees as compared to sole crop in semi-arid region of India. In a study conducted at Avikanagar, Rajasthan with different forage crops, *viz*., *Cenchrus setigerus, Cenchrus ciliaris,* and *Panicum antidotale*, it was found that the yield of grasses was not affected by *A. excelsa*, contrarily the complementary effect was noticed (Jat *et al.,* 2011). The results indicated that under initial stages of agroforestry plantation management, tree components had less detrimental effects on the yield of agricultural crops. However, the resource sharing pattern by trees and crops could be changed as the system matures.

Table 4. Effect of tree spacing and tree species on yield of cluster bean (kg ha^{-1})

Spacings	2018			2019		
	A. excelsa	***P. cineraria***	**Mean**	***A. excelsa***	***P. cineraria***	**Mean**
4m × 4m	718	731	724	946	733	840
6m × 6m	489	695	592	1054	803	929
8m × 8m	566	628	597	954	738	846
Mean	591	685		985	758	
ANOVA	A: NS B: NS A x B: NS			A: NS B: NS A x B : NS		
Sole crop	639			822		

*Tree species (A); Spacing (B); Interaction between tree species and spacings (A × B); Non-significant (NS)

Conclusion

The study demonstrated that *A. excelsa* and *P. cineraria* could be successfully grown in an agroforestry system, which could be an alternative income source to resource poor farmers. *A. excelsa* trees were found more beneficial because of its faster and higher basal diameter and height growth compared to *P. cineraria* for growing under the environmental conditions of arid western part of Rajasthan. Results of the current study supported the idea of successful integration of intercrops in agroforestry systems during the initial years as there was lesser competition with crops, and also the intercrop positively influenced tree growth in *A. excelsa*. Optimum crop yield during the initial years will encourage the farmers of the region to grow trees along with agricultural crops before the trees start to expand their crowns.

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