Original Research Article

Morphological and Physiological analysis of VRI-3 cashew plantations under different planting density systems

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ABSTRACT

Cashewnut (*Anacardium occidentale* L.) is an export-oriented plantation crop. The VRI-3 cashew plantation, utilizing a 7 x 7 m low-density (LD) system with approximately 200 plants ha^{-1}, falls short of meeting the country's import and export demands. Consequently, a high-density planting (HDP) system was developed in Tamil Nadu to enhance India's cashew production. Further advancement through ultra-high-density planting (U-HDP) has proven effective, achieving a plant population of about 1250–1600 plants per hectare. In addition to the increased number of plants in the U-HDP approach, morphological characteristics such as tree height, trunk height, trunk girth, and canopy ground coverage were studied. The impact of these morphological changes resulting from an increased tree population on physiological parameters like Leaf Area Index (LAI) and light extinction coefficient (*k*) was also analysed. This analysis was carried out using the 'Ceptometer' model AccuPAR LP-80 device, aiming to determine how these changes might interfere with productivity and subsequently influence the cashew plantation's production capacity.

Keywords*:*Cashewnut, low density (LD), high-density planting (HDP), ultra-high density planting (U-HDP), LAI and light extinction coefficient (k), production capacity.

1. INTRODUCTION

Cashew (*Anacardium occidentale* L.) is a valuable plantation crop known as waste land's cash crop with a strong export focus, primarily cultivated for its nut, which is a true drupe and often referred to as the 'wonder nut'. This nut holds significant value in global commodity markets and serves as a crucial cash crop, offering the potential to improve the livelihoods of cashew growers, empower rural women in processing activities, create employment opportunities, and generate foreign exchange through exports. India occupies the first place globally in terms of area and production. However, there is a greater need for improving the productivity per unit area of feed processing sectors in the country (as reported by Yuvaraj, 2019)[1].

Cashew plantations in India are primarily known for their extensive layouts with low-density orchards, typically containing 200 trees per hectare. Unfortunately, these orchards exhibit low productivity. The Indian cashew industry grapples with a deficit of raw cashew nuts due to the prevailing low productivity, averaging around 665 kg per hectare. In order to cater to the growing demand, India relies on importing raw cashews, incurring an annual expenditure of approximately Rs. 8,861.59 crores. Consequently, enhancing cashew productivity necessitates the adoption of crucial strategies, including the utilization of high-quality planting material, effective canopy management, integrated nutrient management, and comprehensive integrated pest and disease management

The high-density planting (HDP) system has demonstrated substantial benefits in cashew cultivation, doubling nut yield during the first 10 years after planting. The key factors in this approach include selecting the right variety and planting density. Initially, more grafts are planted per unit area, and thinning out occurs in later stages (typically after 8-10 years) based on canopy expansion rates. For example, in Tamil Nadu, a high-density planting technology with a 5 x 4 m spacing that accommodates 500 plants per hectare was standardized and released for adoption in 2011 (Murali *et al*., 2015)[2]. This system allows a nut yield of 3000 kg/ha to be harvested at the age of six years. The initial plant population should be carefully decided based on soil fertility, climate, and local management practices. In fertile soils, a spacing of 5 x 5 m (400 plants/ha) can provide the highest yield and income, while in less fertile areas, a spacing of 4 x 4 m (625 plants/ha) is recommended.

High-density planting offers several advantages. It is particularly suitable for low-fertility soils, reducing weed growth through early ground coverage by the crop canopy and moderating soil temperature, leading to increased soil moisture content, especially during peak summer seasons. Regular pruning is essential to manage the canopy, and in later years, such as the eleventh year after planting, thinning out the tree population to 50% by removing every alternate tree in each row is necessary. High-density planting can increase cashew yield by 2 to 3 times compared to normal density planting. This technique is more beneficial in poor soils where the rate of expansion is slow. Specific cashew varieties, such as Anakkayam-1 and Dhana, which are relatively short-statured and compact, are well-suited for high-density planting, as the thinning operation can be delayed to more than 10 years. Varieties like VRI-3, popular among Tamil Nadu farmers for its export-grade kernels and amenable to pruning, are also suitable for the HDP system (Aneesa Rani*et al*., 2011a)[3].

Moreover, an ultra-high density planting system provides an innovative solution for the shrinking land area available for cultivation of fruits and vegetables. Planting cashew trees at closer spacing of 4 x 2 m and 3 x 2 m accommodates more plants per unit area, leading to a higher yield per unit area on available land (Aneesa Rani and KeisarLourdusamy, 2006)[4]. Implementing this system, through canopy management along with proper drip and fertigation systems for enhanced soil fertility, can significantly increase cashew productivity in Tamil Nadu and across India (Aneesa Rani *et al*., 2011b)[5]. So as to analyse the physiological basis of this technology, a practical study was conducted to examine how different planting densities influence the growth and yield of VRI-3 cashew varieties in Tamil Nadu conditions. The objective was to identify the physiological response of the VRI-3 variety for the specific planting density that would result in the highest returns per unit area.

2. MATERIAL AND METHODS

The research was conducted during the years 2022–23 at the Regional Research Station of Tamil Nadu Agricultural University located in Vriddhachalam, Cuddalore district, Tamil Nadu, India. This district is known to be the predominant cashew-growing area of the state. The prevailing climate in this area is tropical, which is conducive for cashew cultivation.

2.1 Experiment layout and treatment details

The VRI-3 cashew variety developed by the Regional Research Station, TNAU, Vriddhachalam, was used for the study. The field was raised in 2011. The experimental design encompassed a randomized block design layout, comprising four different plant densities: 200 trees per hectare (T_1-7 m × 7 m), 500 trees per hectare (T_2–5 m × 4 m), 1250 trees per hectare (T_3-4 m × 2 m), and 1666 trees per hectare (T_4-3 m × 2 m). The first foliar spray of NPK 19:19:19 was given on August 15th (new flush stage). A second foliar spray of 1% boron, 2% sulphate of potash (SOP), and 1% mono-ammonium phosphate (MAP) at the flowering stage was given on December 15th (flowered stage).
On July 15th, pruning of tertiary shoots was carried out in T_2-5 × 4 m, T_3-4 × 2 m, and T_4-3 × 2 m, and no pruning was practiced in T_2-7 × 7 m. The tertiary shoot pruning involved removing up to half the length of the tertiary shoots during the

second fortnight of July. This type of pruning is also referred to as lateral shoot pruning. To promote appropriate canopy formation, the lower branches of the cashew trees were uniformly removed during the initial 3-4 years after planting. This practice aimed to ensure the proper shape of the plantation's canopy.

Table 1. Treatment details for the planting systems

Treatments	Tree spacing (m)	Total number of plants ($ha.^{-1}$)	Pruning intensity
T_1	7 × 7	200	Control
T_2	5 × 4	500	50 cm of tertiary shoot
T_3	4 × 2	1250	50 cm of tertiary shoot
T_4	3 × 2	1666	50 cm of tertiary shoot

A yield of 250 kg/ha has been recorded from one-year-old plants at a 5 x 4 m planting density. Pruning during the second week of July (tertiary branch pruning) induces the current season's shoot production. Drip irrigation and liquid fertilizers are provided for high and ultra-high density as per recommendations, leading to an increase in the number of the current season's shoots and flower panicles, effectively doubling the yield.

2.2 Measurements of morphological and growth characteristics

The vegetative parameters, which included tree height, trunk height, canopy height, trunk girth, canopy spread, canopy coverage were assessed on a random selection of five trees during the month of January 2023. The extent of ground coverage by the canopy was determined by following the approach described by Rejani *et al*. (2013)[6].

Canopy ground coverage (GC) is calculated using the formula πr^2, where π is approximately 3.14 and r represents the average canopy diameter, obtained by measuring the spread of the canopy both from north to south and from east to west.

2.3 Physiological parameters

The leaf area index (LAI) and the light extinction coefficient (*k*) were evaluated within the tree canopies. Measurements were conducted in four directions-easts, west, north, and south-using the Decagon's ceptometerAccuPAR model LP-80 PAR/LAI Ceptometer between 10 a.m. and 12 p.m. during January and February of 2023. This Ceptometer is a device used to measure photo-synthetically active radiation (PAR) values of the canopy and has the capability to convert these measurements to provide leaf area index (LAI) values for the same canopy of sample trees. All the readings were taken within 2 minutes to minimize the variation due to the atmosphere.

The instrument automatically determined transmittance (τ) by utilizing PAR (photo-synthetically active radiation) readings obtained from a probe and an external sensor attached to the instrument. Transmittance (τ) represents the ratio between PAR measurements taken below the canopy and the most recent above-canopy PAR reading. These measurements were taken on clear-sky days. To calculate the canopy extinction coefficient (*k*), transmittance measurements were specifically taken when the azimuth angle was greater than 20° relative to the south and the solar zenith angle fell between 10 and 40°. The extinction coefficient was computed using the Beer-Lambert equation:

$$k = \frac{-\ln(\tau)}{LAI}$$

2.4 Measurements of yield parameters

Cashew nut yield was recorded for the 12^{th} year of each treatment under each replication. The nuts were collected manually, separated from cashews, sun-dried for three days, and weighed. The mean nut yield (kg/tree) was calculated during the year 2023.

2.5 Statistical analysis

The experimental data were analysed through the AGRES software and Microsoft spreadsheet. An analysis of variance (ANOVA) was carried out using the randomized block design (RBD) analysis feature of the GRAPES software. The analysis encompassed the evaluation of treatment means, standard error differences, covariance, and critical differences. The significance was determined by assessing the P-value in the ANOVA table, where values less than 0.05 were considered statistically significant.

3. RESULTS AND DISCUSSION

3.1 Effect of planting densities on growth characteristics

The vegetative parameters listed in Table 2. reveal that decreasing tree spacing has a direct effect on the growth of individual trees in a plantation. The T1-7 x 7 m spacing had the highest plant height (8.10 m), trunk height (150 cm), canopy height (6.60 m), stem girth (90 cm), canopy spread (7.43 m), and canopy ground coverage (173.59 m2), whereas the minimum values of plant height (3 m), trunk height (60 cm), canopy height (2.40 m), stem girth (35 cm), canopy spread (1.90 m), and ground coverage (11.35 m2) were observed in T4-3 x 2 m). As the VRI-3 variety chosen for the study is not of dwarf stature to fit into dense spacing, they were pruned in such a way that their canopy architecture does not interfere with the adjacent trees of the plantation. Despite the same level of pruning being followed in treatments T2, T3, and T4, the growth of these plant densities showed marked differences. This reveals that the planting densities adopted had a more significant effect on the growth of the trees than the pruning intensity of the VRI-3 cashew plantation. **Table 2.** demonstrated that raising the tree population from 200 to 1666 trees per hectare had significant effects on cashew growth and development. The data regarding tree height showed that there was a downward pattern as the planting density increased. But the increment of the tree height from before pruning to after pruning was higher in the HDP and the UHDP's systems than in the normal-spaced plantation. This increment in the tree height upon a standard increase in the plant population is because the trees tend to capture the maximum sun light to effectively perform the process of photosynthesis and to thrive better in such densely populated conditions.

From the figure 1, it is obvious that canopy ground coverage shows a downward pattern upon increasing planting densities. The wider-spaced plantation like T1-7 x 7 m, which was maintained without pruning, had the wider ground coverage as there was sufficient space within the plantation, creating less competition for the canopies to compete for nutrients and other natural resources (Gaikwad *et al*., 2017)[7]. It is also evident from the result that canopy ground coverage decreased upon increasing planting densities. The canopy spread in a thick population was minimal because of the overlapping of the branches, making it out of reach from sunlight, leading to stem elongation, and the tree naturally tends to grow taller to meet its physiological needs (Policarpo *et al*., 2006)[8]. According to Rejani *et al*. (2013)[9], there was a significant difference in the canopy coverage of the different varieties when grown at varying densities (via the widest and closest spacing conditions). The observations from the current studies 12 years after planting have proved that such a trend followed even after the latter stages of growth in VRI-3 cashew plantations grown under varied planting densities. As if in the canopy ground coverage, a similar growth pattern was observed in the trunk girth upon increasing planting densities. These results coincide with the studies conducted by Tripathy *et al*. (2015a, b)[10][11]in cashew, Nath *et al.* (2007)[12]in mango, Kundu (2007)[13]in guava, and Kumar *et al.* (2012)[14] in almond.

The morphological observation showed that in T1-7 x 7 m, there is still 10-12% of available space for canopy growth, which indicates the possibility of obtaining a higher yield in subsequent harvests. But in the case of HDPs and UHDPs, the canopy coverage exceeded the given space by 45% to 80% additionally, which demonstrated the unsustainability of these systems for not more than 10 years. These findings are in accordance with the findings of Balasimha and Yadukumar (1993)[15]and Tripathy *et al*. (2015a, b)[10][11] in cashew. So after the tenth year of planting, there is an additional need to remove the overlapping branches and some unwanted intensive shoots to maintain the proper framework of the plantations. The VRI-3 is found to be a slow grower and less vigorous variety, making it highly suitable for HDPs. Janani *et al*., 2022[16] has also suggested that VRI-3 cashew varieties could be a good option for high-density planting systems. This current field experiment proved that VRI-3 cashew could perform well for UHDPs too, when maintained under proper canopy management. Similar morphological variations were also addressed by the reports of Hanumanthappa*et al.* (2014)[17]and Chandrasekhar *et al*. (2018)[18].

3.2 Effect of planting densities on physiological characteristics

From table 3,it is clear that there was an increase in the leaf area index (LAI) when the planting density increased. This shows that the higher planting density and LAI were directly proportional to each other. The treatment T3-4 x 2 m recorded the maximum LAI of 1.25, and the treatment T1-7 x 7 m recorded the least LAI value of 0.52. The light transmittance value was obtained by using the ceptometer 'AccuPAR LP-80'. The light transmittance, also known as Tau (τ), is the ratio between the values of above and below canopy PAR (photo-synthetically active radiation) readings. The PAR measurements are the exact measurements of light wavelengths between 400 and 700 nm from the total solar radiation. The maximum Tau (τ) value was observed in the treatment T1-7 x 7 m (0.72), and the minimum Tau (τ) value was observed in the treatment T4-3 x 2 m (0.55). **From table 3,** it is clear that there was a negative influence of plant densities on light extinction coefficient (*k*) values, which increased with decreasing plant densities.

Therefore, under varying plant populations, physiological parameters like leaf area index (LAI) and light extinction coefficient (*k*) tend to be negatively related to each other. That is, when the LAI increased via an increase in the planting densities, there was a decrease in the light extinction coefficient (*k*), Fig 3. Despite the fact that the loosely-spaced plantation had the maximum number of leaves, it recorded the lowest level of LAI among the four treatments, and the densely spaced plantation had the highest level of LAI. This situation must be due to the canopies of the densely populated plantations being properly distributed and positioned in such a way that they receive uniform sunlight. Additionally, the trees at higher planting densities have occupied the entire space to utilize the maximum solar light in the system. This relationship between the LAI and k was in accordance with the studies conducted by Janani *et al*. (2022)[16] in the high-density planting system of cashew plantations and Kumawat *et al*. (2014)[19] in the high-density plantation of guava orchards.

From the **figure 2,** it is obvious that there is a direct relationship between the LAI and the yield of the VRI-3 cashew trees. The yield of the individual tree was higher in the normal spacing (T1-7 x 7 m), but the capacity of the UHDP to accommodate more plants per unit area boosted the productivity of the VRI-3 cashew yield per hectare. Among the two different UHDP treatments (T3-4 x 2 m and T4-3 x 2 m), the maximum yield potential was exhibited in the spacing T3-4 x 2 m (1250 trees ha-1). Further increased planting density of T4-3 x 2 m (1666 trees ha-1) showed a reduction in productivity; this is due to the very low yield contributed by the individual tree.

3.3 Effect of planting densities on yield characteristics

The planting densities had a direct influence on the yield of the plantation. Table 4 reveals that, when the planting density increased, the nut yield per tree decreased. From the four levels of treatments, T1-7 x 7 m recorded the maximum yield per tree of about 7.66 kg, and the lowest yield per tree was observed in T4-3 x 2 m (2.23 kg). But, increased planting densities have a positive correlation with the nut yield of the trees per unit area. The treatment T3 recorded a maximum yield per hectare of about 4.96 t/ha, and the minimum yield per hectare was obtained from the treatment T1 (1.53 t/ha). The development of appropriate plant spacing has a significant effect on improving the yield per unit area of the cashew variety VRI-3. The increased yield potential was attributed to increased planting density, proper canopy management through pruning strategies, and appropriate nutrient management of the cashew plantation (Yadukumar *et al*., 2001[20]; Mini Poduval and Yadukumar, 2011[21]; Murali *et al*., 2015[2]; Tripathy *et al*., 2015a[10];Mangalassery*et al*., 2019[22]).

Table 2. Effect of plant densities on vegetative growth of VRI-3 cashew variety at 10th harvest (12th year after planting)

Treatment[a]	Plant height (m)	Trunk height (cm)	Canopy height (m)	Trunk girth (cm)	Canopy spread (m)	Canopy ground coverage (m²)
T_1-7 x 7 m	6.10 ±0.38	150 ±11.71	4.60 ±0.33	90 ±4.22	7.43 ±0.31	173.59 ±14.22
T_2-5 x 4 m	4.90 ±0.38	110 ±8.59	3.80 ±0.18	60 ±4.69	4.95 ±0.21	77.05 ±6.31
T_3-4 x 2 m	3.80 ±0.30	80 ±6.24	3.00 ±0.23	45 ±3.51	3.72 ±0.16	43.51 ±3.57
T_4-3 x 2 m	3.00 ±0.23	60 ±2.81	2.40 ±0.19	35 ±2.73	1.90 ±0.08	11.35 ±0.93
Mean	4.45	100	3.45	57.5	4.5	76.375
SE (d)	0.16	3.23	0.17	1.81	0.06	3.64
CV	4.99	5.11	6.76	4.97	2.16	7.53
CD	0.34**	7.05**	0.37**	3.94**	0.13**	7.92**

Each treatment data is represented as mean values ± standard error for five replicates.
[a]SE (d), Standard error difference; CV, coefficient of variance; CD, coefficient of dispersion
** Statistical significance was observed at p values of 0.05 and 0.01

Table 3. Effect of plant densities on LAI and light extinction co-efficient of VRI-3 cashew variety at 10th harvest (12th year after planting)

Treatment[a]	LAI	Tau (µ mol $m^{-2}s^{-1}$)	*k*
T_1-7 x 7 m	0.52 ±0.29	0.72 ±0.12	0.63 ±0.04
T_2-5 x 4 m	0.72 ±0.20	0.51 ±0.11	0.54 ±0.04
T_3-4 x 2 m	1.25 ±0.38	0.70 ±0.08	0.52 ±0.10
T_4-3 x 2 m	1.06 ±0.14	0.55 ±0.04	0.56 ±0.07
Mean	0.89	0.62	0.56
SE (d)	0.19	0.06	0.04
CV	33.76	15.79	11.59
CD	0.41**	0.14*	0.09*

Each treatment data is represented as mean values ± standard error for five replicates.
[a]SE (d), Standard error difference; CV, coefficient of variance; CD, coefficient of dispersion
** Statistical significance was observed at p values of 0.05 and 0.01

* Statistical significance was observed at p value 0.01.

Table 4. Effect of planting density on Yield characters of VRI-3 cashew variety at 10th harvest (12th year after planting)

Treatment[a]	No. of plant/ha. (nos.)	Yield (Kg/tree) [b]	Yield (Kg/ha.)	Yield (t/ha.)
T_1-7 x 7 m	200	7.66 ±0.14	1532	1.53
T_2-5 x 4 m	500	3.90 ±0.32	1950	1.95
T_3-4 x 2 m	1250	3.97 ±0.61	4963	4.96
T_4-3 x 2 m	1666	2.23 ±0.39	3715	3.71
Mean	904	4.44	3040	3.04
SE (d)	42.80	0.27	211.58	0.21
CV	6.68	6.56	6.24	6.24
CD	93.25	0.58	460.99	0.46**

[a]SE (d), Standard error difference; CV, coefficient of variance; CD, coefficient of dispersion
[b]Each data is represented as mean values ± standard error for five replicates.
** Statistical significance was observed at p values of 0.05 and 0.01.

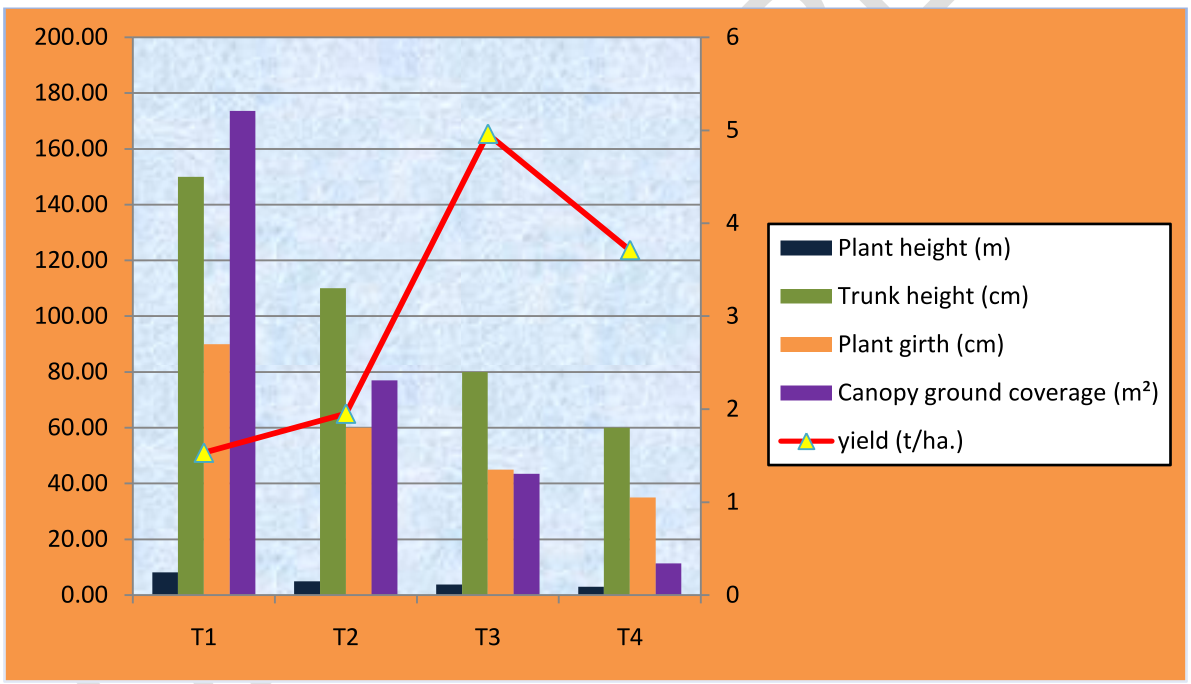

Figure 1. Comparison of the effects of morphological changes due to varying planting density on yield (t/ha) per unit area (12 years after planting)

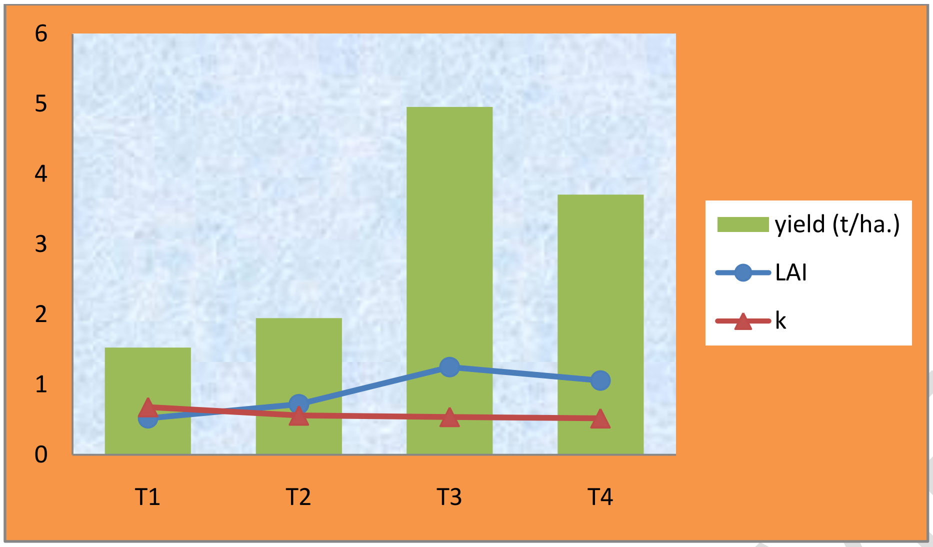

Figure 2.Comparison of theeffects of physiological changes due to varying planting density on yield (t/ha) per unit area (12 years after planting)

4. CONCLUSION

The observation on the twelve-year-old plantation of the study indicated that there was a slight reduction in the yield after 10 years of planting. The present study states that the best suitable number of years to maintain the HDPs and UHDPs plantations on the field is 10 years, after which there is a slight decline in the yield per tree, which affects the productivity per unit area of the plantation, and the T3-4 x 2 m in the hedge row system could provide the maximum yield of 6-7 t ha^{-1} during 9-10 years of age, which was recorded in the VRI-3 cashew plantations.

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