High density planting of cashew (*Anacardium occidentale* L.)

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A density trial of cashew (*Anarcardium occidentale* L.) was carried out at the National Research Centre for Cashew, Experimental Station, Shantigodu, India, during 1982–94 with the objectives of studying growth behaviour, root distribution, photosynthesis, weed biomass, dry branch accumulation, and yield under the varying densities. Densities adopted were 156 trees, 278 trees, 625 trees, 1111 trees, and 2500 trees ha^{-1}. The density was reduced to 50% in the treatment with 1111 trees ha^{-1} and to 25% in the treatment with 2500 trees ha^{-1} in the seventh year. Density was reduced to 50% by the 11th year in the treatment with 625 trees ha^{-1}. Higher density treatment resulted in deeper root penetration, lower moisture at depths above 60 cm, greater light interception, and as a result, greater mutual shading induced drying of branches. Yield levels were maintained in higher density plots by pruning to 80% light interception or at later stages by diagonal thinning. Maintaining a tree density of 625 ha^{-1} (4 m × 4 m) for the first 11 years and diagonal thinning thereafter to reduce the population to 50% (8 m × 5.7 m × 5.7 m) resulted in maximum cumulative nut yield (4.94 ha^{-1}) and profit (U.S. $2464.90 ha^{-1}).

Keywords: Cashew; High density; Photosynthesis; Weed biomass; Yield; Growth behaviour

In recent years, interest has focussed on increasing the plant density in tree monocropping systems to augment income. High-density planting in tree crops, especially in apple (Marshall and Andrews, 1994) and mango (Santram, 1996) have been well documented. Close planting offers immediate economic advantages owing to higher yields that can be obtained initially. To meet the challenge of high productivity, planting initially with a high density population coupled with pruning or thinning is the best option available. Controlling excessive vegetative growth for increased or sustained productivity is the major principle of high-density planting (Santram, 1996). Cashew (*Anacardium occidentale* L.), a tropical crop, does not tolerate severe pruning (Ohler, 1979). Hence, high-density planting to maximise initial yields and thinning later to have an optimum plant population to achieve maximum productivity seems to be a reasonable option at present, since dwarfing the root stock or chemical control of growth have not been identified so far. Under normal tree density planting, the initial yield realised is generally poor due to low tree density and maximum yield per unit area is realised only after a few years. Hence, work on high-density planting was contemplated as no work has been reported so far in cashew. An experiment on high-density planting of cashew was conducted with the objectives of studying growth behaviour, root distribution during initial years, light interception, photosynthesis, and other physiological parameters at different growth stages of the tree subjected to canopy manipulation through pruning as well as before and after thinning. An economic feasibility of the best treatment was determined.

Materials and Methods

Location

The Experimental Station, National Research Centre for Cashew, Shantigodu, Karnataka (latitude 12.25° N, longitude 75.4° E), India, is situated 90 m above mean sea level.

Climate

The climate is seasonally wet–dry tropics (hot humid) with distinct dry seasons (from January to April–May) during which fruit development takes place. Approximately 3500 mm rainfall with distribution from late May to October–November is received annually. Temperature ranges between 28–36°C (maximum) and 19–24°C (minimum).

Soils

The soil at Shantigodu is lateritic and gravelly with very low water-holding capacity (23% field capacity). However, it stores large amounts of water due to its extended depth. Texturally, the soils of the experimental field are classified as sandy clay loam. The soil is slightly acidic, medium in N content, and low in P_2O_5 and K_2O contents (Table 1).

The experiment was laid out as a randomised block design with five replications. The treatments are detailed in Table 2.

The gross plot size was the same in all the treatments where the net plot size changed as per the plant density treatments given above. The control treatment was T_1 where plants were spaced at recommended normal spacing of 8 m × 8 m.

Table 1 Physical and chemical properties of the soil used in the study

	Depth	
Soil properties	0–30 cm[1]	30–60 cm[1]
Sand (%)	61.00	48.00
Silt (%)	14.50	14.20
Clay (%)	32.50	38.00
pH	5.30	5.20
Available P (ppm)	10.30	8.20
Total N (%)	0.08	0.06
Available K (%)	0.03	0.03

[1]Sandy clay loam

Table 2 Treatments and plants per plot and number of plants per hectare

Treat. no.	Treatment (spacings)	No.of plants plot^{-1}		Net plot (m^2)	Plants ha^{-1}
		Gross[1]	Net		
T_1	8 m × 8 m	14	6	384	156
T_2	6 m × 6 m	24	8	288	278
T_3	4 m × 4 m	45	ß15	240	625
T_4	3 m × 3 m	88	28	252	1111
T_5	2 m × 2 m	192	77	303	2500

[1]Gross plot size: 32 m × 24 m
T_1, Control

Crop establishment

Seedling progeny of the cashew clone VTH-174 (4-4-7) was used. After the jungle growth was cleared, pits (60 cm × 60 cm × 60 cm) were opened during pre-monsoon showers. The pits were then filled with a mixture of top soil and 200 g rock phosphate per pit and cashew seedlings were planted in 1982. The base of the plants was mulched. During the initial three years of growth, the lower branches up to 1 m in height were removed uniformly for convenience of cultural operations and to provide proper canopy shape. Every year, recommended doses of fertilizers (500 g N and 125 g each of P_2O_5 and K_2O plant^{-1} yr^{-1}) were applied at the base of the plants during August when rain still persisted and sufficient moisture was present in the soil. Recommended doses of fertilizers were applied at one-third, two-thirds, and full doses during the first year, second year, and third year, respectively. From the third year onwards, full doses of fertilizers were applied. Plant protection measures were taken against tea mosquito and stem and root borer attack as and when required. The cashew orchard was raised as rainfed and no irrigation was given during dry months.

Data collection

Growth parameters

The height (from ground level up to the top of the canopy during the 7th and the 12th years), girth (25 cm above the ground level during the 7th and the 12th years), and spread of the canopy (North–South and East–West every year from the 4th to 12th years) were measured. Observations were taken during October and November in all treatments (six plants per treatment plot). Ground coverage by crop canopy was calculated using πr^2 where π = 3.14 and r = half of the average spread of the canopy (NS+EW/4 = r). Once ground coverage was obtained in terms of square metres per tree, per cent ground coverage was calculated considering the total ground area allotted to the tree for the particular density treatment. The ground coverage in the plots in treatments T_5 (2500 trees ha^{-1}) and T_4 (1111 trees ha^{-1}) was reduced when it reached 100% by thinning the tree density to 25% (625 trees ha^{-1} after thinning) and 50% (555 trees ha^{-1} after thinning), respectively, during the seventh year. In treatment T_3 (625 trees ha^{-1}), the ground coverage peaked (100%) in the seventh year. In order to maintain 80% light interception, the overlapping branches were pruned every year up to a 0.5-m radius around the canopy towards the periphery end to maintain high yield from the seventh year onwards. The net biomass removed was 8 kg tree^{-1} yr^{-1} (5 t ha^{-1}) in the case of treatment T_3. In treatments T_4 and T_5, overlapping branches were not observed as thinning was done during the seventh year. In these cases, with the exception of dry branches, biomass was not removed. In treatments T_1 and T_2, pruning live branches were not done as overlapping of branches did not take place up to 12 years after planting.

Dry branches and weed biomass

Production of dry branches and weed in each treatment plot were determined. Dry branches in each treatment plot were removed and weighed after complete drying in the open sun for one week in the 7th and 12th years once each year soon after the harvest season was over (April and May). Weed biomass was collected after cutting at the ground level in the 7th and 12th years, dried for one week in the open sun, and weighed. Weeding was done only once during November in each year. Weeds collected were identified.

Root studies

The soil block method described for coffee by Leon and Umana (1961) was adopted for root studies by Abdul Khader (1987), and in this study, the root volume and distribution pattern studies method as adopted by Abdul Khader (1987), was followed in the seventh year. The method consisted of digging a series of trenches between two trees starting from one tree to the other. Trenches of 60-cm length, 30-cm width, and 30-cm depth were dug starting 30 cm away from the trunk of the tree. Roots were separated by sieving the soil obtained from each block of 60-cm × 30-cm size. Roots were then washed, dried, weighed, and separated into thick (>2 mm) and fine (<2 mm) roots. Lateral and vertical distribution of roots were quantified by the dry weight of the roots. Dry weight of roots per unit volume of soil excavated was determined and computed to gross root weight per tree as per the procedure adopted by Abdul Khader (1987).

Total biomass

For estimation of biomass production, two representative trees in each treatment were cut in one of the replications in the seventh year and weighed after drying in the open sun for one month. Roots of the same trees were weighed after studying the rooting pattern. The biomass production including trunk, side branches, dried branches, twigs and leaves, and total roots was calculated. Root studies were also conducted during the same period and root weight was included while presenting treatment-wise biomass production.

Thinning

Thinning was done to 25% of the original tree density of 2500 trees ha^{-1} (2 m × 2 m spacing) and 50% in the case of the original plant population of 1111 trees ha^{-1} (3 m × 3 m spacing) by the seventh year. In 4 m × 4 m spacing, thinning was done to 50% of the trees by the 11th year.

Physiological parameters

Physiological parameters, photosynthesis, and photon flux density (P_{fd}) were recorded by using an LCA3 Model photosynthesis system. Observations were taken from 900 h to 1100 h at three different heights of the canopy (top, middle, and bottom) in December of the 9th, 10th, and 11th years. The third or fourth mature leaf of the current growth facing an upright angle to sunlight was used for determining P_{fd} and net photosynthetic rate (P_n).

Soil moisture

Soil moisture content at three different depths (0–30 cm, 31–60 cm, and 61–90 cm) during the peak summer season (March and April) were determined at 1–2 m away from the tree trunk during the sixth and seventh years by the oven-dry method (gravimetric).

Harvest

Fallen nuts were collected tree-wise as well as treatment-wise from each net plot. The nuts were then sun-dried for 2–3 days in the open sun and weighed. Nuts were collected every year from 4–12 years after planting. The weight of the nuts per treatment was converted into weight of nuts per hectare based upon the number of plants present in each plot. The data were subjected to statistical analysis using MSTATC statistical software. The procedures were according to a randomised block design for most of the observations including yield and economics. With respect to the experiments conducted on P_{fd} and P_n, on the top, middle, and bottom canopies, the data analysed were according to a randomised block for factor A, and a split-plot for factor B. The data on dry weight of cashew roots per unit volume in soils and calculated gross weight of roots (seven years after planting) were subjected to statistical analysis for determination of standard error.

Economics

An economic analysis was conducted after extrapolating the data from five replications of each treatment plot to a per hectare basis. Cost of production was determined after considering total cost involved for cultural operations such as jungle clearing and weeding, opening pits and planting cashew, terracing, application of fertilizer, prunning overlapping branches, thin-ning trees, harvesting nuts, storing and market-ing, and cost of materials.

Returns and net profit were calculated based on the current market price for that year.

Results

Growth and canopy development

Different tree densities exhibited significant differences in height, girth, and ground coverage. Trees attained significantly ($P < 0.05$) smaller girth during the 6th and 12th years (43.0 cm and 71.0 cm, respectively) in treatment T_5 compared to treatment T_2 (51 cm and 76 cm, respectively) and treatment T_1 (49 cm and 79 cm, respectively). A significant ($P < 0.05$) increase in plant height was observed with increased tree density. The trees spaced 2 m apart (2500 trees ha^{-1}) attained a height of 749 cm in the 6th year and 872 cm in the 12th year (when the population was thinned to 625 trees ha^{-1} during the 7th year), while trees spaced 8 m apart (156 trees ha^{-1}) attained a significantly ($P < 0.05$) shorter height of 459 cm (6th year) and 715 cm (12th year, Table 3). By the sixth year, the ground coverage by canopy was 100% (Figure 1) in plots with 2500 trees ha^{-1}. In the low tree density plot

Table 3 Effect of different spacing and density on height and girth of cashew trees (6th and 12th years)

Treatment spacings (m)	Density (trees ha^{-1})	6 Years after planting Girth (cm)	6 Years after planting Height (cm)	12 Years after planting Girth (cm)	12 Years after planting Height (cm)
T_1 = 8 × 8	156	49	459	79	715
T_2 = 6 × 6	278	51	541	76	710
T_3 = 4 × 4[1]	625	49	661	75	890
T_4 = 3 × 3[2]	1111	48	745	72	882
T_5 = 2 × 2[3]	2500	43	749	71	872
$CD_{0.05}$		5.1	117	5.1	20.8

[1]4 m × 4 m up to 11 years and 8 m × 5.7 m × 5.7 m after thinning (625 trees ha^{-1} up to 11 years and 312 trees ha^{-1} after thinning)
[2]3 m × 3 m up to 7 years and 6 m × 4.25 m × 4.25 m after thinning (1111 trees ha^{-1} up to 7 years and 555 trees ha^{-1} after thinning)
[3]2 m × 2 m up to 7 years and 4 m × 4 m after thinning (2500 trees ha^{-1} up to 7 years and 625 trees ha^{-1} after thinning)
CD, Critical Difference

(156 trees ha^{-1}), the ground coverage by the crop canopy was 35.7% during the sixth year, indicating that 64.3% of the given area was left unutilised (Figure 1). The ground coverage of 95% observed in treatment T_3 (625 trees ha^{-1}) by the 10th year was reduced to 65% by the 11th year after diagonal thinning to 50% of the population during that year (Figure 1). However, it increased to 82% in the subsequent year.

Light interception by the crop canopy was maximum (86%) in the highest tree density plot (2500 trees ha^{-1}) and minimum (52%) at the lowest tree density plot (156 trees ha^{-1}) six years after planting, indicating that in the normal density (156 trees ha^{-1}), 48% of the light was unutilised by the crop even by the sixth year (Figure 2). Light interception was maximum in high tree densities (treatments T_3 to T_5) throughout except on the year of thinning (Figure 2). When light interception exceeded 75% on the seventh year, the tree population was thinned in high tree density plots (treatments T_4 and T_5) to reduce the light interception from 90–100% to less than 80%. Although a drastic reduction in light interception and yield was observed on the year of thinning (seventh year) it subsequently increased to 70–80% in the 12th year (Figure 2).

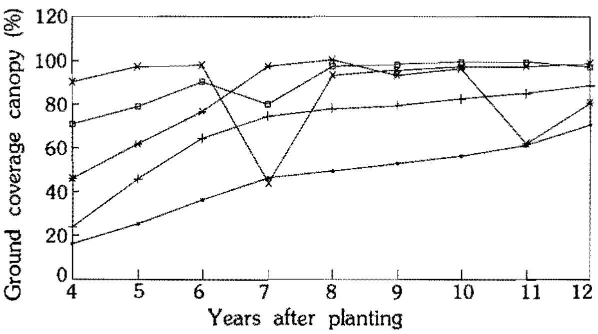

Figure 1 Effect of tree density (trees ha^{-1}) on ground coverage by canopy. —•—, 156 trees ha^{-1}; —+—, 278 trees ha^{-1}; —×—, 625 trees ha^{-1} up to 11 years and 312 trees ha^{-1} after thinning (AT); —□—, 111 trees ha^{-1} up to 7 years and 555 trees ha^{-1} AT; and —✳—, 2500 trees ha^{-1} up to 7 years and 625 trees ha^{-1} AT

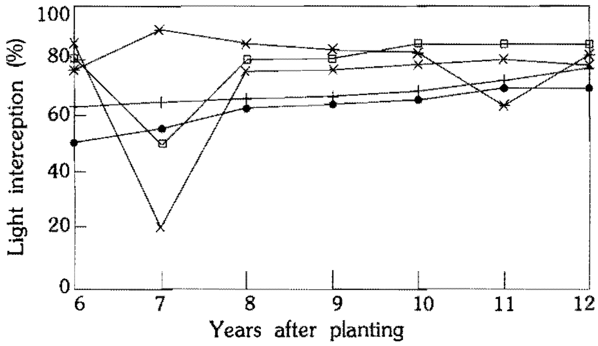

Figure 2 Effect of tree density (trees ha^{-1}) on light interception (%). —•—, 156 trees ha^{-1}; —+—, 278 trees ha^{-1}; —×—, 625 trees ha^{-1} up to 11 years and 312 trees ha^{-1} after thinning (AT); —□—, 111 trees ha^{-1} up to 7 years and 555 trees ha^{-1} AT; and —✳—, 2500 trees ha^{-1} up to 7 years and 625 trees ha^{-1} AT

Photosynthetic efficiency

The P_{fd} and P_n in the top position of the canopy did not differ significantly during the 9th, 10th, and 11th years in all the treatments (Table 4), but they differed significantly in the middle and lower heights of the canopy. Treatments T_1, T_2, and T_3 were similar, but were significantly ($P < 0.01$) greater than those of treatments T_4 and T_5 during the ninth year in the middle and lower heights of the canopy. The P_{fd} and P_n in treatments T_1 and T_2 were significantly ($P < 0.01$) greater than those of treatments T_4 and T_5 in the 10th year. The same trend was observed during the 11th year with the exception of treatment T_3. In treatment T_3, the P_{fd} and P_n in the middle canopy increased significantly ($P < 0.01$) over treatments T_4 and T_5 whereas it remained at par with treatment T_2. The P_n increased in the middle canopy from 5.98 μmol m^2 s^{-1} in the 9th year to 7.48 μmol m^2 s^{-1} in the 11th year in treatment T_3. Overlapping branches were removed each year (8th, 9th, and 10th years) to limit light interception to 80%. The effects of pruning overlapping branches in the 10th year was not evident on yield. Ground coverage and light interception increased to more than 90% and 80%, respectively (Figures 1 and 2) within one year of pruning. When total tree population was reduced to 312 trees ha^{-1} in treatment T_3, the P_n in the remaining trees increased significantly ($P < 0.01$) in the middle of the canopy during the 11th year. But it did not increase in leaves located at the lower canopy height.

Dried branches and weed biomass

The dry branches produced in the different tree density treatments in the sixth year varied from 0.90 t ha^{-1} in the lowest tree density plot to

Table 4 Effect of tree density on photon flux density (P_{fd}) and net photosynthesis (P_n) 9 years, 10 years, and 11 years after planting cashew

Treatment no. and spacing (m)	Density trees (ha^{-1})	Location of observation in canopy	Year after planting P_{fd} (μmol m^{-2} s^{-1}) 9	10	11	P_n (μmol Co_2 m^{-2} s^{-1}) 9	10	11
T_1 = 8 × 8	156	Top	1379	1277	1326	8.80	10.83	10.80
		Middle	1313	1245	1148	9.35	9.60	9.80
		Bottom	1488	1172	1277	7.25	5.70	9.30
T_2 = 6 × 6	278	Top	1315	1217	1268	7.06	9.08	10.02
		Middle	1257	1162	9303	4.72	6.80	6.20
		Bottom	1095	854	755	3.98	5.70	5.00
T_3 = 4 × 4[1]	625	Top	1260	1255	1308	9.65	9.50	11.30
		Middle	927	984	1093	5.98	6.80	7.48
		Bottom	602	476	938	5.60	4.10	5.50
T_4 = 3 × 3[2]	1111	Top	1214	1257	1182	8.70	8.40	9.55
		Middle	639	687	568	6.50	5.90	4.75
		Bottom	767	576	294	2.22	4.50	3.20
T_5 = 2 × 2[3]	2500	Top	1371	1197	1220	8.70	7.50	7.90
		Middle	837	545	580	6.11	4.1	4.40
		Bottom	516	165	281	3.96	2.8	3.30
$CD_{0.01}$ for Top			ns	ns	ns	ns	ns	2.002
$CD_{0.01}$ for Middle			219	477.5	164.3	2.025	4.55	2.073
$CD_{0.01}$ for Bottom			270	186.66	198.4	2.20	2.87	2.356

[1]4 m × 4 m up to 11 years and 8 m × 5.7 m × 5.7 m after thinning (625 trees ha^{-1} up to 11 years and 312 trees ha^{-1} after thinning)
[2]3 m × 3 m up to 7 years and 6 m × 4.25 m × 4.25 m after thinning (1111 trees ha^{-1} up to 7 years and 555 trees ha^{-1} after thinning)
[3]2 m × 2 m up to 7 years and 4 m × 4 m after thinning (2500 trees ha^{-1} up to 7 years and 625 trees ha^{-1} after thinning)
CD, Critical Difference

Table 5 Effect of tree density on mutual shading induced drying of branches and weed biomass (7th year)

Treatment spacing (m × m)	Density (trees ha^{-1})	Dry branches collected (t ha^{-1}) 7 YAP[1]	12 YAP	Dry matter of weeds (t ha^{-1}) 7 YAP	12 YAP
T_1 = 8 × 8	156	0.90	1.24	11.80	2.82
T_2 = 6 × 6	278	1.00	1.58	10.71	2.15
T_3 = 4 × 4	625	3.25	1.79	2.55	0.83
T_4 = 3 × 3	1111	9.30	1.36	1.95	0.60
T_5 = 2 × 2	2500	9.50	2.04	0.43	1.40
SE		0.50	0.112	0.98	0.28
$CD_{0.05}$		2.08	ns	4.08	1.16

[1]YAP, Years after planting
CD, Critical Difference; SE, Standard Error

9.5 t ha^{-1} in the highest tree density plot (Table 5). Drying of branches was more prevalent in the high-density plots. The dry branches produced in the high tree density plots were almost 10 times more than those produced in the widely-spaced trees (low tree density plot).

The weed biomass collected from the low tree density plots (treatments T_1 and T_2) during the seventh year was significantly ($P < 0.05$) higher (11.80 t and 10.71 t ha^{-1}) than the high tree density plots (0.43–2.55 t ha^{-1} in treatments T_3 to T_5, respectively). The trend was similar in the 12th year, but the total weed biomass was almost one-third to one-fifth (2.82 t and 2.15 t ha^{-1}) in treatments T_1 and T_2 and one-third (0.83 t ha^{-1}) in treatments T_3 and T_4 (0.60 t ha^{-1}) compared to those in the seventh year. But in treatment T_5 during the 12th year, it increased three-fold when compared to weed biomass collected in the 7th year. The weeds identified at the end of 12th year were *Euphorbia hirta, Spermacoce ocymoides, Oxalis corniculata, Mikenia conedids, Commelina nodiflora, Desmodium polycarpon, Herpesteis chaemonoides, Jussia repens, Emilia sonchifolia, Mimosa pudica, Solanum nigrum, Scoparia dulcis, Eleusine indica, Setaria glauca, Pennisetum polystachyon, Chromolaena odorata,* and *Ageratum conizoides.*

Soil moisture

In the high tree density plots (2500 trees, 1111 trees, and 625 trees ha^{-1}) moisture content was significantly ($P < 0.01$) higher up to the 60-cm depth, but decreased significantly at lower depths of 61–90 cm compared to the lowest tree density plot (Figure 3). Significantly ($P < 0.01$) higher moisture content at the

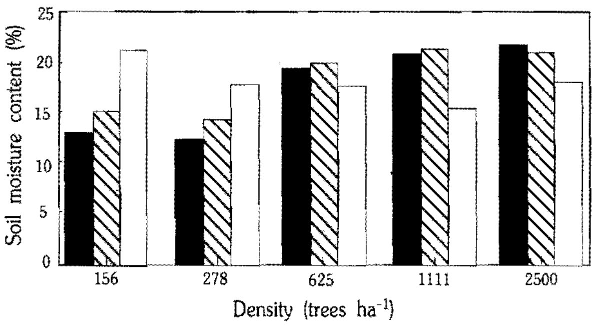

Figure 3 Effect of tree density on soil moisture content (%). Soil depth (cm): ■, 0–30; ▧, 31–60; and □, 61–90

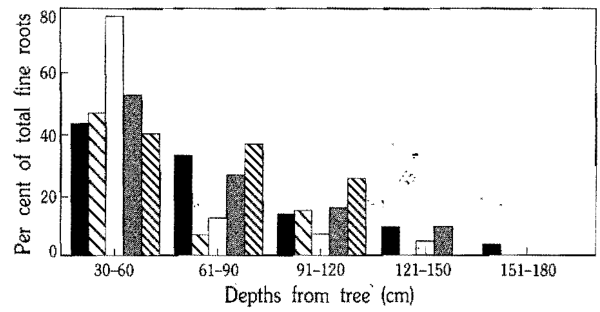

Figure 7 Distribution of fine roots at different distances in relation to tree density. Densities (trees ha^{-1}): ■, 156; ▧, 278; □, 625; ▩, 1111; and ▧, 2500

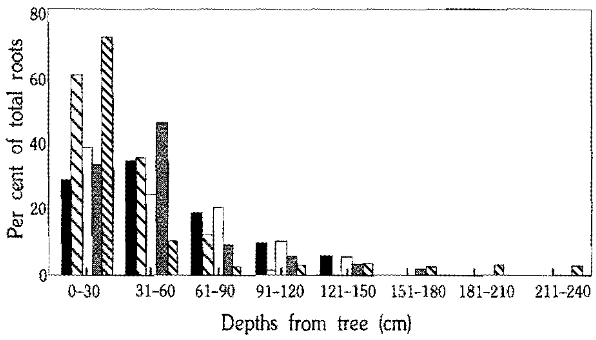

Figure 4 Distribution of roots at different depths in relation to tree densities. Densities (trees ha^{-1}): ■, 156; ▧, 278; □, 625; ▩, 1111; and ▧, 2500

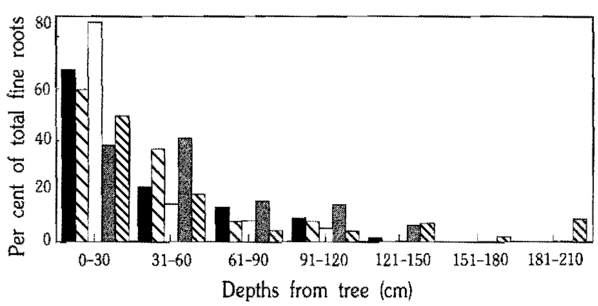

Figure 5 Distribution of fine roots at different depths in relation to tree density. Densities (trees ha^{-1}): ■, 156; ▧, 278; □, 625; ▩, 1111; and ▧, 2500

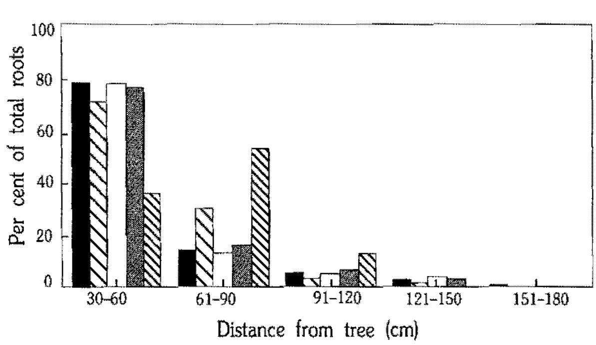

Figure 6 Distribution of roots at different distances in relation to tree densities. Densities (trees ha^{-1}): ■, 156; ▧, 278; □, 625; ▩, 1111; and ▧, 2500

0–30 cm depth was observed in high tree density plots. The weed growth was also minimum in these plots. The soil moisture content at lower depths was significantly ($P < 0.05$) less by 4–5% in the case of high tree density plots (treatments T_3 to T_5) compared to low tree density plots (treatments T_1 and T_2).

Root distribution

Vertical spread

In general, 63.73–97% of the roots were observed from the 0–60 cm depth (Figure 4). The roots penetrated significantly to a greater depth in the case of treatment T_5 compared to the wider spacing of treatments T_1 and T_2. A relatively higher percentage of total fine roots were observed at deeper depths up to 210 cm, in the case of the two highest tree density plots (Figure 5).

Lateral spread

The total roots concentration within a radius of 90 cm from the trunk varied between 71% and 97% in all the treatments. The maximum spread of 180-cm radius was observed in treatment T_1 and a minimum of 120 cm in treatment T_5 (Figure 6). More than 40% of the fine roots were present within the 60-cm distance from the tree trunk and gradually reduced in density as and when the distance from the tree increased. However, 70% of the total fine roots were present within the radius of 120 cm from the tree trunk (Figure 7).

Average root density

A minimum of 0.15 kg of total roots at the highest tree density and a maximum of 1.20 kg of total roots at the lowest tree density were present per cubic metre of excavated soil volume. The corresponding gross weight of roots was 1.46 kg (2500 trees ha^{-1}) and 18.04 kg tree^{-1} (156 trees ha^{-1}; Table 6).

Thinning

Biomass

It was observed that total biomass produced per tree at the two lowest densities was five times

Table 6 Dry weight of cashew roots per unit volume of soil and calculated gross weight of root (seven years after planting)

Treatment no.	Tree density (ha^{-1})	Quantity of soil excavated (m^3)	Weight of roots in sample ($kg\ m^{-3}$) of soil: Total roots	Fine roots	Weight of roots per unit volume ($kg\ m^{-3}$) of soil: Total roots	Fine roots	Calculated gross wt of roots in feeding zone ($kg\ tree^{-1}$): Total roots	Fine roots
T_1	156	1.35	1.602	0.048	1.187	0.036	18.04	0.54
T_2	278	1.08	0.884	0.028	1.037	0.027	10.91	0.29
T_3	625	1.08	0.759	0.033	0.703	0.030	7.45	0.32
T_4	1111	1.08	0.270	0.039	0.248	0.035	3.23	0.28
T_5	2500	1.13	0.174	0.010	0.154	0.008	1.46	0.08
SE					0.206	0.005	2.96	0.07

SE, Standard Error

more than treatment T_5 and 2.5 times more than treatment T_4 by the seventh year. Total biomass on a per hectare basis was lowest in treatments T_1 and T_2 (16.9 t and 26.5 t ha^{-1}, respectively) than in T_4 (47.3 t ha^{-1}) and T_5 plots (49 t ha^{-1}), respectively. Total biomass produced in treatment T_3 was 40.4 t ha^{-1} which was also more than total biomass produced in treatments T_1 and T_2.

Yield

Cumulative yield

The effect of spacing on nut production was significant. Highest yield was obtained in treatments T_3, T_4, and T_5 (high tree densities) compared to treatments T_1 and T_2 (low tree densities) for the first five years (two years of harvests). In treatments T_4 and T_5, the yield was reduced significantly ($P < 0.05$) during the subsequent years (6th and 7th years). Trees in treatments T_4 and T_5 were thinned to 50% and 25%, respectively, of the original population to reduce the interplant competition. The yield was reduced in both treatments in the next year of thinning but, subsequently, it increased up to the 10th year until the canopy covered the remaining ground area. During the 11th year, yields declined but increased by the 12th year. In treatment T_3, yield per unit area was minimum during the 10th and 11th years. The yield declined from 619 kg ha^{-1} by the 9th year to 503 kg and 460 kg ha^{-1} by the 10th and 11th years, respectively. The yield during the next year (12th year) increased to 706 kg ha^{-1} (Table 7). The cumulative yield for this treatment plot (625 trees up to 11 years and 312 trees ha^{-1} after thinning) was the highest (4.944 t ha^{-1}). This was followed by 4.655 t ha^{-1} for treatment T_4 (1111 trees up to seven years and 555 trees thereafter). The yield recorded in treatment T_3 was almost double when compared with treatment T_1 (156 trees ha^{-1}) and was 30% more compared to treatment T_2 (278 trees ha^{-1}).

Yield per tree

Tree yield increased from 1.01 kg $tree^{-1}$ in the 4th year to 2.78 kg by the 12th year in treatment T_1 and a similar trend was seen in treatment T_2 (Table 8). But in the case of treatment T_3, the yield was reduced from 0.95 kg $tree^{-1}$ in the fifth year to 0.75 kg $tree^{-1}$ in the eighth year. Overlapping branches were removed at this stage to maintain the yields up to the 10th year. When no significant increase in yield was noticed (0.80 kg $tree^{-1}$) in spite of

Table 7 Cashew nut yield (kg ha^{-1}) 4–12 years after planting

Treatment spacings (m)	Density no. ha^{-1}	Years: 4th	5th	6th	7th	8th	9th	10th	11th	12th	Total	Mean
T_1 = 8 × 8	156	157	181	186	173	240	311	281	313	433	2275	252.78
T_2 = 6 × 6	278	196	266	209	214	297	469	395	475	661	3182	353.56
T_3 = 4 × 4[1]	625	514	592	601	481	468	619	305	460	706	4944	549.56
T_4 = 3 × 3[2]	1111	657	757	635	402	306	594	369	234	712	4665	518.44
T_5 = 2 × 2[3]	2500	677	780	603	384	256	374	344	269	661	4338	483.11
$CD_{0.05}$		43.3	318.5	325.9	160.8	111.0	142.0	123.0	112.2	108.9	503.0	

[1]4 m × 4 m up to 11 years and 8 m × 5.7 m × 5.7 m after thinning (625 trees ha^{-1} up to 11 years and 312 trees ha^{-1} after thinning)
[2]3 m × 3 m up to 7 years and 6 m × 4.25 m × 4.25 m after thinning (1111 trees ha^{-1} up to 7 years and 555 trees ha^{-1} after thinning)
[3]2 m × 2 m up to 7 years and 4 m × 4 m after thinning (2500 trees ha^{-1} up to 7 years and 625 trees ha^{-1} after thinning)
CD, Critical Difference

Table 8 Cashew nut yield (kg tree^{-1}) 4th year to 12th year after planting

Treatment spacings (m)	Density no. ha^{-1}	Years									
		4th	5th	6th	7th	8th	9th	10th	11th	12th	Mean
T_1 = 8 × 8	156	1.01	1.16	1.19	1.11	1.54	1.99	1.80	2.01	2.78	1.62
T_2 = 6 × 6	278	0.71	0.81	0.75	0.77	1.07	1.69	1.42	1.71	2.38	1.25
T_3 = 4 × 4[1]	625	0.82	0.96	0.96	0.77	0.75	0.99	0.80	0.74	2.26	1.00
T_4 = 3 × 3[2]	1111	0.59	0.68	0.57	0.36	0.55	1.87	0.66	0.42	1.28	0.78
T_5 = 2 × 2[3]	2500	0.27	0.31	0.24	0.15	0.41	0.60	0.56	0.43	1.06	0.45

[1]4 m × 4 m up to 11 years and 8 m × 5.7 m × 5.7 m after thinning (625 trees ha^{-1} up to 11 years and 312 trees ha^{-1} after thinning)
[2]3 m × 3 m up to 7 years and 6 m × 4.25 m × 4.25 m after thinning (1111 trees ha^{-1} up to 7 years and 555 trees ha^{-1} after thinning)
[3]2 m × 2 m up to 7 years and 4 m × 4 m after thinning (2500 trees ha^{-1} up to 7 years and 625 trees ha^{-1} after thinning)

the above corrective measures, 50% of the population was thinned in the 11th year. In the subsequent year, the yield increased to 2.26 kg tree^{-1} with cumulative yield of 706 kg ha^{-1} by the 12th year (Tables 7 and 8). Yield per tree was reduced from 0.59 kg and 0.27 kg in the fourth year to 0.36 kg and 0.15 kg in the seventh year in the case of treatments T_4 and T_5, respectively. It was at this stage that thinning was done to reduce the population to 50% and 25% in treatments T_4 and T_5, respectively. Two years after thinning, the yield per tree increased significantly ($P < 0.05$) to 1.07 kg and 0.60 kg, respectively, but not to the extent observed in treatment T_3.

Economics

The cost of production, total income realised, and net profit realised from the 4th year to the 12th year after planting is presented in Table 9. It was observed that the maximum profit realised was from treatment T_3 (U.S. $2464.83 ha^{-1}) followed by treatment T_4 (U.S. $1899.47 ha^{-1}). The profit realised from treatment T_3 was 2.2 times that of treatment T_1 (normal spacing) and 1.29 times that of treatment T_4 (Table 9).

Table 9 Effect of tree densities on cost of production, total income and net profit (Rs ha^{-1})[1]

Treatment no and spacing	Cost of production	Income	Profit
T_1 = 8 m × 8 m	20 344	52 820	32 476
T_2 = 6.5 m × 6.5 m	23 849	75 294	51 445
T_3 = 4 m × 4 m[2]	40 631	114 578	73 947
T_4 = 3 m × 3 m[3]	47 946	104 932	56 987
T_5 = 2 m × 2 m[4]	56 028	98 521	42 493
$CD_{0.05}$			5 118

[1]U.S. $1 = INR 30 (1994)
[2]4 m × 4 m up to 11 years and 8 m × 5.7 m × 5.7 m after thinning (625 trees ha^{-1} up to 11 years and 312 trees ha^{-1} after thinning)
[3]3 m × 3 m up to 7 years and 6 m × 4.25 m × 4.25 m after thinning (1111 trees ha^{-1} up to 7 years and 555 trees ha^{-1} after thinning)
[4]2 m × 2 m up to 7 years and 4 m × 4 m after thinning (2500 trees ha^{-1} up to 7 years and 625 trees ha^{-1} after thinning)

Discussion

Ground coverage, light interception by canopy, and yield

Palmer and Jackson (1977) reported that production in young high-density apple orchard increased linearly with increasing light interception between 20% and 60%. Wertheim *et al.* (1986) reported that accumulated production of the systems was quadratically related to light interception with maximum yield at 75–80% light interception.

Dense shade due to overlapping branches indicated the need for thinning especially in treatments T_4 and T_5. Dense shade also affected photosynthesis (Balasimha and Yadukumar, 1993) and per tree yield. Balasimha and Yadukumar (1993) reported that P_n had reached a minimum level in high tree densities (treatments T_3–T_5) during the 6th, 7th, and 8th years in the same trial. This was attributed to mutual shading. The differences in P_{fd} and P_n between the tree densities were significant ($P < 0.05$) in this study although differences among the three years (6, 7, and 8 years) were not significant. However, in treatments T_4 and T_5 (1111 trees and 2500 trees ha^{-1}, respectively), both P_{fd} and P_n show-ed higher values in the the 7th and 8th years which was attributed to the thinning undertaken during the seventh year. This is in conformity with the results reported by Balasimha (1991) and Subbaiah (1983).

Ferree (1983) reported that a training and pruning system with lowest levels within the tree canopy had lower yield efficiency than a system with higher levels. Incidence of less light (P_{fd}) in the middle and lower height of the canopy resulting in reduced photosynthesis may be the reason for yield levels per tree not improving to the extent to nullify the effect of reducing tree populations to 50% and 25% through thinning (Tables 3 and 7). Although increase in yield per tree was observed, increased yield per hectare was not observed subsequently after thinning compared to the yield received during the first three harvests (4th, 5th, and 6th years after planting) in treatments T_4 and T_5.

In the case of treatment T_3, overlapping branches were removed (8 kg tree yr^{-1}) every year from the 8th year to the 10th year to limit light interception to 80%. Although yield did not improve in the first year of pruning (8th year) it increased significantly in the ninth year. But again in 10th year, the yield per hectare was reduced significantly compared to the previous year. This may be due to receipt of less intensity of light in the middle and lower canopy height leading to overall reduction in P_n activity and yield per hectare (Tables 4 and 7). Similar results were reported by Ferree (1983) in apple.

Soil moisture, drying of branches, weed growth, and yield

The decrease in yield per unit area as well as per tree in close spacing may be due to water stress developed as water demand of the trees increased with age and canopy cover. This was in agreement with Dagg *et al.* (1967). Root studies conducted in the present studies indicated that total root biomass in trees spaced at wider distance (8 m × 8 m, 156 trees ha^{-1}) was approximately 18.04 kg $tree^{-1}$ which was 2.75 to 12.3 times the root biomass of closely-spaced trees (T_3, 7.45 kg; T_4, 3.23 kg; and T_5, 1.46 kg). The percentage of fine roots were greater in the lower depth in high tree density plots (treatments T_4 and T_5) than in low tree density plots (treatments T_1 and T_2). Ground coverage (GC) by each tree canopy was 41.66 m^2 (65% GC in the given area of 64 m^2) in treatment T_1 (8 m × 8 m) and it ranged between 9.6 m^2 in treatment T_3 and 2.72 m^2 in treatment T_5 during the sixth year after planting. This variation in root density with spacing was also reported in coffee and arecanut by Leon and Umana (1959) and Bhat and Leela (1969), respectively. Thus, widely-spaced trees that are directly situated beneath the canopy could exploit more volume of soil in the initial stages as well as later. As a result, competition was not observed for water in such plots (8 m × 8 m and 6 m × 6 m) as evident from higher moisture content at the lower depths (Figure 3). As canopy of the tree increased with age as in the case of treatments T_3, T_4, and T_5, the lateral root extension was not possible due to overlapping of roots of neighbouring trees. This results in more exploitation of available soil moisture at the soil depth up to which roots have reached. In the present studies on soil moisture, up to 90-cm depth indicated more moisture stress during peak summer season in treatments T_3, T_4, and T_5 than treatments T_1 and T_2 (Figure 3). As a result of less moisture at the lower depths in the high tree density plots compared to the low tree density plots, the lower branches in such plots dried heavily during the peak summer season in addition to drying of branches due to dense shade as explained earlier. Similar results were reported by Pandey and Singh (1993) in mango. One of the reasons for the decline in yield in the high tree density plots later may be due to more moisture stress during peak fruiting season. Dagg *et al.* (1967) reported that water competition was the main cause of the decline in yield at close tree spacings due to interplant root competition for water.

Weed biomass collected was minimum in high tree density plots and maximum in low tree density plots. This was due to maximum light interception in high-density plots and minimum light interception in low density plots. Increase in weed biomass was observed in treatments T_4 and T_5 seven years after planting. This was due to thinning of the population from 2500 trees to 625 trees ha^{-1} (T_5) and 1111 trees to 550 trees ha^{-1} by the seventh year (T_4) which caused exposure of the ground to sunlight and resulted in increased weed growth. Exposure of ground surface to more sunlight in treatments T_1 and T_2 resulted in more weed biomass production during the 7th and 12th years. Exploitation of moisture at the top depth by weeds might have caused significantly less moisture content of the soil in the low tree density plots (treatments T_1 and T_2) than that in the soil of the high tree density plots (treatments T_3 to T_5).

Maintaining a density of 625 trees ha^{-1} (4 m × 4 m) up to the 10th year and thinning on the 11th year to 50% (312 trees) resulted in maximum cumulative yield of nuts (4.94 t ha^{-1}) and profit (U.S. \$2464.90 ha^{-1}). This was followed by a density of 1111 trees ha^{-1} up to the seventh year and 555 trees after thinning gave the best yields. In the control plot, with normal tree density the cumulative yield up to 12 years after planting was 2.27 t ha^{-1} with a net profit of U.S. \$1082.50 ha^{-1}. Similar results were reported in cashew in Kenya by Van Eijnatten and Abubaker (1983) where hedge rows established at 9 m × 3 m accommodating 370 trees ha^{-1}, gave higher yields than at wider spacing (10 m × 10 m). Santram (1996) reported that in mango high tree density orchard (1333 trees ha^{-1}) together with pruning, increased fruit yield eight-fold compared with normal density orcharding (69 trees ha^{-1}).

In high-density planting of cashew, optimum ground coverage and light interception can be obtained with simultaneous high yield per unit area up to the seventh year, and beyond that, either ground coverage can be manipulated by pruning overlapping branches and limiting the light interception to 80% every year, or by thinning the tree population to 50% and 25% depending upon the original tree densities per unit area. In the present study, maintaining a tree population of 625 ha^{-1} for the first 10 years and thinning to 50% (312 trees ha^{-1}, treatment T_3) was found to be the best system compared to low tree density (treatments T_1 and T_2) as well as still higher densities (treatments T_4 and T_5).

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