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Optimising nutrients for papaya as an intercrop in juvenile coconut plantations

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Abstract

Coconut cultivation, predominant in coastal India, faces a prolonged juvenile phase of 3–5 years during which economic returns are minimal. Intercropping with short-duration fruit crops like papaya (*Carica papaya* L.) offers a sustainable solution for income generation during this period. A field experiment was conducted at ICAR-CPCRI, Regional Station, Kayamkulam, to evaluate nutrient management strategies for papaya under a juvenile coconut ecosystem using organic residue recycling. Three papaya varieties—Taiwan 786, Co 8, and Arka Prabhat—were planted in a single row in between coconut palms, under four nutrient treatments at bimonthly intervals using different organic amendments; coconut leaf vermicompost (CLVC), rock phosphate, neem cake, poultry litter, and green manure. The experiment was laid out in factorial randomised block design with four replications. Results indicated that the treatment comprising 2 kg CLVC, 200 g rock phosphate, and 100 g sulphate of potash recorded enhanced growth and yield parameters plant height (174.4 cm), length of leaf midrib (78.88 cm), total dry matter production (2.9 kg plant^{-1}), fruit weight (1.33 kg), and productivity (20.42 fruits plant^{-1}). This treatment also recorded higher chlorophyll content (1.11 %) and reduced stomatal resistance (1.02 mmol m^{-2} s^{-1}) suggesting improved photosynthetic efficiency. Elevated nitrogen and potassium levels in plant tissues further corroborated the superior performance of this nutrient regime. The study highlights the potential of organic nutrient management in optimizing papaya productivity within coconut-based intercropping systems.

***Keywords**:* Coconut, juvenile phase, intercrop, papaya, nutrient management

Introduction

Coconut is one of the most important plantation crops cultivated globally, covering approximately 12.56 million hectares and producing an estimated 67,698 million nuts (ICC, 2021). In India, coconut cultivation spans about 2.17 million hectares, predominantly managed by marginal and small-scale farmers (Annual Report, 2021–22). Over 80% of the agricultural sector in India is dominated by these farmers, who operate with an average landholding of 1.2 hectares (Nihad *et al*., 2023). As a commercial crop primarily grown by smallholders, coconut is particularly vulnerable to economic risks arising from fluctuating market prices and various biotic and abiotic stresses. Due to its unique plant architecture and canopy structure, mature coconut plantations utilize only about 25 % of the total available land area (Maheswarappa *et al.*, 2000; Nihad *et al*., 2021).

Given its perennial nature and prolonged juvenile phase, the adoption of suitable component crops and scientific production technologies at different growth stages is essential for ensuring sustainable income. Component crops should be selected based on light requirements, rooting depth, nutrient demand, seasonality, and market value. The integration of scientific cultivation practices within a systematic coconut-based cropping or farming system can enhance the crop's economic viability, even on small holdings. Such systems not only improve farm income and family nutrition but also contribute agro-biomass for recycling, thereby enhancing soil organic matter and biological activity (Maheswarappa *et al*., 2013; Nihad *et al*., 2023).

During the juvenile phase of coconut, light is not a limiting factor, allowing for the cultivation of light-demanding intercrops. Sole coconut plantations are

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typically unprofitable during their juvenile phase, which can last from three to six years depending on the variety. Intercropping during this period is thus crucial for generating income, as well as ensuring food and nutritional security. In this context, papaya (*Carica papaya* L.) emerges as an ideal intercrop due to its fast growth and early fruiting. It can be cultivated effectively in juvenile coconut plantations, producing continuous yields until the coconut palms begin bearing fruit. Approximately 40% of the area in juvenile plantations can be allocated to papaya, enabling the accommodation of around 1,000 plants per hectare during the initial three years.

Papaya exhibits rapid vegetative growth and begins fruiting within three to four months, with an economic lifespan of two to three years. Widely grown in India, it thrives under tropical conditions and is cultivated both for fresh consumption and processing. However, due to its vigorous growth and high productivity, papaya has significant nutrient demands. Excessive reliance on chemical fertilizers can degrade fruit quality, soil health, and long-term soil productivity. Agricultural diversification, by contrast, enhances nutrient recycling (Nowak *et al*., 2015). Increasingly, sustainable agriculture recognizes the complementary role of organic inputs in maintaining soil health and productivity. Integrated nutrient management (INM), which combines chemical fertilizers, organic manures, and biofertilizers, is one of the most effective strategies for sustaining soil fertility and enhancing crop productivity in coconut-based systems (Nihad and Jessykutty, 2010). It is reported that inclusion of organic manures and biofertilizers improves the growth, yield, and quality of papaya (Ranjan and Ghosh, 2006; Mahendra *et al*., 2009). Studies regarding the scope of growing papaya as a component crop in coconut plantations during its juvenile phase is lacking. In this context, the present study is taken up for standardizing nutrient management practices for cultivating papaya as an intercrop in juvenile coconut plantations, with an emphasis on minimizing external inputs and to ensure sustainable income during the non-bearing phase.

Materials and Methods

The experiment was conducted for two years at the Indian Council for Agricultural Research – Central Plantation Crops Research Institute (ICAR-CPCRI), Regional Station, Kayamkulam (9º082 N latitude, 76º302 E longitude, and 3.05 m above MSL) within an established one year old coconut plantation during 2015-17. The soil at the experimental site is classified as sandy loam under the order *Entisol*, which is porous in nature with low nutrient and water holding capacity. The soil nutrient status of the soil before the experiment is estimated and it recorded a pH of 5.7, organic carbon content of 0.15 %, and the available nutrient levels of 397.3 kg ha^{-1} nitrogen, 53.1 kg ha^{-1} P_2, O_5, 122.3 kg ha^{-1} potassium, 0.022 % calcium, 24.6 ppm magnesium, 1.12 ppm manganese, 13.4 ppm iron, 1.39 ppm copper, and 2.2 ppm zinc (Jackson, 1973). The study was carried out under the natural climatic conditions of the region, which features an average maximum temperature of 32.3 ºC, minimum temperature of 24.2 ºC, and a mean annual rainfall of 2469.3 mm. Relative humidity averaged 92.2 % in the forenoon and 78.6 % in the afternoon, with a mean daily evaporation of 3.53 mm.

Description of treatments imposed

The experiment was laid out in a factorial randomized block design (FRBD) with three papaya varieties (Arka Prabhat, CO 8, and Taiwan 786) under four types of nutrition and four replications with six plants per treatment per replication.

One month old papaya seedlings were planted in a single row during August 2015 in between two rows of coconut palms which were planted at a distance of 7.5 m × 7.5 m. A spacing of 2 m was given within the row of papaya seedlings. The seedlings were planted in pits of size 30 cm × 30 cm × 30 cm filled with topsoil mixed with 2.5 kg vermicompost and 0.5 kg neem cake. The nutrient treatments as per the technical programme were supplied from three months after planting at bimonthly intervals. All the nutrients were supplied in six times a year during the months January, March, May, July, September and November. Hose irrigation was given uniformly (6 to 8 litres of water) to the plants during summer months.

N_1: 40: 40: 80 g NPK per plant (KAU POP, 2016)

N_2: 2 kg CLVC (coconut leaf vermicompost) + 200 g Rock phosphate + 100 g SOP (Sulphate of Potash)

N_3: 1.25 kg CLVC + 600 g Poultry manure + 100 g SOP

N_4: 1.25 kg CLVC + 500 g Neem cake + *Green manure cow pea

*Green manure cowpea (50 g plant^{-1}) was sown during June and September and was incorporated to the basin during its peak vegetative phase which is calculated as 10 kg fresh biomass per plant per year.

The nutrient composition of the organic manures is estimated as

Coconut Leaf Vermicompost (CLVC)– 1.8: 0.3:1 % NPK

Poultry manure – 2.2: 1.8: 1.1 % NPK

Cowpea fresh biomass – 2.77: 0.25: 2.33 % NPK (Maheswarappa *et al.,* 2005)

For the dioecious variety CO 8, three to four seedlings were initially planted per pit. Following flowering, only one healthy female plant was retained per pit. Male plants were retained at a 1:10 ratio to ensure adequate pollination and maximize fruit yield.

The plant characters such as height of plant, total number of leaves, central vein length, were recorded at monthly intervals after transplanting. In this study, the observations recorded at peak vegetative phase (four months after planting) and the total dry matter production was recorded at peak reproductive phase (18 months after planting). Yield parameters such as number of days taken to first harvest (March 2016) from the day of transplanting, number of fruits produced per plant per year (March 2016 to February 2017), average fruit weight and fruit yield per hectare per year were also estimated. Leaf stomatal resistance was measured at peak fruiting stage using porometer (Porometer AP4, Delta-device, Cambridge, UK) and expressed as seconds per centimetre (s cm^{-1}). The stomatal resistance was measured from the adaxial surface of the youngest fully opened leaf between 11 am and 12 noon. The leaf chlorophyll content was determined spectrophotometrically (Saini *et al*., 2001) from the youngest fully opened leaf of plants with respect to different nutrient levels and varieties were also estimated during its peak fruiting stage.

Statistical analysis was done for each parameter based on factorial randomized block design (FRBD) using SAS 9.3. Differences in parameters were compared using replicated measures analysis of variance (ANOVA) with respect to different treatments.

Results and Discussion

Effect of nutrients on plant growth parameters and physiological responses

Plant height varied significantly with both varietal and nutrient treatments.Among the varieties CO8 (V_2) recorded maximum height (205.7 cm) showing vigorous vegetative growth. Among nutrient levels, CLVC + rock phosphate + SOP (N_2) resulted in maximum height (174.4 cm). In general, the taller plants overall were obtained under V_2N_2 (222.7 cm), suggesting that this variety–nutrition combination provided the most favourable environment for vertical growth. The significant interaction effect (CD v × n = 14.6) highlights that varietal performance depends strongly on the nutrient regime supplied. Similar varietal and nutrient interactions in papaya have been reported, where integrated organic and inorganic nutrition enhanced growth and canopy development (Reddy *et al*., 2009).

The number of leaves was influenced by both variety and nutrient treatments, with the maximum observed in V_3N_2 (88.5). However, the non-significant interaction indicates that while nutrients and varieties independently affected leaf proliferation, their combined effect was not synergistic. This agrees with earlier findings that leaf production in papaya is largely governed by inherent varietal traits, although adequate nutrient supply enhances photosynthetic surface area (Manjunath *et al*., 2020).

The maximum total chlorophyll content was recorded in V_1N_2 (1.26 %), followed by V2N1 (1.11 %) and V_2N_2 (1.08 %). The significant differences across varieties, nutrients, and their interactions suggest that chlorophyll biosynthesis is sensitive to both genotype and nutrient management. Integrated nutrient management in papaya enhances chlorophyll concentration by improving nitrogen assimilation and overall photosynthetic efficiency (Singh *et al*., 2010). Stomatal resistance (Table 1) varied with variety, being consistently higher in var. Taiwan 786, indicating an inherent physiological trait that influences transpiration and water use efficiency. These differences underscore the importance of varietal physiology in determining responses to nutrient availability, in line with findings that papaya varieties exhibit distinct water regulation strategies under varying nutrient regimes (Bindu and Renjan, 2024).

Leaf anatomical development, measured as central vein length, was greatest in V_2N_2 (84.05 cm) and V_2N_4 (83.90 cm). Significant varietal, nutrient, and interaction effects suggest that balanced nutrient regimes enhance vascular development, supporting assimilate translocation and overall plant vigour (Singh *et al*., 2010).

Dry matter accumulation was highest in V_2N_4 (3.81 kg $plant^{-1}$), closely followed by V_2N_2 (3.77 kg $plant^{-1}$). This indicates that CO8 allocates more biomass under nutrient-rich regimes, consistent with its superior height and leaf traits. Dry matter partitioning into vegetative tissues enhances yield potential and biomass accumulation (Bindu and Renjan, 2024).

Table 1. Effect of different treatments on plant growth parameters and physiological responses

Treatments	Plant height (cm)	No. of leaves	Total chlorophyll content (%)	Stomatal resistance(mmol m^{-2} s^{-1})	Length of central vein of leaf (cm)	Total dry matter production (at the time of harvest)- kg $plant^{-1}$
V_1N_1	134.2	68.0	0.68	1.26	52.28	2.95
V_1N_2	155.7	81.5	1.26	1.12	76.70	3.52
V_1N_3	169.3	79.3	0.85	1.12	72.03	3.08
V_1N_4	144.3	76.8	0.78	1.28	64.55	3.45
V_2N_1	182.8	66.8	1.11	0.94	72.73	2.36
V_2N_2	222.7	85.0	1.08	0.94	84.05	3.77
V_2N_3	209.9	82.3	0.83	0.92	79.15	3.45
V_2N_4	207.2	81.0	1.02	1.14	83.90	3.81
V_3N_1	148.1	67.5	0.67	1.08	60.60	1.76
V_3N_2	144.9	88.5	1.00	1.08	75.88	2.02
V_3N_3	156.7	86.3	0.79	1.08	72.50	0.98
V_3N_4	142.0	82.8	0.66	0.89	69.60	0.66
CD_{var} ($p<0.05$)	7.3	2.9	0.03	0.05	3.82	0.18
$CD_{nutri.}$ ($p<0.05$)	8.4	3.4	0.03	0.06	4.41	0.20
$CD_{var\ x\ nut.}$ ($p<0.05$)	14.6	NS	0.05	0.10	7.64	0.35

Effect of nutrients on yield and yield parameters

Being dioecious in nature, variety CO-8 took more days to first harvest, compared to gynodioecious varieties; Taiwan 786 and Arka Prabhat. These differences suggest a trade-off between earliness and biomass accumulation, as taller and more vegetatively vigorous plants tend to reach reproductive maturity later. The treatments supplied with sulphate of potash recorded improved fruit weight and delayed maturity. Similar trends have been documented in papaya, where nutrient-rich conditions extend vegetative growth duration before flowering (Reddy *et al.*, 2009) which might have resulted in higher fruit weight.

Fruit set was highest in V_2N_2 (24.50 fruits $plant^{-1}$ $year^{-1}$), followed by V_1N_2 (21.50), with significant varietal, nutrient, and interaction effects (Fig.1 & 2). The higher fruit count in V_2N_2 suggests that this treatment promoted floral retention and reproductive efficiency, likely due to improved carbohydrate availability with more photosynthetic leaf area. The balanced nutrient regimes improve fruit set by reducing floral abscission and supporting reproductive sink strength (Bindu and Renjan, 2024).

Fig.1. Fruit set of Var.CO8 in juvenile coconut garden

Fig.2. Fruit set of Var. Arka Prabhat in juvenile coconut garden

The maximum fruit weight was recorded under V_1N_2 (1661.5 g), followed by V_2N_2 (1463.3 g). This indicates that while CO8 excelled in fruit number, V_1 under optimal nutrition produced larger individual fruits. Such differences can be attributed to genotypic variation in assimilate partitioning between fruit size and number of papaya yield traits (Agarwal and Sahu., 2021).

Total fruit yield was recorded in V_2N_2 (20.40 t ha^{-1}), followed by V_1N_2 (19.31 t ha^{-1}). Despite V_1 producing heavier fruits, the superior fruit number in V_2N_2 translated into greater overall productivity (Table 2). This demonstrates that yield advantage arises not only from individual fruit weight but also from reproductive efficiency. Integrated nutrient management has previously been shown to enhance papaya yields through balanced vegetative and reproductive growth (Manjunath *et al*., 2020).

Fig.3. Fruits of Var. Red Lady under best treatment

Fig.4. Effect of nutrients on fruit size Var. Arka Prabat

Fig. 5. Effect of nutrients on fruit size Var.CO8

Table 2. Effect of different treatments on yield parameters and yield

Treatments	Number of days to first harvest	Number of fruits produced/plant/yr	Fresh fruit weight (g)	Fruit yield (t) per Ha IC
V_1N_1	134.6	8.25	784.5	9.05
V_1N_2	155.7	21.50	1661.5	19.31
V_1N_3	169.3	16.50	1263.8	13.05
V_1N_4	144.3	19.25	1375.0	16.54
V_2N_1	182.8	11.50	652.5	10.69
V_2N_2	225.7	24.50	1463.3	20.40
V_2N_3	209.9	20.50	1281.0	16.39
V_2N_4	207.2	19.50	1144.8	13.96
V_3N_1	148.1	8.75	603.5	3.31
V_3N_2	144.9	15.25	851.3	8.14
V_3N_3	156.7	13.75	807.0	6.93
V_3N_4	142.0	9.25	766.0	4.43
CD_{var}($p<0.05$)	7.3	4.6	21.13	0.38
$CD_{nutri.}$($p<0.05$)	8.4	5.3	24.40	0.45
$CD_{var\ x\ nut.}$ ($p<0.05$)	14.6	9.3	42.26	0.75

Soil and leaf nutrient status

Growing papaya plants in the interspaces through organics enhances the soil organic matter content thus helping in better soil aeration, root development and establishment of the coconut garden through improved micro climatic conditions. The soil and plant nutrient content varied with different treatments (Fig. 6 and Fig.7)

Fig.6. Effect of different treatments on plant nutrient status such as leaf and stem NPK contents at peak fruiting stage (%)

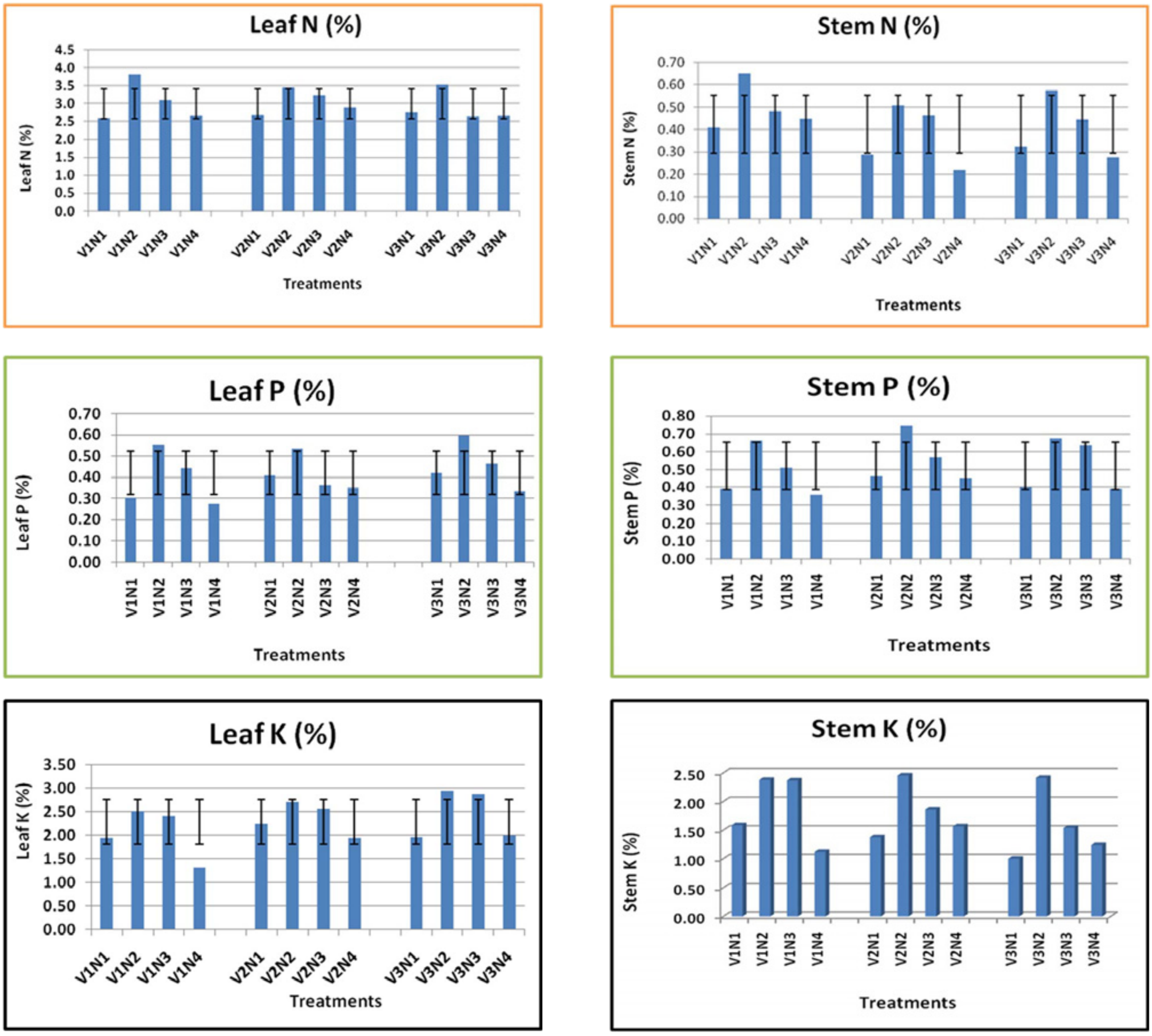
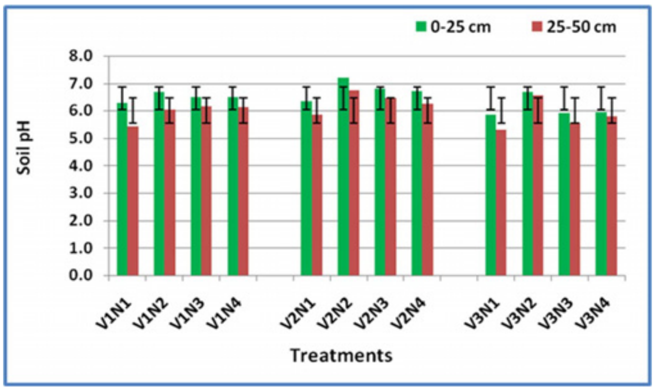
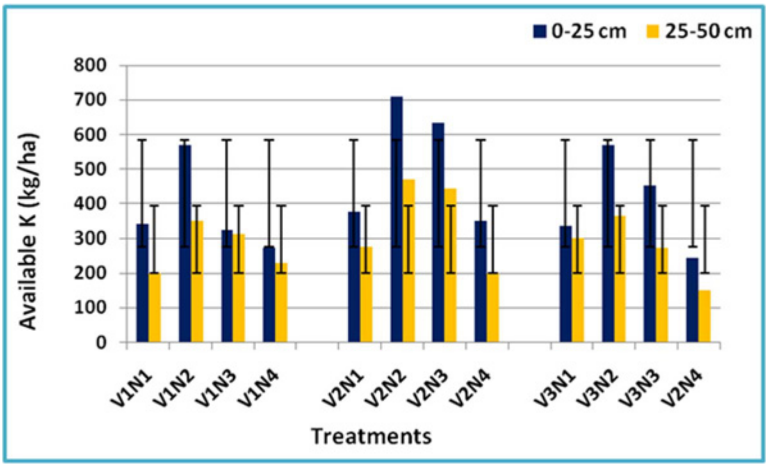


Fig. 7. Effect of different treatments on soil properties such as pH, organic carbon, available potassium and phosphorous at two different depths during peak fruiting stage

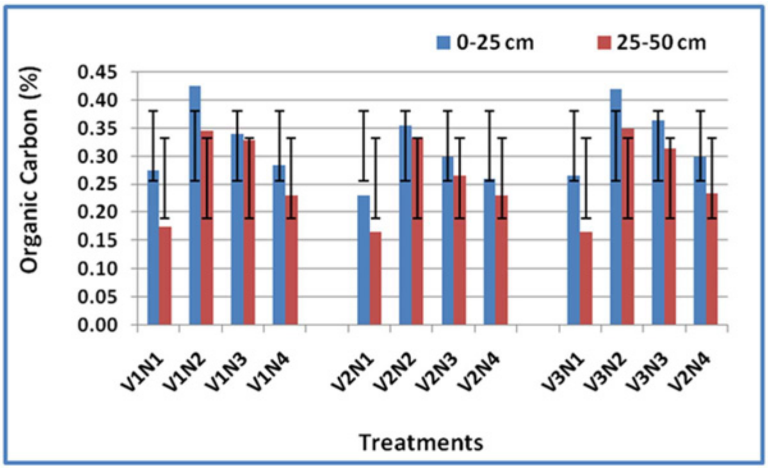
Soil pH



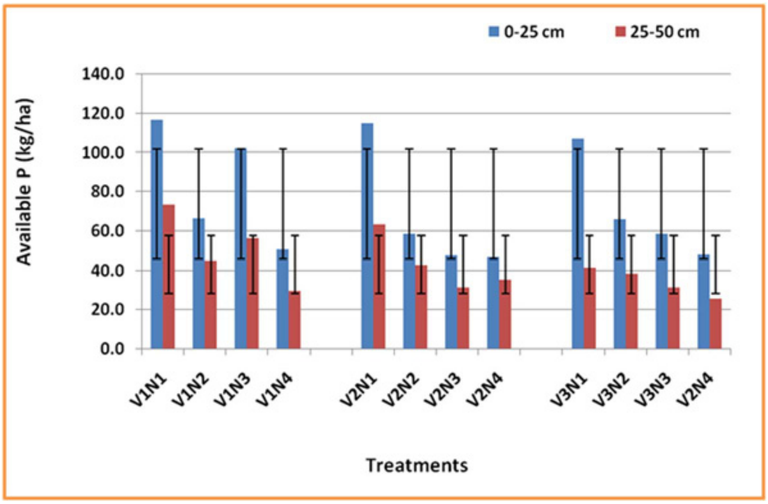
Available K in soil



Organic Carbon in soil



Available P in soil



Soil pH strongly influences nutrient solubility and uptake. Papaya generally prefers slightly acidic to neutral soil pH (5.5–7.0), where macronutrient and micronutrient availability is optimized. The treatment N_2 showed a higher pH of near neutral among all treatments irrespective of the varieties. Our findings indicate that optimal pH levels are critical for nutrient availability (Nihad *et al*., 2023) and yield as balanced pH is particularly important for papaya as it ensures continuous nutrient supply to support rapid growth and fruiting.

The leaf and stem nitrogen were the highest in N_2 treatment and which reflected in the higher number of leaves and the chlorophyll content (Aslantas *et al*., 2007). Balanced nitrogen application is very important for better fruit set and quality of fruits in papaya (Santos *et al*., 2015).

The treatment N_2 recorded the highest available K in soil followed by N_3. The leaf and stem K were also the highest in these treatments. The lowest available K was recorded by N_4 irrespective of the varieties as external application of the nutrient was not done through SOP. This suggests that the availability of the nutrients through the composition of the treatment was not sufficient leading to higher crop removal. Potassium is a very important nutrient for fruit quality, size, taste etc in papaya as it helps in translocation of sugar and soluble solids in the fruits (Kumar *et al.*, 2010) in N_2 treatment was the highest followed by N_3. The higher soil K is linked with increased fruit size, sweetness, and improved post-harvest quality in horticultural crops (Reddy *et al.,* 2009).

Sampling for soil nutrients and organic carbon was done from the plant basin which was supplied with different amendments at bimonthly intervals. The organic carbon content varied among treatments based on the application of the amendments. Soil organic carbon was the highest of treatment N_2 followed by N_3 regardless of the varieties. The lowest organic carbon was recorded by the treatment N_1. Integration of papaya intercropping through organic recycling enhanced soil organic matter status, resulting in improved soil aeration and root proliferation, and favouring establishment of juvenile coconut garden through the development of an improved micro climatic condition. In the case of available phosphorus, the treatment N_1 recorded the highest value due to external application of phosphatic fertiliser in the treatment and other treatments showed varying trend among the different varieties. In the case of leaf P and stem P the highest values were recorded by the treatment N_2 irrespective of the varieties which might be due to the supply of P through rock phosphate. Application of phosphorus fertilizers improved plant height, girth, leaf number, flowering time which indirectly implies better N uptake since these are nitrogen dependent processes.

Economics of the treatment

Papaya can be cultivated in juvenile coconut plantations using organic amendments or integrated nutrient management (INM) utilizing the available organic resources in the system. Under INM, basal inputs are supplemented, with bimonthly applications of urea (90 g plant $^{-1}$), rock phosphate (200 g plant^{-1}), and MOP (130 g plant $^{-1}$), along with an additional dose of dried cow dung (10 kg plant $^{-1}$) after one year of planting. Under organic cultivation, the basal organic dose is complemented by bimonthly applications of coconut leaf vermicompost (2.5 kg plant $^{-1}$), bone meal (100 g plant^{-1}), and sulphate of potash (150 g plant^{-1}).

Based on the coconut spacing of 7.5 m x 7.5 m and the available interspace for intercropping papaya, in a one-hectare juvenile coconut plantation, considering the root spread of main crop and light availability in the interspaces, forty per cent area can be allocated for intercropping, accommodating 1,000 plants. Papaya initiates flowering at about three months after transplanting, fruit setting commences in four months and harvesting of mature fruits starts from six to seven month onwards, with an average annual yield of 22 fruits plant^{-1}.

With 40 % of the plantation area utilized, papaya (*Carica papaya* L.) functions as an efficient intercrop capable of generating substantial income from the fourth month onward for a period of two consecutive years. The total fruit yield obtained from 1,000 plants averaged 30,000 kg per year. The annual cost of cultivation including expenses related to seed procurement, sowing, nursery management, land preparation, input application, transplanting, plant protection, and fruit harvesting was estimated at Rs. 1,26,000 per year during the second and third years of establishment of coconut garden. On average market price of Rs. 12 per kg, the system produced a gross income of Rs. 3,60,000, corresponding to an estimated net return of Rs. 2,34,000 per hectare This is an additional income to the coconut farmers as the main crop comes to bearing and harvest only after three years of planting.

Conclusion

Intercropping papaya in juvenile coconut plantations offers a viable strategy for augmenting farmer income during the unproductive early years of coconut cultivation. Both variety and nutrient management significantly influence physiological and yield traits. Papaya variety Red Lady showed a strong balance of early harvest (155.7 days) and high yield (19.31 t/ha). Among the evaluated nutrient regimes, the application of coconut leaf vermicompost in combination with rock phosphate and sulphate of potash (N2) recorded significantly higher fruit yield and consistently improved growth performance highlighting potential balanced nutrition for papaya in coastal sandy loam condition.

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