PERFORMANCE OF HIGH YIELDING VARIETIES OF CASHEW (*ANACARDIUM OCCIDENTALE* L.) UNDER DIFFERENT PLANTING DENSITIES

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Abstract. The effect of four planting densities on plant growth and yield of nine cashew varieties in India were studied. The results revealed the significant influence of planting densities and varieties on plant growth and yield of cashew. The tree height (6.90 m) and canopy coverage (185.46%) were maximum under planting density S_4 (500 trees ha^{-1}) while density at S_1 (200 trees ha^{-1}) recorded the minimum tree height (5.86 m) and canopy coverage (77.04%). The maximum cumulative nut yield was recorded under plant densities S_4 (8.86 t ha^{-1}) and S_3 (8.19 t ha^{-1}) respectively. The variety Bhaskara under 200 trees ha^{-1} and adoption of HDP (500 trees ha^{-1}) with Ullal-3 and Bhaskara varieties could be recommended for high production until up to the 10th year of planting under the West coast conditions of Karnataka. The less vigorous varieties VRI-3 and NRCC Selection-2 are suitable for HDP. Furthermore, the present study demonstrated that the adoption of high-density planting for cashew and proper pruning practices increases the yield and net income from cashew plantation.
Keywords: *cashew, plant density, tree growth, canopy coverage, LAI and yield*

Introduction

The cashew (*Anacardium occidentale* L.), an important export-oriented high-value commodity crop was introduced into India by the Portuguese in the 16th century for afforestation and soil conservation purposes. Presently, the total production of cashew in India is 7,38,000 MT from 11.36 lakh ha of land with a productivity of 665 kg/ha (Hubballi, 2021). India exports 67,647 MT of cashew kernel and 4,605 MT of cashew nut shell liquid to over 65 countries worldwide. Cashew orchards in India are mostly characterized by widespread plantations with low-density orchards (156 to 175 trees ha^{-1}) and low productivity**.** Indian cashew industries face a shortage of raw cashew nuts due to low productivity (665 kg/ha). To meet the rising demand, India imports raw cashews worth Rs. 8,861.59 crores annually (Hubballi, 2021). Therefore, to improve the productivity of cashew, it is necessary to adopt important strategies such as the use of quality planting material, proper canopy management, integrated nutrient management and integrated pest and disease management. By adopting High Density Planting (HDP) system (500 plants ha^{-1}), the cashew yield can be increased by 2.2 compared to normal density planting (156 plants ha $^{-1}$) for the first ten years (Yadukumar et al., 2011). Varietal selection is the most critical decision in the high-density planting system (Salam, 1999). There are more than 50 varieties of cashew widely cultivated in various agroecological conditions of India (Nayak and Muralidhara, 2018). Variations in morphological and yield characteristics of cashew varieties indicate the need for a different density for different varieties for optimal yield. Beneficial effects of combining planting density with varieties have been demonstrated in mango (Gunjate et al., 2009) and almond (Kumar et

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al., 2012). In the light of the circumstances mentioned above, a field experiment was carried out to find out the effect of planting density on growth and yield of cashew varieties under west coast conditions to recommend the best combination of variety and planting density to realize highest returns from cashew in the first decade of plantation.

Methodology

Experimental site

This study (2006-07 to 2016-17) was conducted at the Experimental Station of ICAR-Directorate of Cashew Research (DCR), Puttur, Dakshina Kannada District, Karnataka, India (latitude 12°46′36″N, longitude 75°16′08″ and altitude 72 m above MSL) in the west coast region of India. The climate of this study site was tropical, with an annual rainfall of 3500 mm per year. The average temperature was 27.6 °C with a relative humidity of 60–70%. The soil was characterized by sandy loam with acidic pH (4.8–5.3) and available nutrients ranged from 203–247 kg ha^{-1} for nitrogen, 7.0 to 7.3 kg ha^{-1} for phosphorous and 112 to 198.0 kg ha^{-1} for potassium.

Experimental layout and treatment details

The experiment was laid out in a split-plot design consisting of four plant densities as main plot *viz*., 200 (S_1-10 m × 5 m), 236 (S_2-6.5 m × 6.5 m), 384 (S_3-6.5 m × 4 m) and 500 (S_4-5m × 4m) trees ha^{-1} and nine cashew varieties as sub-plot treatments such as T_1-VRI-3, T_2-Ullal-3, T_3-Vengurla-4, T_4-Bhaskara, T_5-Madakkathara-2, T_6- NRCC Sel-2, T_7-Vengurla-7, T_8-Ullal-1 and T_9-Dhana with three replications and nine plants per treatment. One-year-old grafts of cashew seedlings of nine varieties were planted in July 2007 at a spacing of 10 m × 5 m, 6.5 m × 6.5 m, 6.5 m × 4 m and 5 m × 4 m which gives a tree density of 200, 236, 384 and 500 trees/ha under rainfed conditions. The recommended dose of fertilizer is 500 g N, 125 g each of P and K per tree per year. During the first year of planting, 1/5 of a full dose of fertilizer was applied annually during October. Similarly, in the second, third and fourth year of planting, 2/5, 3/5 and 4/5 of the dose and from the 5^{th} year onwards the full dose of fertilizer was applied. Lower branches of cashew trees are removed uniformly during the first 3-4 years to facilitate proper canopy shape to the plantation.

Measurements of morphological and growth parameters

The vegetative parameters (tree height, trunk girth and canopy spread) were measured on four randomly selected trees (in December 2016). The tree trunk cross-sectional area (TCSA) was calculated according to Westwood et al. (1963). The rate of canopy ground coverage was calculated according to Rejani et al. (2013) and expressed in percentage. Leaf Area Index (LAI) and light extinction coefficient (*k*) were measured inside the canopies of trees in four directions (east, west, north and south directions) using a canopy analyzer (CI-110, CID international, USA) between 10 AM to 12 PM during January/February of 2017.

Measurements of yield parameters

Cashew nut yield was recorded year wise from four trees in each treatment under each replication. The nuts were collected manually and separated from cashew, sun-

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dried for three days and weighed. The mean nut weight (g/tree) and nut yield (kg/tree) were calculated for the periods 2009-10 to 2016-17. The economics of plant densities with different varieties was calculated based on production cost and economic benefits per year.

Statistical analysis

The experimental data were analyzed using the SAS software (SAS Institute Inc., 2011). ANOVA was performed using the PROC GLM procedure of SAS. The mean differences were separated with Fisher's protected least significant difference (LSD) test at the probability ($p \leq 0.05$).

Results

The vegetative growth of different varieties under different planting densities

The results indicated that increasing plant population from 200 to 500 trees ha^{-1} had marked influences on the growth parameters of cashew (*Table 1*). Plants under HDP (S_4) recorded the highest plant height (6.90 m), which was on par with S_3 and S_2 (6.73 m and 6.59 m) whereas, the minimum plant height increment (4.68 m) was recorded in plants of S_1. The data revealed that by the 10^{th} year of planting, trees under S_1 (200 trees ha^{-1}) had a significantly lower percentage (77.04) of ground coverage by the canopy as compared to S_3 (137.08) and S_4 (185.46). The cashew varieties had a significant impact on tree height, trunk girth and TCSA, yet the interaction of plant densities x varieties had no significant influence on vegetative traits. The maximum plant height (7.95 m), trunk girth (73.08 cm) and TCSA (429.72 cm^2) were recorded with Madakkathara-2, mainly due to the inherent vigor of variety. VRI-3 recorded minimum plant height (4.68 m), trunk girth (53.79 cm), TCSA (235.00 cm^2), canopy spread (6.36 m) and ground coverage of canopy (108%) indicating its suitability for high-density planting.

Variability of LAI and k in different varieties under different densities of planting

The LAI values increased with increasing plant densities (*Table 2*). The varieties under study had a significant influence on LAI values and the highest (1.74) and lowest (1.45) LAI values were recorded in T_5 (Madakkathara-2) and T_6 (NRCC Selection-2) respectively. The data revealed the negative influence of plant densities on *k* values as it increased with decreasing plant densities (*Table 3*). Among the combinations, 200 trees ha^{-1} with Madakkathara-2 (S_1T_5) recorded the highest *k* value (0.95) and 384 trees ha^{-1} with Vengurla-7 (S_3T_7) recorded the least *k* value (0.79).

Effect of planting density and varieties on yield and benefits derived from cashew

The wide range of variation was observed for the yield of different varieties of cashew in different plant densities during the growing season (*Table 4*). Plant densities at S_3 and S_1 (384 and 200 trees ha^{-1}) recorded relatively higher nut yield which accounted for 1.51 and 1.44 t ha^{-1} respectively at 10^{th} year after planting (*Table 4*). Among the varieties, Bhaskara recorded the highest nut yield (1.65 t ha^{-1}) while it was least in NRCC Selection- 2 and VRI-3 (1.20 and 1.15 t ha^{-1}), which were on par with each other. However, the synergistic effect of plant density and varieties had no

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significant effect on nut yield in 10th year of planting. The effect of density on the nut yield showed significant variation during the experiment period, except in the two initial years and eighth years after planting (*Fig. 1*). The highest (8.86 t ha^{-1}) and the lowest (4.97 t ha^{-1}) cumulative nut yield up to 10th year of planting was recorded at plant densities 500 and 200 trees ha^{-1} respectively.

Table 1. *Effect of plant densities and varieties on vegetative growth of cashew at 8th harvest (10th year after planting)*

Treatments	Plant height (m)	Plant girth (cm)	TCSA (cm^2)	Canopy spread (m)	Ground coverage by canopy (%)
Spacing					
S_1	5.86 ± 1.07	64.57 ± 9.58	3364.42 ± 981.38	6.93 ± 0.86	77.04
S_2	6.59 ± 0.93	62.22 ± 6.45	3089.31 ± 621.17	7.35 ± 1.18	103.19
S_3	6.73 ± 1.00	64.76 ± 4.98	3363.25 ± 523.00	6.67 ± 0.86	137.08
S_4	6.90 ± 1.08	62.94 ± 7.09	3160.39 ± 714.77	6.81 ± 0.85	185.46
Mean	6.52	63.63	3244.34	6.94	125.69
SE (d)	0.44	3.03	307.80	2.32	16.29
LSD ($p \leq 0.05$)	0.40**	ns	ns	ns	19.06**
Varieties					
T_1	4.68 ± 0.87	53.79 ± 6.91	2317.04 ± 627.49	6.36 ± 0.59	108.00
T_2	6.94 ± 0.88	66.83 ± 5.39	3525.57 ± 571.82	7.31 ± 0.81	138.58
T_3	6.07 ± 0.51	57.29 ± 10.22	2651.22 ± 980.95	7.01 ± 1.28	129.53
T_4	6.97 ± 0.93	65.83 ± 7.44	3442.42 ± 807.38	7.16 ± 1.14	133.01
T_5	7.95 ± 1.66	73.08 ± 6.60	4236.91 ± 742.46	6.82 ± 0.76	122.52
T_6	5.73 ± 1.15	59.08 ± 9.37	2802.61 ± 914.60	6.44 ± 1.21	109.25
T_7	6.83 ± 1.14	63.21 ± 6.19	3160.07 ± 620.31	7.21 ± 0.93	134.95
T_8	6.91 ± 1.09	64.42 ± 6.58	3296.05 ± 645.08	6.93 ± 0.63	121.33
T_9	6.60 ± 0.98	69.08 ± 4.52	3767.18 ± 480.62	7.24 ± 1.09	134.05
Mean	6.52	63.63	3244.34	6.94	125.69
SE (d)	0.44	3.03	307.80	2.32	16.29
LSD ($p \leq 0.05$)	0.88**	6.05**	614.91**	ns	ns
Interaction effect for S X T (densities × varieties)					
LSD ($p \leq 0.05$)	ns	ns	ns	ns	ns

The data are represented as mean values ± standard deviation for triplicates. **Statistical significance was at 0.05 p value, ns: not significant, LSD = least significant difference at 5% level of significance

Cumulative nut yield was also significantly influenced by the varietal response. Among the varieties, T_4 (Bhaskara) recorded maximum cumulative nut yield (7.90 tha^{-1}) while a lower nut yield of 5.67 t ha^{-1} was recorded in T_1 (VRI-3) (*Fig. 2*). The highest cumulative nut yield (10.43 and 10.39 t ha^{-1}) was recorded in S_4T_2, closely followed by S_4T_4 (500 trees ha^{-1} with Ullal-3 and Bhaskara) while the lowest cumulative yield of 3.64 t ha^{-1} with S_1T_1 (200 trees ha^{-1} with VRI-3) (*Fig. 3*). T_6 and T_9 (NRCC Selection-2 and Dhana) performed better under hedgerow planting (9.13 and 8.80 t ha^{-1}) and other

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varieties performed better in HDP. The cumulative yield performance of the varieties also indicated that the varieties such as Ullal-3 (T_2) Bhaskara (T_4), Madakkathara-2 (T_5) and Vengurla-7(T_7) were constantly high yielding compared to other varieties

Table 2. *Effect of plant density and varieties on leaf area index (LAI)*

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean
S_1	1.46 ± 0.20	1.36 ± 0.07	1.34 ± 0.04	1.47 ± 0.20	1.75 ± 0.25	1.38 ± 0.09	1.62 ± 0.25	1.36 ± 0.09	1.80 ± 0.10	1.50
S_2	1.46 ± 0.08	1.55 ± 0.18	1.52 ± 0.34	1.59 ± 0.10	1.67 ± 0.08	1.54 ± 0.27	1.53 ± 0.10	1.47 ± 0.24	1.48 ± 0.11	1.53
S_3	1.46 ± 0.18	1.46 ± 0.04	1.57 ± 0.23	1.70 ± 0.05	1.89 ± 0.57	1.30 ± 0.23	1.73 ± 0.31	1.50 ± 0.17	1.55 ± 0.12	1.58
S_4	1.69 ± 0.19	1.53 ± 0.01	1.63 ± 0.04	1.57 ± 0.07	1.65 ± 0.15	1.59 ± 0.03	1.44 ± 0.02	1.58 ± 0.16	1.63 ± 0.11	1.59
Mean	1.52	1.48	1.52	1.58	1.74	1.45	1.58	1.48	1.61	1.55
		S	T	S X T						
SE (d)		0.05	0.08	0.15						
LSD ($p \leq 0.05$)		ns	0.15**	ns						

The data are represented as mean values ± standard deviation for triplicates. **Statistical significance was at 0.05 p value, ns: not significant, LSD = least significant difference at 5% level of significance

Table 3. *Effect of plant density and varieties on k (Light extinction coefficient) value*

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean
S_1	0.88 ± 0.08	0.90 ± 0.05	0.84 ± 0.12	0.94 ± 0.02	0.95 ± 0.03	0.82 ± 0.07	0.89 ± 0.08	0.83 ± 0.04	0.85 ± 0.04	0.88
S_2	0.84 ± 0.02	0.94 ± 0.04	0.84 ± 0.06	0.92 ± 0.02	0.91 ± 0.07	0.83 ± 0.11	0.85 ± 0.02	0.83 ± 0.06	0.90 ± 0.04	0.87
S_3	0.91 ± 0.02	0.79 ± 0.04	0.87 ± 0.06	0.83 ± 0.02	0.90 ± 0.07	0.82 ± 0.06	0.90 ± 0.10	0.91 ± 0.06	0.93 ± 0.01	0.87
S_4	0.84 ± 0.08	0.83 ± 0.02	0.90 ± 0.06	0.86 ± 0.05	0.84 ± 0.11	0.89 ± 0.05	0.81 ± 0.03	0.83 ± 0.09	0.86 ± 0.06	0.85
Mean	0.87	0.86	0.86	0.89	0.90	0.84	0.86	0.85	0.89	0.87
		S	T	S X T						
SE (d)		0.01	0.02	0.04						
LSD ($p \leq 0.05$)		ns	ns	0.09**						

The data are represented as mean values ± standard deviation for triplicates. **Statistical significance was at 0.05 p value, ns: not significant, LSD = least significant difference at 5% level of significance

The cost-benefit analysis of cashew has revealed that the highest cumulative total return of USD 5928/ha was obtained in S_4 (5 m × 4 m) with BCR of 2.54. However, the highest B:C ratio (2.77) with cumulative total return (USD 5854/ha) was recorded in S_3, followed by S_1 (2.48) (*Table 5*). Meanwhile, the maximum BCR (3.10) was obtained in normal density with Bhaskara variety (S_1T_4) followed by S_2T_4 (2.98) and the lowest 1.78 in S_1T_1 (*Table 6*).

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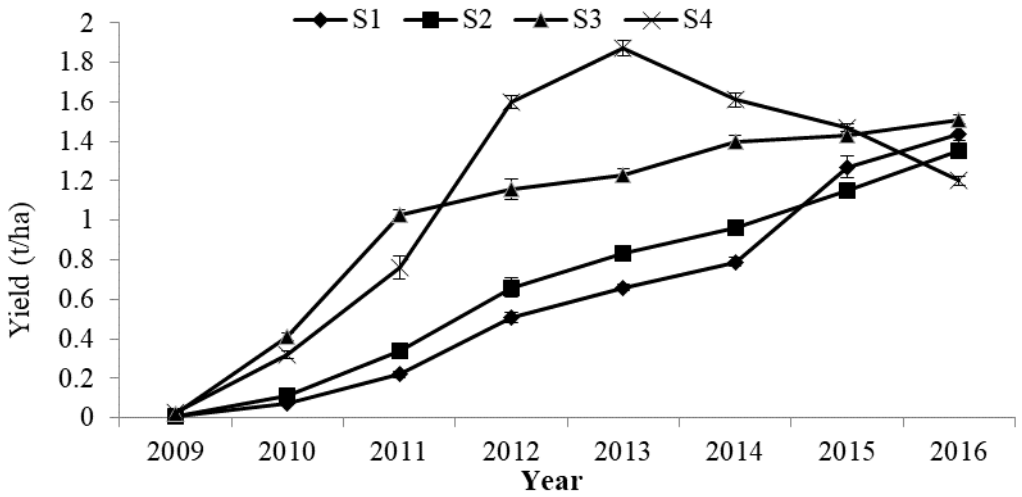

Figure 1. *Effect of plant densities on raw cashew nut yield (t ha $^{-1}$)*

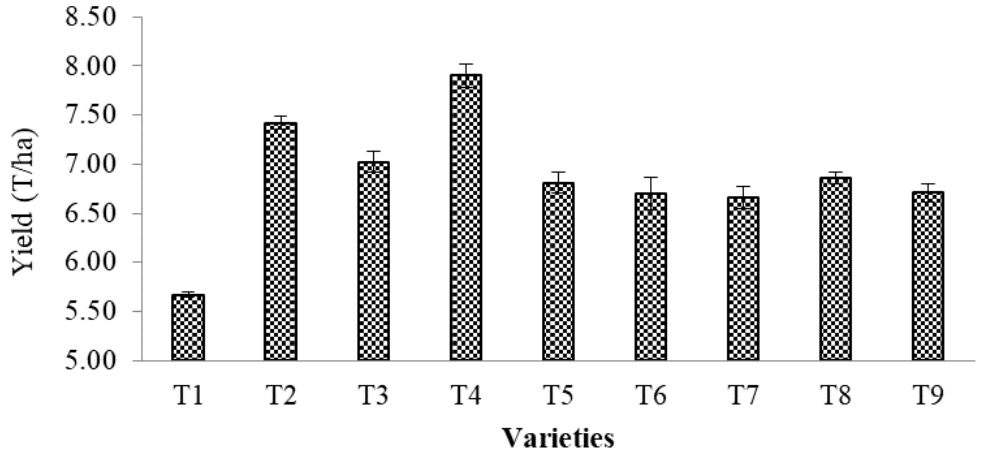

Figure 2. *Effect of varieties on cumulative nut yield (t ha^{-1}) of cashew*

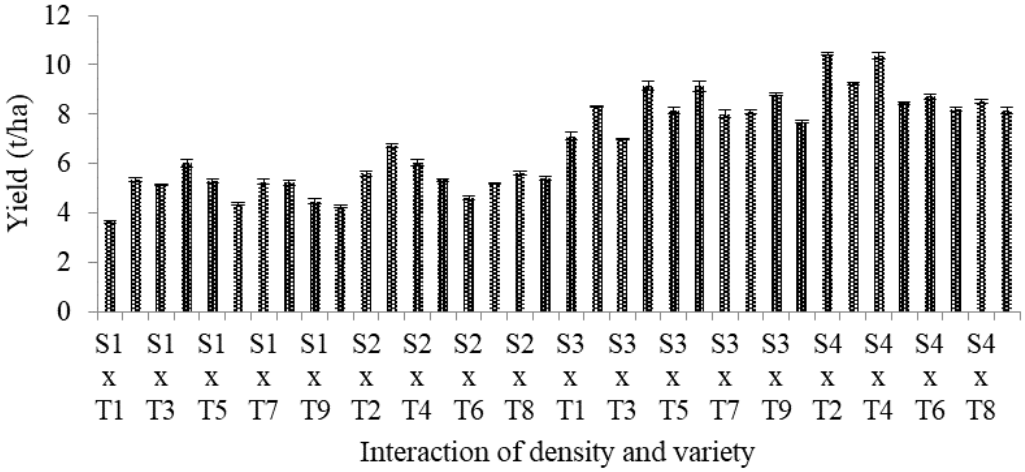

Figure 3. *Combined effect of planting densities and varieties on cumulative cashew nut yield (t ha $^{-1}$) (2009-10 to 2016-17)*

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Table 4. *Effect of planting density and varieties on raw cashew nut yield (t ha^{-1}) (10thyear)*

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean
S_1	1.09 ± 0.06	1.61 ± 0.03	1.49 ± 0.04	1.70 ± 0.04	1.59 ± 0.03	1.23 ± 0.03	1.57 ± 0.04	1.31 ± 0.06	1.33 ± 0.04	1.44
S_2	1.07 ± 0.07	1.45 ± 0.07	1.40 ± 0.02	1.71 ± 0.05	1.41 ± 0.03	1.13 ± 0.04	1.36 ± 0.05	1.37 ± 0.05	1.28 ± 0.05	1.35
S_3	1.33 ± 0.08	1.58 ± 0.33	1.44 ± 0.10	1.75 ± 0.16	1.63 ± 0.10	1.36 ± 0.14	1.51 ± 0.05	1.53 ± 0.20	1.48 ± 0.06	1.51
S_4	1.13 ± 0.22	1.28 ± 0.22	1.38 ± 0.01	1.45 ± 0.11	1.23 ± 0.20	1.10 ± 0.08	1.12 ± 0.13	1.03 ± 0.20	1.06 ± 0.02	1.20
Mean	1.15	1.48	1.43	1.65	1.47	1.20	1.39	1.31	1.29	1.37
		S		T		S X T				
SE (d)		0.03		0.05		0.09				
LSD ($p \leq 0.05$)		0.07**		0.10**		ns				

The data are represented as mean values ± standard deviation for triplicates. **Statistical significance was at 0.05 p value, ns: not significant, LSD = least significant difference at 5% level of significance

Table 5. *Economics of different plant density planting based on cumulative yield (2006-2016)*

Spacing (density)	Nut yield (t/ha)	Cost of cultivation (USD/ha)	Total return (USD/ha)	Net return (USD/ha)	BCR
S_1	4.97	2369	5873	3505	2.48
S_2	5.42	2529	6247	3718	2.47
S_3	8.19	3298	9152	5854	2.77
S_4	8.86	3853	9781	5928	2.54

Table 6. *Effect of planting density and varieties on economics of raw cashew nut cumulative yield (2006-2016)*

Treatments	BC ratio				Mean
	S_1	S_2	S_3	S_4	
T_1	1.78	1.92	2.42	2.22	2.09
T_2	2.67	2.46	2.92	2.95	2.75
T_3	2.68	2.80	2.52	2.64	2.66
T_4	3.10	2.98	2.93	2.85	2.97
T_5	2.58	2.45	2.76	2.53	2.58
T_6	2.14	2.25	2.87	2.44	2.43
T_7	2.55	2.39	2.74	2.42	2.53
T_8	2.59	2.57	2.77	2.47	2.60
T_9	2.23	2.43	2.95	2.35	2.49
Mean	2.48	2.47	2.77	2.54	

Discussion

Adopting appropriate planting density combined with high yielding varieties has been found to contribute towards a significant increase in yield per unit area. The yield

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of cashew in response to density depends on the choice of variety, integrated nutrient management and environmental factors (Yadukumar et al., 2001; Mini Poduval and Yadukumar, 2011; Tripathy et al., 2015a; Yuvaraj et al., 2015; Mangalassery et al., 2019). The results indicated that increasing plant population from 200 to 500 trees ha^{-1} had marked influences on the growth parameters of cashew. In the 10^{th} year, data on plant height and ground coverage by the canopy showed an increasing trend with increasing plant density. Under HDP, tree height increased to compete with one another in search of a light for photosynthesis that could be due to stem elongation and overlapping of plant canopies, reducing the penetration of light into the leaves (Policarpo et al., 2006). While a wider spacing exhibited a decrease in plant height, which is due to the maximum availability of space for the spread of plants and less competition for natural resources leading to reduced height as there was enough space for spreading of the canopy (Gaikwad et al., 2017). The relatively higher trunk girth and trunk cross-sectional area under wider spacing are due to lesser competition for natural resources, nutrients and photosynthates. A similar trend was reported by Tripathy et al. (2015a, b) and Yuvaraj et al. (2015) in cashew, Nath et al. (2007) in mango, Kundu (2007) in guava and Kumar et al. (2012) in almond**.**

During the early years, the canopy spread of the varieties under different densities recorded significant differences between the widest spacing and closer spacing (Rejani et al., 2013). The present results indicated that canopy spread did not show any significant variations which could be due to the stabilization of the canopy spread in all the treatments. A similar pattern of results was observed by Das and Jana (2012) in mango. The results revealed that under wider spacing, there is still 23% of available space for canopy growth, which indicates the possibility of obtaining a higher yield in subsequent harvests. While under HDPs, tree canopy coverage exceeded the allocated space by an additional 35% to 85%, which indicates the unsustainability of HDP system over a long period (i.e., by 10^{th} year). These findings are in accordance with the findings of Balasimha and Yadukumar (1993); Tripathy et al. (2015a, b) in cashew.

The maximum plant height, girth of collar and TCSA of the tree were recorded with the Madakkathara-2 variety (T_5), mainly due to the inherent vigor of the tree. The trees of NRC Selection-2 (T_6) and VRI-3 (T_1) varieties grew slowly and less vigorous than other varieties. The results revealed that Madakkathara-2, Bhaskara, Ulla-3 and Vengurla -7 were vigorous varieties and VRI-3 and NRCC Selection -2 were the least vigorous varieties, indicating their suitability for high-density planting. A similar variation of vegetative growth parameters was reported by Hanumanthappa et al. (2014) and Chandrasekhar et al. (2018). Yadukumar (2016) recommended that VRI-3, NRCC Selection-2, K-22-1 and Ullal-1 cashew varieties are highly suitable for HDP.

At different plant densities, LAI and *k* values were negatively related as LAI values increased with decreasing *k* values while LAI and *k* were positively related under the different varietal influence. The canopies overgrew in the allotted space under high density, which led to an overlapping of adjacent canopies, resulting in a LAI that is on par with normal density. In the present experiment, higher *k* value was associated with the low-density planting system, indicating that canopy light interception was lower than that in HDP. Similarly, previous studies reported that light extinction coefficient has decreased through plant density in guava (Kumawat et al., 2014). Yadukumar et al. (2001) observed that light interception by the canopy was approximately 70-80% which determined cashew yield. The differences in LAI among the varieties were significant due to their genetic variability. The results indicated that Madakkathara-2 and Dhana

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had a denser canopy with more foliage components, while NRCC Selection- 2 exhibited the least foliage component. In mango, Rajan et al. (2001) found that the variation in canopy characters of mango cultivars depended on vegetative growth, crop regularity, and growth cycle. These results provide an idea for the researcher to select varieties for optimal canopy architecture for improving photosynthetic efficiency suitable for HDP and achieving higher yields.

Cashew nut yield (t ha^{-1}) increased with an increase of plant density up to the sixth year and then decreased with a further increase in plant density. The present data indicated that during initial years in S_1, S_2 and S_3, the yield of an individual tree was low, this showed an increasing trend in subsequent years. However, in normal and medium density orchards, the yield stabilized after 7-8 years. The response of yield to plant density was not constant, as it varied according to the variety and geographical location. In the 10^{th} year, individual trees showed a high yield potential under medium and low density because there was less competition among trees for natural resources. Balasimha and Yadukumar (1993) found that photosynthesis and transpiration were higher in widely spaced trees, parallel with higher irradiances. In the present study, the highest nut yield and optimum ground coverage by the canopy and light interception were obtained in hedgerow planting. From the results, hedgerow planting (S_3) could be considered as a threshold level of cashew. The results are supported by Gaikwad et al. (2017), Kerutagi et al. (2017) Rajbhar et al. (2016) in mango, Zec et al. (2015) in peach and nectarines Kumar et al. (2012) in almond, Milosevic et al. (2008) in plum, Elkins et al. (2008) and Robinson (2010) in pear reported that the maximum yield was recorded under high plant density than traditional planting. For ten years of study, the maximum mean nut yield of 7.90 t ha^{-1} was recorded in Bhaskara, while it was least in VRI-3 (5.67 t ha^{-1}) over the years. Sundararaju et al. (2006) confirmed that Bhaskara variety performed better under normal density and HDP in the coastal region of Karnataka. The cumulative yield performance of the varieties also indicated that the varieties such as Bhaskara, Vengurla-7, Madakkathara-2 and Ullal-3 (T_4, T_7, T_5 and T_2) were constantly high yielding compared to other varieties. The present results are in agreement with the findings of Hanumanthappa et al. (2014) reported that the varieties Vengurla -7, Vengurla-4, Dhana, Ullal-1 and Ullal-3 performed better in coastal Karnataka. Similarly, Odisha conditions in BPP-8 by Dasmohapatra et al. (2012) Chandrasekhar et al. (2018) and Konkan region of Maharashtra, H-303 hybrids recorded highest nut yield (Gajbhiye et al., 2018). The synergetic effect of density and variety significantly influenced the cumulative nut yield, the highest cumulative net yield (10.43 and 10.39 t ha^{-1}) was recorded in an Ullal-3 and Bhaskara at a density of 500 trees ha^{-1}. Thus, it may be concluded that the highest cumulative yield was under HDP due to accommodating more plants and higher production per unit area. The results of present investigation corroborate the findings of Samal et al. (2006) and Tripathy et al. (2015a) under Odisha condition, Yadukumar et al. (2011), Mangalassery et al. (2019) in Karnataka; Mini Poduval and Yadukumar (2011) in West Bengal; Anon (2011) under Tamil Nadu. According to Caliskan et al. (2007), the increase in plant density decreased growth and yield per plant but an increase in productivity per unit area.

Conclusion

In the present study, planting density and varieties had a significant influence on the growth and yield of cashews. Based on observations on various aspects, it may be

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concluded that cashew growers can adopt the hedgerow planting system to achieve higher productivity per unit area (higher B: C ratio: 2.77) under the West coast of India. For variety- wise spacing recommendation, cultivating Dhana, NRCC Selection 2, Madakkathara-2, Ullal-1, Vengurla-7, and VRI-3 varieties under hedgerow planting (S_3) Bhaskara with low-density planting (S_1), Vengurla-4 with medium density planting (S_2) Ullal-3 under high density planting (S_4) performed better with a BCR of 2.95, 2.87, 2.76, 2.77, 2.74, 2.42, 3.10, 2.80 and 2.95 respectively. The highest cumulative nut yield ha^{-1} with the highest BCR (3.10) can be realized under low-density planting accommodating 200 plant ha^{-1} with Bhaskara variety, for 8 harvests (first decade of the plantation) in cashews under West coast conditions. In conclusion, the results showed that the selection of varieties and planting density should take into account the vigor and productivity per unit area. Strong research is needed on timing and intensity of pruning, use of dwarfing rootstocks, development of dwarf varieties that have an erect growth with lower canopy area and application of plant growth regulators need to be further investigated.

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Conflict of interests. The authors declare that they have no conflict of interests.

REFERENCES

[1] Anonyomus (2011): High Density Planting System in Cashew. – In: Directorate of Research, Tamil Nadu (ed.) New Crop Implements and Management Technologies. Agricultural University, Coimbatore.

[2] Balasimha, D., Yadukumar, N. (1993): Effect of plant density on photosynthesis in cashew. – Indian Journal of Plant Physiology XXXVI(1): 5-7.

[3] Caliskan, S. M., Aslan, M., Uremis, I., Caliskan, M. E. (2007): The effect of row spacing on yield and yield components of full season and double-cropped soybean. – Turkish Journal of Agriculture and Forestry 31: 147-154.

[4] Chandrasekhar, M., Sethil, Tripathy, K., Mukherjee, P. S. K., Panda, P. K., Roy, A. (2018): Performance of released cashew (Anacardium occidentale L.) varieties under hot and humid climatic zone of Odisha. – Indian Journal of Agricultural Research 52(2): 152-156.

[5] Das, B., Jana, B. (2012): Effect of canopy management on growth and yield of mango cv. Amrapali planted at close spacing. – Journal of Food, Agriculture and Environment 10(3): 328-33.

[6] Dasmohapatra, R., Rath, S., Pattnaik, A. K. (2012): Performance of cashew entries/varieties under eastern coastal plain of Odisha. – Environment and Ecology 30(3): 770-772.

[7] Elkins, R. B., Klonsky, K., DeMoura, R., DeJong, T. M. (2008): Economic evaluation of high density versus standard orchard configurations; case study using performance data for Golden Russet Bosc pear. – Acta Horticulturae 800(2): 739-746.

[8] Gaikwad, S. P., Chalak, S. U., Kamble, A. B. (2017): Effect of spacing on growth, yield and quality of mango. – Journal of Krishi Vigyan 5(2): 50-53.

[9] Gajbhiye, R. C., Pawar, S. N., Salvi, S. P., Zote, V. K., Haldavanekar, P. C. (2018): Performance of different cashew (*Anacardium occidentale* L.) genotypes under Konkan region of Maharashtra. – International Journal of Chemical Studies 6(5): 1939-1942.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2003_23812392

[10] Gunjate, R. T., Kumbhar, A. R., Thiamaiah, I. M., Amin, S. M. (2009): Growth and fruiting of some mango cultivars under high density plantation in arid conditions of Gujarat (India). – Acta Horticulturae 820: 463-467.
[11] Hanumanthappa, M., Patil, R. S., Sudhir Kamath, K. V., Vinod, V. R., Dhananjaya, B., Shankar, M. (2014): Performance of different cashew cultivars in coastal Karnataka. – Environment and Ecology 32(3): 891-895.
[12] Hubballi, N. V. (2021): Cashew Development in India - Challenges and Opportunities. – In: Souvenir of National Conference on Cashew Development in India "Challenges and Opportunities," Panaji, Goa, pp. 9-14.
[13] Kerutagi, M. G., Deshetti, M. B., Abhilash, K. (2017): Comparative economics of traditional *viz* high density mango cultivation in Karnataka. – Asian Journal of Agricultural Extension, Economics and Sociology 18(3): 1-12.
[14] Kumar, D., Ahmed, N., Verma, M. K. (2012): Studies on high density planting in almond in Kashmir valley. – Indian Journal of Horticulture 69(3): 328-32.
[15] Kumawat, K. L., Sarolla, D. K., Kaushik, R. A., Jodha, A. S. (2014): Effect of different spacing on newly planted guava cv. L-49 under high density planting system. – African Journal of Agricultural Research 9(51): 3729-3735.
[16] Kundu, S. (2007): Effect of High Density Planting on Growth, Flowering and Fruiting of Guava (*Psidium guajava* L.). – In. Singh, G., Kishun, R., Chandra, E. (eds.) Proceedings of the First International Guava Symposium. Acta Horticulture 735: 267-270.
[17] Mangalassery, S., Rejani, R., Singh, V., Adiga, J. D., Kalaivanan, D., Rupa, T. R., Prabha, S. P. **(**2019)**:** Impact of different irrigation regimes under varied planting density on growth, yield and economic return of cashew (*Anacardium occidentale* L.). – Irrigation Science 37: 483-494.
[18] Milosevic, T., Zornic, B., Glisic, I. (2008): A comparison of low-density and high-density plum plantings for differences in establishment and management costs, and in returns over the first three growing seasons - a mini-review. – Journal of Horticultural Science and Biotechnology 83(5): 539-542.
[19] Minipoduval, Yadukumar, N. (2011): Effect of different doses of fertilizers on different densities of cashew plantation. – Journal of Plantation Crops 39: 35-40.
[20] Nath, V., Das, B., Rai. M. (2007): Standardization of high-density planting in mango (*Mangifera indica* L.) under sub-humid Alfisols of Eastern India. – Indian Journal of Agricultural Sciences 77: 3-7.
[21] Nayak, M. G., Muralidhara, B. M. (2018): Cashew Varieties: Recent Developments in India. – In: Handbook of Cashew, pp. 11-13.
[22] Policarpo, M., Talluto, G., Bianco, R. L. (2006): Vegetative and productive responses of 'Conference' and 'Williams' pear trees planted at different in-row spacing's. – Scientia Horticulture 109: 322-331.
[23] Rajan, S., Ram Kumar, Negi, S. S. (2001): Variation in canopy characteristics of mango (*Mangifera indica* L.) cultivars from diverse eco-geographical regions. – Journal of Applied Horticulture 3(2): 95-97.
[24] Rajbhar, Y. P., Singh, S. D., Lal, M., Singh, G., Rawat, P. L. (2016): Performance of high density planting of mango (*Mangifera indica* L.) under a mid-western plain zone of Uttar Pradesh. – Indian Journal of Agricultural Sciences 12: 298-301.
[25] Rejani, R., Adiga, J. D., Yadukumar, N. (2013): Performance of different varieties of cashew under high density planting system. – Journal of Plantation Crops 41(1): 28-33.
[26] Robinson, T. L. (2010): High-density pear production: an opportunity for NY growers. – New York Fruit Quarterly 18: 5-9.
[27] Salam, A. M. (1999): Cashew and pepper live in harmony. – The Cashew 13(3): 54-55.
[28] Samal, S., Lenka, P. C., Rout, G. R. (2006): Evaluation of cashew varieties under Bhubaneswar condition for major plant characters and nut yield. – The Cashew 2: 8-13.
[29] SAS Institute Inc. (2011): SAS Statistical Software. – SAS Institute Inc., Cary.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2003_23812392

[30] Sundararaju, D., Yadukumar, N., Shivarama Bhat, P., Raviprasad, T. N., Venkattakumar, R., Sreenath Dixit. (2006): Yield performance of Bhaskara cashew variety in coastal Karnataka. – Journal of plantation crops 34(3): 216-219.
[31] Tripathy, P., Sethi, K., Patnaik, A., K., Mukherjee, S. K. (2015a): Nutrient Management in High-Density Cashew Plantation under Coastal Zones of Odisha. – International Journal of Bio-resource and Stress Management 6(1): 93-97.
[32] Tripathy, P., Sethi, K., Patnaik, A., K., Mukherjee, S. K., Saroj, P. L. (2015b): Efficacy of plant density and nutrient management in cashew (*Anacardium occidentale* L.). – Progressive Horticulture 47(2): 2015213-217.
[33] Westwood, M. N., Reimer, F. C., Quackenbush, V. L. (1963): Long term yield as related to ultimate tree size of three pears varieties grown on rootstocks of five *Pyrus* species. – Proceedings of the American Society for Horticultural Science 82: 103-8.
[34] Yadukumar, N. (2016): High Density and Ultra-High Density in Cashew - Merits and Demerits. – In: Souvenir of National Conference on Cashew and Cocoa: Production to Marketing, Panaji, Goa, pp. 4507-4508.
[35] Yadukumar, N., Bhaskara Rao, E. V. V., Mohan, E. (2001): High density planting of cashew (*Anacardium occidentale* L.). – Tropical Agriculture 78(1): 19-28.
[36] Yadukumar, N., Rejani, R., Rupa, T. R., Srividya, B. R. (2011): Optimal nutrient requirement and plant density for enhancing cashew productivity. – Journal of Plantation Crops 30(1): 26-29.
[37] Yuvaraj, K. M., Reddy, M. L. N., Umamaheswararao, K. (2015): Nutrient management in high density cashew plantation under coastal sandy soils of Andhra Pradesh. – Advances in Life Sciences 4(1): 26-28.
[38] Zec, G., Solic, S., Vulic, T., Milatovic, D., Djordjevic, B., Djurovic, D., Velickovic, M. (2015): Influence of planting density on yield of peach and nectarine. – In: Fifth International Scientific Agricultural Symposium, University of East Sarajevo, Faculty of Agriculture, Jahorina, pp. 204-208.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2003_23812392