Journal of Agricultural Studies
ISSN 2166-0379
2026, Vol. 14, No. 2

Impacts of Organic and Inorganic Fertilization on Coconut Productivity, Fruit Quality and Soil Health

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Received: June 22, 2026 Accepted: July 28, 2026 Published: July 30, 2026

doi:10.5296/jas.v14i2.23957 URL: https://doi.org/10.5296/jas.v14i2.23957

Abstract

Coconut (*Cocos nucifera* L.) is a high-value perennial crop essential to global tropical and sub-tropical agriculture, but its yield potential is frequently limited by imbalanced soil nutrition and unsustainable management practices. Hence, this study investigated the efficacy of the combined application of organic and inorganic fertilizers on coconut growth, yield, quality, and soil fertility in order to determine the suitable fertilization strategy. The field experiment was conducted over two consecutive years in a Completely Randomized Design with five treatments and three replicates, using 16-year-old palms of the coconut cultivar 'BARI Narikel-2'.The treatments were viz. T_1 (RDF): $N_{450}P_{120}K_{1000}S_{50}Zn_{25}B_{6.8}$ g per plant, T_2 (150%RDF+CD): $N_{675}P_{180}K_{1500}S_{75}Zn_{37.5}B_{10.2}$ g plant^{-1}+10 kg cowdung (CD) plant^{-1}, T_3 (125%RDF + CD): $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}, T_4 (FP): $N_{200}P_{70}K_{300}$ g plant^{-1}+20 kg CD plant^{-1} and T_5: Control (without fertilizer). Parameters measured included growth characteristics, annual nut count, fruit size, copra quality, nut yield, soil health indicators etc. Results revealed that treatment T_3 significantly improved coconut growth, yield and quality metrics. The highest nut yield (115 kg plant^{-1}) was achieved in T_3, representing a 195% increase over the control and a 67.9 % increase over farmer practice (T_4). This yield was primarily driven by a higher single fruit weight (1.70 kg) and an increased number of fruits plant^{-1} (75.5). Additionally, T_3 enhanced meat thickness (12.8 mm), total soluble solids (7.25 ^{0}Brix), vitamin C (3.23 mg/100g) and protein content (12.0%). Regarding soil health, T_3 increased organic carbon by 10% and total nitrogen by 11%. This treatment was also highly economically viable, yielding a gross return of 108 US$ and a gross margin of 77.6 US$ per plant. Correlation analysis and PCA confirmed a strong positive correlation between growth and yield parameters and the fruit quality traits of coconut. Therefore, results suggest that the fertilizer strategy T_3 ($N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}) optimizes the physiological yield potential, improves fruit quality, and sustains soil fertility, offering a climate-resilient solution for sustainable coconut management.

Keywords: *Cocos nucifera*, copra quality, growth, INM, nut yield, soil health

1. Introduction

Coconut (*Cocos nucifera* L.) is a multi-purpose perennial crop foundational to the socio-economic framework of tropical and subtropical regions worldwide (Mat et al., 2022). Belonging to the *Arecaceae* (*Palmae*) family of monocotyledons, the coconut palm is a tall tree that supports essential rural livelihoods and drives significant export markets for its oil, meat, water, and fiber (Ismail et al., 2022; Mat et al., 2022). Frequently celebrated as the "tree of life" or "tree of paradise" due to its versatility, coconut finds extensive applications in cosmetics, medicine, and nutrition (Karandeep et al., 2019; Mat et al., 2022). Furthermore, coconut meal-a byproduct of milk and oil extraction is highly nutritious, containing 14%–25% protein and 45%–60% dietary fiber (Shakeela et al., 2024). This byproduct offers significant nutraceutical benefits, including antioxidant, antidiabetic, and prebiotic properties (Karandeep et al., 2019; Shakeela et al., 2024). Due to its year-round vegetative growth, continuous flowering, and heavy production cycles, the coconut palm places enormous, continuous nutritional demands on the soil medium (Atapattu et al., 2025; Ismail et al., 2022). Sustaining optimal fruit production over the palm's multi-decade lifespan represents a perpetual agronomic battle against nutrient depletion (Ismail et al., 2022; Mohandas, 2012). For decades, conventional production systems have heavily relied on synthetic inorganic fertilizers to meet these high macronutrient requirements. While synthetic inputs offer immediate, highly targeted nutrient availability that can rapidly stimulate fruit set, their exclusive, long-term application has driven widespread agronomic degradation (Quddus et al., 2025). Intensive chemical fertilization accelerates the decline of fundamental soil health by suppressing beneficial microbial populations, disrupting the localized biological ecosystem, and lowering soil water-holding capacity (Atapattu et al., 2025; Selva Rani et al., 2024). Consequently, this plants established cultivated area highly vulnerable to environmental stressors such as moisture fluctuations and prolonged droughts (Atapattu et al., 2025).

To counter these ecological challenges, there is a growing emphasis on replacing or augmenting synthetic nutrients with organic amendments, such as decomposed cow manure (Ismail et al., 2022; Quddus et al., 2026). Organic material modifies physical soil attributes by lowering bulk density, increasing porosity, improving aeration, and creating favorable microhabitats for beneficial microbial communities that drive biogeochemical cycling (Quddus et al., 2025; Selva Rani et al., 2024). However, purely organic management possesses inherent limitations for intensive perennial agriculture (Moyin-Jesu and Ogochukwu, 2014). Due to slow decomposition kinetics and low base concentrations of primary macronutrients, relying solely on organic amendments often fails to meet the peak macronutrient thresholds required by heavy-fruiting cultivars during critical reproductive phases (Quddus et al., 2024). Consequently, integrated nutrient management (INM)—the strategic coordination of organic and inorganic resources—presents a realistic and economically viable pathway toward sustainable production (Ismail et al., 2022; Selva Rani et al., 2024). Blending chemical inputs with organic manures not only maintains short-term yield expectancies but also enhances overall chemical fertilizer use efficiency (Mohandas, 2012; Selva Rani et al., 2024). Despite widespread acknowledgment of the basic benefits of INM in annual cropping systems (Shinde et al., 2020; Selim, 2021), a distinct research gap persists regarding its specific, multi-year optimization for long-term tree crops like the coconut palm. Historically, coconut fertility research has measured success almost exclusively by yield parameters, specifically tracking the number of nuts harvested per palm (Mohandas, 2012). There remains a critical lack of integrated data examining how coordinated organic-inorganic inputs simultaneously influence coconut productivity and fruit quality attributes alongside long-term rhizospheric health. Furthermore, how organic amendments paired with inorganic fertilization promote nutrient availability and structural soil restoration in perennial zones remains under-explored. To address these limitations, it was hypothesized that the integration of organic and inorganic fertilization strategies enhances coconut productivity, fruit quality, and soil health while reducing nutrient leaching losses in the root zone. Therefore, this study was undertaken to evaluate the effect of pairing organic fertilizer with synthetic fertilizer regimes on coconut fruit set, yield, quality, profitability and long-term soil fertility.

2. Materials and Methods

2.1 Site Descriptions Including Climate and Soil

From 2020 to 2022, the Pomology Division of the Horticulture Research Centre at Bangladesh Agricultural Research Institute (BARI), Gazipur, conducted a study on coconut palms in the research field of Pomology Division. The research site is situated 8.4 meters above sea level at 23°59'4.56" N and 90°24'38.08" E. According to Quddus et al. (2022a), this area experiences a sub-humid tropical and subtropical continental monsoon climate. During the experimental period, temperatures at the site ranged from 13.3 to 35.8 °C, humidity fluctuated between 71.7% and 89.9%, and monthly rainfall varied from 0 to 478 mm (Figures 1a & b). The 2020–2021 (Figure 1a) seasons were warmer than 2021–2022 (Figure 1b), showing higher average minimum and maximum temperatures. Conversely, 2021–2022 (Figure 1b) saw significantly higher rainfall, except during July and August (Figures 1a & b).

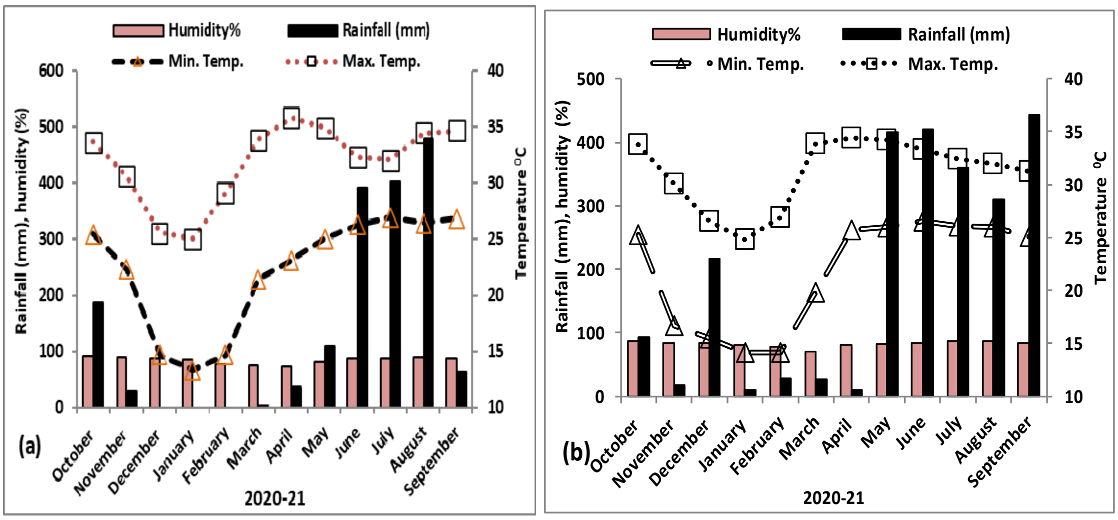

Figure 1. Monthly average minimum and maximum temperature, rainfall and monthly average humidity during the experimental period of 2020-21 (a) and 2021-22 (b).

The experimental soil belongs to the Chhiata series (Grey Terrace) within the Madhupur Tract (Agro-Ecological Zone 28) and follows the USDA Soil Taxonomy classification described by Quddus et al. (2022b). Initial soil samples were collected from a 0–20 cm depth using the method outlined by Quddus et al. (2024). Table 1 details the physical and chemical properties of these samples, which were analyzed according to standard procedures.

Table 1. Physico-chemical properties of initial soil of the experimental site

Physico-chemical properties	Soil test value	Critical level	Soil test interpretation*
Sand (%)	27.33%		
Silt (%)	37.09%		
Clay (%)	35.58%		
Textural class	clay loam		
Moisture content (%)	26.8%		
Particle density (g/cc)	2.55		
Bulk density (g/cc)	1.42		
pH	5.87	5.5-6.5	Slightly acidic
Soil EC (dS/m)	0.26	-	Non saline
Organic matter (%)	1.26	-	Low
Ca (meq/100 g soil)	5.50	2.0	Optimum
Mg (meq/100 g soil)	1.23	0.5	Optimum
Total N (%)	0.066	0.12	Very low
Available P (mg/kg)	14.5	7	Medium
K (meq/100 g soil)	0.14	0.12	Low
S (mg/kg)	13.9	10	Low
Zn (mg/kg)	0.89	0.6	Medium
B(mg/kg)	0.16	0.2	Low

(Ahmmed et al., 2018)*

Standard procedures were employed for all soil analyses. The soil properties were determined as follows: textural class by the hydrometer method (Bouyoucos, 1962); particle and bulk densities by the volumetric flask and core sampler methods, respectively (Black, 1965); measurement of soil electrical conductivity (EC) was recorded using a Groline direct soil meter (HI98331), while soil moisture was quantified using a spot moisture tester (Model DM-15, Tokyo, Japan); soil pH using a glass electrode meter at a 1:2.5 soil-to-water ratio (Page et al., 1982); and organic carbon via wet oxidation (Page et al., 1982), with organic matter calculated using a Van Bemmelen factor of 1.73. Total N was determined by the micro-Kjeldahl method (Page et al., 1982); exchangeable K by 1N NH_4OAC extraction (Jackson, 1973); available P according to Bray and Kurtz (1945); available S by turbidimetry (Fox et al., 1964); available Zn by DTPA extraction (Lindsay and Norvell, 1978); and available B by the azomethine-H method (Page et al., 1982).

2.2 Planting Materials, Treatments, Design and Fertilizer Application

The experiment was conducted during two consecutive years of 2020-21 and 2021-22 at the Fruit Research Farm of the Horticulture Research Centre, BARI, on 16-year-old coconut palms of the high yielding variety 'BARI Narikel-2'. This is a high-yielding variety characterized by large, oval-shaped fruits. Matured fruits are typically harvested 11 to 12 months after flowering, while green coconuts are harvested after 5 to 6 months. The experiment consisted of five treatments arranged in a Completely Randomized Design (CRD) with three replications. The treatments were viz. T_1 (RDF): $N_{450}P_{120}K_{1000}S_{50}Zn_{25}B_{6.8}$ g plant^{-1} (Ahmmed et al., 2018), T_2 (150%RDF+CD): $N_{675}P_{180}K_{1500}S_{75}Zn_{37.5}B_{10.2}$ g plant^{-1}+10 kg cowdung (CD) plant^{-1}, T_3 (125%RDF + CD): $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}, T_4 (FP): $N_{200}P_{70}K_{300}$ g plant^{-1}+20 kg CD plant^{-1} and T_5: Control (no use of fertilizer). For the experimental treatments, organic and inorganic fertilizers were applied in two equal splits (September–October and April–May). However, traditional farmer practice only utilized a single application during September–October. Based on preliminary interviews with five local farmers living near the experimental site regarding their homestead coconut tree management, treatment T_4 ($N_{200}P_{70}K_{300}$ g plant^{-1}+20 kg CD plant^{-1}) was established to reflect local farmer practices. The inorganic fertilizer sources utilized for N, P, K, S, Zn, and B were urea (46% N), triple superphosphate (20% P, 1.3% S, and 14% Ca), muriate of potash (50% K), gypsum (18% S and 20% Ca), zinc sulfate heptahydrate (10.5% S and 21% Zn), and boric acid (17% B), respectively. Both the chemical and organic (cow dung) fertilizers were procured from a local entrepreneur in Gazipur Sadar, Bangladesh. For the first split application, 50% of both the inorganic and organic (decomposed cow dung) fertilizers were applied during the first week of October. Using the circular basin method, a 1.0-meter radius around the base of the coconut palm was left clear, and the fertilizer was manually mixed into a 0.8-meter zone of soil beyond that point. A light irrigation was applied immediately after mixing.

2.3 Agronomic Management in Coconut Cultivation

A clean and weed-free basin with a radius of 1.0 meters was maintained around the base of each coconut palm. Shallow digging was performed within the basin to destroy weeds and break the soil crust, taking extreme care not to dig deeper than 12 to 15 cm to avoid damaging the dense mat of surface-feeding roots. Additionally, the interspaces between palms were spaded twice a year to loosen the soil, improve aeration, and incorporate organic weeds into the ground. Irrigation was properly provided as per the requirements. Plant protection measures were also strictly executed. For instance, severely infested coconut leaves along with the adults and nymphs of whiteflies were cut, removed, and burned. To ensure effective pest control, a rotational spraying schedule was implemented: the chemical insecticide Tundra 20 SP was applied at a rate of 1 g L^{-1} of water, alternating with the biopesticide Fizimite and Bioclean at a rate of 1 ml L^{-1} of water. The management was administered at 15-day intervals and repeated three times for optimal results. Diseases of gray leaf spot and bud rot infestations were controlled by spraying Autostin 50 WDG and Dithane M-45 fungicides at a concentration of 2 g L^{-1} of water, applied twice at a 15-day interval. The second installment of fertilizers, consisting of the remaining 50% of the organic and inorganic fertilizers, was applied during the last week of April according to the specific treatment protocols (excluding the farmers' practice). The fertilizers were thoroughly incorporated following the same procedure as the first installment. Mature coconuts were harvested at physiological maturity, approximately 11 to 12 months after flowering, whereas green coconuts were harvested after 5 to 6 months.

2.4 Data Collection Procedure

Plant height was measured from the ground level to the tip of the tallest leaf using a calibrated measuring rod. The base girth was recorded at a fixed height of 25 cm above ground level using a standard measuring tape. The total number of inflorescences per palm was determined by visual counting throughout the production cycle. Inflorescence length was measured from the basal node of the peduncle to the apex of the spike using a measuring tape. The number of bunches per plant was recorded at regular monthly intervals by counting all visible, fruit-bearing spadices throughout the year. For the female flower count, emerged inflorescences were evaluated at the anthesis stage. Female flowers, identified by their larger, globose structure at the base of the rachillae, were counted manually per inflorescence to determine the potential fruit set. Leaf chlorophyll content was measured using a portable chlorophyll meter (Model SPAD-502 Plus, Konica Minolta, Tokyo, Japan). Readings were taken from six healthy leaflets selected from the middle section of the frond's rachis, sampled evenly as three leaflets from the left side and three from the right side. On each leaflet, SPAD measurements were recorded from the lamina adjacent to the midrib. Annual coconut yield was calculated as the total number of harvested nuts per plant. For postharvest analysis, a representative sample of five nuts per treatment was transported to the laboratory to evaluate yield-contributing traits and quality attributes. Nut length and diameter were measured using a standard scale. Whole nut weight and de-husked nut weight (shell) were determined using a digital balance. Furthermore, the volume of coconut water from both green and mature coconuts was measured using a graduated cylinder. Mean values for all yield attributes data were considered.

For fruit quality analysis, harvested samples were evaluated for copra (solid endosperm) thickness, total soluble solids (TSS), vitamin C (ascorbic acid) content, titratable acidity (TA), total sugar, reducing sugar, water pH, and protein content. Copra thickness was measured using a standard graduated scale. To determine fruit quality attributes, the copra from each treatment was sliced and pressed to extract the juice. The TSS was measured by placing approximately 0.4 mL of juice onto the prism surface of a digital hand refractometer (Model PAL-1, Atago Ltd., Tokyo, Japan), with results expressed in °Brix (Anonymous, 1994); the prism was thoroughly rinsed with distilled water between measurements. Vitamin C content was determined according to standard AOAC methods (Anonymous, 1994). Titratable acidity was estimated following the procedure described by Ranganna (1986); briefly, a 2 mL aliquot of juice was diluted to 10 mL with distilled water, titrated against 0.1 N NaOH using phenolphthalein as an indicator, and adjusted to a pH endpoint of 8.2. The total and reducing sugar contents were quantified according to the methods outlined by Ranganna (1986). The pH of the coconut water was recorded using a digital pH meter (Mettler-Toledo GmbH, CH-8603, Schwerzenbach, Switzerland).

2.4.1 Protein Content Estimation

Coconut copra samples were prepared by oven-drying at 70°C for 48 hours, followed by grinding in a Cyclotec™ 1093 sample mill (Sweden). The ground samples were then digested using a 5:1 **HNO_3-$HClO_4$** di-acid mixture, following the method described by Piper (2019). After digestion, the samples were analyzed for nutrient content. Nitrogen content was determined using the Micro-Kjeldahl method described by Page et al. (1982). Finally, the crude protein content in the dry copra was calculated by multiplying the N content by the standard food factor of 6.25 (Hiller et al., 1948; Aktar et al., 2026).

2.5 Analysis of Postharvest Soil Chemical Properties for Coconut Tree Following a One-Year Cropping Cycle

Postharvest soil samples were collected from each treatment at a depth of 0–20 cm within the active root zone, measured 1 m out from the base of the trunk. Soil samples were collected using a soil auger from four distinct quadrants (North, South, East and West) within the circular basin of each treatment tree. These sub-samples were then composited to form a single representative sample per treatment. All composite samples were transported to the laboratory of the Soil and Water Management Section, Horticulture Research Centre, BARI, Gazipur. The collected soil samples were air-dried systematically according to the method described by Sultana et al. (2022) and preserved it in plastic containers for subsequent analysis. Postharvest soil samples were analyzed using the same standard methods applied to the initial soil samples.

2.6 Cost and Return Analysis

The total variable cost (TVC) for coconut cultivation across all experimental treatments was calculated on a per-plant basis. This expenditure included agronomic procedures such as labor costs and plant protection measures using insecticides and fungicides. The costs of required inputs, including decomposed cow dung and inorganic fertilizers, were also included. General operational costs remained constant across all treatments, including the control. Fixed costs, such as land rent, were excluded from this economic analysis. The gross return was determined based on the coconut fruit yield, which was converted to kilograms per plant and multiplied by the prevailing local market price. The gross margin was subsequently calculated by subtracting the TVC from the gross return. Finally, the benefit-cost ratio (BCR) was calculated using the formula outlined by Quddus et al. (2026).

$$\text{BCR} = \text{Gross Return} \div \text{Total Variable Cost}\text{----------} \quad (1)$$

2.7 Statistical Analysis

Statistical analysis was executed using Statistix 10 (Statistix LLC, Tallahassee, FL, USA). Data concerning coconut palm growth, flower and yield attributes, quality traits, economic metrics, and post-harvest soil nutrient status were subjected to a two-way analysis of variance (ANOVA). Treatment means were compared using the Least Significant Difference (LSD) test at significance levels of $p \leq 0.05$, $p \leq 0.01$, or $p \leq 0.001$. To ensure the precision and reliability of the experimental data, the standard error of the mean (SEm) and the coefficient of variation (CV%) were also calculated. Pearson’s correlation analysis was performed using the "corrplot" package to examine the relationships between variables. Principal Component Analysis (PCA) and the subsequent PCA biplot were generated using the "FactoMineR" and "factoextra" packages, with visualizations enhanced by "ggplot2" (Quddus et al., 2026).

3. Results

3.1 Growth, Reproductive and Physiological Parameters

According to Table 2, the cultivation year significantly affected all growth parameters including plant height, base girth, bunches per plant, female flowers per bunch, and fruits per bunch, except for inflorescence length and number per plant and leaf chlorophyll (SPAD value). Growth performance was consistently higher in the second year compared to the first year. The combined application of organic and inorganic fertilizers significantly enhanced the growth parameters of the coconut palm (Table 2). The highest plant height (6.45 m) was achieved with the application of 125% of the recommended dose of inorganic fertilizer + 30 kg of cow dung per plant (T_3), which was statistically identical with most other treatments. Conversely, the minimum plant height was recorded in the control (T_5). Similarly, the maximum base girth per plant (1.34 m) was observed in T_3, which was comparable to T_2 (150% recommended dose of inorganic fertilizer + 10 kg of cow dung per plant), while the control (T_5) recorded the lowest base girth. Regarding inflorescence characteristics, treatment T_3 produced a significantly longer inflorescence (60.2 cm). The maximum number of inflorescences per plant (13.2) was also recorded in the T_3 treatment, which was significantly higher than the other treatments. Conversely, the minimum values for both inflorescence parameters were observed in the control (T_5) treatment. The highest number of bunches per plant (12.3) was significantly higher in T_3, whereas the lowest number of bunches was recorded in the control treatment (T_5). Similarly, the maximum number of female flowers per bunch (18.1) and the highest number of fruits per bunch (12.1) were observed in T_3, with the latter followed closely by the T_2 treatment. In contrast, the lowest values for both parameters were recorded in the control group (T_5). The highest leaf chlorophyll content of coconut was recorded in the T_3 treatment, with a significant SPAD value of 62.3. Conversely, the lowest SPAD value was observed in the control (T_5) treatment.

Table 2. Effect of cultivation year, decomposed cow dung, and inorganic fertilizers on the growth and floral attributes of coconut

Cultivation year (Y)	Plant height (m)	Base girth of plant (m)	Inflorescence Length (cm)	No. of Inflorescence /plant	Number of bunch/plant	Number of female flower/bunch	Number of fruit /bunch	SPAD value
2020-21	5.73±0.13b	1.15±0.04b	52.4±1.47a	10.2±0.50a	9.39±0.44b	14.2±0.85b	8.96±0.57b	57.8±0.81a
2021-22	6.43±0.13a	1.24±0.04a	52.7±1.47a	10.5±0.51a	9.79±0.44a	15.4±0.86a	10.1±0.58a	58.3±0.81a
F-test	***	*	ns	ns	*	***	***	ns
CV (%)	5.36	9.56	3.45	9.03	5.43	5.43	5.83	3.30
LSD(0.05)	0.25	0.09	1.39	0.72	0.40	0.62	0.43	1.47
Treatment (T)								
T_1	6.26±0.22a	1.17±0.03bc	54.1±0.66b	10.1±0.37bc	9.30±0.10c	16.6±0.45b	9.90±0.27b	57.7±0.77bc
T_2	6.30±0.23a	1.27±0.04ab	55.2±0.55b	11.2±0.37b	10.3±0.17b	17.1±0.45b	11.5±0.45a	59.6±0.72b
T_3	6.45±0.17a	1.34±0.05a	60.2±0.73a	13.2±0.20a	12.3±0.38a	18.1±0.45a	12.1±0.32a	62.3±0.74a
T_4	6.09±0.18a	1.14±0.06bc	48.1±0.81c	9.15±0.44cd	8.30±0.11d	12.4±0.28c	7.35±0.27c	55.9±0.70cd
T_5	5.30±0.17b	1.07±0.02c	45.1±0.30d	8.15±0.20d	7.80±0.20d	9.86±0.27d	6.93±0.29c	54.8±0.38d
F-test	***	**	***	***	***	***	***	***
CV (%)	5.36	9.56	3.45	9.03	5.43	5.43	5.83	3.30
LSD(0.05)	0.40	0.14	2.20	1.14	0.63	0.97	0.68	2.32
Interaction (Y*T)	ns	ns	ns	ns	ns	ns	ns	ns

Means within the same column followed by dissimilar letters are significantly different according to the least significant difference (LSD) test at a 5% ($P \leq 0.05$) level of probability. CV = coefficient of variation. T_1 (RDF): $N_{450}P_{120}K_{1000}S_{50}Zn_{25}B_{6.8}$ g per plant, T_2 (150%RDF+CD): $N_{675}P_{180}K_{1500}S_{75}Zn_{37.5}B_{10.2}$ g plant^{-1}+10 kg cowdung (CD) plant^{-1}, T_3 (125%RDF + CD): $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}, T_4 (FP): $N_{200}P_{70}K_{300}$ g plant^{-1}+20 kg CD plant^{-1} and T_5: Control (no use of fertilizer). Note: ns designates not significant, * designates significance at $p \leq 0.05$, ** designates significance at $p \leq 0.01$ and *** designates significance at $p \leq 0.001$ according to ANOVA; ± signify the standard error mean (n=3).

3.2 Yield Parameters

Table 3 indicates that the cultivation year had a significant effect on the number of fruits per plant, nut dimensions (length and diameter), single nut weight, and single shell weight. However, the volume of single coconut water, green coconut water, and fruit yield per plant remained unaffected. The performance of all yield traits in this study was consistently superior in the second year compared to the first. The application of integrated organic and inorganic fertilizers significantly improved the yield-contributing parameters and yield of coconut palms (Table 3). The number of fruits per plant differed significantly among the treatments, with the highest number observed in T_3 (75.5 fruits) and the lowest in the control (T_5). Similarly, the maximum nut length (23 cm) and nut diameter (20.8 cm) were recorded in T_3 (application of $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}). While the values for T_3 were statistically comparable to those of the T_2 treatment, they were significantly superior to all other treatments; the lowest values were recorded in the control (T_5). Furthermore, the single nut weight (1.70 kg) and single shell weight (1.42 kg) were significantly highest in the T_3 treatment and lowest in the control (T_5). The volume of single mature coconut water (370 mL) and single green coconut water (1006 mL) also reached a maximum in T_3, with both parameters being lowest in T_5. Consequently, the highest total fruit yield (115 kg plant^{-1}) was recorded in the T_3 treatment, which was significantly different from all other treatments, while the lowest yield was observed in the control (T_5).

Table 3. Effect of cultivation year, decomposed cow dung and inorganic fertilizers on the yield attributes and fruit yield of coconut

Cultivatior year (Y)	Number o fruits/plant	Nut (fruit length (cm)	Nut diameter (cm)	Single nu weight (kg	Single shel weight (kg)	Amount of singl coconut water (ml	Amount o single gree coconut water (ml)	Fruit yiel (kg/plant)
2020-21	64.5±2.12b	18.9±0.88b	16.7±0.91b	1.19±0.08b	0.90±0.07b	246±24.3a	788±49.9a	80.4±7.08a
2021-22	66.6±2.12a	20.1±0.88a	17.9±0.91a	1.59±0.08a	1.30±0.07a	256±24.3a	801±49.9a	82.5±7.09a
F-test	*	**	*	***	***	ns	ns	ns
CV (%)	3.18	5.52	7.82	8.99	9.07	11.7	9.23	7.47
LSD(0.05)	1.60	0.83	1.04	0.10	0.08	22.6	56.2	4.67
Treatment (T)								
T_1	67.1±0.85c	20.6±0.45b	18.6±0.45b	1.49±0.10b	1.15±0.10b	259±19.8c	867±22.1b	88.3±0.87c
T_2	71.0±1.18b	21.9±0.48ab	19.7±0.77ab	1.52±0.12b	1.30±0.09a	315±11.2b	907±36.6b	96.6±0.87b
T_3	75.5±0.58a	23.0±0.45a	20.8±0.45a	1.70±0.09a	1.42±0.10a	370±5.91a	1006±36.6a	115±5.13a
T_4	60.8±0.58d	18.0±0.45c	15.4±0.45c	1.32±0.09c	1.01±0.10c	185±4.28d	686±4.68c	68.5±0.60d
T_5	53.4±0.92e	14.1±0.48d	11.9±0.48d	0.90±0.10d	0.63±0.09d	125±4.28e	507±18.4d	39.0±0.60e
F-test	***	**	***	***	***	***	***	***
CV (%)	3.18	5.52	7.82	8.99	9.07	11.7	9.23	7.47
LSD(0.05)	2.53	1.31	1.64	0.15	0.12	35.9	88.9	7.38
Interaction (Y*T)	ns	ns	ns	ns	ns	ns	ns	ns

Means within the same column followed by dissimilar letters are significantly different according to the least significant difference (LSD) test at a 5% ($P \leq 0.05$) level of probability. CV = coefficient of variation. T_1 (RDF): $N_{450}P_{120}K_{1000}S_{50}Zn_{25}B_{6.8}$ g per plant, T_2 (150%RDF+CD): $N_{675}P_{180}K_{1500}S_{75}Zn_{37.5}B_{10.2}$ g plant^{-1}+10 kg cowdung (CD) plant^{-1}, T_3 (125%RDF + CD): $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}, T_4 (FP): $N_{200}P_{70}K_{300}$ g plant^{-1}+20 kg CD plant^{-1} and T_5: Control (no use of fertilizer). Note: ns designates not significant, * designates significance at $p \leq 0.05$, ** designates significance at $p \leq 0.01$ and *** designates significance at $p \leq 0.001$ according to ANOVA; ± signify the standard error mean (n=3).

3.3 Fruit Quality Attributes

Table 4 shows that the cultivation year had a significant effect on copra (meat) thickness, meat TSS, vitamin C, titratable acidity, total sugar, and reducing sugar; however, water pH and protein content remained unaffected. Notably, all quality traits evaluated in this study were consistently superior in the second year compared to the first. The application of integrated organic and inorganic fertilizers significantly improved the fruit quality traits of the coconut palms (Table 4). In this study, the highest meat thickness (12.8 mm) was obtained from the T_3 (application of $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}), while the lowest value was observed in the control (T_5). Similarly, the maximum TSS (7.25 ^{0}Brix) and the highest vitamin C content (3.23 mg/100g) were recorded in T_3, whereas the lowest values were found in T_5. Titratable acidity, however, showed inconsistent trends; the highest titratable acidity (0.28%) was recorded in T_2, which was comparable to the T_5 treatment. Furthermore, the highest total sugar (6.48 g/100g) and reducing sugar (2.52 g/100g) contents were recorded in the T_3 treatment, which was significantly superior to all other treatments, while the lowest values were in the control (T_5). Coconut water pH also showed inconsistent results, with the highest water pH (5.67) being closely comparable to the T_1 treatment. Finally, the highest protein content (12.0%) was recorded in T_3, which was statistically identical to T_1, while the lowest protein value was observed in the control (T_5).

Table 4. Effect of cultivation year, decomposed cow dung, and inorganic fertilizers on the fruit quality attributes of coconut

Cultivation year (Y)	Copra (meat) thickness (mm)	Meat TSS (^{0}Brix)	Vitamin C (mg/100g)	Titratable acidity (%)	Total sugar (g/100 g)	Reducing sugar (g/100g)	Water pH	Protein content (%)
2020-21	10.4±0.40b	5.70±0.26b	2.82±0.08b	0.27±0.0042a	6.17±0.09b	2.18±0.09b	5.52±0.04a	10.4±0.37a
2021-22	10.9±0.40a	6.20±0.26a	2.86±0.08a	0.25±0.0043b	6.21±0.09a	2.22±0.09a	5.53±0.04a	10.9±0.37a
F-test	***	***	**	**	**	***	ns	ns
CV (%)	0.87	1.08	1.24	5.92	0.49	0.98	0.58	11.5
LSD(0.05)	0.07	0.05	0.03	0.01	0.023	0.02	0.03	0.94
Treatment (T)								
T_1	10.5±0.13c	5.80±0.11c	2.92±0.02b	0.26±0.005bc	6.32±0.02c	2.13±0.01d	5.66±0.008a	10.7±0.7a-c
T_2	11.8±0.11b	6.57±0.11b	2.95±0.01b	0.28±0.009a	6.43±0.01b	2.44±0.01b	5.31±0.02c	11.2±0.47ab
T_3	12.8±0.11a	7.25±0.11a	3.23±0.01a	0.25±0.006c	6.48±0.02a	2.52±0.01a	5.50±0.01b	12.0±0.49a
T_4	9.56±0.11d	5.75±0.11c	2.79±0.01c	0.26±0.006bc	6.13±0.01d	2.35±0.01c	5.49±0.008b	9.94±0.25bc
T_5	8.61±0.11e	4.37±0.12d	2.33±0.01d	0.27±0.009ab	5.57±0.02e	1.58±0.02e	5.67±0.008a	9.25±0.15c
F-test	***	***	***	*	***	***	***	**
CV (%)	0.87	1.08	1.24	5.92	0.49	0.98	0.58	11.5
LSD(0.05)	0.11	0.08	0.04	0.02	0.037	0.03	0.04	1.49
Interaction (Y*T)	ns	ns	ns	ns	ns	ns	ns	ns

Means within the same column followed by dissimilar letters are significantly different according to the least significant difference (LSD) test at a 5% ($P \leq 0.05$) level of probability. CV = coefficient of variation. T_1 (RDF): $N_{450}P_{120}K_{1000}S_{50}Zn_{25}B_{6.8}$ g per plant, T_2 (150%RDF+CD): $N_{675}P_{180}K_{1500}S_{75}Zn_{37.5}B_{10.2}$ g plant^{-1}+10 kg cowdung (CD) plant^{-1}, T_3 (125%RDF + CD): $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}, T_4 (FP): $N_{200}P_{70}K_{300}$ g plant^{-1}+20 kg CD plant^{-1} and T_5: Control (no use of fertilizer). Note: ns designates not significant, * designates significance at $p \leq 0.05$, ** designates significance at $p \leq 0.01$ and *** designates significance at $p \leq 0.001$ according to ANOVA; ± signify the standard error mean (n=3).

3.4 Correlation Coefficient Analysis

Pearson's correlation coefficients for both consecutive years (A = 2020–21 and B = 2021–22) showed similar trends regarding the growth, yield, and quality attributes of the coconut cultivar 'BARI Narikel-2' (Fig. 2). The growth traits of the coconut showed a highly significant positive correlation ($p < 0.001$) with its yield attributes. Particularly, fruit yield (FYd.) was strongly correlated ($r = 0.96$) with the number of female flowers per bunch (NFF) and inflorescence length (IL), whereas the slightly lower correlation coefficient ($r = 0.87$) was observed for the SPAD value of the coconut leaves. A moderate correlation ($r = 0.71$, $p < 0.01$) was observed between plant height (PH) and the number of branches per plant (NBP). In contrast, fruit quality attributes showed an irregular response to growth and yield traits. Particularly, nut water acidity did not correlate significantly with any of the attributes. However, nut water pH showed a significant negative correlation with total soluble solids (TSS), reducing sugar (Red.S), total sugar (T.Sugar), single shell weight (SSWt), nut length (NutL), number of fruits per plant (NFP), and meat thickness (M.Thick). At $p < 0.05$, reducing sugar (Red.S) was positively correlated with protein (Prot.) and plant base girth (BG). Meanwhile, Red.S exhibited a higher significance ($p < 0.01$) when correlated with the number of branches per plant (NBP), number of inflorescences per plant (NIP), SPAD value, inflorescence length (IL), and number of fruits per bunch (NFB). Additionally, meat thickness showed a moderate correlation ($p < 0.01$) with both base girth ($r = 0.75$) and plant height ($r = 0.74$). Single coconut water volume (NWr) was strongly correlated ($p < 0.001$) with all fruit quality and growth traits. Subsequently, green coconut water volume (Gre.Wat.) showed a similarly strong correlation, except with base girth, where the correlation was slightly lower ($r = 0.76$).

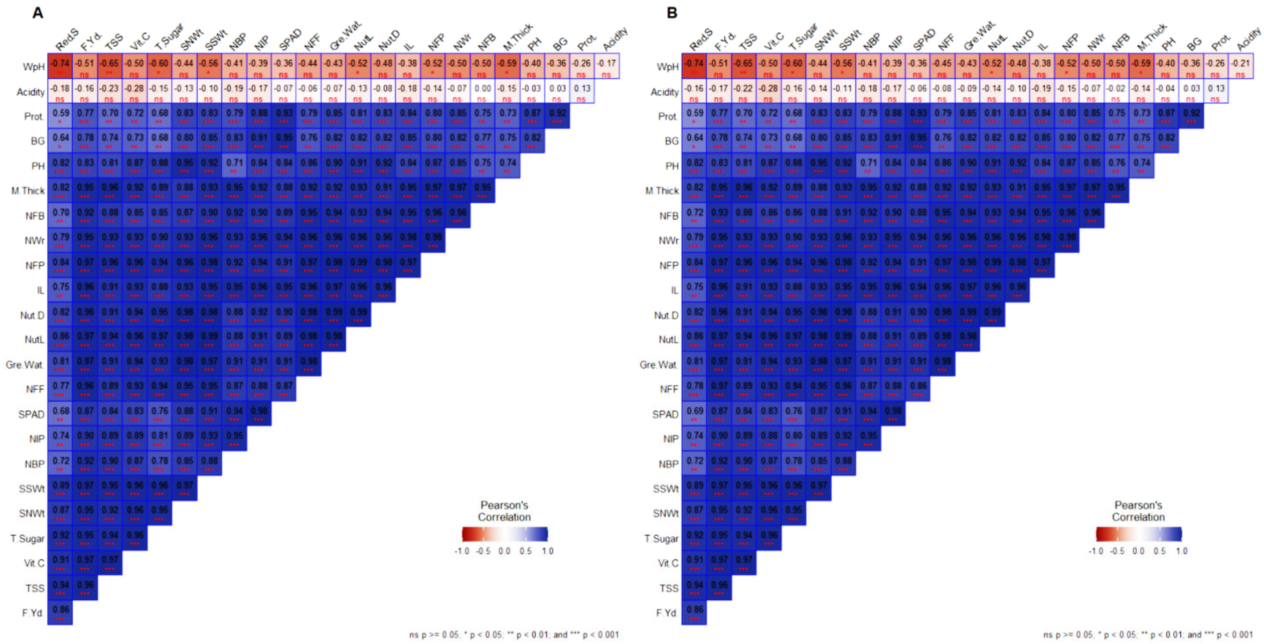

Figure 2. Pearson's correlation analysis for correlation matrix (23×23) consisting 8 growth and floral contributing attributes, 8 yield attributes and 8 fruit quality attributes of the five treatments in two consecutive years (A= 2020-21 and B= 2021-22). The color intensity scales indicate the strength and direction of coefficient correlation. Asterisks indicate statistically significant correlations between traits: *, **, and *** correspond to significance levels of 5%, 1%, and 0.1%, respectively. Correlations that are not statistically significant (p>0.05) are represented by ns. PH=Plant Height (m), BG=Base girth of plant (m), IL=Inflorescence Length (cm), NIP=No. of Inflorescence/plant, NBP=Number of bunch/plant, NFF=Number of female flower/bunch, NFB=Number of fruit /bunch, SPAD=SPAD value, NFP=Number of fruits/plant, NutL=Nut (fruit) length (cm), Nut.D=Nut diameter (cm), SNWt=Single nut weight (kg), SSWt=Single shell weight (kg), NWr=Single coconut water (ml), Gre.Wat.=green coconut water (ml), F.Yd.= Fruit yield (kg/plant), M.Thick= Meat (Copra) thickness (mm), TSS=Meat TSS (^{0}Brix), Vit.C=Vitamin C (mg/100g), Acidity=Titratable acidity (%), T.Sugar=Total sugar (g/100 g), Red.S=Reducing sugar (g/100g), WpH=Water pH and Prot.=Protein content%.

3.5 Principal Component Analysis (PCA)

The principal component analysis (PCA) biplot (Fig. 3) illustrates the effect of treatments on the multi-trait response for two consecutive years (A= 2020–21 and B= 2021–22). The multi-trait response showed similar behavior along the two years with two principal components (PC1 and PC2) producing cumulative variance of 94.1% (PC1=87.8% and PC2= 6.3%) in 2020–21 and 94.4% (PC1=87.9% and PC2= 6.5%) in 2021–22. The variables were mostly clustered and tends to same direction which reflected the strong correlation among the traits like fruit yield (F.Yd.), green coconut water (Gre.Wat.), nut diameter (Nut.D), nut length (NutL), number of fruits per plant (NFP), single nut weight (SNWt), SPAD value, number of female flower per brunch (NFF), TSS, number of fruits per brunch (NFB), total sugar, meat thickness (M.Thick), single nut weight (SNWt.), single shell weight (SSWt.), plant height (PH), and base girth (BG). However, number of brunches per plant (NBP), inflorescence length (IL), vitamin C, and number of inflorescences per plant (NIP) strongly correlated and showed weak correlation with reducing sugar (Red. S), the nut water pH (WpH) and acidity showed negative correlation. The vector length exhibited the loading attributes in PC1 and PC2. Most of the variants contributed high positive loadings for PC1 except nut water pH and acidity. For PC2, the variants contributed positive loadings were nut water pH (WpH) while acidity showed high negative loadings. In the contrast to the effect of treatments, T_3 (125%RDF + CD) in the 1st quadrant reflected the high positive response for PC1 and PC2, similarly T_1 (RDF) positioned in the very same quadrant and closer to baseline showed average positive response for the principal components. T_5 (control) coordinated far in the 2nd quadrant showing negative response for PC1 but positive for PC2 while T_4 in the 3rd quadrant responded negative for both the components. Notably, T_2 (150%RDF+CD) was positioned in the fourth quadrant, where it was positively influenced by PC1 but negatively by PC2.

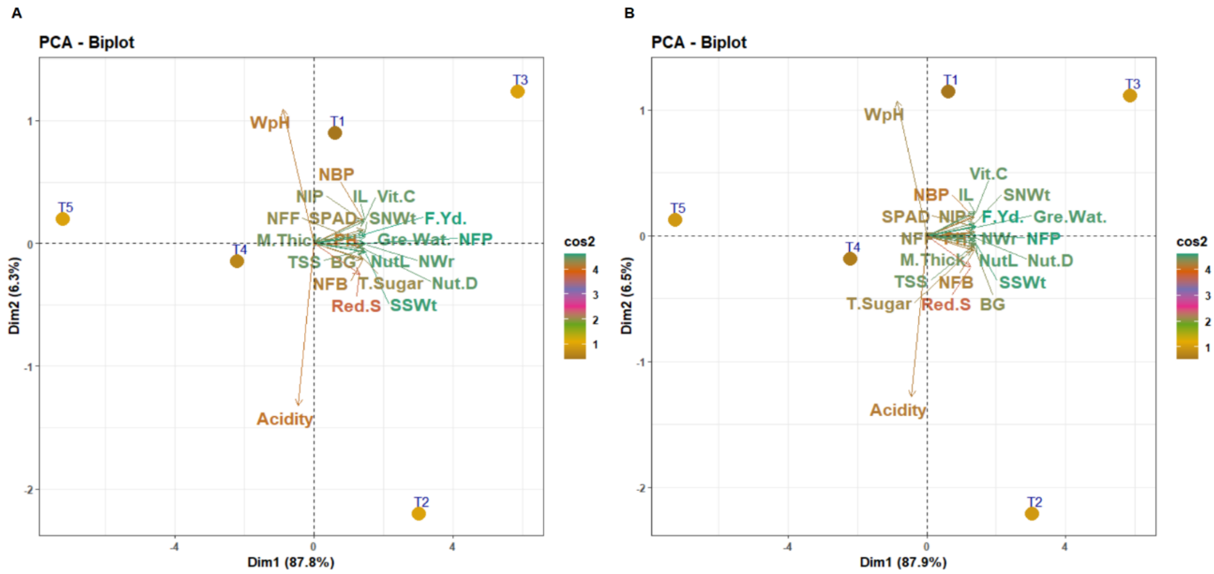

Figure 3. Principal component analysis (PCA) -biplot for 5 treatments and a total variable of 24 growth and floral contributing, yield and fruit quality attributes over two consecutive years (A=2020-21, B= 2021-22). The contribution and intensity of variables in Principal Component 1 (PC1) and Principal Component 2 (PC2) are depicted by individual arrows. PH=Plant Height (m), BG=Base girth of plant (m), IL=Inflorescence Length (cm), NIP=No. of Inflorescence/plant, NBP=Number of bunch/plant, NFF=Number of female flower/bunch, NFB=Number of fruit /bunch, SPAD=SPAD value, NFP=Number of fruits/plant, NutL=Nut (fruit) length (cm), Nut.D=Nut diameter (cm), SNWt=Single nut weight (kg), SSWt=Single shell weight (kg), NWr=Single coconut water (ml), Gre.Wat.=green coconut water (ml), F.Yd.= Fruit yield (kg/plant), M.Thick= Meat (Copra) thickness (mm), TSS=Meat TSS (^{0}Brix), Vit.C=Vitamin C (mg/100g), Acidity=Titratable acidity (%), T.Sugar=Total sugar (g/100 g), Red.S=Reducing sugar (g/100g), WpH=Water pH and Prot.=Protein content (%);

T_1 (RDF): $N_{450}P_{120}K_{1000}S_{50}Zn_{25}B_{6.8}$ g per plant, T_2 (150%RDF+CD): $N_{675}P_{180}K_{1500}S_{75}Zn_{37.5}B_{10.2}$ g plant^{-1}+10 kg cowdung (CD) plant^{-1}, T_3 (125%RDF + CD): $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}, T_4 (FP): $N_{200}P_{70}K_{300}$ g plant^{-1}+20 kg CD plant^{-1} and T_5: Control (no use of fertilizer).

3.6 Monitoring the Post-harvest Soil Chemical Properties During Crop Season

Table 5 shows that the year of cultivation significantly affected postharvest soil pH, organic matter, total N, K, S, Zn, and B, whereas its effect on available soil P was non-significant. These soil chemical properties were more pronounced in the second year of cultivation than in the first. Post-harvest soil properties were significantly influenced by the application of different rates of organic and inorganic fertilizers (Table 5). The postharvest soil pH of coconut palm under the T_3 treatment was the highest (5.93), which was statistically identical to most other treatments, while the lowest pH was observed in the T_2 treatment. Generally, the soil pH in most treatments increased slightly compared to the initial reference status. The maximum organic matter (OM) (1.33%) and total nitrogen (N) (0.073%) contents were recorded in T_3, followed by T_2 treatment. Except for the control (T_5), OM and total N contents in all treatments increased slightly over their initial status. Furthermore, post-harvest soil K, P and S contents varied significantly among treatments; they exhibited a slight upward trend compared to initial levels, whereas the T_5 treatment showed a decreasing trend. Finally, the highest Zn and B contents were recorded in the T_3 treatment, which was statistically similar to T_2. Except for the control treatment, Zn and B levels were slightly improved in most treatments compared to the initial soil status (Table 5).

Table 5. Effect of cultivation year, decomposed cow dung and inorganic fertilizers on postharvest soil chemical properties within the active root zone of coconut palm during third week of October 2021 and 2022

Cultivation year (Y)	pH	OM (%)	Total N (%)	K meq.100 g^{-1}	P mg·kg^{-1}	S	Zn	B
2020-21	5.88±0.006b	1.28±0.007b	0.068±0.0006b	0.13±0.003b	14.7±0.26a	14.6±0.24b	0.91±0.01b	0.17±0.007b
2021-22	5.93±0.009a	1.33±0.010a	0.071±0.0008a	0.16±0.005a	14.9±0.28a	14.8±0.26a	0.94±0.014a	0.21±0.009a
F-test	***	***	**	***	ns	*	***	***
CV (%)	0.46	2.26	2.78	9.68	6.25	1.79	2.10	9.28
LSD(0.05)	0.02	0.02	0.001	0.01	0.71	0.20	0.01	0.01
Treatment (T)								
Initial soil	5.87	1.26	0.066	0.14	14.5	13.9	0.89	0.16
T_1	5.86±0.014c	1.29±0.014b	0.068±0.0009bc	0.15±0.009a	15.2±0.37a	14.7±0.09b	0.94±0.009b	0.20±0.009b
T_2	5.91±0.015ab	1.31±0.015ab	0.070±0.001b	0.15±0.01a	15.3±0.30a	15.7±0.11a	0.97±0.01a	0.22±0.01a
T_3	5.93±0.017a	1.33±0.017a	0.073±0.0008a	0.16±0.01a	15.3±0.37a	15.6±0.10a	0.96±0.012ab	0.22±0.01a
T_4	5.90±0.015ab	1.31±0.017ab	0.071±0.001ab	0.15±0.01a	14.7±0.37a	14.2±0.13c	0.89±0.01c	0.17±0.012c
T_5	5.89±0.015b	1.26±0.015b	0.065±0.0008c	0.13±0.01b	13.5±0.21b	13.3±0.11d	0.86±0.013d	0.15±0.011c
F-test	*	*	***	*	*	***	***	***
CV (%)	0.46	2.26	2.78	9.68	6.25	1.79	2.10	9.28
LSD(0.05)	0.03	0.04	0.002	0.02	1.12	0.32	0.02	0.02
Interaction (Y*T)	ns	ns	ns	ns	ns	ns	ns	ns

Means within the same column followed by dissimilar letters are significantly different according to the least significant difference (LSD) test at a 5% ($P \leq 0.05$) level of probability. CV = coefficient of variation. T_1 (RDF): $N_{450}P_{120}K_{1000}S_{50}Zn_{25}B_{6.8}$ g per plant, T_2 (150%RDF+CD): $N_{675}P_{180}K_{1500}S_{75}Zn_{37.5}B_{10.2}$ g plant^{-1}+10 kg cowdung (CD) plant^{-1}, T_3

(125%RDF + CD): $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}, T_4 (FP): $N_{200}P_{70}K_{300}$ g plant^{-1}+20 kg CD plant^{-1} and T_5: Control (no use of fertilizer). Note: ns designates not significant, * designates significance at p≤0.05, ** designates significance at p≤0.01 and *** designates significance at p≤0.001 according to ANOVA; ± signify the standard error mean (n=3).

3.7 Cost and Return Analysis

The cultivation year did not significantly influence the gross return, gross margin, and benefit-cost ratio (BCR) of coconut cultivation (Data not presented). However, the overall economic performance including gross return, gross margin, and BCR was better in the second year (2021-22) than in the first year (2020-21). The combined application of organic (cow dung) and inorganic fertilizers significantly affected the gross return, gross margin, and BCR (Figures 4a & b). Particularly, the T_3 treatment (application of $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}) yielded the highest gross return (US$ 108 plant^{-1}) and gross margin (US$ 77.6 plant^{-1}), whereas the lowest values were recorded in the control group (T_5) (Figure 4a). On the other hand, the highest benefit-cost ratio (BCR) of 3.90 was achieved under T_4 (farmers' practice), followed by the T_3 treatment. The BCR was comparatively lower in T_3 than in T_4 because T_3 incurred the highest total variable cost. The minimum BCR was observed in the control (T_5) (Figure 4b).

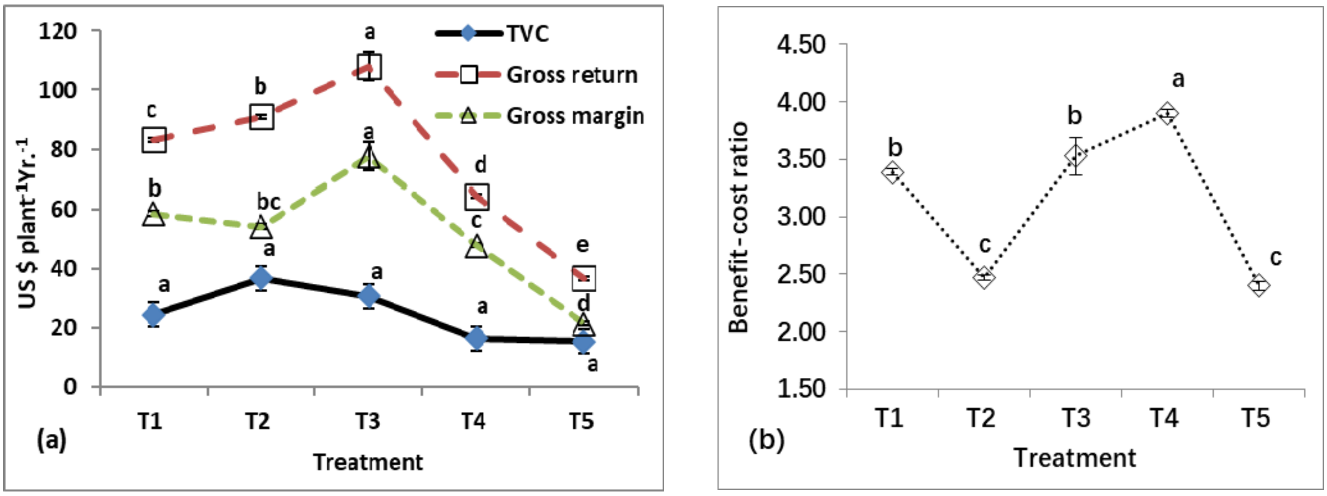

Figure 4. Influence of combined application of decomposed cow dung, and inorganic fertilizers on gross return, gross margin (a) and benefit-cost ratio (b) of coconut. Vertical bars represent the standard error of the mean (n=3); the mean values indicated by the common letters are not significantly different at the 5% level according to the least significant difference test; T_1 (RDF): $N_{450}P_{120}K_{1000}S_{50}Zn_{25}B_{6.8}$ g per plant, T_2 (150%RDF+CD): $N_{675}P_{180}K_{1500}S_{75}Zn_{37.5}B_{10.2}$ g plant^{-1}+10 kg cowdung (CD) plant^{-1}, T_3 (125%RDF + CD): $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}, T_4 (FP): $N_{200}P_{70}K_{300}$ g plant^{-1}+20 kg CD plant^{-1} and T_5: Control (no use of fertilizer); TVC= Total variable cost.

Output price: Coconut fruit US$ at 0.94 kg^{-1}.

Input prices: Urea= US$ 0.19 kg^{-1}, T.S.P= US$ 0.26 kg^{-1}, MoP= US$ 0.21 kg^{-1}, Gypsum= US$ 0.18 kg^{-1}, Zinc sulphate= US$ 16.5 kg^{-1}, Boric acid= US$ 14.1 kg^{-1}, Wage rate= US$ 5.9 day^{-1}, Autostin 50 WDG fungicide= US$ 3.29/100g, Dithane M-45= US$ 1.76 /100g, Ripcord 10 EC= US$ 2.14 100^{-ml}, Tundra 20 SP (acetamiprid) insecticide= US$ 4.70/100g, Cowdung= US$ 0.05 kg^{-1}, The gross return was calculated based on the farm-gate price of coconuts in Gazipur, Bangladesh, without considering land costs. All monetary data were converted using an exchange rate of 85 BDT per USD.

4. Discussion

Significant enhancements in coconut growth, yield and fruit quality highlight the benefits of combining organic and inorganic fertilizers. Coconut palms require a continuous nutrient supply to support leaf development and chlorophyll synthesis. While inorganic fertilizers deliver highly soluble ions for rapid initial growth, they are prone to rapid leaching (Quddus et al., 2026). Conversely, organic fertilizers release nutrients steadily while improving soil structural stability and nutrient retention (Atapattu et al., 2025). Integrating both strategies into an integrated nutrient management (INM) framework is therefore essential for sustainable crop development.

Growth, reproductive and physiological parameters

In this study, the T_3 treatment (INM) yielded the maximum plant height and base girth. While the inorganic components supplied immediate macronutrients to stimulate rapid cell division and elongation during vegetative phases (Mehedi et al., 2012), the addition of 30 kg of cow dung acted as a slow-release reservoir. Gradual decomposition extends nutrient availability later into the growth cycle, preventing nutrient hunger (Frank et al., 2020). Furthermore, this organic amendment improves soil organic matter (SOM), increases water-holding capacity, and enhances effective cation exchange capacity (ECEC) (Frank et al., 2020). This structural enhancement prevents the leaching of chemical inputs, ensuring the elevated inorganic dose (125%) is absorbed by plant roots rather than lost to the environment. In contrast, treatment T_2 utilized a higher inorganic dose (150%) but a lower organic fraction (10 kg of cow dung); excessive chemical inputs without adequate organic matter can lead to localized soil acidification or nutrient imbalances (Wang et al., 2024). Thus, T_3 struck the ideal stoichiometric balance between chemical inputs and organic buffering. Treatment T_3 significantly outperformed other treatments in inflorescence length and the number of inflorescences per plant. The transition from vegetative to reproductive growth requires substantial phosphorus (P) and energy. Although chemical fertilizers supply P, it is easily fixed into insoluble forms in many soils. However, the organic acids released during cow dung decomposition compete for soil binding sites, significantly boosting P bioavailability (Gao et al., 2023; Wang et al., 2024). Additionally, cow dung stimulates native rhizosphere microorganisms, such as *Bacillus* strains (Gao et al., 2023). This microflora exhibits plant growth-promoting rhizobacteria (PGPR) traits, synthesizing endogenous phytohormones like auxins and gibberellins that directly regulate inflorescence elongation and primordia initiation. The superior number of bunches, female flowers, and fruits per bunch in T_3 demonstrates that combining organic and inorganic fertilizers stabilizes a prolonged source-to-sink relationship. The sustained uptake of nitrogen and magnesium facilitated by cow dung enhances chlorophyll synthesis and prolongs green leaf area duration (Quddus et al., 2026). This extended photosynthetic capacity provides the carbon skeletons and sugars required to support a higher number of reproductive sinks without triggering premature fruit abortion. Together, the chemical fertilizers and cow dung introduce the nutrients necessary for floral fertility, successful pollination, and fruit set (Frank et al., 2020). Consequently, the T_3 treatment resulted in the highest SPAD values. Nitrogen serves as the core structural component of the porphyrin ring in chlorophyll molecules, and high N availability directly increases the synthesis of the Rubisco enzyme and thylakoid proteins-a relationship captured linearly by SPAD meters (Zhuang et al., 2025). Simultaneously, potassium acts as the primary osmoticum regulating stomatal opening, driving the cellular turgor pressure needed for leaf expansion, and stabilizing the cytoplasmic pH required for chlorophyll-synthesizing enzymes (Quddus et al., 2019).

Yield parameters

The significant increases in fruit yield, dimensional attributes, and water volumes observed under the T_3 treatment (application of $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1}+30 kg CD plant^{-1}), highlight the biological importance of balanced, site-specific nutrient management in perennial palms (Zhang et al., 2025). Particularly, T_3 achieved a 195% yield increase over the control (T_5), alongside a higher fruit count. This boost is primarily driven by the substantial application of nitrogen and potassium (K), the latter of which is heavily consumed by coconuts. Potassium regulates stomatal conductance and osmotic potential, thereby enhancing overall carbon assimilation (Moraes et al., 2023). During reproductive development, K drives the translocation of photoassimilates from leaves directly to the developing nuts, increasing both single nut weight and dimensions (length and diameter). Furthermore, the integrated nitrogen and phosphorus supply promotes early spikelet survival and minimizes bunch drooping and immature nut fall. The inclusion of Zn, B, and cow dung (CD) provided a distinct advantage over standard chemical treatments. Boron is essential for cell wall synthesis, pollen tube germination, and effective fertilization, which prevents spikelet sterility and button shedding (Quddus et al., 2022a). Concurrently, Zn catalyzes tryptophan synthesis—a critical precursor to indole-3-acetic acid (IAA). This IAA-regulated cell division and expansion explains the significant increase in single shell weight and nut volume (Moraes et al., 2023). As an organic amendment, CD acts as a slow-release nutrient reservoir that increases soil cation exchange capacity (CEC) and moisture retention (Atapattu et al., 2025). In Gazipur's specific soil conditions, CD likely mitigated the leaching of mobile NO_3^- and K^+ ions, extending nutrient availability across seasons. A notable finding was the sharp increase in both green and mature coconut water volumes under T_3. Mechanistically, the accumulation of coconut water which originates from cytological fluids in the embryo sac cavity-depends heavily on cellular osmotic pressure (Yong et al., 2009). High potassium and sulfur levels increase internal solute concentrations within the liquid endosperm, generating a strong osmotic gradient that draws water into the nut cavity via aquaporin pathways. While the decline in water volume from the green to the mature stage across all treatments reflects normal physiological development wherein the liquid endosperm cellularizes to form the solid kernel (Yong et al., 2009) the T_3

treatment maintained a clear advantage. Because T_3 provided superior initial sink strength and a larger nut cavity, it retained a significantly higher fluid volume at maturity than the nutrient-starved control.

Fruit quality attributes

The enhanced coconut fruit quality under treatment T_3 highlights the synergistic efficacy of combining inorganic nutrients with organic amendments (cow dung). Key quality traits including meat thickness, total soluble solids (TSS), total sugars, and reducing sugars were maximized by the higher application rates of nitrogen and potassium. Specifically, potassium drives phloem loading and the long-distance translocation of photoassimilates from source leaves to the fruit sink (Moraes et al., 2023). This accelerated influx of sucrose into the developing endosperm drives both cellular expansion in the coconut meat and higher solute concentrations within the cavity fluid. Furthermore, boron acts synergistically with potassium by forming sugar-borate complexes that facilitate the transport of sugars across cellular membranes, directly increasing solid endosperm (meat) thickness and sweetness (Quddus et al., 2022a: Quddus et al., 2019). The significant boost in vitamin C (ascorbic acid) under T_3 can be attributed to the balanced presence of zinc and sulfur, which function as critical cofactors in the carbohydrate metabolic pathways that yield precursors for ascorbic acid synthesis. Additionally, the high protein content in T_3 is a direct result of optimized nitrogen and sulfur assimilation. Nitrogen is the fundamental building block of amino acids, while sulfur is indispensable for synthesizing the sulfur-containing amino acids (methionine and cysteine) that dictate protein tertiary structures (Wang et al., 2026). Particularly, the statistical equivalence of T_2 and T_3 in protein content suggests that nitrogen availability reached a metabolic saturation point for protein synthesis at these thresholds. The integration of 30 kg of cow dung (CD) provided a sustained biostimulatory effect. Organic matter elevates the soil's cation exchange capacity (CEC), buffering highly mobile ions like NO_3^- and K^+ against heavy leaching (Atapattu et al., 2025). This mechanism created a steady nutrient supply during the critical stages of endosperm cellularization, avoiding the nutrient dips common in purely inorganic regimes. Conversely, the unstable trends observed in titratable acidity and water pH across treatments point to shifting buffering dynamics within the cellular fluid of the embryo sac. Coconut water pH and organic acid concentrations are highly dependent on the internal balance of malic, citric, and succinic acids, which fluctuate as fruits transition from the green to the mature stage (Yong et al., 2009). The lack of a linear response to the fertilizer treatments suggests that organic acid metabolism is governed more tightly by genetic homeostasis and maturity stages than by external nutrient loading alone.

Correlation coefficient and principal component analysis (PCA)

The correlation matrix illustrates the interdependent significance of the evaluated variables. Interrelated growth attributes demonstrated strong, significant correlations, which consequently influenced yield parameters. Specifically, fruit yield and the number of fruits per bunch were strongly correlated with the number of female flowers per bunch and inflorescence length. This indicates that reproductive traits positively affect overall yield, aligning with the findings of Suchithra and Paramaguru (2018). Similarly, Louis et al. (2010) and Odufale et al.

(2022) reported positive correlations between inflorescence length and fruit weight, as well as between fruit weight and single nut water content. Furthermore, the total soluble solids (TSS) of the coconut water were significantly and positively correlated with meat thickness, but showed no significant correlation with acidity, consistent with the study by Terdwongworakul et al. (2009). Additionally, TSS, reducing sugars and total sugars were strongly correlated with growth factors. This relationship likely occurs because the synergistic formation of sugar-borate complexes positively influences meat thickness, TSS, and subsequent sugar accumulation (Quddus et al., 2022a).

The dimension-reduced multivariate traits demonstrated a clear response to the treatments. While most growth and yield traits were strongly correlated, the fruit quality attributes exhibited variable responses. The fertilizer doses elicited diverse effects across PC1 and PC2. Specifically, the treatment response in PC1 and PC2 was prominent and positive for T_3 (125%RDF + CD). This indicates that augmenting organic matter with an elevated inorganic fertilizer dose (125% RDF) enhanced performance across most traits, which complies with the findings of Quddus et al. (2026). Conversely, T_5 (control) exhibited the weakest effect, demonstrating a negative response for PC1, which accounts for the vast majority of the total variance (87.8% and 87.9%). According to Frank et al. (2020), Suchithra and Paramaguru (2018), and Maheswarappa et al. (2013), reproductive traits are significantly influenced by the combined application of organic and inorganic fertilizers. The treatment effects were also evident in the coconut water (NWr.) and green coconut water (Gre.Wat.) attributes, as their vectors were strongly directed toward T_3, a trend supported by Yong et al. (2009). However, Yong et al. (2009) also noted that coconut water pH and acidity vectors responded diversely to treatments, as these quality traits depend primarily on the internal organic acid balance at different maturity stages rather than external agricultural inputs.

Postharvest soil status

The significant rise in postharvest soil pH under the T_3 treatment and the general upward trend observed across most treatments compared to the initial reference status can be mechanistically linked to the decomposition of organic amendments and the subsequent release of basic cations (Shinde et al., 2020; Quddus et al., 2025). During the mineralization of organic matter (OM), functional groups (such as carboxyl and phenolic groups) consume hydrogen ions (H^+) through buffering reactions. Furthermore, the microbial degradation of organic complexes releases basic cations (Ca^{2+}, Mg^{2+} and K^+) into the soil solution, shifting the equilibrium and effectively neutralizing exchangeable acidity (Atapattu et al., 2025). Conversely, the lower pH observed in the T_2 treatment may indicate a higher rate of nitrification and a localized dominance of ammonium-based chemical fertilizers, where the biological oxidation of ammonium (NH_4^+) to nitrate (NO_3^-) generates protons (H^+), thereby reducing the surrounding soil pH. Post-harvest soil analysis revealed that available K, P, and S contents varied significantly across treatments; they displayed a slight upward trend in the fertilized plots but decreased slightly in the control (T_5). Specifically, the upward trend in available K within the fertilized treatments indicates that the application rate successfully outpaced both the crop's aggressive uptake and potential leaching losses. This finding aligns with previous studies demonstrating that combining organic and inorganic fertilization can effectively maintain or elevate soil potassium levels

(Broschat, 2009; Sultana et al., 2022). Mechanistically, the improvement in available P and S can be directly attributed to increased soil organic matter (SOM) and an upward shift in pH. Organic anions released during SOM decomposition compete with phosphate (PO_4^{3-}) for binding sites on soil sesquioxides (iron and aluminum oxides), effectively mitigating P fixation through competitive adsorption. Moreover, as the pH shifts toward a more neutral 5.93, iron- and aluminum-mediated phosphate precipitation is minimized, significantly increasing P solubility and spatial availability within the palm's active root zone. For sulfur, which is primarily bound within native organic complexes (such as ester sulfates and carbon-bonded sulfur) and inherently inaccessible to plant roots, the slight upward trend in availability across treatments stems from accelerated microbial mineralization pathways. The integrated amendments in T_3 stimulate the heterotrophic microbiome, increasing the production of extracellular enzymes like arylsulfatase (Ammar et al., 2023; Quddus et al., 2024). The highest levels of available Zn and B recorded in the T_3 and T_2 treatments highlight a clear synergy with integrated soil management (Broschat, 2009). The slight improvement in Zn and B relative to the initial reference baseline indicates that these treatments either directly supplied these micronutrients or fundamentally altered the soil chemistry to enhance their availability. Conversely, the declining or stagnant values in the T_5 (Control) validate that without targeted fertilization or organic recycling; the heavy, continuous demand of coconut palm growth rapidly depletes native soil micronutrient reserves (Atapattu et al., 2025; Quddus et al., 2019).

Economic performance

The application of combined organic and inorganic fertilizers under the T_3 treatment resulted in significantly higher gross returns and gross margins compared to the unfertilized control (T_5). Mechanistically, this economic superiority is driven by synergistic interactions within an Integrated Plant Nutrient System (IPNS) (Kalpana et al., 2008), a view supported by Gao et al. (2023) and Wang et al. (2024). The sustained-release mechanism of the IPNS optimizes the crop's net photosynthetic rate and sink-source metabolic partitioning, translating into maximum physical yields and greatest absolute financial returns. Conversely, the minimal biological and financial performance recorded in T_5 highlights the severe limitations of native soil reserves under intensive vegetative production (Antonangelo et al., 2024). However, a distinct economic trade-off occurred regarding the Benefit-Cost Ratio (BCR) defined as the ratio of gross return to total variable cost (TVC). The farmers' practice (T_4) achieved the highest BCR, closely followed by T_3. While the comprehensive nutrient regime of T_3 maximized coconut yield, gross returns, and gross margins, it also augmented TVC. In contrast, T_5 relied on a low-input selection of chemical applications and reduced organic manure volumes. This lowered initial financial expenses, thereby yielding a higher BCR. Nevertheless, from a standpoint of long-term agro-system sustainability, relying exclusively on high-BCR, low-input methods like T_4 is short-sighted; it risks mining soil nutrient reserves over consecutive seasons and fails to match the high absolute gross margin secured by the integrated approach (T_3).

Seasonal variation

An assessment of coconut cultivation across two consecutive growing seasons revealed that growth, yield, quality, and economic performance parameters were significantly superior during the second season (2021-22) compared to the first (2020-21). These fluctuations are primarily attributed to varying macroclimatic dynamics and the cumulative residual effects of integrated organic and inorganic fertilization regimes. Meteorological data indicated that the first year was characterized by elevated average temperatures, whereas the second experienced lower temperatures alongside substantially higher total precipitation. The variation in agronomic parameters highlights the sensitivity of perennial tree crops to seasonal macroclimatic shifts. Coconut palms require highly consistent climatic ranges for optimal physiological performance, ideally thriving in well-distributed annual rainfall between 1,300 and 2,300 mm and mean temperatures of 20-29 °C. The improved performance during the second year aligns with these requirements, supporting the observations of Kumar and Aggarwal (2013) and Ponce et al. (2024). Furthermore, post-harvest soil analysis demonstrated enhanced nutrient profiling and fertility retention in the second year, which directly drove the observed physiological and yield improvements-a view corroborated by Sande et al. (2024).

5. Conclusions

Based on the experimental results, it can be concluded that the combined application of inorganic and organic fertilizers is essential for the sustainable improvement of coconut yield and fruit quality. Specifically, the integrated application of $N_{563}P_{150}K_{1250}S_{62.5}Zn_{31.25}B_{8.5}$ g plant^{-1} along with 30 kg of cow dung (CD) plant^{-1} significantly improves soil health and mitigates long-term soil degradation. Furthermore, this balanced nutrient treatment directly translates into optimized physiological growth, superior fruit quality such as fruit size, weight and increasing total soluble solids (TSS), ascorbic acid (vitamin C), and protein content, and higher cumulative coconut yields. This strategy is safeguarding economic returns for growers. Ultimately, adopting these integrated nutrient management strategies provides a resilient, ecologically sound way that successfully balances intensive production demands with the imperative of preserving soil health for future generations.

Acknowledgments

The authors are grateful to the NATP-2/PIU-BARC authority for financial support to this research. Sincere gratitude is also extended to the personnel of Soil Science Division, the Soil and Water Management Section, and the Postharvest Section of the Horticulture Research Centre at the Bangladesh Agricultural Research Institute (BARI) for providing access to laboratory facilities for soil, plant, and fruit sample analysis.

Author contributions

M.A.Q., M.A.I., and M.J.R. conceived the study. Data analysis and software execution were carried out by M.A.Q., M.T.I., M.M.K., J.C.S., M.A.I., and Z.H.F. The methodology was designed by M.A.Q., Z.H.F., M.A.I., M.J.H., and A.M., who were also responsible for visualization and validation. M.A.Q., S.R.H., M.A.I., M.S.A. and M.J.R. drafted the initial manuscript, while M.A.Q., Z.H.F., M.A.I and M.J.R. performed subsequent revisions. Experimental supervision was provided by M.A.Q., M.J.R., and M.S.A. All authors have read and approved the final submission.

Funding

This research work was funded by NATP-2/PIU-BARC (Bangladesh Agricultural Research Council) under the project 'Development of integrated crop management technologies for higher production of coconut in Bangladesh' (Project ID: 026). Logistical support was provided through internal institutional allocations.

Competing interests

The authors hereby affirm that there are no conflicts of interest associated with the conduct or reporting of this research.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Macrothink Institute.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

Reference

Ahmmed S., Jahiruddin M., Razia S., Begum R.A., et al. (2018) Fertilizer Recommendation Guide—2018. Bangladesh Agricultural Research Council (BARC), Dhaka 1215, Bangladesh, 223p.

Aktar, S., Amin, M. R., Saha, B. K., Uddin, M. K., Quddus, M. A., Ahmed, I., … &

Chowdhury, M. A. H. (2026) Agronomic Zinc Bio-fortification Enhances Productivity, Quality, and Nutrient Use Efficiency in Lentil Genotypes. *Journal of Soil Science and Plant Nutrition*, *26*, 7242-7261. https://doi.org/10.1007/s42729-026-03333-2

Ammar, E. E., Rady, H. A., Khattab, A. M., Amer, M. H., Mohamed, S. A., Elodamy, N. I., … & Aioub, A. A. A. (2023) A comprehensive overview of eco-friendly bio-fertilizers extracted from living organisms. *Environmental Science and Pollution Research*, *30*, 113119-113137. https://doi.org/10.1007/s11356-023-30260-x

Anonymous. (1994). Official Methods of Analysis. Association of Official Agricultural Chemists. Washington, D.C.

Antonangelo, J. A., Culman, S., & Zhang, H. (2024). Comparative analysis and prediction of cation exchange capacity via summation: influence of biochar type and nutrient ratios. *Frontiers in Soil Sciece*, *4*, 1371777. https://doi.org/10.3389/fsoil.2024.1371777

Atapattu, A. J., Nuwarapaksha, T. D., Udumann, S. S., & Dissanayaka, N. S. (2025). Integrating Organic Fertilizers in Coconut Farming: Best Practices and Application Techniques. *Crops*, *5*, 17. https://doi.org/10.3390/crops5020017

Black, C. A. (1965). Methods of Soil Analysis: Part 1 and Part 2, Physical and Mineralogical Properties. *American Society of Agronomy*, Madison, USA, p.1143. https://doi.org/10.2134/agronmonogr9.1

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal*, *54*(5), 464-465. https://doi.org/10.2134/agronj1962.00021962005400050028x

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Science*, *59*, 39-46. https://doi.org/10.1097/00010694-194501000-00006

Broschat, T. K. (2009). Palm nutrition and fertilization. HortTechnology, *19*(4), 690-694. https://doi.org/10.21273/horttech.19.4.690

Fox, R. L., Olsen, R. A., & Rhoades, H. F. (1964). Evaluating the sulphur status of soil by plant and soil test. Soil Science Society of America Journal, *28*(2), 243-246. https://doi.org/10.2136/sssaj1964.03615995002800020034x

Frank, O. O, Paul, O. J., & Amhakhian, S. O. (2020). Influence of Combined Application of Cattle Dung and NPK Fertilizer on Soil Physico-Chemical Properties, Growth, Nutrient Uptake and Yield of Fluted Pumpkin (Telfairia occidentalis) in Anyigba, Kogi State, Nigeria. *South Asian Research Journal of Agriculture and Fisheries*, *02*(01), 1–14. https://doi.org/10.36346/sarjaf.2020.v02i01.001

Gao, F., Ye, L., Mu, X., Xu, L., Shi, Z., & Luo, Y. (2023). Synergistic effects of earthworms and cow manure under reduced chemical fertilization modified microbial community structure to mitigate continuous cropping effects on Chinese flowering cabbage. *Frontiers in Microbiology*, *14*. https://doi.org/10.3389/fmicb.2023.1285464

Hiller, A., Plazin, J., & Vanslyke, D. D. (1948). A study of conditions of Kjeldhal determination of nitrogen in proteins. *Journal of Biological Chemistry*, *176*(3), 1401-1420. https://doi.org/10.1016/S0021-9258(18)57154-4

Ismail, K., Ismail, A. A., & Husin, M. A. (2022). Influence of Integrated Nutrient Management on Yield of Coconut (*Cocos Nucifera*) on Sandy Soils. *Asian Journal of Applied Science and Technology*, *6*(1), 38–49. https://doi.org/10.38177/ajast.2022.6106

Jackson, M. L. (1973). Soil chemical analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

Kalpana, M., Gautam, B., Srinivasulu, B., Rao, D. V. R., Arulraj, S., & Jayabose, C. (2008). Impact of integrated nutrient management on nut yield and quality of coconut under coastal ecosystem. *Journal of Plantation Crops*, *36*(3), 249-253.

Karandeep, K., Navnidhi, C., Poorva, S., Garg, M., & Anil, P. (2019). Coconut meal: Nutraceutical importance and food industry application. *Foods and Raw Materials*, *7*, 419–427. https://doi.org/10.21603/2308-4057-2019-2-419-427

Kumar, S. N., & Aggarwal, P. K. (2013). Climate change and coconut plantations in India: Impacts and potential adaptation gains. *Agricultural Systems*, *117*, 45–54. https://doi.org/10.1016/j.agsy.2013.01.001

Lindsay, W., & Norvell, W. A. (1978). Development of a DTPA soil test for Zn, Fe, Mn and Cu. *Soil Science Society of America Journal,* *42*, 421-428. https://doi.org/10.2136/sssaj1978.03615995004200030009x

Louis, K. J., Raloul, S. S., Pierre, N. G. S., Thierry, L. T., & Kouassi, A. L. L. O. U. (2010). Assessment of vegetative growth and production of new improved coconut (*Cocos nucifera* L.) hybrids. *Journal of Applied Biosciences, 26,* 1664-1674.

Maheswarappa, H. P., Dhanapal, R., Subramanian, P., & Palaniswami, C. (2013). Evaluation of coconut based high density multi-species cropping system under organic and integrated nutrient management. *Journal of Plantation Crops*, *41*(2), 130-135.

Mat, K., Abdul Kari, Z., Rusli, N. D., Che Harun, H., Wei, L. S., Rahman, M. M., … & Goh, K. W. (2022). Coconut Palm: Food, Feed, and Nutraceutical Properties. *Animals*, *12*, 2107. https://doi.org/10.3390/ani12162107

Mehedi, T. A., Siddique, M. A., & Shahid, S. B. (2012). Effects of urea and cowdung on growth and yield of carrot. *Journal of the Bangladesh Agricultural University*, *10*(1), 9–13. https://doi.org/10.3329/jbau.v10i1.12012

Mohandas, S. (2012). Integrated Nutrient Management in East Coast Tall Coconut. *Madras Agricultural Journal*, *99*(1-3):92–95. https://doi.org/10.29321/maj.10.100022

Moraes, A. R. A. de, Araújo, Suzana R., Silva Junior, M. L. da, Lins, P. M. P., Gomes, M. S., … & Dias, V. H. R. (2023). Fertilization with zinc improves the growth and photosynthetic performance of dwarf green coconut seedlings. *Brazilian Journal of Agricultural and*

Environmental Engineering, *27*(11), 864–872. https://doi.org/10.1590/1807-1929/agriambi.v27n11p864-872

Moyin-Jesu, E. I., & Ogochukwu, A. I. (2014). Comparative evaluation of different organic fertilizer effects on soil fertility, leaf chemical composition and growth performance of coconut (*Cocos nucifera* L.) seedlings. *International Journal of Plant & Soil Sciience*, *3*(6), 737–750. https://doi.org/10.9734/IJPSS/2014/4338

Odufale, O. O., Oluwaranti, A., Odewale, J. O., Adaigbe, V. C., Koloche, M. I., Ozurumba, J. C., … & Yusuf, A. O. (2022). Correlation and path-coefficient analyses of yield and vegetative traits of tall coconut accessions. *Thai Journal of Agricultural Science*, *55*(2), 73-83.

Page, A. L., Miller, R. H., & Keeney, D. R. (1982). Methods of soil analysis. Part 2, Chemical and microbial properties. Am. Soc. Agron. No. 9 (Part 2), Agronomy Series. Soil Science Society of America, Madison, WI. https://doi.org/10.2134/agronmonogr9.2.2ed

Piper, C. S. (2019). Soil and plant analysis. Adelaide University Press, Adelaide, Australia.

Ponce, M. A. M., Napa, I. M. P., Pincay, J. M. C., & Vera, M. J. V. (2024). Climatic variability and its impact on coconut production in Rocafuerte canton, Ecuador. *Visions for Sustainability*, *22*, 431-453.

Quddus, A., Ahmed, R., Khan, S. U., Purnota, S. J., Islam, T., Sultana, N. A., … & Uddin, K. (2026). Sustainable garden pea cultivation: a comprehensive evaluation of organic, inorganic, and bio-fertilizer impacts on productivity, quality and nutrient dynamics. *International Journal of Plant Production*, *20*, 22. https://doi.org/10.1007/s42106-025-00398-4

Quddus, A., Rahman, A., Tashzi, S., Ahmed, B., Islam, M., Arfin, S., … & Hossain, A. (2024) Improvement of productivity, quality and nutrient use efficiency of Indian spinach (*Basella alba* L.) by organic and inorganic nutrition. *Journal of Soil Science and Plant Nutrition, 24*, 8174– 8191, https://doi.org/10.1007/s42729-024-02105-0.

Quddus, M. A., Hossain, M. A., Naser, H. M., Anwar, B., Siddiky, M. A., & Ali, M. R. (2019). Influence of Potassium Addition on Productivity, Quality and Nutrient Uptake of Mungbean (*Vigna radiata* L.). *Journal of Agricultural Studies*, *7*(1), 21-40. https://doi.org/10.5296/jas.v7i1.14269

Quddus, M. A., Ahmed, R., Islam, M., Haque, M. E., Islam, M. A., Alam, A., … & Hossain A. (2025). Organic and inorganic fertilizers influence the productivity, fruit quality and nutrient use efficiency of strawberry (*Fragaria × ananassa* Duch.). *Scientific Reports*, *15*, 26252. https://doi.org/10.1038/s41598-025-10787-4

Quddus, M. A., Siddiky, M. A., Ali, M. R., Ahmed, R., Sarker, K. K., & Arfin, M. S. (2022a). Influence of boron and zinc on yield, nutrient uptake and quality of strawberry, *Journal of Plant Nutrition*, *45*(6), 866-882. https://doi.org/10.1080/01904167.2021.1998528

Quddus, M. A., Siddiky, M. A., Hussain, M. J., Rahman, M. A., Ali, M. R., & Masud, M. A. T. (2022b). Magnesium influences growth, yield, nutrient uptake, and fruit quality of tomato.

International Journal of Vegetable Science, *28*(5), 441-464. https://doi.org/10.1080/19315260.2021.2014614

Ranganna, S. (1986). Handbook of analysis and quality control for fruit and vegetable products, 2nd ed. Tata McGraw Hill Pub. Co. Ltd., New Delhi, India.

Sande, T. J., Tindwa, H. J., Alovisi, A. M. T., Shitindi, M. J., & Semoka, J. M. (2024). Enhancing sustainable crop production through integrated nutrient management: a focus on vermicompost, bio-enriched rock phosphate, and inorganic fertilisers–a systematic review. *Frontiers in Agronomy*, *6*, 1422876. https://doi.org/10.3389/fagro.2024.1422876

Selim, M. M. (2021). Introduction to the Integrated Nutrient Management Strategies, and Contribution on Yield and Soil Properties. *Journal of Plant Sciences, 9*(4), 139-150. https://doi.org/10.11648/j.jps.20210904.13

Selva Rani, A., Subbulakshmi, S., Sudha, R., Kavitha, K., Nazreen Hassan, S. H., Muthulakshmi, M., … & Suresh, S. (2024). Synergizing Sustainability: Integrated Nutrient Management and Intercropping for Optimal Coconut Cultivation in South India. *Horticulturae*, *10*, 653. https://doi.org/10.3390/horticulturae10060653

Shakeela, H., Mohan, K., & Nisha, P. (2024). Unlocking a nutritional treasure: health benefits and sustainable applications of spent coconut meal. *Sustainable Food Technology*, *2*, 497-505. https://doi.org/10.1039/d3fb00247k

Shinde, V. V., Maheswarappa, H. P., Ghavale, S. L., Sumitha, S., Wankhede, S. M., & Haldankar, P. M. (2020). Productivity and carbon sequestration potential of coconut-based cropping system as influenced by integrated nutrient management practices. *Journal of Plantation Crops*, *48*(2), 103-110. https://doi.org/10.25081/jpc.2020.v48.i2.6368

Suchithra, M., & Paramaguru, P. (2018). Variability and correlation studies for vegetative, floral, nut and yield characters in indigenous and exotic coconut genotypes. *International Journal of Current Microbiology and Applied Sciences,* *7*(7), 3040-3054. https://doi.org/10.20546/ijcmas.2018.707.355

Sultana, M., Quddus, M.A., Siddiky, M. A., Rahman, M., & Rahman, M. B. (2022). Effect of vermicompost and inorganic fertilizer on the yield and quality of cabbage. *Bangladesh Journal of Agricultural Research*, *47*, 433–449. https://doi.org/10.3329/bjar.v47i4.91445

Terdwongworakul, A., Chaiyapong, S., Jarimopas, B., & Meeklangsaen, W. (2009). Physical properties of fresh young Thai coconut for maturity sorting. *Biosystems engineering*, 103(2), 208-216. https://doi.org/10.1016/j.biosystemseng.2009.03.006

Wang, H., Fu J., Gong, H., Kuang, L., Song, Y., Ma, Z., He, L., … & Gao, Q. (2026). Coordinated application of nitrogen and sulfur synergistically enhances grain yield and grain protein concentration of rice by regulating plant growth. *Plants, 15*, 1058. https://doi.org/10.3390/plants15071058

Wang, J., Qin, H., Zhang, L., Tang, Y., Long, J., Xu, H., & Zhu, B. (2024). Synergistic effects of rhizosphere effect and combined organic and chemical fertilizers application on soil bacterial diversity and community structure in oilseed rape cultivation. *Frontiers in Microbiology*, *15*, 1374199. https://doi.org/10.3389/fmicb.2024.1374199

Yong, J. W. H., Ge, L., Ng, Y. F., & Tan, S. N. (2009). The chemical composition and biological properties of coconut (*Cocos nucifera* L.) water. *Molecules*, *14*(12), 5144–5164. https://doi.org/10.3390/molecules14125144

Zhang, H., Zhai, H., Zan, R., Tian, Y., Ma, X., Ji, H., & Zhang, D. (2025). Balanced Fertilization Improves Crop Production and Soil Organic Carbon Sequestration in a Wheat–Maize Planting System in the North China Plain. *Plants*, *14*, 838. https://doi.org/10.3390/plants14060838

Zhuang, H., Tang, X., Ning, Z., Zhou, C., Zhao, Q., Wang, H., … & Zhang, A. (2025). The Impact of Reduced Nitrogen Fertilizer Application and Arbuscular mycorrhizal fungi Inoculation on Nitrogen Utilization in Intercropped *Areca catechu* L. and *Vanilla planifolia* Andrews. *Plants, 14*, 3207. https://doi.org/10.3390/plants14203207