



Empowering coconut farmers through innovation and economic assessment of TNAU Coconut Tonic

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ABSTRACT

The present study aims to assess the economic association between TNAU Coconut Tonic adoption and farm performance among coconut growers in Coimbatore, Tamil Nadu, in the 2023–24. A survey of 120 farmers (60 users and 60 non-users) was conducted by employing cost-benefit, partial budgeting, Propensity Score Matching (PSM), and regression analysis. Findings indicated that tonic users produced higher yields (24,254 nuts/ha) and net income (₹2.10 lakh/ha) than non-users (19,092 nuts/ha; ₹1.30 lakh/ha). Though variable costs were marginally higher, users registered higher profitability with a benefit-cost ratio of 1.25, an Internal Rate of Return (IRR) of 15.4%, and a reduced payback period of 17.7 years. The PSM results revealed a positive and significant Average Treatment Effect on the Treated (ATT) of 5,162.56 nuts/ha, indicating that tonic adopters obtained approximately 27% higher yield than comparable non-adopters. Regression analysis indicated a positive association between tonic application and coconut yield, in addition to phosphorus and potassium fertilisers, while that of plantation age was negative. Farmers reported higher yield, larger nut size and reduced button shedding following tonic adoption. The major constraints identified were poor knowledge of proper application and low uptake of tonic. The study concludes that adoption of TNAU Coconut Tonic was associated with improved productivity and economic performance among coconut growers in the study area.

Keywords: Coconut growers, Cost and benefit, Farm profitability, TNAU Coconut Tonic

Coconut (*Cocos nucifera* L.), commonly known as the 'Tree of Life', is a vital crop with extensive agricultural, economic, and medicinal significance belonging to the Arecaceae family. In 2022–23, India was the world's largest coconut-producing country, contributing 30.93% of global coconut production. The country had 2.20 mha under coconut cultivation and produced about 20.7 billion nuts, with a productivity of 9,346 nuts/ha (Coconut Development Board 2023). During 2024–25, Tamil Nadu had 5.04 lakh hectares under coconut cultivation and produced 6,218.10 million nuts, with an average productivity of 12,338 nuts/ha. Coimbatore had the largest area under coconut cultivation in the state, covering 94,047 ha (Coconut Development Board 2025). Coimbatore district, with the largest coconut cultivation area (91,809 ha) and production (14,252 lakh nuts) in Tamil Nadu, has ideal agroclimatic conditions and proximity to the Western Ghats, supporting a thriving coconut-based economy Gandhimathi (2023).

To address nutritional deficiencies and to enhance

productivity, the Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu introduced the TNAU coconut tonic in 2002 as an innovative crop booster, providing essential nutrients and growth regulators in liquid form for effective root absorption Kalarani *et al.* (2009). This intervention is particularly significant for small and marginal farmers, as it offers a low-cost, easily adoptable technological solution that integrates well with existing agronomic practices. By improving nutrient use efficiency, root activity, and physiological performance of palms, the tonic has been promoted to improve nutrient use efficiency and farm performance (Alagarswamy *et al.* 2024). Evaluating its cost–benefit ratio, yield response, and long-term sustainability will provide valuable insights for policy formulation and extension strategies in coconut-based farming systems. Such evidence-based assessment supports climate-resilient agriculture and strengthens rural livelihoods in major coconut-growing regions across southern India. In this context, this study aims to evaluate the economic performance and farm-level association of TNAU Coconut Tonic adoption in coconut cultivation.

MATERIALS AND METHODS

Study area and sampling: The present study was

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conducted during 2023–24 in Coimbatore, Tamil Nadu, which was purposively selected due to its leading position in coconut area and production. Three major coconut-growing blocks, namely Pollachi North, Pollachi South, and Anaimalai, were selected. Lists of TNAU Coconut Tonic adopters were obtained from TNAU extension records, while lists of non-adopters were prepared with the assistance of local agricultural officers. These lists served as the sampling frame for the study, and each farmer was assigned a unique identification number before selection. From each group, 60 farmers were selected through simple random sampling, resulting in a total sample of 120 respondents. Primary data on farm characteristics, input use, costs, yields, and returns were collected using a structured questionnaire. Cost-benefit analysis, partial budgeting, multiple linear regression, and Propensity Score Matching (PSM) were employed to evaluate the economic performance and yield association of TNAU Coconut Tonic adoption. West Coast Tall was the predominant coconut variety cultivated in the study area.

Cost-benefit analysis: Cost-benefit analysis in coconut involves evaluating the economic returns over the crop's productive life by comparing the total benefits with the total costs. It includes establishment costs incurred during the initial non-yielding years, along with annual variable costs such as labour, inputs, and maintenance, and fixed costs like depreciation, land rental, and interest on capital.

Amortized cost: It was calculated to spread the high initial investment of establishing coconut plantations over their entire productive life, thereby estimating the annualized fixed costs. This method is critical in long-gestation crops to reflect annualised capital recovery Kishore (2017). The establishment cost incurred during the first seven years was evenly distributed into annual instalments, beginning from the seventh year and continuing throughout the productive lifespan of the coconut plantation. For West Coast Tall coconut varieties, the economic life is 70 years.

$$A = (p \times r) \times \frac{(1 + r)^n}{(1 + r)^n - 1}$$

Where A, Annual amortisation cost in rupees; p, Total capital investment in seven years; r, Discount rate; n, Expected life period of the orchard.

Farm income measures: Farm income measures were calculated to assess the profitability of coconut cultivation, including gross income and net income, following the approach used by Reddy *et al.* (2017).

Gross income: It refers to the total revenue earned from the sale of the main product and by-products before deducting any costs.

$$\text{Gross income} = \text{Yield} \times \text{Price per unit}$$

Net income: It is the amount remaining after deducting all production costs from the gross income.

$$\text{Net income} = \text{Gross income} - \text{Total cost of cultivation}$$

Benefit-Cost ratio: It measures the economic efficiency

of coconut cultivation by comparing returns to costs:

$$\text{Benefit-Cost Ratio} = \frac{\sum_{i=0}^n \frac{B_n}{(1+r)^n}}{\sum_{j=0}^n \frac{C_n}{(1+r)^n}}$$

Where B_n , Benefits in period n; C_n , Cost in period n; r, Discounted rate; n, Economic life period.

Net Present Value (NPV): It measures the present value of future cash inflows and outflows from coconut cultivation, considering the time value of money. A positive NPV indicates that investing in coconut plantation is economically beneficial for growers.

$$\text{Net Present Value} = \sum_{i=0}^n \frac{B_n - C_n}{(1+r)^n}$$

Payback Period (PP): It was used to assess the time required to recover the initial investment in coconut cultivation.

$$\text{Payback Period} = \frac{I}{A}$$

Where I, Initial investment in coconut cultivation; A, Annual cash inflow in coconut cultivation.

Internal Rate of Return (IRR): It is the discount rate at which the Net Present Value (NPV) of an investment becomes zero. A higher IRR than the required rate of return indicates that the project, such as coconut cultivation, is financially attractive to growers.

$$\text{Internal rate of return} = r_1 \frac{\text{NPV}_1}{\text{NPV}_1 - \text{NPV}_2} \times (r_2 - r_1)$$

Where r_1 , Lower discount rate; r_2 , Higher discount rate; NPV_1 , Net present value at lower discount rate; NPV_2 , Net present value at higher discount rate.

Propensity Score Matching (PSM): Propensity Score Matching (PSM) was employed to assess the association between TNAU Coconut Tonic adoption and coconut yield while reducing selection bias arising from observable differences between adopters and non-adopters (Rosenbaum and Rubin 1983). Propensity scores were estimated using a binary logistic regression model:

$$P(X_i) = P_r(D_i = 1 | X_i)$$

Where $P(X_i)$, Propensity score; D_i , Adoption status of the farmer ($D_i = 1$ for adopters and $D_i = 0$ for non-adopters), and X_i , Vector of explanatory variables including age, farm size, annual income, farming experience, number of coconut trees, plantation age, training participation, FPO membership and education level.

The logit model was specified as:

$$\ln \left[\frac{P_i}{1 - P_i} \right] = \beta_0 + \beta_1 X_1 + \beta_2 X_1 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \epsilon_i$$

Where P_i , Probability of adopting TNAU Coconut Tonic; β_0 , Intercept term; β_i , Parameters to be estimated, and ϵ_i , Random error term.

The estimated propensity scores were used to match

adopters with non-adopters through Nearest-Neighbour Matching (1:1), while Inverse Probability Weighting (IPW) was applied as a robustness check. The impact of adoption was measured using the Average Treatment Effect on the Treated (ATT):

$$ATT = E(Y_{1i} - Y_{0i} | D_i = 1)$$

Where Y_{1i} , Observed coconut yield of adopters and Y_{0i} , Counterfactual yield. A positive and statistically significant ATT indicates that Coconut Tonic adoption contributes to higher coconut productivity.

Partial budgeting: Partial budgeting was used to evaluate the economic impact of adopting the TNAU Coconut Tonic among coconut farmers. It measured the net change in income by comparing added returns and reduced costs against additional costs and reduced returns Balan *et al.* (2019):

$$\text{Net Gain loss} = \text{Total revenue} - \text{Total cost}$$

Multiple linear regression: Multiple linear regression analysis is a method used to determine the contribution of different factors to the coconut yield. Multiple Linear Regression analysis as follows:

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_6 X_6 + b_7 X_7 + b_8 X_8 + U$$

Where Y, Yield (Nuts); a, Constant; b_i , Regression coefficient; X_1 , Manures (kg); X_2 , Nitrogen (kg); X_3 , Phosphorus (kg); X_4 , Potassium (kg); X_5 , Coconut tonic (L); X_6 , Plant protection chemical (L); X_7 , No. of trees (Nos.); X_8 , Age of plantation (yr).

Problem faced index: To identify the severity among the problems, Problem Faced Index (PFI) was determined for each problem by using the following formula Rahman *et al.* (2023):

$$PFI = P_n \times 0 + P_l \times 1 + P_m \times 2 + P_s \times 3$$

Where PFI, Problem Faced Index; P_n , Number of farmers who faced no problem; P_l , Number of farmers faced low problems; P_m , Number of farmers faced moderate problems; P_s , Number of farmers who faced severe problems.

Thus, PFI of the problems could range from 0 to 240, where '0' indication no problem and '240' indicates the highest problem, as the number of farmers was 60.

Standardised Problem Faced Index (SPFI) was determined for each problem by using the following formula:

$$SPFI = \frac{\text{PFI of the Problem}}{\text{Highest Possible}} \times 100$$

Thus, SPFI of the problems could range from 0 to 100, where '0' indication no problem and '100' indicates the highest problem.

Weighted average analysis: It was conducted to assess the benefits of the TNAU Coconut Tonic. This method helps determine which factor provides the highest benefit based on its assigned weightage. The analysis ensures an accurate evaluation of the tonic's effectiveness in coconut

cultivation Karthickraja *et al.* (2023):

$$W = \sum_{i=1}^n w_i X_i / \sum_{i=1}^n w_i$$

Where W, Weighted average; n, Number of observations; w_i , Weight applies to X values; X_1 , Decreases button shedding; X_2 , Increased number and size of nuts; X_3 , Increased nut yield by upto 20%; X_4 , Increased longevity and vigour of the palm; X_5 , Resistance to pest, disease and environmental stresses; $\sum_{i=1}^n w_i X_i$, Sum of the observation value and corresponding weight.

RESULTS AND DISCUSSION

The socio-economic variables analysis showed significant differences between tonic users and non-users in their age, size of farm, annual income, and farming experience, all of which are statistically significant.

The results indicate substantial differences between tonic users and non-users. Tonic users were older (47 yr) and had longer experience in farming (16 yr) compared to non-users (40 yr and 11 yr), suggesting that more experienced farmers were more likely to adopt the tonic. They possess more extensive farms (3.09 ha compared to 2.19 ha) and greater annual income (₹2,41,356 compared to ₹2,00,678), which indicates stronger economic performance among tonic users (Supplementary Table 1).

Cost-benefit analysis: The cost-benefit analysis indicates that farmers adopting TNAU Coconut Tonic recorded higher yield and profitability than non-users. The benefit-cost ratio indicates strong economic viability and sustainable returns for farmers. The total establishment cost of coconut cultivation amounts to ₹6.18 lakh, including the first seven years. This cost is spread annually for a realistic profitability assessment (Supplementary Table 2). The investment covers 12 key operations, fencing (₹1.50 lakh, 25.14%); drip irrigation (₹1.25 lakh, 20.23%); labour (₹0.74 lakh, 11.99%); manure application (₹0.72 lakh, 11.64%); fertiliser application (₹0.47 lakh, 7.67%); basal formation (₹0.44 lakh, 7.20%); weeding (₹0.37 lakh, 6%); plant protection (₹0.20 lakh, 3.34%); planting materials (₹0.15 lakh, 2.47%); pit formation and planting (₹0.12 lakh, 2.01%); land preparation (₹0.12 lakh, 1.95%); and gap filling (₹0.02 lakh, 0.35%). Infrastructure, mainly fencing and irrigation, accounts for nearly half of the total cost, while labour, inputs, and maintenance contribute significantly to productivity. Despite high initial investment, these practices are essential for the long-term success and economic viability of coconut farming. Kishore (2017) reported that the initial investment in coconut cultivation in Karnataka was ₹63,708/ha, accounting for 11.96% of the total establishment cost of ₹5,37,266/ha. This included expenditures on land preparation, fencing, planting, and implements, while most of the cost during the gestation period was attributed to maintenance activities, particularly labour and fixed costs such as land rent and depreciation. Similarly, Chinniah and Suresh (2013) estimated the establishment cost in Tamil Nadu at ₹2,92,426.39/ha, covering the entire pre-yield phase from land development to planting and input application,

reflecting the capital-intensive nature of early-stage coconut cultivation. Supporting this, Reddy *et al.* (2017) found that in Andhra Pradesh, the major components of establishment costs included land preparation, pit digging, planting materials, irrigation setup, and fencing, underscoring the significance of initial investments in ensuring long-term productivity and viability of coconut orchards.

The cost comparison between coconut tonic users and non-users highlights significant differences, especially in variable costs (Table 1). The establishment and fixed costs are nearly identical for both groups, at ₹0.74 lakh and ₹0.40 lakh respectively, indicating that tonic use does not affect initial or fixed investments. However, variable costs are notably higher for tonic users at ₹1.37 lakh, compared to ₹1.19 lakh for non-users, a difference of ₹0.18 lakh. Significant increases at the 1% level were observed in expenses for plant protection chemicals, intercultural activities, irrigation, labour, and harvesting. Machine power costs also rose significantly at the 5% level. Overall, the

total cultivation cost was ₹2.51 lakh for tonic users versus ₹2.33 lakh for non-users, mainly due to increased operational intensity associated with tonic use.

The comparative analysis showed that coconut tonic users achieved significantly higher yields (24,254 nuts) than non-users (19,092 nuts), resulting in a yield gain of 5,162 nuts. With both groups receiving ₹19/nut, tonic users earned a higher gross income of ₹4.61 lakh versus ₹3.63 lakh, a difference of ₹98,078 significant. Net income was also notably higher for users at ₹2.10 lakh, compared to ₹1.30 lakh for non-users, a net gain of ₹79,869 significant. However, the input-output ratio was higher for tonic users (1.83) than non-users (1.55), indicating higher returns but reduced cost-efficiency (Table 2). Reddy *et al.* (2017) estimated the establishment cost of coconut cultivation in Andhra Pradesh at ₹17,926.47/ha and annual maintenance cost at ₹58,425.35/ha. Gross and net incomes were ₹72,421.35 and ₹13,996.20/ha, with a BCR of 1.23, NPV of ₹47,371.18, and IRR of 24.25%.

Table 1 Cost-Benefit analysis of coconut

S. No	Particulars	Coconut tonic users		Coconut tonic non-users		Difference over coconut tonic users	't' Value
		Values (₹)	per cent	Values (₹)	per cent		
A	Amortized Annual Establishment Cost (₹/ha/year)	74,163	29.51	74,163	31.82	-	
B	Fixed Cost						
	Depreciation	15,372	6.12	15,217	6.53	155	
	Rental value of owned land	22,000	8.75	22,000	9.44	-	
	Land tax	105	0.04	105	0.05	-	
	Total	37,477	14.91	37,322	16.01	155	
	Interest on fixed capital (7%)	2,623	1.04	2,613	1.12	10	
	Total fixed cost	40,100	15.96	39,935	17.13	165	
C	Maintenance cost						
	Manures (kg)	9,913	8.17	9,656	9.16	257	1.54
	Fertilisers (kg)	22,197	18.27	21,522	20.43	675	1.45
	Plant protection chemicals (L)	3,053	2.52	2,782	2.64	271***	2.76
	Weeding	7,855	6.47	7,587	7.20	268	0.94
	Intercultural activities	8,519	7.02	8,224	7.81	295***	3.43
	Irrigation	18,387	15.16	16,688	15.84	1699***	4.39
	Labour charges	13,545	11.17	12,274	11.65	1,271***	8.58
	Harvesting	28,756	23.71	24,820	23.56	3,936***	9.84
	Machine power	1,825	1.50	1,756	1.67	69**	2.41
	Coconut Tonic Cost (L)	7,271	6.00	-	-	7,271	
	Total maintenance cost	1,21,286	48.26	1,05,308	45.18	15,978***	12.20
	Interest on working capital (13%)	15,767	6.27	13,691	5.87	2,076	
	Total maintenance cost	1,37,053	54.53	1,18,999	51.05	18,054	
	Total cost (A+B+C)	2,51,316	100	2,33,097	100	18,219	

** , Significant at 5% level; *** , Significant at 1% level.

Table 2 Average yield and returns in coconut farm

S. No	Particulars	Value (Coconut tonic users)	Value (Coconut tonic non-users)	Difference	't' Value
1	Average yield (Nuts) (Per ha/yr)	24,254	19,092	5,162***	15.96
2	Average price (₹/Nut)	19	19	-	-
3	Gross income (₹)	4,60,826	3,62,748	98,078***	16.07
4	Net income (₹)	2,09,525	1,29,656	79,869***	15.43
5	Input-output ratio	1.83	1.55		

***, Significant at 1% level.

Kerutagi *et al.* (2017) found higher returns in high-density mango planting (HDP) compared to traditional methods, with establishment costs of ₹2,98,676/acre (HDP) and ₹1,84,823/acre (traditional), and maintenance costs of ₹48,132 and ₹21,783/acre, respectively. HDP gave an average return of ₹2,04,320/acre with a BCR of 2.00 and IRR of 26%, while traditional gave ₹90,950/acre, BCR of 1.49, and IRR of 18%. Kalarani *et al.* (2009) observed that TNAU Coconut Tonic use improved net income from ₹6,620–₹10,208/acre and raised BCR from 1:2.49 to 1:3.04. Kishore (2017) reported coconut cultivation costs at ₹1,61,827/ha with copra offering the highest net return of ₹22,856/ha. Govindasamy (2018) noted gross returns of ₹81,908/acre for small farmers.

West Coast Tall coconut is a long-lived perennial crop that begins economic production after about seven years and has an estimated economic life of around 70 years Nath (2022). Financial owing to its long gestation period and substantial initial investment requirements, financial evaluation is essential for assessing its economic viability. Therefore, the present analysis adopted a 12% discount rate, following the approach of (Gunathilake and Jayasinghe 2021, Selva Rani 2024).

The economic feasibility analysis (Table 3) revealed

Table 3 Evaluation of the economic feasibility and profitability of investing in a coconut plantation and Break-Even Analysis for Coconut Tonic users and non-users

S. No	Parameters	Coconut Tonic users	Coconut Tonic non-users
1	Discounted payback period (yr)	17.72	31.18
2	Net present value (₹)	3,55,042	55,002
3	Benefit cost ratio	1.25	1.04
4	Internal rate of return (%)	15.4	12.24
5	Total fixed cost (₹)	40,100	39,935
6	Total variable cost (₹)	1,37,053	1,18,999
7	Variable cost/unit (₹/Nut)	5.65	6.23
8	Average price (₹/Nut)	19	19

*Discounted rate: 12%.

that coconut tonic users achieved superior financial performance compared to non-users. The discounted payback period was substantially lower for users (17.72 yr) than for non-users (31.18 yr), indicating faster recovery of investment. Similarly, tonic users recorded a higher net present value (₹3,55,042) compared to non-users (₹55,002), reflecting greater economic returns over the plantation life cycle. The Benefit-cost ratio (1.25) and IRR (15.40%) were also higher among users than non-users (1.04 and 12.24%, respectively), suggesting better profitability and financial viability. Overall, the results indicate that tonic users achieved stronger economic performance under the assumptions adopted in this study. Coconut farming is a lucrative and economically viable business venture, even though it is expensive to establish and maintain. Dusang (2023) also indicated that in Sindhudurg, the investment/ha was ₹3,15,710 with NPV worth ₹2,78,299, BCR 1.54, IRR 24.92%, and payback period 10–11 yr, verifying the economic viability of coconut farming.

Propensity Score Matching (PSM): The logit regression results revealed that age, farm size, annual income, farming experience, training participation, FPO membership and education level significantly influenced the adoption of TNAU Coconut Tonic, whereas the number of coconut trees and plantation age were not statistically significant (Table 4). Annual income (OR = 7.946) and farm size (OR = 5.372) emerged as the most important determinants of adoption, indicating that farmers with higher incomes and larger farms were more likely to adopt the technology. The diagnostic statistics confirmed excellent model fit and predictive performance, validating the estimated propensity scores. The propensity score matching results, Table 5 indicated a positive and statistically significant impact of TNAU Coconut Tonic adoption on coconut yield. The nearest-neighbour matching estimate showed an ATT of 5,162.56 nuts/ha, implying that adopters obtained approximately 27% higher yield than comparable non-adopters. The IPW estimator produced a similar ATT of 5,135.76 nuts/ha, confirming the robustness of the findings. The consistency of estimates across alternative methods suggests that Coconut Tonic adoption is associated with higher coconut productivity after controlling for observable differences among farmers. These findings are consistent with the impact evaluation framework of (Rosenbaum and

Table 4 Logit regression results for adoption of TNAU coconut tonic

Variables	Coefficient (β)	Std. error	Odds ratio
Age (yr)	0.919***	0.183	2.507
Farm size (ha)	1.681***	0.151	5.372
Annual income (₹)	2.073***	0.140	7.946
Farming experience (yr)	0.886***	0.160	2.426
Number of coconut Trees	-0.010	0.162	0.990
Plantation age (yr)	0.107	0.137	1.113
Training attended	0.890***	0.148	2.436
FPO membership	0.686***	0.155	1.985
Education level	0.602***	0.160	1.826

*** Significant at 1% level.*Model Diagnostics: McFadden $R^2 = 0.943$; Nagelkerke $R^2 = 0.972$; Hosmer–Lemeshow p -value = 0.760; N = 120.

Rubin1983) and similar agricultural technology adoption studies that reported significant productivity gains from improved farm inputs and management practices.

Partial budgeting: Table 6 showed that applying coconut tonic requires an additional investment of ₹0.07 lakh but generates added returns of ₹0.98 lakh, resulting in net returns of ₹0.91 lakh. With a return on investment of 12.5, the analysis highlights that the cost increase is minimal compared to the gain. This indicates that coconut tonic use is a cost-effective practice, offering strong economic justification for adoption due to its potential to significantly boost farm profitability. Partial budgeting, as shown by Balan *et al.* (2019) revealed that coconut

farmers using the TNAU mobile app earned higher returns despite slightly increased costs, due to better market prices. Similarly, Jeong and Kim (2021) found that switching to high-density mango cultivation yielded a net benefit of 38.96 million/ha, making it economically viable. Wander (2001) emphasized partial budgeting as a practical tool to assess farm changes by comparing added gains with additional costs and losses.

Multiple linear regression: The multiple linear regression results (Table 7) revealed that TNAU Coconut Tonic was positively and significantly associated with coconut yield among adopters (coefficient = 1188.69; $p < 0.01$). The recommended dosage was 40 mL/palm/application, applied twice annually, corresponding to an average application rate of 14.16 L/ha/yr. Among tonic users, phosphorus (36.78, $p < 0.05$) and potassium (18.38; $p < 0.01$) showed significant positive associations with coconut yield, whereas plantation age exerted a significant negative influence (-69.07, $p < 0.01$). Among non-users, phosphorus (29.08, $p < 0.10$), manures (0.29, $p < 0.05$), plant protection chemicals (231.86, $p < 0.05$), and number of trees (76.32, $p < 0.01$) were positively associated with yield, while plantation age remained negatively associated with productivity (-49.29, $p < 0.05$). The regression models exhibited satisfactory explanatory power, with R^2 values of 0.88 and 0.74 for tonic users and non-users, respectively. The overall models were highly significant ($F = 51.34$ and 21.82 , $p < 0.01$), indicating the joint contribution of the explanatory variables in explaining yield variations. All VIF values were below 4, confirming the absence of multicollinearity. Durbin–Watson statistics (1.86 and 1.64) indicated no serious autocorrelation, while Shapiro–Wilk statistics (0.99 and 0.98) confirmed the normality of residuals. Furthermore, the White and Ramsey RESET tests suggested the absence of

Table 5 Effect of TNAU coconut tonic adoption on coconut yield: Propensity score matching estimates

Estimation method	Yield of adopters (Nuts/ha)	Yield of non-adopters (Nuts/ha)	ATT (Nuts/ha)	Yield increase (%)	t-value
Nearest-Neighbour Matching (1:1)	24,254.79	19,092.24	5,162.56***	27.0	15.77
Inverse Probability Weighting (IPW)	24,229.31	19,093.55	5,135.76***	26.9	–

***, Significant at 1% level. *ATT, Average Treatment Effect on the Treated.

Table 6 Partial budgeting analysis of coconut user and non-user of coconut tonic

Cost			Returns		
S. No	Particulars	Value (₹)	S. No	Particulars	Value (₹)
A.	Added cost		C.	Added returns	
	Total added cost (Coconut Tonic)	7,271.24		Total added returns	98,078
B.	Reduced returns		D.	Reduced cost	
	Total reduced returns	(–)		Total reduced cost	(–)
E.	Total cost (A+B)	7,271.24	F.	Total revenue (C+D)	98,078
Net gain (F-E)			₹90,806.76		

Table 7 Factors influencing the coconut yield among users and non-users of coconut tonic

Variables (X)	Coconut tonic user			Coconut tonic non-user		
	Co-efficient	SE	VIF	Co-efficient	SE	VIF
Regression constant	-2465.25	2564.6	-	93.04	3820.29	-
Manures (kg)	0.08	0.12	1.38	0.29**	0.14	1.52
Nitrogen (kg)	10.61	6.71	1.47	8.05	10.77	1.83
Phosphorus (kg)	36.78**	16.64	1.39	29.08*	15.08	1.65
Potassium (kg)	18.38***	4.68	1.41	4.38	3.37	1.41
TNAU Coconut Tonic (L)	1188.69 ***	249.96	1.95	-	-	-
Plant protection chemicals (L)	43.31	120.69	1.17	231.86**	87.81	1.66
No. of Trees (Nos.)	21.40	15.90	3.86	76.32***	20.24	1.15
Age of Plantation (yr)	-69.07***	16.12	1.77	-49.29**	19.65	2.03
R ²		0.88			0.74	
Multiple Correlation Coefficients (R)		0.94			0.86	
F-statistic		51.34			21.82	
Durbin-Watson statistic		1.86			1.64	
Shapiro-Wilk Test		0.99			0.98	
White Test		37.48			46.02	
Ramsey RESET		0.99			1.7	

*Significant at 10%; ** Significant at 5% level; ***, Significant at 1%. VIF, Variance inflation factor.

heteroscedasticity and specification errors, confirming the statistical reliability of the estimated models. The positive contribution of nutrient inputs to coconut productivity observed in the present study is consistent with the findings of Parthiban and Anjugam (2021), who reported significant effects of farmyard manure and bio-fertilisers on coconut yield. Gaude Priolkar (2017) also observed that manures, bearing trees, and irrigation significantly influenced coconut production. Nasrin (2020) reported that farmyard manure, phosphorus, potash, and irrigation significantly enhanced coconut yield in Coimbatore district.

Problem Faced Index: The SPFI analysis indicates that the most significant problem faced by farmers is poor knowledge about the proper application of coconut tonic, with the highest SPFI of 62.8, ranking first. This is followed by low uptake of tonic (SPFI 60.6) and high cost (SPFI 48.3), showing that these are key barriers to effective adoption. Difficulty in application and limited availability at TNAU also pose moderate challenges. Lack of awareness is another issue, though comparatively less severe. The least concerning problem is the perception of no difference in yield, with the lowest SPFI of 12.2. These findings emphasise the need for better education, accessibility, and cost-effective solutions to improve the adoption and proper use of the coconut tonic (Table 8).

Weighted Average Analysis: The weighted average analysis used the advantages of using TNAU Coconut Tonic based on weighted averages. The most significant benefits are an increased number and size of nuts (76.32) and reduced button shedding (75.17), indicating that the tonic

effectively enhances coconut development and minimises premature nut drop. Additionally, nut yield increased by up to 20% (74.77), reinforcing its positive impact on productivity (Supplementary Table 3). Moderate benefits include resistance to pests, diseases, and environmental stresses (56.62) and increased longevity and vigour of palm trees (51.57), suggesting improvements in tree health and resilience. Based on Karthickraja *et al.* (2023), coconut farmers using TNAU Coconut Tonic experienced limitations, including root identification challenges, shortage of labour. However, the use of tonic was associated with several advantages such as improved yield, less button shedding, and improved resistance to pests and environmental stress.

The study assessed the economic performance and farm-level association of TNAU Coconut Tonic adoption among coconut growers in Coimbatore district of Tamil Nadu. The findings revealed that coconut tonic adopters achieved better productivity, profitability and overall farm performance compared to non-adopters. The results of cost-benefit analysis, economic feasibility analysis, partial budgeting and propensity score matching consistently indicated favourable outcomes associated with tonic adoption. Multiple linear regression analysis showed that coconut tonic application and balanced nutrient use contributed positively to coconut yield, highlighting the importance of improved crop management practices. Farmers also perceived notable benefits in terms of enhanced nut development, increased yield and reduced button shedding. However, inadequate knowledge regarding proper application emerged as an

Table 8 Constraints in the use of Coconut Tonic- Results of the standardised problem faced index with rank

Problems	Number of farmers based on the extent of problem faced					Problem Faced Index (PFI)	SPFI *	Rank
	Severe	Moderate	Low	No problem	Total			
Coconut Tonic is available only at TNAU	4	17	25	14	60	71	39.4	V
High cost	8	23	17	12	60	87	48.3	III
Lack of awareness	2	12	25	21	60	55	30.6	VI
Low uptake of tonic	21	16	14	09	60	109	60.6	II
No difference in yield	-	05	12	43	60	22	12.2	VII
Difficulty in application	7	15	22	16	60	73	40.6	IV
Poor Knowledge about the proper application	25	12	14	09	60	113	62.8	I

*Standardised Problem Faced Index with Rank Order

important constraint affecting its effective utilisation. The findings underscore the potential of TNAU Coconut Tonic as a viable technological intervention for improving coconut farm performance. Strengthening extension efforts, farmer training programmes and timely availability of the tonic may facilitate wider adoption and contribute to sustainable coconut production in the study area.

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