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RESEARCH ARTICLE

Influence of arecanut based cropping systems and nutrient management practices on growth, flowering and yield of arecanut

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Abstract

Arecanut (*Areca catechu* L.) has a lot of unused area in monocropping, which makes medicinal and aromatic plants a good way to increase production. However, there isn't much research on integrated nutrition management in arecanut systems under agroclimatic conditions of Odisha. Hence, a field study was conducted during 2021–22 and 2022–23 in a five-year-old fruit-bearing arecanut plantation (cv. Mohitnagar). The experiment followed a split plot design with three cropping systems as main factor, such as C_1: arecanut + *Curcuma longa* (turmeric) + *C. caesia* (black turmeric); C_2: arecanut + *Andrographis paniculata* (kalmegh) + *Ocimum sanctum* (tulsi); C_3: arecanut + *Withania somnifera* (ashwagandha) + *Rauvolfia serpentina* (sarpagandha). The sub-factor included three nutrient management treatments: N_1: organic recycling + 100 % nitrogen (N), phosphorus (P) and potassium (K) through recommended dose of fertilizer (RDF); N_2: organic recycling + 100 % NPK through soil test based dose (STD) and N_3: organic recycling + 75 % NPK (STD) + biofertilizer consortia. Pooled results over the two-year study showed that organic recycling of biomass with application of 100 % NPK (STD) in the arecanut + ashwagandha + sarpagandha cropping system recorded maximum vegetative growth in terms of plant height, canopy spread and annual leaf production. Meanwhile, cropping system applied with 75 % NPK (STD), biofertilizer consortia and organic recycling of biomass, resulted in highest number of flowering bunch (3.62), fruit set (32.16 %), number of fruits (326.35), fruit weight (48.11 g) and fresh fruit yield (15.13 kg palm^{-1}).

Keywords: : arecanut based cropping system; biofertilizer; chali yield; nutrient management practices; organic matter recycling

Introduction

Arecanut (*Areca catechu* L.) is an important plantation crop in India and belongs to the family Arecaceae. It serves as a primary livelihood source for around ten million individuals, mainly small and marginal farmers. India is the foremost producer and consumer of arecanut globally (1). However, monocropping in arecanut plantation often leads to inefficient utilization of natural resources. Even when planting density is optimal, large portions of the area beneath the canopy remain unutilized, resulting in low economic returns. These vacant spaces are prone to weed growth, which competes with arecanut palms for essential resources like water and nutrients, thereby reducing overall yields. The single-crop cultivation of arecanut does not make full use of environmental resources.

Studies reveal that the palm's tall structure creates a microclimate conducive to intercropping by permitting adequate light penetration and maintaining soil-level humidity. Arecanut palms absorb just 43 % of incident light, which can be increased to 95 % through intercropping (2). Furthermore, with a root spread of about 2.27 m^2, accounting for 68.9 % of the area, there remains ample scope to incorporate additional crops. Assured irrigation in arecanut gardens enhances the scope for growing multiple crops (3).

Given these advantages, relying solely on arecanut monoculture underutilizes natural resources. During the early growth stages within the first five to six years, short-duration annual and biennial crops can be cultivated (4, 5). In later years, various shade-tolerant crops can be integrated. During the pre-bearing period, low-growing crops like rhizomes, tubers, vegetables and flowers are suitable intercrops. High-value crops such as vanilla and medicinal and aromatic plants (MAPs) are also feasible. Several studies support the practicality and benefits of intercropping within arecanut plantations (3, 6-8). Intercrops like banana, pepper, cocoa, elephant foot yam, citrus, betel vine and MAPs can enhance land productivity and resource use efficiency.

Arecanut based cropping systems have demonstrated potential to secure stable income, enhance nutrition, preserve soil health, protect against climatic adversities and improve overall agricultural output. The long pre-bearing stage of arecanut results in low initial returns, making it essential to integrate crops that utilize sunlight, air, water and soil nutrients more efficiently while generating additional income. This system aims to increase overall farm productivity, profitability and sustainability by optimizing economic returns from the available land (Fig. 1).

Incorporating multiple cropping systems also increases labour demand significantly up to 900 man-days annually compared to 405 days under monoculture (9). In developing nations, only about 10 % of MAPs are cultivated, while 90 % are still harvested from the wild (10). Hence, there is a growing need to identify existing cropping systems capable of supporting MAP cultivation under near-natural conditions. Fruit orchards offer one such solution, as their extended gestation phase provides an opportunity to intercrop MAPs, even in mature stages, without adversely affecting shade-tolerant medicinal species (11). While intercropping may sometimes cause yield reductions in one component, the overall returns often exceed those from monoculture systems, making them both economically and environmentally beneficial (12, 13).

The integration of MAPs into arecanut plantations enhances net profitability, reduces pest and disease issues, improves soil fertility and contributes to the national economy through export earnings (14-16). The global demand for herbal and Ayurvedic products has surged, particularly following the COVID-19 pandemic, leading to greater interest in immunity-boosting natural formulations. This shift has amplified the demand for MAPs. To promote MAP cultivation, the Indian government has established the Ministry of AYUSH and the national medicinal plant board, which offer incentives and infrastructure under the national mission on medicinal plants. Each state also has its own medicinal plant board to support sustainable raw material production for Ayurvedic industries.

Odisha's tropical climate and the structural arrangement of arecanut palms make it ideal for MAP cultivation, including crops like turmeric, black turmeric, kalmegh and sarpagandha (2). Many farmers in Odisha remain unaware of MAP cultivation practices and are reluctant to grow them as sole crops due to long gestation periods. Intercropping MAPs with perennials like arecanut present a viable alternative. Species like *R. serpentina*, *O. basilicum* and *Piper longum* have shown high net returns per rupee invested (1.95-4.25) and yield enhancements in arecanut ranging from 11 % to 53 % (3). Proper nutrient management is essential for maintaining productivity in such systems. The combined use of chemical fertilizers, bio-fertilizers and organic amendments such as farmyard manure (FYM) and crop residues improves soil fertility and crop performance (17-19). Since arecanut is a perennial crop with long-term productivity, managing nutrient competition in intercropped systems requires thorough planning and research to achieve optimal results.

To address these challenges, sustainable integrated nutrient management strategies have to be developed for the arecanut cropping systems. In the present-day context, the right combination of organic amendments, biofertilizers and chemical fertilizers is advocated to enhance crop productivity sustainably.

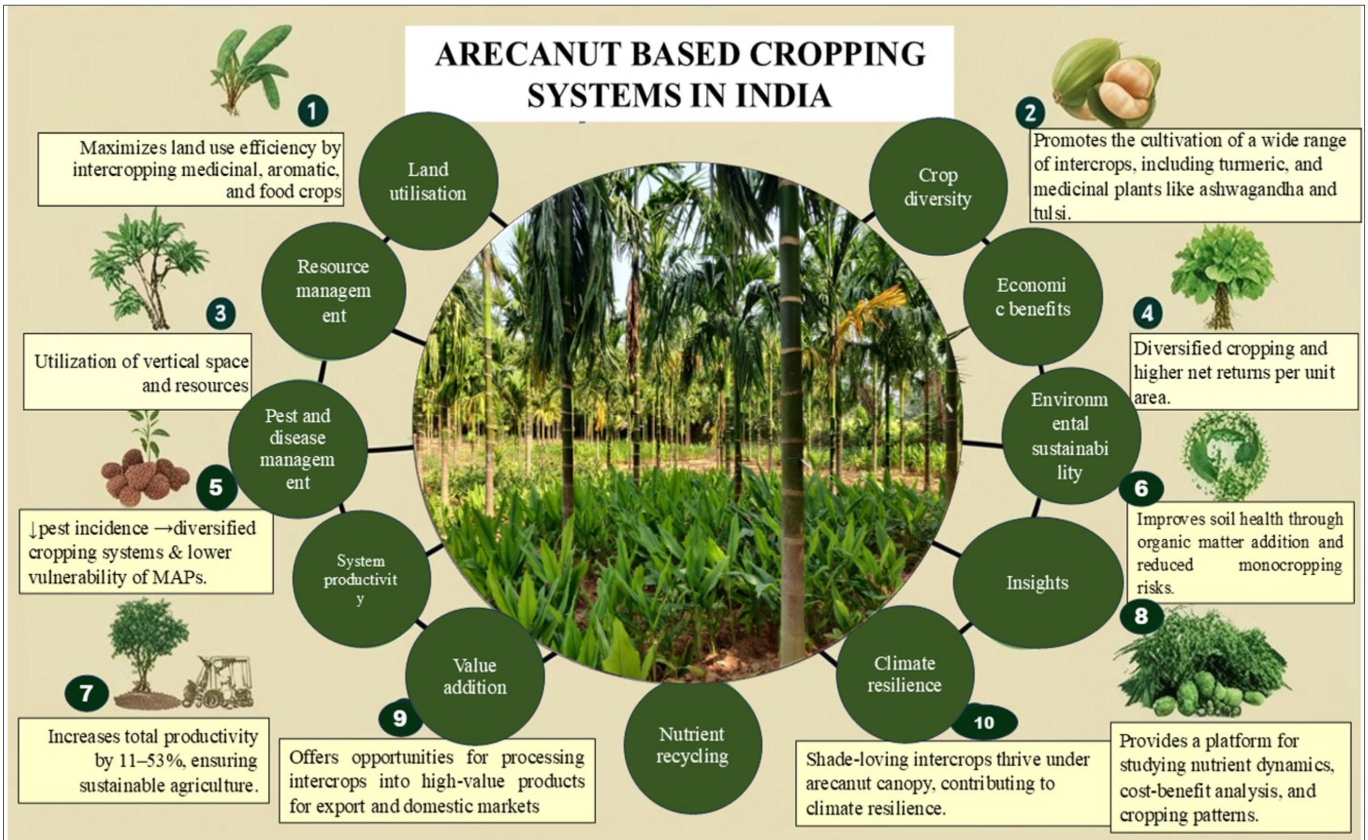

Fig. 1. Scope of medicinal plants in arecanut based cropping system in India.

Materials and Methods

The current study was conducted from 2021 to 2023 at the experimental field of the All India Coordinated Research Project on Medicinal & Aromatic Plants and Betel vine, Horticulture Research Station, Odisha University of Agriculture and Technology, Baramunda, Bhubaneswar. The experiment consisted of two factors: the main factor with three levels of cropping systems (C), such as C_1: arecanut + turmeric (*C. longa*) + black turmeric (*C. caesia*); C_2: arecanut + kalmegh (*A. paniculata*) + tulsi (*O. sanctum*) and C_3: arecanut + ashwagandha (*W. somnifera)* + sarpagandha (*R. serpentina*). The sub-factor has three levels of nutrient management practices (N) such as N_1: recycling of organic matter along with application of 100 % NPK through a recommended dose of fertilizer (RDF); N_2: organic recycling of biomass along with incorporation of 100 % NPK through soil test-based fertilizer dose (STD) and N_3: organic recycling of biomass along with incorporation of 75 % NPK (STD) + biofertilizer consortia.

Design and layout

The experimental area was divided into 27 plots of 8.1 m × 8.1 m (65.61 m^2 area) and each plot consisted of 6 arecanut plants, thus accommodating 162 plants in an area of 1200.0 m^2 under the experiment. The experiment was laid out as per split plot design (SPD) consisting of three main plots and three sub-plot treatments with three replications.

Inputs used

The nutrient management practices as per the treatments were followed for each crop consisting of organic and inorganic components. The nutrients applied in inorganic form were sourced from urea (46 % N), single super phosphate (16 % P_2O_5) and Muriate of Potash (60 % K_2O). The organic treatments consisted of the *in-situ* recycling of organic matter (OMR) generated from the different cropping systems in different treatments. Additionally, in some treatments, biofertilizers, such as consortia mixture [*Azotobacter, Azospirillum* and phosphate solubilizing bacteria (PSB) in 1:1:1 ratio] obtained from the Department of Soil Science and Agricultural Chemistry, OUAT, Bhubaneswar were applied to arecanut and intercrops as per the treatment.

Antecedents of the experimental field

The present study was conducted in a five-year-old established arecanut plantation (cv. Mohitnagar) sourced from ICAR-Central Plantation Crops Research Institute Regional Research Centre, Mohitnagar, West Bengal, planted at a spacing of 2.7 m × 2.7 m. The experimental site was initially prepared during the first week of May 2021 and again in May 2022 to undertake the experiment. Intercrops, such as turmeric (cv. Roma), black turmeric (cv. Pottangi Local), sarpagandha (cv. RS-1), tulsi (cv. CIM Soumya), kalmegh (cv. Anand Kalmegh-1) and ashwagandha (cv. Jawahar Ashwagandha 20), were sown or transplanted in the arecanut plantation leaving a 0.75 m radius around each arecanut plant (Fig. 2).

Observations recorded

The biometric observations on the main crop (arecanut) and intercrops were recorded during the experimentation period i.e., June 2021 to May 2022 and from June 2022 to May 2023.

Vegetative growth characters of arecanut

The height of six palms was measured from the base of the trunk to the tip of the crown and was expressed in meters. The height of each palm was initially recorded in June 2021, i.e., at the beginning of the experiment and subsequently at the end of the first year (May 2022) and at the end of the second year (May 2023). The average incremental palm height for both years was expressed in centimetres. The canopy spread is defined as the horizontal distance measured in two directions, i.e., from North-South (N-S) and East-West (E-W). It was measured for six palms with the help of a marked bamboo pole in June 2021, i.e., at the beginning of the experiment and subsequently after the first year (May 2022) and at the end of the second year (May 2023). The average incremental canopy spread for both years was expressed in centimetres. The number of fully opened leaves produced by six palms was counted during the experimental period by marking them on the spindle leaf. The average value of the number of leaves produced per palm per year was calculated for both years and expressed in numbers.

Reproductive parameter of arecanut

The total number of fully opened spadices produced per palm was counted throughout the investigation period. The average for both years was computed and expressed numerically. Fruit setting percentage was calculated by taking the ratio of the number of fruit set at initial stage (one month after opening of spadix) to the total number of female flowers (buttons) present in the bunch and the result was expressed in percentage. It was calculated for both the years and its average was computed and expressed in percentage.

The number of fruits per palm was determined by counting the number of matured fruits produced from all bunches of a palm during the investigation period, expressed as a numerical value. The average weight of ten randomly selected mature fruits was recorded from each palm's bunch and the average weight of fruits produced from all bunches per palm per annum during the investigation period was determined using a digital weighing scale, expressed in grams. The total fruit yield was calculated by weighing the matured fruit (9 months old) harvested from all bunches of a palm produced during the investigation period and was expressed in kilogram. The average value for both years was computed and was expressed in kilogram.

Statistical analysis

The data were analyzed using analysis of variance (ANOVA) to assess the impact of cropping systems and nutrient management on the arecanut based cropping systems, along with the statistical significance of treatment effects. Treatment means were separated using Duncan's multiple range test (DMRT) at a significance level of $p \leq 0.05$, executed through R Studio software (version 4.1.2). Additionally, principal component analysis (PCA), a multivariate statistical technique, was employed to visualize the relationships among variables by reducing data dimensionality and constructing spatial representations based on the covariance matrix.

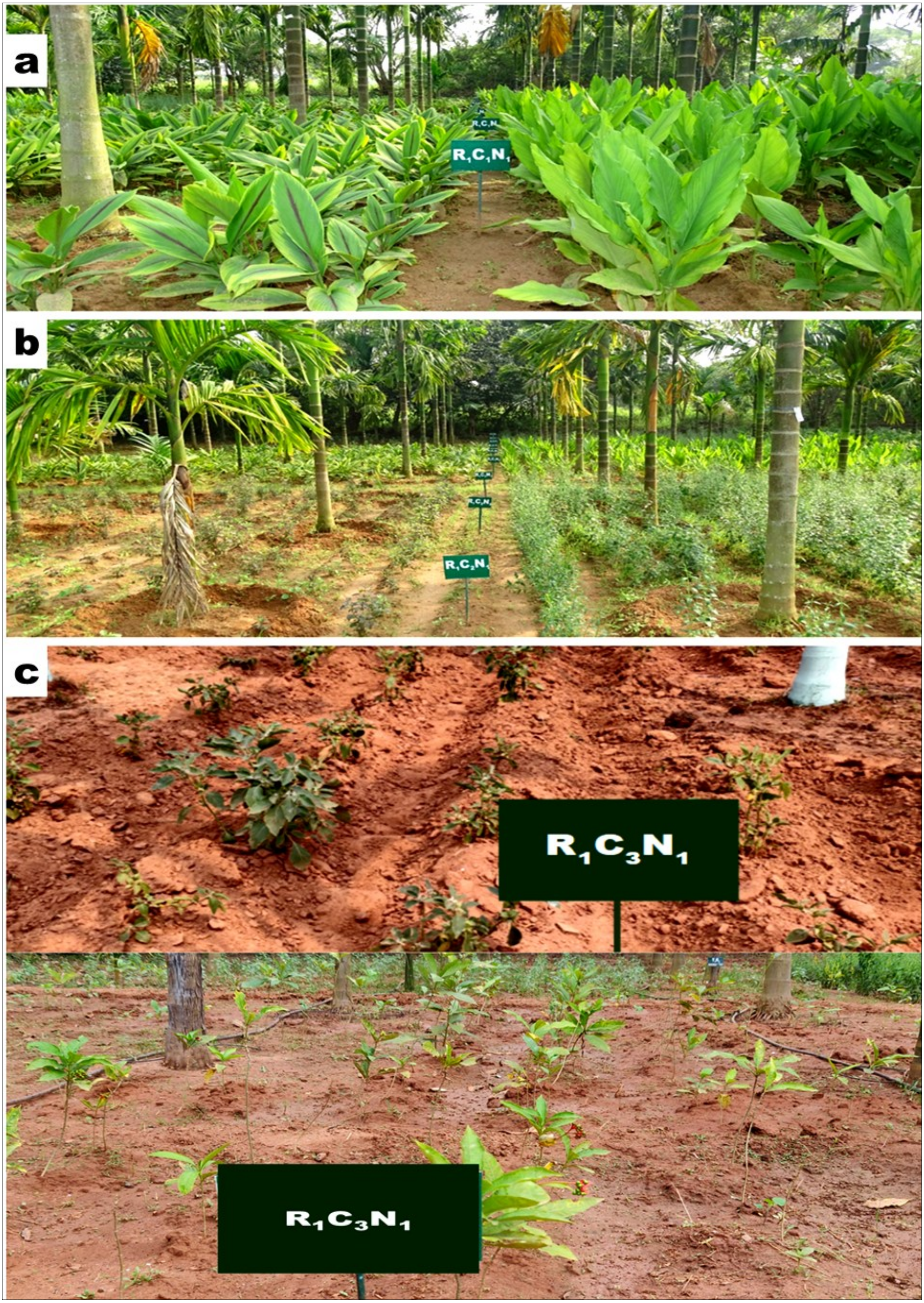

Fig. 2. Treatments plots: **a**. Arecanut + turmeric + black turmeric cropping system; **b**. Arecanut + kalmegh + tulsi cropping system; **c**. Arecanut + ashwagandha + sarpagandha cropping system.

Results and Discussion

Vegetative growth parameters of arecanut

The intercropping of medicinal plants along with nutrient management practices in arecanut garden resulted significant impact on arecanut palm (Table 1). The maximum increment in palm height (73.98 cm) was observed in C_3, which was significantly superior to all other treatments while the minimum increment in palm height (68.51 cm) was noted in C_1. Among the nutrient management practices, the maximum increase in palm height (76.26 cm) was observed in N_2, while the minimum increase in palm height (67.57 cm) was recorded with N_1. The interaction effect of the cropping system and nutrient management practices revealed that there was a significant variation among the treatments. The maximum increase in palm height (78.27 cm) was found in the treatment, C_3N_2, whereas the minimum increase in palm height (63.54 cm) was observed in C_1N_1.

The data recorded on incremental canopy spread in North-South (N-S) direction of arecanut as influenced by arecanut based cropping system, nutrient management practices and their interaction are presented in Table 1. The maximum increment in canopy spread in N-S direction (32.06 cm) was observed in C_3, which was significantly superior to all other treatments while the minimum increment in canopy spread in N-S direction (27.83 cm) was noted in C_1. Among the nutrient management practices, the maximum increase in canopy spread in N-S direction (33.34 cm) was observed in N_2, while the minimum increase in canopy spread in N-S direction (26.56 cm) was recorded with N_1. The interaction effect of the cropping system and nutrient management practices revealed that there was a significant variation among the treatment. The maximum increase in canopy spread in N-S direction (35.05 cm) was found in the treatment, C_3N_2, whereas the minimum increase in canopy spread in N-S direction (24.77 cm) was observed in C_1N_1.

The data related to the incremental canopy spread in East-West (E-W) direction of arecanut, as influenced by arecanut based cropping system, nutrient management practices and their interaction, are presented in Table 1. The maximum increment in canopy spread in the E-W direction (31.69 cm) was observed in C_3, which was significantly superior to all other treatments. In contrasts, the minimum increment (28.31 cm) was recorded in C_1. Among the nutrient management practices, the highest increase in canopy spread in the E-W direction (34.64 cm) was recorded under N_2, whereas the lowest increase (28.93 cm) was observed with N_1. The interaction effect of the cropping system and nutrient management practices was found to be non-significant.

The annual leaf production in the arecanut crown was significantly influenced by arecanut based cropping system and nutrient management practices (Table 1). The maximum number of annual leaf production in the arecanut crown (9.94) was observed in C_3, which was significantly superior to all other treatments while the minimum (9.33) was recorded in C_1. Among the nutrient management practices, the maximum number of annual leaf production in the arecanut crown (10.27) was observed in N_2, while the minimum (9.17) was recorded with N_1. The interaction effect of the cropping system and nutrient management practices was found to be non-significant.

Table 1. Effect of arecanut based cropping system on vegetative growth of arecanut.

Treatment	Incremental			Leaf production
	Palm height (cm)	Canopy spread in N-S (cm)	Canopy spread in E-W (cm)	
Cropping system				
C_1	68.51 c	27.83 c	28.31 c	9.33 c
C_2	70.35 b	28.65 b	30.25 b	9.65 b
C_3	73.98 a	32.06 a	31.69 a	9.94 a
S.E. (m)±	0.15	0.13	0.119	0.017
C.D. (0.05)	0.47	0.44	0.387	0.055
Nutrient management				
N_1	67.57 c	26.56 c	26.72 c	9.17 c
N_2	76.26 a	33.34 a	34.64 a	10.27 a
N_3	69.01 b	28.65 b	28.89 b	9.49 b
S.E. (m)±	0.25	0.12	0.126	0.018
C.D. (0.05)	0.73	0.34	0.367	0.053
Interaction: cropping system (C) × nutrient management (N)				
C_1N_1	63.54 g	24.77 h	24.70	8.88
C_1N_2	74.45 c	32.01 c	32.82	9.92
C_1N_3	67.53 e	26.72 f	27.40	9.20
C_2N_1	69.57 d	25.50 g	26.93	9.22
C_2N_2	76.06 b	32.96 b	34.80	10.25
C_2N_3	65.41 f	27.51 e	29.04	9.47
C_3N_1	69.59 d	29.41 d	28.53	9.41
C_3N_2	78.27 a	35.05 a	36.32	10.64
C_3N_3	74.08 c	31.74 c	30.23	9.79
S.E. (m)±	0.43	0.20	0.218	0.031
C.D. (0.05)	1.26	0.60	NS	NS
S.E. (m)± for C x N x Year	0.61	0.29	0.308	0.044
C.D. (0.05) for C x N x Year	1.78	NS	0.899	NS

C: Cropping system, **C_1**: Arecanut + turmeric + black turmeric, **C_2**: Arecanut + kalmegh + tulsi, **C_3**: Arecanut + ashwagandha + sarpagandha, **N**: Nutrient management, **N_1**: Organic recycling + 100 % NPK (RDF), **N_2**: Organic recycling + 100 % NPK (STD), **N_3**: Organic recycling + 75 % NPK (STD) + biofertilizer consortia.

The application of 100 % recommended dose of NPK (STD) alongside organic biomass recycling in the arecanut + ashwagandha + sarpagandha system resulted in a notable increase in palm height and canopy spread in both the N-S and E-W directions. This enhancement in vegetative growth can be attributed to the synergistic effects of balanced nutrient supply and improved soil physical properties due to organic matter addition. Organic amendments improve soil structure, water retention and aeration, facilitating better root development and nutrient uptake. Moreover, medicinal plants may contribute to soil health through unique root exudates that stimulate microbial activity, further enhancing nutrient availability and plant growth (20, 21). Under the humid tropical climate of Odisha, the complementary relationship between arecanut and suitable medicinal intercrops helps improve the microclimate, regulate soil temperature and retain soil moisture, factors that are essential for healthy vegetative growth. Additionally, studies have reported improvements in plant height, girth and canopy area of arecanut when intercropped with compatible species (22 -29).

Flowering and fruiting behaviour of arecanut

The data recorded on number of bunches per arecanut palm as influenced by arecanut based cropping system, nutrient management practices and their interaction are presented in Table 2. The maximum number of bunches per arecanut palm (3.28) was observed in C_3, which was significantly superior to all other treatments while the minimum (2.86) was recorded in C_1. Among the nutrient management practices, the maximum number of bunches per arecanut palm (3.43) was observed in N_3, while the minimum (2.76) was recorded with N_1. The interaction effect of the cropping system and nutrient management practices revealed that there was a significant variation among the treatment. The maximum number of bunches per arecanut palm (3.62) was recorded in C_3N_3, whereas the minimum (2.51) was observed in C_1N_1. The flowering behaviour of arecanut palm of arecanut + ashwagandha + sarpagandha with organic recycling of biomass + 75 % NPK (STD) + biofertilizer consortia treatment is displayed in Fig. 3.

The cropping system and nutrient management has a significant impact on fruit set (Fig. 4). The maximum fruit set in arecanut palm (31.57 %) was observed in C_3, which was significantly superior to all other treatments, while the minimum (30.38 %) was recorded in C_1. Among the nutrient management practices, the maximum fruit set in arecanut palm (31.62 %) was observed in N_3, while the minimum fruit set in arecanut palm (30.16 %) was recorded with N_1. The interaction effect of the cropping system and nutrient management practices revealed that there was a significant variation among the treatment. The maximum fruit set in arecanut palm (32.16 %) was recorded in C_3N_3, whereas the minimum (29.49 %) was noted in C_1N_1.

The cropping system and nutrient management significantly influenced the number of fruits per arecanut palm. The maximum number of fruits per arecanut palm (322.47) was observed in C_3, which was significantly superior to all other treatments while the minimum (318.20) was recorded in C_1. Among the nutrient management practices, the maximum number of fruits per arecanut palm (323.51) was observed in N_3, while the minimum number of fruits per arecanut palm (317.49) was recorded with N_1. The interaction effect of the cropping system and nutrient management practices was found to be significant. The maximum number of fruits per arecanut palm (326.35) was recorded in C_3N_3, whereas the minimum (315.38) was observed in C_1N_1.

Table 2. Effect of arecanut based cropping system on flowering and fruiting behaviour of arecanut.

Treatment	Number of bunch/palm	Number of fruits/palm	Fruit weight (g)
Cropping system (C)			
C_1	2.86 c	318.20 c	44.42 c
C_2	3.04 b	320.90 b	45.37 b
C_3	3.28 a	322.47 a	46.82 a
S.E. (m)±	0.012	0.12	0.07
C.D. (0.05)	0.038	0.39	0.22
Nutrient management (N)			
N_1	2.76 c	317.49 c	43.47 c
N_2	2.99 b	320.55 b	46.03 b
N_3	3.43 a	323.51 a	47.11 a
S.E. (m)±	0.011	0.10	0.06
C.D. (0.05)	0.032	0.29	0.18
Interaction: cropping system (C) × nutrient management (N)			
C_1N_1	2.51 h	315.38 h	42.32 g
C_1N_2	2.79 f	319.01 f	44.72 e
C_1N_3	3.28 c	320.20 e	46.22 c
C_2N_1	2.71 g	317.89 g	42.96 f
C_2N_2	3.00 e	320.80 d	46.16 c
C_2N_3	3.40 b	323.99 b	47.00 b
C_3N_1	3.06 e	319.20 f	45.14 d
C_3N_2	3.17 d	321.85 c	47.21 b
C_3N_3	3.62 a	326.35 a	48.11 a
S.E. (m)±	0.019	0.17	0.10
C.D. (0.05)	0.056	0.50	0.30
S.E. (m)± for C x N x year	0.027	0.24	0.15
C.D. (0.05) for C x N x year	NS	NS	NS

C: Cropping system, **C_1**: Arecanut + turmeric + black turmeric, **C_2**: Arecanut + kalmegh + tulsi, **C_3**: Arecanut + ashwagandha + sarpagandha, **N**: Nutrient management, **N_1**: Organic recycling + 100 % NPK (RDF), **N_2**: Organic recycling + 100 % NPK (STD), **N_3**: Organic recycling + 75 % NPK (STD) + biofertilizer consortia.

Fig. 3. Flowering stages of arecanut palm in arecanut + ashwagandha+ sarpagandha with organic recycling + 75 % NPK (STD) + biofertilizer consortia treatment (**a**. Arecanut flowers; **b**. Nut setting in arecanut; **c**. 8 months old areca nut).

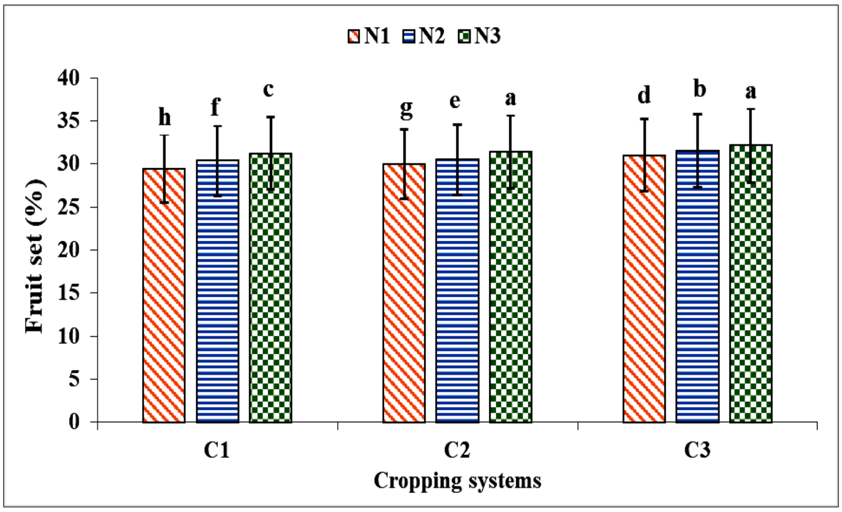

Fig. 4. Fruit set of arecanut as influenced by arecanut based cropping systems and nutrient management practices.

The maximum fruit weight of arecanut (46.82 g) was observed in C_3, which was significantly superior to all other treatments while the minimum (44.42 g) was noted in C_1. Among the nutrient management practices, the maximum fruit weight of arecanut (47.11 g) was observed in N_3, while the minimum (43.47 g) was recorded with N_1. The interaction effect of the cropping system and nutrient management practices found to be significant. The maximum fruit weight of arecanut (48.11 g) was recorded in C_3N_3, whereas the minimum (42.32 g) was noted in C_1N_1.

The application of 75 % NPK (STD) combined with a biofertilizer consortium (*Azotobacter, Azospirillum* and PSB) and organic biomass recycling in the arecanut + ashwagandha + sarpagandha cropping system led to superior reproductive performance. The pooled analysis data revealed that the treatment as mentioned above recorded the highest number of bunches per palm, fruit set percentage, fruits per palm and individual fruit weight. The enhanced reproductive metrics under reduced chemical fertilizer input highlight the efficacy of biofertilizers in improving nutrient use efficiency. *Azotobacter* and *Azospirillum* are known for their nitrogen-fixing capabilities, while phosphate-solubilizing bacteria enhance phosphorus availability, collectively contributing to improved plant nutrition and yield. This integrated nutrient management approach not only sustains high productivity but also promotes environmental sustainability by reducing chemical fertilizer dependency.

Intercropping systems have demonstrated significant improvements in soil nutrient availability, particularly nitrogen and potassium, which are crucial for enhancing reproductive parameters such as the number of bunches, female flowers per palm and fruit set percentage (20, 21, 30). Alternative cropping systems, including arecanut combined with banana, cocoa or pepper proved to be more productive options compared to monoculture practices (31-34). Appropriate intercropping systems can provide substantial yield advantages over sole cropping without compromising soil health in mango based cropping system (35).

Yield of arecanut

The pooled data of both the year study exhibits that the cropping system and nutrient management has a significant impact on fresh fruit yield of arecanut (Fig. 5). The maximum fresh fruit yield of arecanut (14.64 kg $palm^{-1}$) was observed in C_3, which was significantly superior to all other treatments while the minimum (14.02 kg $palm^{-1}$) was noted in C_1. Among the nutrient management practices, the maximum fresh fruit yield of arecanut (14.81 kg $palm^{-1}$) was observed in N_3, while the minimum (13.73 kg $palm^{-1}$) was recorded with N_1. The

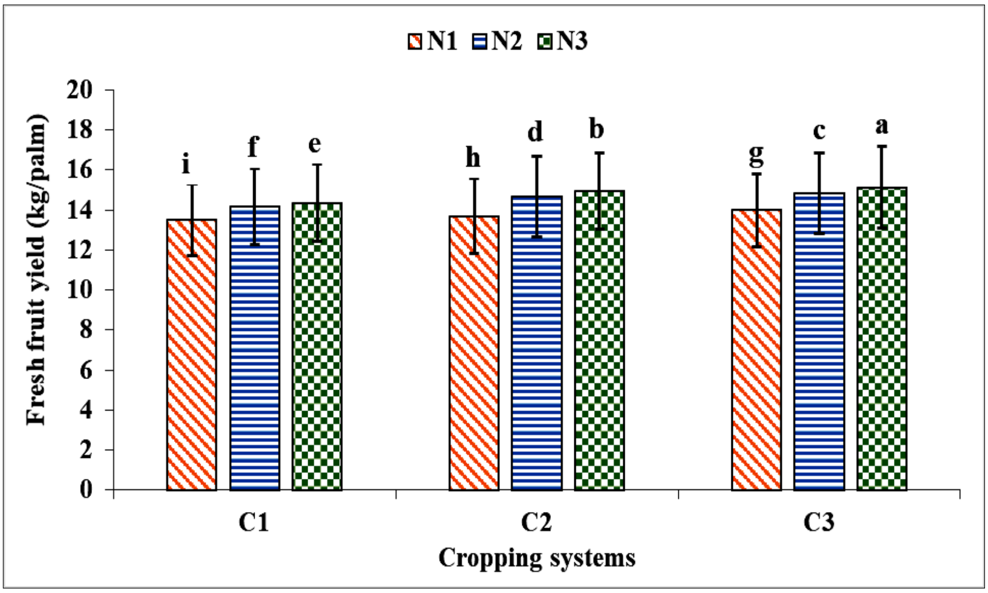

Fig. 5. Fresh fruit yield of arecanut as influenced by arecanut based cropping systems and nutrient management practices.

interaction effect of the cropping system and nutrient management practices revealed that there was a significant variation among the treatment. The maximum fresh fruit yield of arecanut (15.13 kg palm^{-1}) was recorded in C_3N_3, whereas the minimum (13.53 kg palm^{-1}) was noted in C_1N_1.

The enhanced nut yield and weight in the arecanut + ashwagandha+ sarpagandha cropping system can be attributed to the efficient utilization of natural resources such as solar radiation, soil moisture and nutrients, resulting from the complementary interactions between component crops (24, 36, 37). Integrating fruit trees with medicinal crops can enhance fruit productivity, while intercrops not only increase the yield of the main fruit crop but also enrich orchard soil and offer a sustainable revenue source for orchardists (38-42). Overall, intercropping presents significant benefits in boosting productivity and reducing fruit drop.

Principal component analysis of yield attributing parameters as influenced by arecanut based cropping system

The orthogonal projections have been utilized from the first and second principal components for assessing the impact of arecanut based cropping system on yield-attributing parameters of arecanut. By analyzing the interrelationship among number of bunch per palm (BPP), fruit set (FS), number of fruit per palm (FPP), fruit weight (FW) and fresh fruit yield (FFY) across different cropping systems and nutrient levels, we elucidated that the PCA biplot derived from scaled dataset accounted for 94.52 % (PC1) (Fig. 6). Further, the PCA analysis also elucidated the contribution of different variables towards fresh fruit yield. Under the different cropping systems and nutrient management practices, the variables with the most significant contribution followed the order: FPP > FW > BPP > FS. The research work related to principal component analysis carried out in arecanut based cropping system is limited.

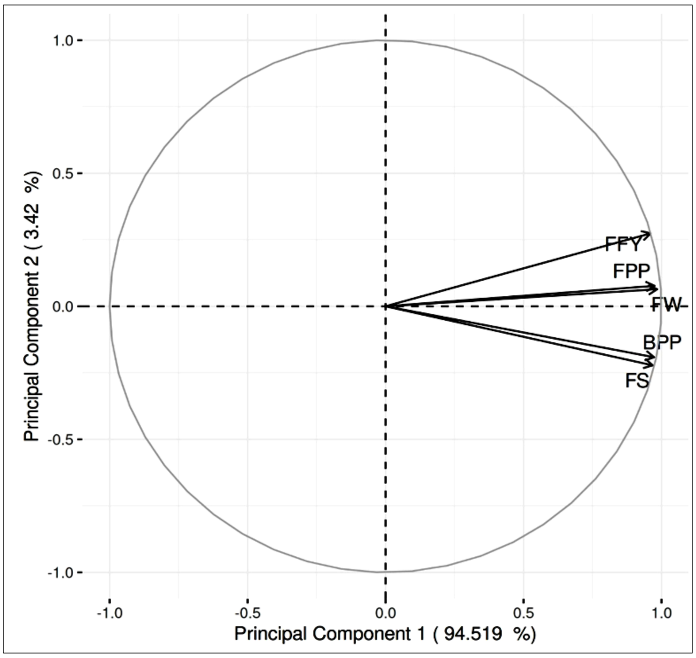

Fig. 6. Principal component analysis (PCA) of yield attributing parameters associated with chali yield in arecanut based cropping system, where **BPP** = Number of bunch per palm, **FS** = Fruit set (%), **FPP** = Number of fruits per palm, **FW** = Fruit weight (g) and **FFY**= Fresh fruit yield (kg palm^{-1}).

However, it is carried out in several other plantation crops like coconut, where the principal component analysis indicated that key traits for distinguishing WCT palms included the length of the spikelet-bearing portion, the number of rachillae, the count of female flowers per inflorescence, the total number of bunches and the number of nuts (43).

Conclusion

The study indicated that adoption of different arecanut based cropping systems along with nutrient management practices resulted in significant influence on plant growth and development of arecanut palm. The organic recycling of biomass with application of 75 % NPK (STD) and biofertilizer consortia (*Azotobacter* + *Azospirillum* + PSB) in the arecanut + ashwagandha + sarpagandha cropping system resulted maximum flowering, fruit set and fresh fruit yield. The findings underscore the importance of a balanced and site-specific nutrient management approach to ensure the long-term sustainability of arecanut cultivation. Future study should focus on improving the long-term productivity and sustainability of arecanut based intercropping systems in a variety of agro-ecological situations by finding the best ways to manage nutrients and crop combinations.

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Authors' contributions

SM carried out the research work with formal analysis and drafted the manuscript. SCS participated in curating the research work methodology and data and revised the manuscript. SS participated in manuscript writing and data curation. RKN participated in the nutrient-related methodology curation. RB participated in the design of study. ZAM performed the statistical analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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