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Synergizing Sustainability: Integrated Nutrient Management and Intercropping for Optimal Coconut Cultivation in South India

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Abstract: The study highlights the importance of integrating organic resources, such as vermicompost and biofertilizers with inorganic fertilizers to sustain coconut yields and manage costs. The experimental trial was conducted from 2016 to 2020 in a 47-year-old East Coast Tall coconut garden at Coconut Research Station in South India. The research evaluated four nutrient management treatments viz., T₁ (75% Recommended Dose of Fertilizer (RDF) + 25% N organic), T₂ (50% RDF + 50% N organic), T₃ (100% N organic) and a control (100% RDF). Intercrops included black pepper (*Piper nigrum*), banana (*Musa acuminata*) and cocoa (*Theobroma cacao*). Organic manure significantly improved soil physical properties, water retention and overall soil health. The T₂ treatment achieved the highest yields for coconut, cocoa, banana and black pepper. The added soil health parameters supported to these findings, with T₂ showing the highest fungal (15.27×10^3 cfu/g of soil) and bacterial populations (17.25×10^5 cfu/g of soil), along with a significant earthworm population (26/m²), indicating enhanced soil ecosystem health. Additionally, soil moisture content was highest under T₃ (100% organic) across various depths, followed by T₂, highlighting the critical role of organic matter in improving soil moisture conservation. The economic feasibility analysis, including a net present value (NPV), benefit/cost ratio (B/C ratio) and an internal rate of return (IRR), revealed T₂ to be the most economically viable nutrient management strategy. This study highlights the economic benefits of intercropping coconuts using an integrated nutrient management (INM) approach, demonstrating its superiority over traditional monocropping practices.

Keywords: integrated nutrient management; sustainability; intercropping; crop productivity; net present value; benefit cost ratio; internal rate of return



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1. Introduction

Coconut (*Cocos nucifera* L.) is extensively grown in tropical and subtropical regions across 97 countries. Remarkably, Indonesia, Philippines, India, Sri Lanka, Thailand and Malaysia together account for 80% of the global coconut cultivation area, significantly contributing to the world's coconut production [1]. India holds the top position as the top coconut-producing nation, with a cultivation area of 21.77 lakh hectares and an annual output of 135.18 lakh tons, according to the Ministry of Agriculture and Farmers Welfare, India, 2022–2023. Coconut palm serves as a multipurpose resource in rural areas, satisfying

numerous needs such as food, shelter, oil, medicinal products, fuel, construction materials and beverages [2].

The coconut-based cropping system (CBCS) is a method that integrates the farming of compatible crops along with coconut plants. These intercropped plants play a vital role in compensating for economic losses. Adopting CBCS represents a strategic approach aimed at optimizing natural resources like land, water, light and space. This approach ultimately leads to improved land productivity, enhanced resource utilization, economic viability and contributes to global food security [3].

Fertigation significantly affects the growth of coconut plants, fruit yield and overall water quality [4]. In terms of nutrient management, organic manures are crucial for maintaining soil fertility and productivity, especially in perennial crops like coconut. Numerous organic manures, including vermicompost, vermiwash, biofertilizer, composted coir pith and in situ green manuring, have demonstrated significant improvements in coconut growth and yield.

Integrated nutrient management (INM) is a method aimed at enhancing productivity in coconut plantations through a combination of various nutrient inputs [5]. The integration of organic manure with chemical fertilizers has been shown to effectively increase nutrient content and expand microbial community structure in the rhizospheric soil [6]. This approach revolves around protecting soil fertility, thereby promoting sustained progress over time [7]. Furthermore, the implementation of the INM system not only enhances soil fertility but also ensures its preservation without subsequent degradation, highlighting its importance in agricultural practices [8].

Organic fertilization is not a vital practice in coconut farming, irrespective of its significance. Maintaining optimal soil organic content levels presents challenges in coconut cultivation, particularly in sandy soils with limited organic matter, leading to slowed crop growth and diminished yields. The application of organic manure offers various advantages, particularly in improving soil physical attributes like water retention capacity, water flow, infiltration rate, bulk density, porosity, soil structure, aeration and overall stability [9,10].

Furthermore, the utilization of organic manure has the potential to boost yields by improving soil productivity and enhancing the efficiency of chemical fertilizer utilization [11–13]. In coconut farming, integrating green manure is vital for boosting soil microflora activity and controlling soil-borne plant pathogens, resulting in enhanced coconut production. Additionally, intercropping has been proven to raise crop yields, improve soil nutrient levels and positively influence the various functions of soil microorganisms and enzymes [14,15]. In many coconut farming regions, the spaces between coconut trees are utilized for growing flowering plants, cocoa, pepper and bananas [16]. Integrated nutrient management (INM) practices increase nutrient use efficiency and sustainability, leading to higher net present values (NPVs) and internal rates of return (IRRs) [17]. This research, carried out in Tamil Nadu, showcased a significant increase in coconut production within coconut-based cropping systems (CBCSs) by employing integrated nutrient management (INM) instead of relying on recycled organic manures [18]. The study's specific objectives focus on providing a comprehensive understanding of how integrated nutrient management and intercropping approaches can be effectively utilized to maximize sustainable coconut yields, ensuring both environmental and economic viability.

2. Materials and Methods

2.1. Experiment Location

The research was carried out at the Coconut Research Station in Veppankulam, Tamil Nadu, India, over five years from 2016 to 2020. The study site is situated at around 10°29' N latitude and 79°23' E longitude, with an elevation of 20 m above sea level. The experiment was conducted on a 47-year-old coconut farm predominantly planted with the East Coast Tall coconut variety, with trees spaced at 7.5 m by 7.5 m intervals. The soil at the research site is sandy loam with moderate nitrogen and phosphorus levels, minor potassium levels

and a pH ranging from 6.5 to 7.0. Furthermore, the area naturally receives an average annual rainfall of 1125 mm (Figure 1).

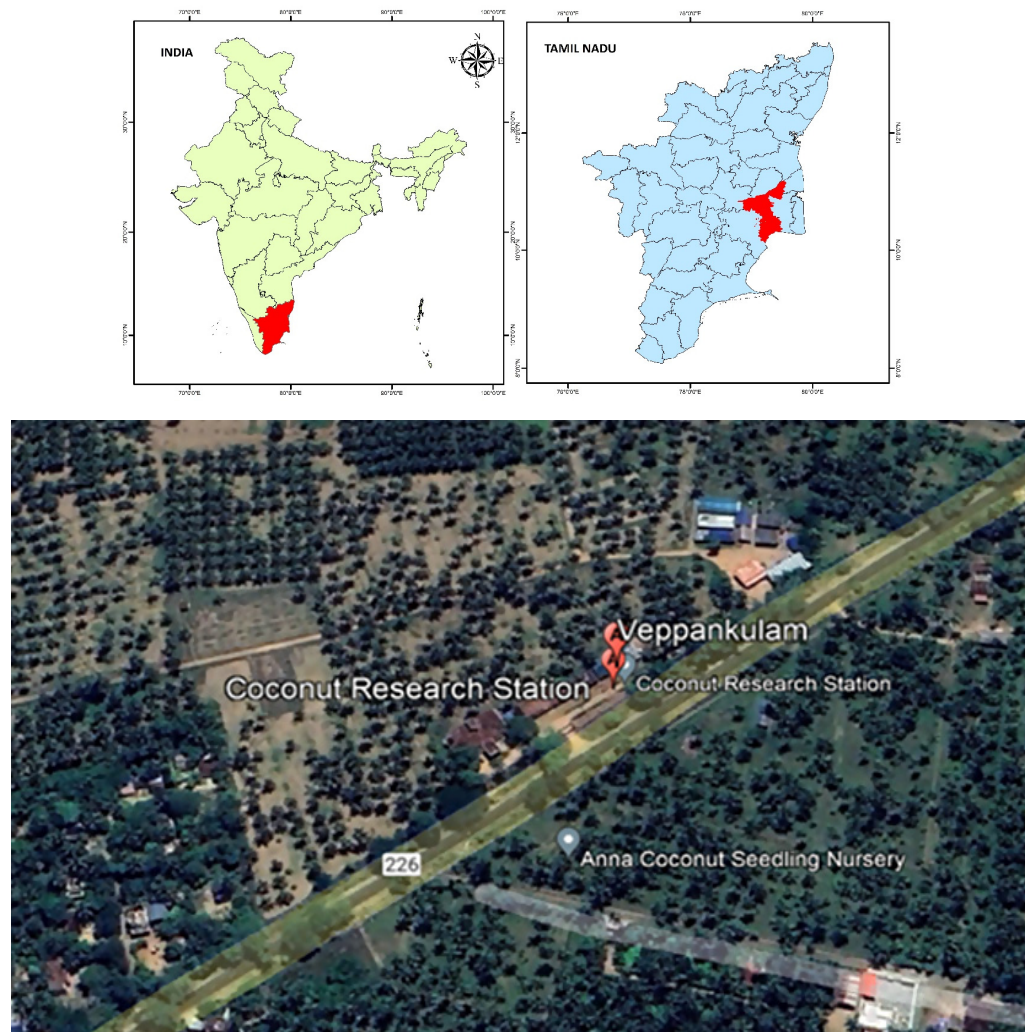


Figure 1. Study area map of the experiment.

2.2. Treatments and Layout

A coconut-based cropping system (CBCS) involves the strategic integration of various crops within a coconut plantation. In the CBCS in the East Coast region of Tamil Nadu, East Coast Tall variety coconuts were intercropped with black pepper (*Piper nigrum*—Panniyur 1), banana (*Musa acuminata*—G9) and cocoa (*Theobroma cacao*—F1 hybrid). By intercropping compatible plants with coconut trees, farmers can achieve better resource utilization, increased economic returns and sustainable agricultural practices. Four nutrient management treatments were implemented: Treatment 1 (75% recommended NPK + 25% N through vermicompost), Treatment 2 (50% recommended NPK + 50% N through vermicompost, vermiwash, biofertilizer and in situ green manuring), Treatment 3 (100% organic-N through vermicompost, vermiwash, biofertilizer, in situ green manuring, green leaf manuring, composted coir pith husk incorporation every 3 years and mulching with coconut leaves) and Treatment 4 (control—recommended NPK and organic manure) from 2016 to 2020. The research investigated the effectiveness of an intercropping strategy with coconut against the conventional monocropping method within a coconut farm. The study utilized a non-replicated experimental design to assess four nutrient management treatments, each applied to a separate 7.5 m by 7.5 m plot containing 27 coconut palms arranged in three rows. The recommended dose of fertilizers (RDF) for coconuts was 500 g N, 320 g P₂O₅ and 1200 g K₂O per palm

annually. Organic inputs such as vermicompost and biofertilizers were administered based on the treatment requirements (Figure 2).

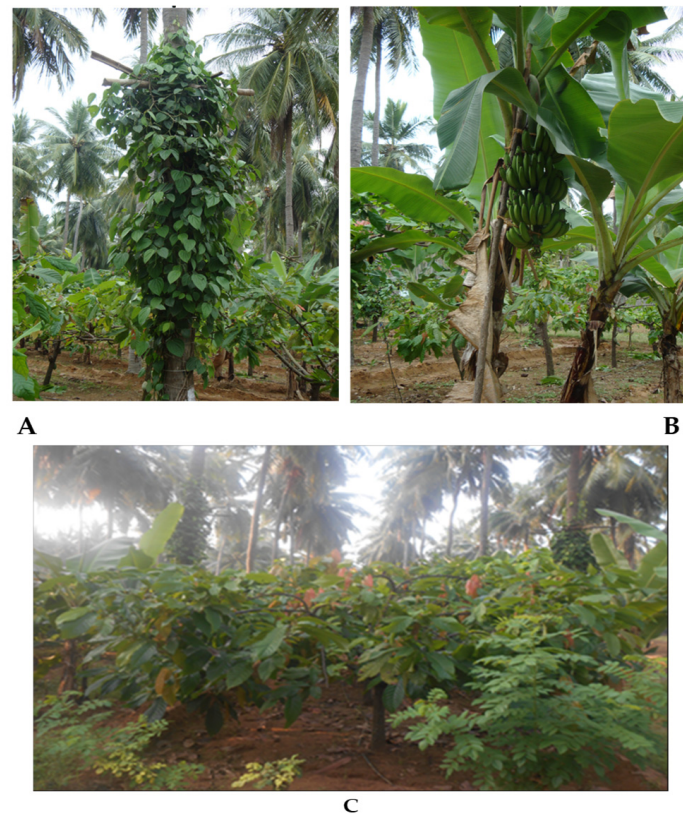


Figure 2. (A) Pepper, (B) banana and (C) cocoa as intercropping in coconut plantation.

2.3. Irrigation Management and Nutrition

Continuous regular agronomic practices were undertaken for all treatments regarding irrigation, weed control and pest management. Organic matter was administered based on treatment needs and irrigation was managed to sustain ideal soil moisture levels.

2.4. Sampling and Analysis

This evaluation was conducted to assess soil health and biological activity.

(i) Soil Health Indicator

Soil microbes: Soil microbial populations were evaluated by sampling soil from the rhizosphere of coconut palms. Fungal and bacterial populations were quantified using serial dilution and plate count techniques.

Earthworm population: The abundance of earthworms was determined by sampling soil from designated areas within each treatment plot.

(ii) Soil Moisture Content

Soil moisture levels were measured at three different depths: 0–30 cm, 30–60 cm and 60–90 cm. Quarterly samples were collected and analyzed using the gravimetric method to accurately determine moisture content at various soil depths.

2.5. Statistical Analysis

Since the experiment utilized a non-replicated design, a descriptive analysis was conducted on the collected data. The observations from each treatment were compared to evaluate the impacts of diverse nutrient management approaches on different parameters.

2.6. Crop (Nut) Equivalent Yield (CEY)

The crop (nut) equivalent yield (CEY) in intercropping systems was determined and the economic analysis was conducted using the average market prices of cocoa, pepper, banana and coconut, as follows:

$$\text{Crop equivalent yield} = \frac{(\text{Yield of intercrop (kg/ha)} \times \text{price of intercrop (USD./kg)})}{\text{Prevailing market price of nut (USD.)}}$$

2.7. Economic Analysis

The economic evaluation of the cropping system was conducted by considering the prevailing market prices of inputs and outputs during the specific timeframe. Annual cash outflows and inflows for the coconut plantation were estimated over a 25-year span. Data on yield and profits from the previous five years were averaged to determine the mean yield and income. The financial viability of investing in a coconut plantation for both groups was assessed through various financial metrics such as net present value (NPV), benefit/cost ratio (BCR), and internal rate of return (IRR). These indicators aid in assessing the long-term profitability and sustainability of different agricultural practices [19].

2.7.1. Net Present Value (NPV)

This represents the discounted value of the net cash flows of the project, and is calculated as follows:

$$NPV = \sum_{t=1}^n \frac{B_t}{(1+r)^t} - \sum_{t=1}^n \frac{C_t}{(1+r)^t} \quad (1)$$

where B_t is the benefit in year ' t ', C_t is the cost in year ' t ' and r is the discount rate (12% for the present study).

Please note that the World Bank applied a discount rate of 12% for project appraisals in developing nations, considering it suitable for the estimation method.

Nutrient treatments that showed a zero or positive net present value when discounted at the opportunity cost of capital were considered economically viable.

2.7.2. Benefit/Cost Ratio

The benefit/cost ratio was determined by dividing the discounted benefits by the discounted costs throughout the lifespan of the coconut plantation. This calculation method was employed to assess the project's financial feasibility, as follows:

$$BCR = \sum_{t=1}^n \frac{B_t / (1+r)^t}{C_t / (1+r)^t} \quad (2)$$

where B_t is the benefit in year ' t ', C_t is the cost in year ' t ' and r is the discount rate (12% for the present study).

2.7.3. Internal Rate of Return (IRR)

The discount rate denotes the rate at which the present value of cash flows equals zero, representing the average return on investment over the project's duration. The formula utilized calculates this rate, as follows:

$$IRR = \left[\begin{array}{c} \text{Lower} \\ \text{discount} \\ \text{rate} \\ \text{(at which} \\ \text{NPV} \\ \text{is positive)} \end{array} \right] + \left[\begin{array}{c} \text{Difference} \\ \text{between the} \\ \text{higher and} \\ \text{lower} \\ \text{discount} \\ \text{rates} \end{array} \right] + \left\{ \begin{array}{c} \text{Present worth} \\ \text{of cashflow at} \\ \text{lower discount} \\ \text{rate} \end{array} \left| \begin{array}{c} \text{Absolute} \\ \text{difference} \\ \text{between the} \\ \text{present worth} \\ \text{of the cash flow} \\ \text{at the higher} \\ \text{and lower} \\ \text{discount rates} \end{array} \right. \right\}$$

A discount rate of 12%, close to the opportunity cost, was selected for the purpose of discounting cash flows in the context of coconut farming.

3. Results

3.1. Soil Microbes and Earthworm Population

The information presented details the impact of various nutrient management strategies on the populations of soil fungi, bacteria and earthworms in the coconut rhizosphere, as illustrated in Table 1.

Table 1. Soil microbes and earthworm population in coconut rhizosphere.

Treatment	Fungi 10^{-3} cfu/g of Soil	Bacteria 10^{-5} cfu/g of Soil	Earthworm Population (Nos.)/m ²
T ₁ —75% RDF + 25% Organic	10.24	11.75	22
T ₂ —50% RDF + 50% Organic	15.27	17.25	26
T ₃ —100% Organic	11.22	13.15	27
T ₄ —Control	10.38	10.20	18

cfu/g refers to colony-forming units per gram of soil, and worms/m² refers to the number of earthworms per square meter of soil; RDF—recommended dose of fertilizers.

Among the treatments, Treatment 2 (T₂) exhibited the highest fungal population (15.27×10^3 cfu/g of soil), indicating that a balanced mix of inorganic and organic fertilizers significantly boosts fungal activity in the soil. Similarly, T₂ also showed the highest bacterial population (17.25×10^5 cfu/g of soil), showcasing the effectiveness of combining organic matter with inorganic fertilizers to enhance bacterial activity, compared to the control treatment (T₄), which had the lowest bacterial population (10.20). This underscores the benefits of organic inputs for earthworm populations, which play a vital role in soil health.

The results indicate that combining organic inputs with inorganic fertilizers, especially in the T₂ treatment, significantly enhances the populations of soil fungi, bacteria and earthworms in the coconut rhizosphere. These results emphasize the vital importance of organic materials in nurturing a balanced soil ecosystem, crucial for the sustainability of coconut cultivation.

3.2. Soil Moisture Content at Coconut Rhizosphere (%)

The statistics provided illustrate the soil moisture levels at different depths (0–30 cm, 30–60 cm and 60–90 cm) in the coconut rhizosphere under different nutrient management approaches, as outlined in Table 2.

Table 2. Soil moisture content in coconut rhizosphere (%).

Treatment	60–90 cm	30–60 cm	0–30 cm
T ₁ —75% RDF + 25% Organic	15.00	14.55	13.05
T ₂ —50% RDF + 50% Organic	20.25	19.26	17.23
T ₃ —100% Organic	21.00	20.00	19.00
T ₄ —Control	13.42	10.05	9.55

RDF—recommended dose of fertilizers

The results obviously demonstrate that incorporating organic inputs leads to a notable enhancement in soil moisture levels throughout various soil depths in the coconut rhizosphere. The T₃ treatment (100% organic) consistently showed the highest moisture retention, followed by the T₂ treatment. These findings emphasize the vital role of organic fertilizers in enhancing soil moisture retention, key for sustaining coconut productivity, especially in regions susceptible to water scarcity.

3.3. Growth and Yield of Coconut

To address the challenge of meeting the nutritional needs of the highly demanding coconut palm without relying solely on fertilizers, it is recommended to utilize organic resources such as coconut by-products, intercrops, vermicompost and biofertilizers. The combined application of these organic sources with a suitable fertilizer mix has proven effective in enhancing crop yields and maintaining soil health. An analysis of average data collected over a five-year period, from 2016 to 2020, shows a significant impact of both inorganic and organic nutrient management strategies on coconut nut yield, as detailed in Table 3.

Table 3. Effect of nutrient management on nut yield of coconut in coconut-based cropping system.

Treatments	Mean Nut Yield of Coconut—(2016–2020) (No. of nuts ^{−1} palm ^{−1} year ^{−1})					Mean Yield
	2016	2017	2018	2019	2020	
T ₁ —75% RDF + 25% Organic	100	103	107	112	113	107
T ₂ —50% RDF + 50% Organic	114	112	124	123	122	119
T ₃ —100% Organic	109	112	113	114	117	113
T ₄ —Control	99	96	103	101	101	100

RDF—recommended dose of fertilizers

The nutrient management approach, combining 50% inorganic fertilizer with 50% organic sources, as demonstrated in T₂, significantly increased nut yield to 119 nuts per palm per year. This is remarkably higher than the 100 nuts per palm per year attained with the recommended inorganic fertilizer application in the coconut monocropping scenario (T₄) during the period from 2016 to 2020. The integration of 50% RDF and 50% organic fertilizers is crucial in enhancing coconut nut yield [20–22].

Among the various treatments, T₂, which combines 50% recommended NPK and 50% organic recycling with vermicompost, vermiwash, biofertilizer and in situ green manuring, resulted in higher yields.

3.4. Yield of Coconut and Component Crops

Intercropping enhances resilience against pests and diseases, improves land productivity per unit area and serves as a sustainable and resource efficient farming approach, thereby contributing to both food and environmental security [23]. The productivity of nut yield, cocoa dry bean yield, banana fruit yield and dried black pepper yield in the CBCS was strongly affected by the levels of inorganic and organic nutrient management, as detailed in Table 4.

Table 4. Effect of nutrient management on yield of coconut and constituent crops.

Treatments	Mean Yield (2016–2020)			
	Coconut (Nuts ha ^{−1})	Cocoa (kg·ha ^{−1})	Banana (kg·ha ^{−1})	Pepper (kg·ha ^{−1})
T ₁ —75% RDF + 25% Organic	16,050	290.00	22,340	38.30
T ₂ —50% RDF + 50% Organic	17,850	300.20	24,650	41.12
T ₃ —100% Organic	16,950	219.80	22,312	36.42
T ₄ —Control	15,000	-	-	-

RDF—recommended dose of fertilizers.

Among the various nutrient management treatments, T₂ showed outstanding performance in terms of coconut nut yield (17,850 nuts·ha^{−1}·year^{−1}), cocoa dry bean yield (300.20 kg·ha^{−1}), banana fruit yield (24,650 kg·ha^{−1}) and dried black pepper yield (41.12 kg·ha^{−1}). This was closely followed by 100% organic nutrient management, which involved organic recycling

with vermicompost, vermiwash, biofertilizer, in situ green manuring, green leaf manuring (*Gliricidia sepium*), composted coir pith husk incorporation (once in 3 years) and mulching with coconut leaves.

Coconut palms exhibit a synergistic outcome in intercropping systems, leading to enhanced coconut yields. Studies have shown that appropriate management practices can sustain yields over time, even as intercrops grow dynamically and utilize nutrients and soil moisture.

3.5. Crop (Nut) Equivalent Yield

The crop (nut) equivalent yield of intercrops, as shown in Figure 3, significantly increase in T₂, for cocoa (6004 nuts ha⁻¹ year⁻¹), banana (20,542 nuts ha⁻¹ year⁻¹) and pepper (2741 nuts ha⁻¹ year⁻¹). Following closely was T₃, representing wholly organic nutrient management. The productivity of the intercropping system with coconut, measured in terms of coconut crop (nut) equivalent yield, showed a significant increase in T₂—50% of recommended NPK + 50% of N concluded organic recycling with vermicompost + vermiwash + biofertilizer + in situ green manuring, reaching 29,287 nuts ha⁻¹ year⁻¹ [24].

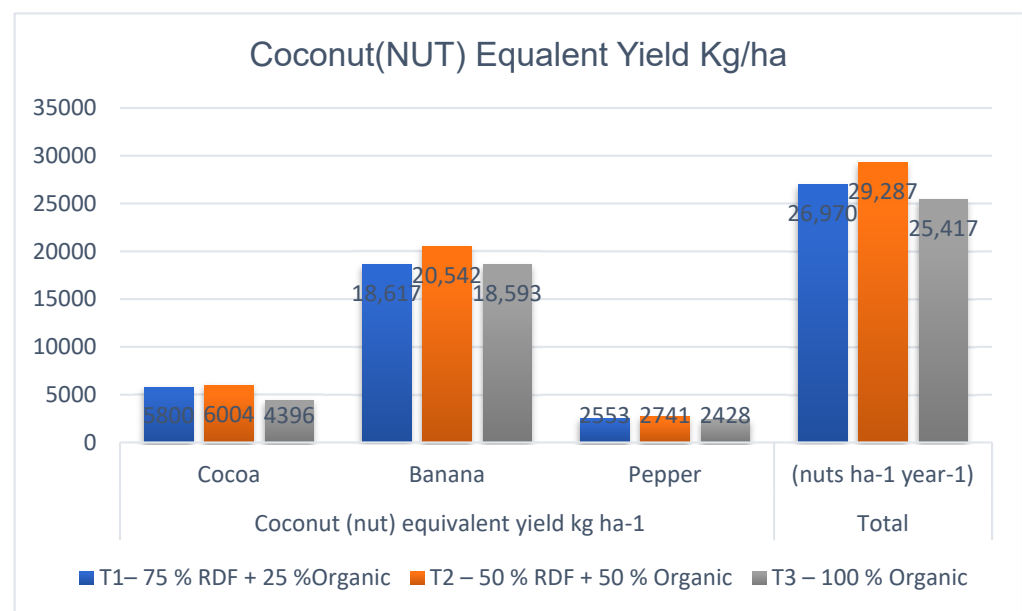


Figure 3. Effect of nutrient management on coconut (nut) equivalent yield.

These experiments demonstrate the feasibility of growing green manure crops within coconut basins and incorporating it into the soil to supply nitrogen and enhance organic matter content. Biofertilizers, appreciated for their cost-effectiveness, efficacy and renewable nature, act as an important nutrient source for plants alongside chemical fertilizers. They play a crucial part in integrated plant nutrient management for sustainable farming, presenting significant potential to enhance crop yields [25].

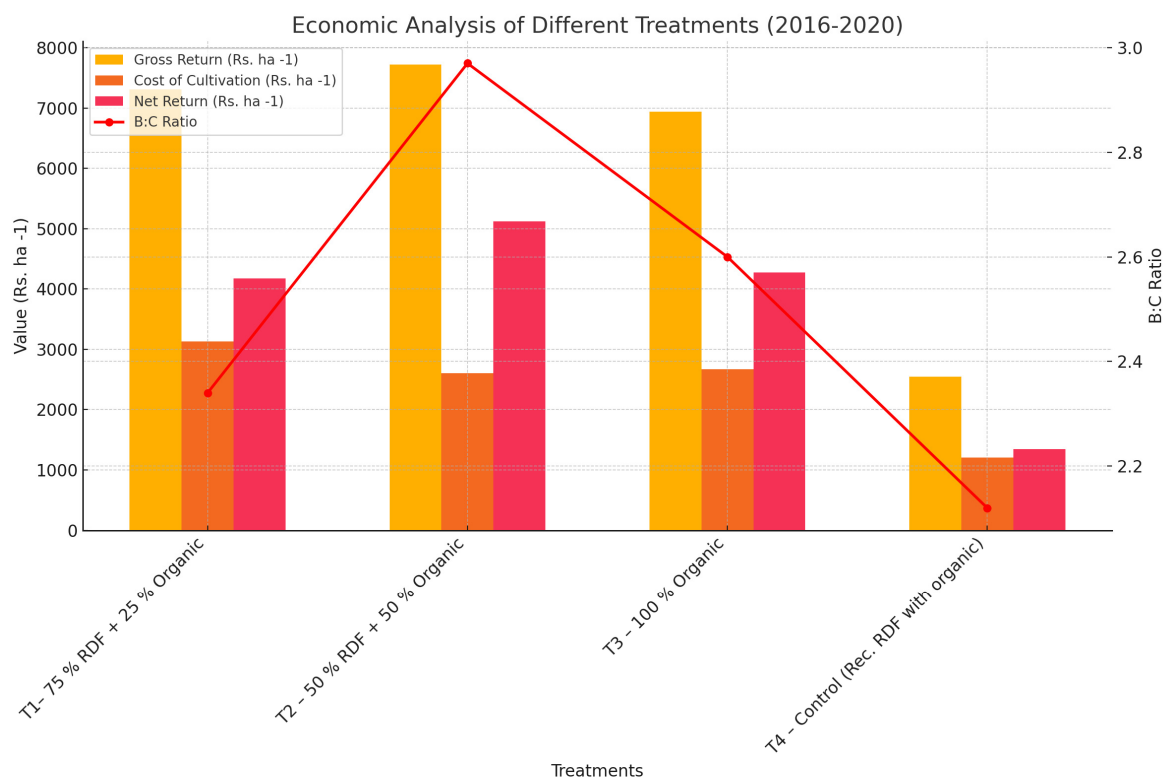
3.6. Economics of Coconut-Based Intercropping Systems

The important metrics to consider are gross return, cultivation cost, net return and benefit/cost (B/C) ratio. These metrics support our understanding of the profitability and efficiency of each treatment. In CBCS, four different treatments were evaluated over a period between 2016 and 2020. The economic outcomes of the INM treatment in the coconut-based cropping system are summarized in Table 5 and Figure 4.

Table 5. Economics of INM treatment in coconut-based cropping system (USD·ha^{−1}).

Treatment	Mean Value of Economics (Rs·ha ^{−1})—(2016–2020)			
	Gross Return	Cost of Cultivation	Net Return	(B/C) Ratio
T ₁ —75% RDF + 25% Organic	7309.21	3130.78	4178.43	2.34
T ₂ —50% RDF + 50% Organic	7724.45	2602.75	5121.70	2.97
T ₃ —100% Organic	6940.00	2666.37	4273.62	2.60
T ₄ —Control	2549.86	1205.88	1343.98	2.12

RDF—recommended dose of fertilizers.

**Figure 4.** Comparison of economic performance of INM treatment in CBCS (2016–2020).

Treatment 2 (T₂), which includes nutrient management with 50% inorganic fertilizer and 50% organic nutrient management, yielded the highest gross income [20,21] of 7724.45 USD per hectare per year (Table 5). This was closely followed by T₃, which represents 100% organic nutrient management, including organic recycling with vermicompost, vermiwash, biofertilizer, in situ green manuring, green leaf manuring (*Gliricidia* leaves), composted coir pith husk incorporation (once in 3 years) and mulching with coconut leaves, yielding a net income of 6940.00 USD per hectare per year. In contrast, the monocropping of coconut with the recommended dose of fertilizer application documented the lowest net income of 2549.86 USD per hectare per year. This balanced approach provides a sustainable and profitable model for farmers looking to maximize their returns from intercropping systems. The outcomes [26] of the research support the evidence that intercropping can increase the primary crop's production of nuts. The coordinated use of resources increases overall efficiency, leading to increased coconut crop yields [27]. Similar benefits have been perceived with vegetables [28] and medicinal and aromatic plants [29,30].

3.7. Economic Feasibility Analysis

The economic viability of different integrated nutrient management (INM) treatments in a coconut-based cropping system is assessed using key financial indicators such as net present value (NPV) and internal rate of return (IRR). The financial feasibility of intercropping in a coconut-based cropping system is outlined in Table 6.

Table 6. Economic feasibility of intercrops in coconut-based cropping system (USD·ha^{−1}).

Treatment	Mean Value of Economics (USD·ha ^{−1})—2016–2020	
	NPV > 0	IRR > 12%
T ₁ —75% RDF + 25% Organic	6007.81	30%
T ₂ —50% RDF + 50% Organic	8824.73	38%
T ₃ —100% Organic	6101.67	29%
T ₄ —Control	4847.12	10%

RDF—recommended dose of fertilizers.

NPV is a crucial metric for measuring investment profitability, determined by deducting the present value of cash outflows from cash inflows over a specific time period. Assessments of NPV for coconut plantations, taking into account different fertilizer combinations in both intercropping and monocropping scenarios, highlight the diverse impacts of these strategies. At a nominal interest rate of 12% per annum, Treatment 2 (T₂), incorporating 50% inorganic fertilizer with 50% organic nutrient management, exhibited the highest NPV of 8824.73 USD. In contrast, Treatment 4 (T₄), involving the recommended dosage of inorganic fertilizers in a monocropping control scenario, resulted in a lower NPV of 4847.12 USD.

An internal rate of return (IRR) exceeding the standard cost of capital, often set at 12% for agricultural projects, signifies a promising investment position. In the study, IRR values reveal that, for coconut intercropping, the T₂ treatment (50% inorganic fertilizer + 50% organic nutrient management) had the highest IRR at 38%, followed by T₁ at 30%. Conversely, in the coconut monocropping scenario, T₄ exhibited the lowest IRR at 10%. Overall, the NPV and IRR values for both intercropping and monocropping, considering different combinations of organic and inorganic fertilizers, highlight T₂ as particularly promising. Based on the financial feasibility analysis, T₂ emerges as the most attractive option due to its superior profitability and efficiency.

4. Discussion

This study, conducted in South India and focusing on sustainable coconut farming, integrating nutrient management and intercropping, has provided valuable insights into enhancing coconut productivity while ensuring environmental sustainability. This Section 4. thoroughly analyzes the key findings and implications of the study.

The excessive use of chemical fertilizers can lead to water contamination, particularly through nitrate leaching, which poses environmental risks and hazards to human and animal health. The integration of inorganic and organic fertilizers through integrated nutrient management (INM) has emerged as a crucial strategy for sustainable coconut agriculture. In Treatment 2 (T₂), utilizing a combination of 50% recommended NPK and 50% organic recycling with vermicompost, vermiwash, biofertilizer and in situ green manuring has demonstrated superior performance in terms of coconut nut yield, cocoa dry bean yield, banana fruit yield and dried black pepper yield.

Microorganisms, whether in symbiosis with leguminous plant roots or existing independently, have the ability to convert atmospheric nitrogen into a functioning form through biological methods [31]. Furthermore, the presence of *Gliricidia* in the soil not only increased potassium (K) levels but also elevated other essential plant nutrients, such as phosphorus (P), calcium (Ca) and magnesium (Mg). A comprehensive global meta-analysis on organic farming systems revealed that integrating conservation tillage, cover cropping

and organic amendments significantly improved soil health by augmenting soil organic matter and microbial biomass [32].

This approach not only improves crop yields but also enhances soil health by increasing organic matter content and improving soil physical and chemical properties. Moreover, organic manure offers numerous benefits, enhancing soil physical properties such as water holding capacity, infiltration rate, bulk density, porosity, tilth, aeration, soil structure and overall stability [10,33,34].

Moreover, intercropping has been highlighted as a beneficial practice in coconut cultivation [35,36]. The study demonstrates that intercropping with compatible crops such as black pepper, banana and cocoa can significantly increase overall crop yield. The crop (nut) equivalent yield (CEY) of intercropping systems was notably higher compared to monocropping, showcasing the economic advantages of diversifying crop species in coconut plantations.

Additionally, intercropping has been identified as a beneficial practice in coconut cultivation, significantly increasing overall crop yield when combined with compatible crops such as black pepper, banana and cocoa. Economic analysis further supports the viability of integrated nutrient management and intercropping systems, with Treatment 2 (T_2), combining 50% inorganic fertilizer and 50% organic nutrient management, emerging as the most financially viable option with the highest net income, benefit/cost ratio (BCR), net present value (NPV) and internal rate of return (IRR).

The study underscores the importance of research and development programs in identifying suitable crop species and models for intercropping. Promoting the integration of economically valuable crop species as intercrops in coconut plantations can lead to improved productivity, resource utilization and economic outcomes, highlighting its cost-effectiveness, environmentally friendly nature and ability to sustain coconut production over time [22].

5. Conclusions

The conclusion of this study on sustainable coconut cultivation through integrated nutrient management and intercropping in South India underscores the significance of adopting integrated approaches for enhancing coconut productivity while ensuring environmental sustainability and economic viability.

The key findings of the study highlight the following points:

The effectiveness of integrated nutrient management (INM): The integration of inorganic and organic fertilizers through INM has shown superior performance in terms of coconut nut yield, cocoa dry bean yield, banana fruit yield and dried black pepper yield. This approach not only improves crop yields but also contributes to soil health by enhancing organic matter content and improving soil physical and chemical properties.

The beneficial nature of the practice of intercropping: Intercropping with compatible crops such as black pepper, banana, and cocoa has significantly increased overall crop yield. The crop equivalent yield (CEY) of intercropping systems was notably higher compared to monocropping, highlighting the economic advantages of diversifying crop species in coconut plantations.

The financial viability of integrated approaches: The economic analysis revealed that Treatment 2 (T_2), which incorporates 50% inorganic fertilizer and 50% organic nutrient management, emerged as the most financially viable option with the highest net income, benefit/cost ratio (BCR), net present value (NPV), and internal rate of return (IRR). This indicates the economic sustainability of adopting integrated approaches in coconut-based cropping systems.

The importance of research and development: The study emphasizes the importance of ongoing research and development programs in identifying suitable crop species and models for intercropping. Promoting the integration of economically valuable crop species as intercrops in coconut plantations can lead to improved productivity, resource utilization and economic outcomes for farmers.

In conclusion, the study provides valuable insights into sustainable coconut cultivation practices that can contribute to long-term environmental conservation, soil health improvement and economic prosperity for coconut farmers in South India. Adopting integrated nutrient management and intercropping strategies is essential for achieving these goals and ensuring the sustainability of coconut-based cropping systems.

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