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Effect of Integrated Nutrient Management with Recycling of Crop Biomass on Yield of Coconut-based Cropping System in East Coast Region of Andhra Pradesh

A. KIREETI[1]*, B.V.K. BHAGAVAN[2], G. RAMANANDAM[3], E. PADM[4],
N.B.V. CHALAPATHI RAO[1], B. NEERAJA[1], V. GOVARDHAN RAO[1],
and B. SRINIVASULU[1]

[1]Dr. YSR Horticultural University-Horticultural Research Station, Ambajipeta,
Dr. B.R. Ambedkar Konaseema - 533 214, Andhra Pradesh, India
[2]Dr. YSR Horticultural University-Horticultural Research Station, Peddapeta,
Srikakulam - 532 445, Andhra Pradesh, India
[3]Dr. YSR Horticultural University-Horticultural Research Station, Kovvur,
East Godavari - 534 350, Andhra Pradesh, India
[4]Dr. YSR Horticultural University-College of Horticulture, Venkataramannagudem,
West Godavari - 534 101, Andhra Pradesh, India

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An experiment was conducted during 2014-2020 at the Horticultural Research Station, Dr. YSRHU, Ambajipeta, Dr. B.R. Ambedkar Konaseema district, Andhra Pradesh, to evaluate the impact of integrated nutrient management (INM) on the productivity of coconut and intercrops in a coconut-based cropping system (CBCS), as well as on soil fertility and plant nutrient content. The treatments were T_1 - 75% of Recommended NPK (RDF) + vermicompost, T_2 - 50% of RDF + vermicompost + vermiwash + biofertilizer + *in situ* green manuring, T_3 - Fully organic: Vermicompost + vermiwash + biofertilizer + *in situ* green manuring + green leaf manuring (*Gliricidia*) + composted coir pith + mulching with coconut leaves, T_4 - 100% RDF with mono cropping of coconut. Among the treatments, T_1 (75% RDF + vermicompost) recorded the maximum yields of coconut (157.34 nuts palms^{-1} and 27848 nuts ha^{-1}), cocoa (2.6 kg plant^{-1}), banana (12.68 kg plant^{-1}), elephant foot yam (2.48 kg plant^{-1}), and pineapple (0.903 kg plant^{-1}). This treatment also recorded the highest benefit-cost ratio of 3.22. Integrated nutrient management practices significantly improved coconut yield (by 15-20%), intercrop productivity, net returns (by 2.5 times), soil organic carbon (1.2%), soil moisture content (2%) and the population of beneficial soil micro-organisms. Based on the results, the application of 75% of RDF + vermicompost (prepared from biomass within CBCS) is recommended for sustainable cultivation in coconut-based cropping systems. This ensures enhanced yields and profitability while maintaining soil health.

(***Key words:*** *Biomass recycling, Coconut-based cropping system, Integrated nutrient management, Soil fertility, Vermicompost)*

Coconut (*Cocos nucifera* L.) is an important perennial oil-yielding crop of the humid tropics of India, cultivated over an area of 2165.20 thousand ha with an annual production of 21373.62 million nuts and an average productivity of 9871 nuts ha^{-1}. Andhra Pradesh although coconut is grown extensively in the coastal districts, the crop is cultivated across the state in a total area of 107.37 thousand ha, producing 1707.08 million nuts annually. The state records the highest productivity in India, with 15899 nuts ha^{-1} (Coconut Development Board, 2024).

In recent years, several studies have investigated the integration of compatible intercrops and cropping models within coconut orchards to optimize interspace utilization, ensure adequate sunlight penetration, and improve overall land productivity through the efficient use of resources such as light, soil, water, and labour (Thiruvassan and Maheswarappa, 2014; Padma *et al.*, 2018; Basavaraju *et al.*, 2018). A study conducted at the Horticultural Research Station, Dr. YSR Horticultural University, Ambajipeta, demonstrated that coconut-based cropping systems (CBCS) incorporating intercrops such as cocoa (*Theobroma cacao*), banana (*Musa* spp.), pineapple (*Ananas comosus*), elephant foot yam (*Amorphophallus paeoniifolius*), and heliconia (*Heliconia* spp.) are particularly suitable for the coastal districts of Andhra Pradesh (Padma *et al.*, 2016).

Nutrient management plays a crucial role in

**Corresponding author:* E-mail: itsmekireeti@yahoo.com

optimizing the yields of both coconut and intercrops in coconut-based cropping systems. Sole dependence on chemical fertilizers for nutrient supply can lead to the degradation of soil health, depletion of soil organic matter (Bhattacharyya *et al.*, 2015), and contamination of groundwater. Increased concentrations of Na, K, Ca, and Mg in groundwater have been attributed to intensive agricultural and industrial activities, with higher calcium levels being particularly attributed to the excessive use of nitrogenous fertilizers in the erstwhile East Godavari district (Anil and Ramesh, 2015).

Integrated nutrient management (INM), involving the use of vermicompost and other organic inputs, offers a holistic approach that minimizes the use of chemical fertilizers by recycling farm waste in an eco-friendly manner, thereby improving soil health and sustaining system productivity. Despite significant quantities of waste biomass generated in coconut-based cropping systems, limited efforts have been made to utilize this biomass effectively for nutrient recycling. There is a paucity of information on the recycling of waste biomass from CBCS for integrated nutrient management and its impact on coconut and intercrop yields, economic viability, and soil health. Therefore, the present study was undertaken to evaluate the effect of INM on the productivity of a coconut-based cropping system, soil fertility status, plant nutrient content, and soil moisture conservation.

MATERIALS AND METHODS

Experimental site

A field trial was conducted during 2014 to 2020 at Dr. YSR Horticultural University-Horticultural Research Station, Ambajipeta, located in Dr. B.R. Ambedkar Konaseema district of Andhra Pradesh (16°59'38" N latitude, 81°56'37" E longitude and 14 m above MSL) under the ICAR-All Indian Coordinated Research Project (AICRP) on Palms on effect of nutrient management with recycling of crop biomass on yield of coconut based cropping system (CBCS). The study site lies in the east coast region of Andhra Pradesh under the Krishna-Godavari agro-climatic zone, characterized by a tropical humid climate with distinct summer, monsoon, and winter seasons. During the experimental period, the site received an average annual rainfall of 859.68 mm, mean temperature ranged from a minimum of 27.1°C to a maximum of 32.9°C and the relative humidity varied between 65.7% and 87.2%, as recorded by the Automatic Weather Station installed at the site by the India Meteorological Department. The experimental soil was coastal alluvial in nature, with a texture ranging from clay loam to clay. The initial soil pH and electrical conductivity (EC) measured in 1:2 soil water suspension was 8.21 and 0.10 dS m^{-1}, respectively, organic carbon content was 0.60%, while the available nitrogen (N), phosphorus (P), and potassium (K) were 240, 16.2, and 220 kg ha^{-1}, respectively.

Experimental design and treatments

The experiment was conducted in a 27-year-old coconut orchard planted with the hybrid 'Godavari Ganga' (East Coast Tall × Ganga Bondam Green Dwarf), developed for early flowering and high yield. A randomized block design was adopted with four nutrient management treatments replicated six times. The total experimental area was 0.8 ha, and each plot measured 0.03 ha, accommodating six coconut palms. The coconut-based cropping system (CBCS) included intercrops such as cocoa (*Theobroma cacao*), banana (*Musa spp.*), elephant foot yam (*Amorphophallus paeoniifolius*), pineapple (*Ananas comosus*), tomato (*Solanum lycopersicon*) and heliconia (*Heliconia* spp.).

The four treatments were as follows: T_1 - 75 % of recommended dose of NPK (N 0.46 kg, P 0.32 kg, and K 1.5 kg $plant^{-1}$) + vermicompost (produced from biomass of CBCS), T_2 - 50% of recommended dose of NPK + vermicompost (produced from biomass of CBCS) + vermiwash application + biofertilizer application + *in situ* green manuring, T_3 - Fully organic: vermicompost (produced from biomass of CBCS) + vermiwash application + biofertilizer application + in situ green manuring + green leaf manuring (*Gliricidia*) + composted coir pith and mulching with coconut leaves, T_4 - 100% recommended dose of NPK with mono cropping of coconut. All the fertilizers, biofertilizers and vermicompost were applied in two equal splits once in June-July and the other in December-January of each year. The details of the intercrops, variety, planting details and fertiliser and manure doses applied are given in Table 1.

Vermicompost preparation

Vermicompost was prepared by utilizing the waste

Table 1. *Details of intercrops, variety, plant population, dosage of NPK, vermicompost, biofertilizer applied for different crops*

Crop	Variety	Spacing	Plant population ha^{-1}	75% of Rec. NPK*	50% of Rec. NPK**	Vermicompost!	Biofertilizer#
Coconut	Godavari Ganga	7.5 x 7.5 m	175	N: 370 g $plant^{-1}$ P: 240 g $plant^{-1}$ K: 900 g $plant^{-1}$	N: 250 g $plant^{-1}$ P: 160 g $plant^{-1}$ K: 600 g $plant^{-1}$	25 kg $palm^{-1}$	*Azospirillum*: 100 g $plant^{-1}$ Phosphobacteria: 100 g $plant^{-1}$
Banana	TC Keli	1.5 x 1.5 m	796	N: 150 g $plant^{-1}$ P: 150 g $plant^{-1}$ K: 300 g $plant^{-1}$	N: 100 g $plant^{-1}$ P: 100 g $plant^{-1}$ K: 200 g $plant^{-1}$	8 kg $plant^{-1}$	*Azospirillum*: 50 g $plant^{-1}$ Phosphobacteria: 50 g $plant^{-1}$
Cocoa	Foresteroe	2.75 x 7.5 m	265	N: 75 g $plant^{-1}$ P: 30 g $plant^{-1}$ K: 105 g $plant^{-1}$	N: 50 g $plant^{-1}$ P: 20 g $plant^{-1}$ K: 70 g $plant^{-1}$	3 kg $plant^{-1}$	*Azospirillum*: 50 g $plant^{-1}$ Phosphobacteria: 50 g $plant^{-1}$
Pineapple	Kew	0.45 x 0.45 m	2125	N: 6 g $plant^{-1}$ P: 3 g $plant^{-1}$ K: 6 g $plant^{-1}$	N: 4 g $plant^{-1}$ P: 2 g $plant^{-1}$ K: 4 g $plant^{-1}$	5 t ha^{-1}	*Azospirillum*: 2.5 kg ha^{-1} Phosphobacteria: 2.5 kg ha^{-1}
Heliconia	Golden Torch	0.45 x 0.45 m	810	N: 15 Kg ha^{-1} P: 15 Kg ha^{-1} K: 15 Kg ha^{-1}	N: 10 kg ha^{-1} P: 10 Kg ha^{-1} K: 10 kg ha^{-1}	2.5 t ha^{-1}	*Azospirillum*: 2.5 kg ha^{-1} Phosphobacteria: 2.5 kg ha^{-1}
Tomato	Lakshmi	0.60 x 0.60 m	1195	N: 36 kg ha^{-1} P: 18 kg ha^{-1} K:18 kg ha^{-1}	N: 24 kg ha^{-1} P: 12 kg ha^{-1} K: 12 kg ha^{-1}	2.5 t ha^{-1}	*Azospirillum*: 2.5 kg ha^{-1} Phosphobacteria: 2.5 kg ha^{-1}
Elephant foot yam	Gajendra	0.60 x 0.60 m	1195	N: 36 kg ha^{-1} P: 18 kg ha^{-1} K: 18 kg ha^{-1}	N: 24 kg ha^{-1} P: 12 kg ha^{-1} K: 12 kg ha^{-1}	2.5 t ha^{-1}	*Azospirillum*: 2.5 kg ha^{-1} Phosphobacteria: 2.5 kg ha^{-1}

* applied only in treatment T_1; ** applied only in treatment T_2; ! applied in treatments T_1, T_2 and T_3; # applied in treatments T_2 and T_3

biomass of coconut, banana, cocoa, heliconia, pineapple leaves, and other organic waste materials from CBCS. The biomass was transferred to cement tubs after 15-20 days incubation, earth warm (*Eudrilus eugeniae*) were released into the composting unit. After 85-90 days, 80-90% of the biomass was converted into granular form, and then the vermicompost was harvested and stored in shade. The nutrient content of the vermicompost ranged from 1.36-1.72% N, 0.20-0.27% P, and 1.68-2.04% K. For collecting the vermiwash, the earthworms were placed in a container filled with organic matter for composting. The compost was moistened regularly to facilitate the collection of mucous secretions and excretory products after 15-20 days by opening the tap at the bottom to collect the pale yellow liquid known as vermiwash.

Soil analyses

Soil samples were collected at the beginning and end of the experiment to assess the properties of the soil. Soil pH and electrical conductivity (EC) was measured in 1:2 soil water suspension as per Jackson (1973). Soil organic carbon content was determined following Walkley and Black's wet oxidation method (Walkley and Black, 1934) as outlined by Vasundhara *et al.* (2021). Available nitrogen was determined by Kjeldahl method (Goyal *et al.*, 2022), available phosphorus by Olsen's method (Olsen *et al.*, 1954), the available potassium was measured using a flame photometer (Jackson, 1973).

Microbial and earthworm population

The microbial population *viz.*, bacteria and Trichoderma in CBCS plots and monocrop coconut plot was estimated by serial dilution, plating and culturing methods (Kai *et al.*, 2016; Yuan *et al.*, 2022). Earthworm population was determined using the soil monolith method by excavating a pit of size 25 cm × 25 cm × 30 cm in each plot, and earthworms were manually sorted, counted, and recorded (Anderson and Ingram, 1993).

Crop growth and yield parameters

Growth observations and yield parameters including number of functional leaves, number of bunches, nuts palm^{-1} year^{-1}, copra yield (kg palm^{-1} year^{-1}), oil yield (kg palm^{-1} year^{-1}) of coconut and yield of component crops were recorded. The mean values were computed and the performance coconut in CBCS was compared with that of mono-cropped coconut.

Economic analysis

Economics of the coconut based cropping system was worked out considering the cost of cultivation estimated based on the inputs like fertilizers, FYM, pesticides and labour cost (harvesting, fertilizer application and irrigation) and outputs for corresponding years were collected according to the market price and calculated for unit area (hectare) fixed cost, cash flow analysis, economic viability indicators (*viz.*, benefit-cost ratio, net returns) returns were computed in terms of rupees based on prevailed market price of the produce during the respective years (Kireeti *et al.*, 2023).

RESULTS AND DISCUSSION

Growth and yield parameters of coconut

The difference in growth parameters of coconut was observed to be non-significant under integrated nutrient management in coconut-based cropping system (CBCS) compared with monocropping. Data pertaining to the mean yield of coconut, sole crop and in CBCS during the years 2014-20 (Table 2), revealed that the maximum nut yield was recorded in T_1 (75% of recommended NPK + vermicompost) with 157.34 nuts palm^{-1} and 27848 nuts ha^{-1}. followed by T_2 (50% of recommended NPK + vermicompost + vermiwash application + biofertilizer application + *in situ* green manuring) with 151.22 nuts palm^{-1} and 26724.97 nuts ha^{-1}. The lowest nut yield was recorded in T_4 (100% recommended dose of NPK with mono cropping of coconut) with 130.71 nuts palm^{-1} and 23135.88 nuts ha^{-1}. The copra content and oil content per palm are directly proportional to the nut yield. Accordingly, the highest copra content (25.10 kg palm^{-1}) and oil yield (16.34 kg palm^{-1}) were recorded in the treatment T_1, with 23.80 kg palm^{-1} and 15.50 kg palm^{-1}. All the INM (T_1 and T_2) and organic (T_3) treatments improved the yield of coconut compared to treatment T_4 (100% recommended dose of NPK with mono cropping of coconut), despite regular irrigation through drip and fertilizer application. The increase in yield might be due to increased availability of nutrients in soil (Table 8), resulting from the application of chemical fertilizers and organic manure that might have enhanced microbial activity which in turn prolonged the availability of native nutrients to the plant resulting in higher nutrients uptake and increased nutrients use efficiency (Maheswarappa *et al.*, 2014). Vermicompost and verminwash are reported to contain nitrogen fixing bacteria (*Azotobacter* sp., *Agrobacterium* sp. and *Rhizobium* sp.) and phosphate-solubilising bacteria, which influenced the growth of the plant and helped sustain the yield of coconut in all the treatments except T_4 (Jadhav *et al.*, 2015).

Application of chemical fertilizers with mono cropping was not able to improve the yield of coconut, as evident in treatment T_4 with only 130.71 nuts palm^{-1} and 23,135 nuts ha^{-1}. The increased yield in treatments T_1, T_2 and T_3 might be due to increased fruit set during the stress period by adopting integrated cropping system in coconut, improved soil moisture holding capacity and moisture retention in summer months (Table 7). The results conform with the findings of Shinde *et al.* (2024), who reported that a favourable microclimate in multistoried plantations leads to reduced evapotranspiration rate and improved overall water use efficiency. Under certain situations, like rainfed and surface irrigation, the total water requirement of all the crops in the system may be similar to that of a monocrop of coconut.

Table 2. *Growth and yield of coconut in nutrient management with recycling of crop biomass under coconut-based cropping system (average of 6 years)*

Treatments	No. of functional leaves	No. of bunches produced palm^{-1}	No. of nuts palm^{-1}	Copra yield (Kg palm^{-1})	Oil yield (Kg palm^{-1})	Nut yield (Nuts ha^{-1})
T_1	31.99	12.03	157.34	25.10	16.34	27848.95
T_2	31.75	11.67	151.22	23.80	15.50	26724.97
T_3	30.02	10.69	145.88	21.51	14.01	25600.15
T_4	29.97	11.67	130.71	19.24	12.53	23135.88
SEm ±	1.09	0.38	1.82	0.38	0.24	344.88
CD (5%)	NS	NS	5.61	1.16	0.75	1062.69

Yield of intercrops

The data recorded on the yield of intercrops revealed that treatment T_1 (75% recommended NPK + vermicompost) recorded the maximum yield among all the treatments (Table 3). The cocoa and pineapple yields were 2.6 kg plant^{-1} (0.65 t ha^{-1}) and 0.902 kg plant^{-1} (1.92 t ha^{-1}), respectively, in T_1. This was at par with the yields of 2.44 kg plant^{-1} (0.61 t ha^{-1}) and 0.870 kg plant^{-1} (1.85 t ha^{-1}) for cocoa and pineapple, respectively, recorded in T_2 (50% recommended NPK + vermicompost + vermiwash + biofertilizer + *in situ* green manuring). The yield of banana was recorded to be maximum in T_1 with 12.68 kg plant^{-1} (10.09 t ha^{-1}), which was significantly superior to other treatments and was followed by T_2 (11.64 kg plant^{-1}, 9.26 t ha^{-1}). The maximum tuber yield of elephant foot yam was recorded in T_1 with 2.48 kg plant^{-1} (2.65 t ha^{-1}), which was statistically at par with T_2 (2.12 kg plant^{-1}, 2.47 t ha^{-1}). The tomato yield per plant was statistically non-significant among the treatments, however, the per ha yield was significantly higher in T_1 (1.32 t ha^{-1}). The spike yield of heliconia was also highest in T_1 with 13 spikes plant^{-1} and 12,253 spikes ha^{-1} and was significantly superior to other treatments under evaluation (Table 3). The increased yield of intercrops in treatment T_1 (75% of recommended NPK + vermicompost) compared to other two treatments T_2 (50% of Rrecommended NPK + vermicompost + vermiwash application + biofertilizer application + *in situ* green manuring) and T_3 (Fully organic: vermicompost + vermiwash application + biofertilizer application + *in situ* green manuring + green leaf manuring (*Gliricidia*) + composted coir pith and mulching with coconut leaves) can be attributed to a favourable micro-climate, optimum nutrient availability, higher organic carbon content and reduced evaporative loss compared to open conditions. The availability of moisture and nutrients favoured the development of good biomass in intercrops (Table 5), which in turn increased the yield of banana, cocoa, pineapple and tomato in treatment T_1. INM in CBCS, with the incorporation of vermicompost to the intercrops, conserved soil moisture, facilitated the development of beneficial soil microbes and earthworms, resulting in increased corm weight in elephant foot yam. The heavy leaf-shedding nature of cocoa also helped retain soil moisture during stress periods, particularly benefiting banana, thereby highlighting the complementary interaction among the intercrops in this coconut-based cropping system for good yield. The superior yield of intercrops in T_1 can also be linked with higher amounts of nutrients in the soil. (Table 6). Earlier studies by Rani *et al.* (2019) and Bhalerao *et al.* (2021) have also reported that improved microclimate, relative humidity, and soil water availability contribute to increased yield of intercrops.

Economic returns

Gross and net returns (Table 4) over a five-year period revealed that maximum gross of ₹ 3,67,278 ha^{-1} and net returns ₹ 2,53,974 ha^{-1} was obtained in T_1 (75% of recommended NPK + vermicompost), followed by T_2 (50% of recommended NPK + vermicompost + vermiwash application + biofertilizer application + *in situ* green manuring) with gross returns of ₹ 3,47,446 ha^{-1} and net returns ₹ 2,36,598 ha^{-1}. The lowest gross returns (₹ 1,35,400 ha^{-1}) and net returns of ₹ 72,153/- were recorded in T_4 (100% recommended dose of NPK). The highest benefit-cost ratio was recorded in T_1 (3.22), indicating that this treatment was more profitable than the rest. The results revealed that INM in coconut-based cropping system increased the net returns as compared to the sole crop of coconut with 100% NPK fertilizer. The better economic returns under the INM and organic treatments (T_1 to T_3) can be attributed to the higher yields and reduced input and labour costs resulting from less usage of fertilizers, pesticides and efficient crop management practices like harvesting of intercrops, training and pruning of cocoa, as compared

Table 3. *Effect of integrated nutrient management on the yield of intercrops (average of 6 years)*

Treatments	Cocoa		Pineapple		Banana		Elephant foot yam		Tomato		Heliconia	
	Kg plant^{-1}	t ha^{-1}	Kg plant^{-1}	t ha^{-1}	Kg plant^{-1}	t ha^{-1}	kg plant^{-1}	t ha^{-1}	Kg plant^{-1}	t ha^{-1}	Spikes plant^{-1}	Spikes ha^{-1}
T_1	2.61	0.65	0.903	1.92	12.68	10.09	2.48	2.65	1.38	1.32	13	12253
T_2	2.44	0.61	0.870	1.85	11.64	9.26	2.28	2.47	1.26	1.20	11	10896
T_3	2.04	0.50	0.792	1.68	10.43	8.30	2.12	2.29	1.18	1.12	7	8737

Table 4. *Effect of INM on gross returns, cost of cultivation, net returns and benefit cost ratio (average of 6 years)*

Treatments	Gross returns (₹)	Cost of cultivation (₹)	Net returns (₹)	B:C ratio
T_1	3,67,278	1,13,304	2,53,974	3.22
T_2	3,47,446	1,10,848	2,36,598	3.11
T_3	2,89,722	1,11,645	1,78,078	2.62
T_4	1,45,126	72,973	72,153	1.99

Table 5. *Effect of nutrient management on biomass and vermicompost production in coconut-based cropping system*

Treatments	Biomass (t ha $^{-1}$ year^{-1})	Vermicompost (t ha^{-1} year^{-1})
T_1	36.80	19.90
T_2	32.00	16.50
T_3	30.20	15.80
T_4	7.00	3.20
S.Em ±	1.36	1.52
CD (5%)	4.19	4.68

to monocropping of coconut in T_4. These results are in line with Bhalerao *et al.* (2021), who reported that crop diversification in combination with integrated nutrient management enhances economic returns in coconut based cropping systems.

Biomass and vermicompost production

The cultivation of intercrops like cocoa, banana, elephant foot yam, tomato and heliconia increased the bio-mass production per unit area in treatments T_1 to T_3 where as in T_4 (monocropping of coconut) yielded the lowest biomass (Table 5). The maximum biomass production was recorded in T_1 (36.8 t ha^{-1} year^{-1}), followed by T_2 (32.0 t ha^{-1} year^{-1}) and T_3 (30.2 t ha^{-1} year^{-1}), which were all significantly superior to T_4 (7.0 t ha^{-1} year^{-1}). The amount of vermicompost produced from the biomass using *Eudrilus* sp. was 19.90 t ha^{-1} in T_1, 16.50 t ha^{-1} in T_2, 15.80 t ha^{-1} in T_3 and 3.20 t ha^{-1} in T_4. The enhanced biomass in T_1 to T_3 treatments reflects the positive impact of integrated nutrient management and crop diversification. The recycled biomass produced from the coconut-based cropping system increased soil nitrogen and helped the proliferation of beneficial microbes, leading to enhanced biomass production as compared to the monocrop system.

Soil nutrient status, microbial population and soil moisture content

Soil nutrient content was improved with integrated nutrient management as revealed from the data presented in Table 6. Nitrogen content gradually increased from 240 kg ha^{-1} in 2014 (initial) in T_1 to 299.14 kg ha^{-1} in 2016 and to 393.4 kg ha^{-1} in 2019. A similar trend was observed in T_2, where N content increased to 292.42 kg ha^{-1} in 2016 and to 387.1 kg ha^{-1} in 2019. In T_3, fully organic treatment, the N content varied from 268.34 kg ha^{-1} in 2016 and to 272.0 kg ha^{-1} in 2019. In contrast, T_4 recorded a decline in nitrogen content to 220.47 kg ha^{-1} in 2016 and slightly increased to 228.20 kg ha^{-1} in 2019 compared to the initial N content. The increased availability of nitrogen may be due to the increase of beneficial microbes that promote nitrogen fixation from the atmosphere and improved nutrient retention capacity of the soil, reduced nitrogen losses through denitrification and nitrate leaching, along with enhanced nutrient use efficiency and improved nutrient recovery by crops. These factors together contribute to sustaining higher crop yields and ensuring long-term sustainability of the system (Lamessa 2016).

There was also an improvement in the P content in T_1 and T_2, as compared to T_4, increasing to 21.89 and 17.33 kg ha^{-1}, respectively, in 2019 due to regular application of P containing fertilizers and favourable soil pH. Similarly in T_4, P content increased to 22.43 kg ha^{-1} in 2019 as compared to 15.64 kg ha^{-1} during 2016. While in T_3 it decreased in 2019 which could be due to no external application of fertilizers and its higher utilization by tuber crops like Elephant foot yam (Ragab *et al.*, 2015). Potassium content (220 kg ha^{-1} prior to treatments imposition) was observed to be relatively stable in T_1 (220.7 kg ha^{-1} in 2016 and 219.8 kg ha^{-1} in 2019) and T_4 (225.47 kg ha^{-1} and 228.2 kg ha^{-1} during the same years). However, a decline in K content was observed in T_2 and T_3. In T_2, potassium content decreased from 151.67 kg ha^{-1} in 2016 to 117.0 kg ha^{-1} in 2019, while in T_3 it dropped from 151.67 kg ha^{-1} to 101.8 kg ha^{-1} over the same period. The reduced availability of potassium content in T_2 and T_3 might be due to variation in input content of K fertilizers in the treatments, and more uptake by banana and coconut crops.

Soil organic carbon (SOC) content (Table 6) was also recorded highest in T_1 (1.02 %) followed by T_2 (0.99 %), while the lowest SOC was recorded in T_4 (0.42%). The incorporation of vermicompost (produced from recycling of biomass generated from CBCS) and biofertilizers may have had a positive effect on the growth of beneficial microorganisms, which improved the soil's carbon sink capacity of the soil (Shinde *et al.*, 2020).

Table 6. *Nutrient content of soil influenced by INM with recycling of crop biomass in coconut-based cropping system*

Treatments	pH		EC		OC (%)		N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha $^{-1}$)	
	2016	2019	2016	2019	2016	2019	2016	2019	2016	2019	2016	2019
T_1	8.13	8.52	0.16	0.18	0.75	1.02	299.14	393.4	18.34	21.89	220.27	219.8
T_2	7.34	8.29	0.19	0.19	0.74	0.99	292.42	387.1	17.24	17.33	152.63	117.0
T_3	7.24	8.06	0.15	0.07	0.82	0.94	268.34	272.0	17.34	15.46	151.67	101.8
T_4	7.48	7.95	0.12	0.11	0.52	0.42	240.34	221.6	15.64	22.43	220.47	228.2

The effect of integrated nutrient management under coconut-based integrated cropping system on earthworm population revealed that under the complete organic system (T_3), the earthworm abundance was significantly improved (Table 7). Initially, the population was 3 earthworms m^{-2} of soil at 0-60 cm depth. After 5 years of the treatment application, the earthworm population increased to 28 m^{-2} in T_3 (fully organic), which was significantly higher than in other treatments, followed by T_2 (20 m^{-2}) and T_1 (15 m^{-2}). In contrast, the earthworm population under T_4 (inorganic fertilizer with monocropping) remained low at 4 m^{-2}.

Similarly, the microbial population was positively influenced by INM, however, the differences among the treatments were not statistically significant. The bacterial population, did not vary much under the treatments, T_1 to T_3, increasing from 6.05×10^5 cfu g^{-1} in 2014 to 6.90×10^5 cfu g^{-1} in 2020 under T_1, and from 6.12×10^5 to 7.80×10^5 cfu g^{-1} in T_3. The highest bacterial count in 2020 was observed in T_2 (7.50×10^5 cfu g^{-1}). However, in T_4, the bacterial population declined from 6.45 × 105 in 2014 to 5.1×10^5 cfu g^{-1} in 2020, indicating adverse effects of continuous chemical fertilizer application without organic inputs. A similar trend was observed for Trichoderma populations, however, the differences among the treatments were statistically significant only in the year 2020. The highest count in 2020 was recorded in T_3 (9.90×10^3 cfu g^{-1}), followed by T_2 (9.60×10^3 cfu g^{-1}) and T_1 (9.45×10^3 cfu g^{-1}), all showing improvement over 2014 levels. In contrast, T_4 recorded a sharp decline from 8.15×10^3 to 5.97×10^3 cfu g^{-1} over the same period. These findings are consistent with those of Maheswarappa *et al.* (2014), who reported that organic amendments when applied alone or in combination with inorganic fertilizers enhance soil biological activity, particularly the populations of beneficial organisms such as bacteria, fungi, actinomycetes, etc.

The soil moisture content was consistently higher by 2-3% in the soil profile (0-90 cm) in the treatments T_1 to T_3 compared to T_4 (Table 8). The soil moisture content was decreased across the different depths over the months. The mean moisture content, at 0-90 cm depth in 2014, during the summer months of March to June ranged from 17.13 to in T_1 and 16.91% in T_2 to 17.47% in T_3, while T_4 recorded 16.74%. The results recorded (Table 8) in 2019 clearly exhibited varying levels of soil moisture content across the depths and months in various treatments and the maximum mean soil moisture content was observed in T_3 (20.20%) compared to T_4 (15.61%). This might be due to application of organic manures, green manuring, composted coir pith and mulching with coconut leaves that helped improving the soil moisture retention. T_1 also maintained higher mean soil moisture (18.47%) compared to T_4 (15.61%), in the 0-90 cm profile reflecting optimized water management through intercropping and organic amendments. These findings corroborate with earlier reports that intercropping, mulching, and addition of organic manure improved soil moisture retention in coconut-based cropping systems (Rani *et al.*, 2019 and Bhalerao *et al.*, 2021).

CONCLUSION

The study revealed that integrated nutrient management with recycling of biomass from coconut-based cropping system significantly enhanced the productivity of coconut as well as that of the intercrops. There was a 15-20% increase in coconut yield in terms

Table 7. *Earthworm and microbial population in integrated nutrient management with recycling of crop biomass under coconut-based cropping system*

Treatments	Earthworm population in 60 cm soil depth (No. m^{-2})		Bacterial population (Nutrient agar medium) (x 10^5 cfu g^{-1})		*Trichoderma* (*Trichoderma* specific media) (x 10^3 cfu g^{-1})	
	2014	2020	2014	2020	2014	2020
T_1	3	15	6.05	6.90	8.35	9.45
T_2	2	20	6.24	7.50	8.25	9.60
T_3	3	28	6.12	7.80	8.35	9.90
T_4	3	4	6.45	5.10	8.15	5.97
SEm ±	0.10	1.21	0.25	0.32	0.12	0.24
CD (5%)	NS	3.73	NS	NS	NS	0.75

Table 8. *Soil moisture content at different depths (%) influenced by INM in coconut-based cropping system*

Month & soil depth	T_1		T_2		T_3		T_4	
	2014	2019	2014	2019	2014	2019	2014	2019
March								
0-30 cm	15.4	16.5	15.6	18.4	15.8	18.5	14.5	14.8
30- 60 cm	19.8	20.4	20.5	22	21.4	23.5	19.7	16.9
60-90 cm	22.5	22.8	21.9	24.3	23.4	24.8	21.8	17.4
April								
0-30 cm	15.6	16.5	13.9	17.5	14.2	18.2	13.1	14.0
30- 60 cm	16.2	18.4	15.8	19.1	17.3	19.3	17.8	17.2
60-90 cm	18.5	20.5	17.8	22.1	17.8	22.3	18.5	17.2
May								
0-30 cm	13.5	16.1	13.9	16.2	13.8	17.5	12.8	13.5
30- 60 cm	15.8	17.3	15.6	17.2	16.1	18.5	14.6	14.1
60-90 cm	16.9	17.7	17.2	18.5	17.4	19.2	17.9	15.4
June								
0-30 cm	14.3	15.2	14.8	16.4	15.8	18.3	13.9	14.5
30- 60 cm	17.8	16.1	18.2	17.3	17.9	19.2	17.5	16.2
60-90 cm	19.8	17.3	20.15	18.2	20.5	19.3	19.8	17.4
Mean across depth and months	17.13	18.47	16.91	19.48	17.47	20.20	16.74	15.61

of copra content and oil yield, along with substantial productivity of intercrops such as cocoa, pineapple, banana, and elephant foot yam. The application of organic manures along with chemical fertilizers improved the soil nutrient status and soil organic carbon content, enhanced soil moisture retention and supported a favourable micro-climate. These factors promoted biomass production and vermicompost generation, enabling residue recycling. Economically, the treatment T_1 (75% of recommended NPK + vermicompost) yielded the highest returns with benefit:cost ratio of 3.2. This highlights the efficiency and sustainability of INM approach that improved soil nutrient status, soil moisture retention, earthworm activity and microbial populations, contributing to the overall system productivity of the coconut-based cropping system. The treatment T_1, consisting of 75% of recommended NPK + vermicompost (produced from biomass of coconut-based cropping system), can be recommended for adoption in coconut-based cropping systems due to its superior productivity, ecological sustainability, and economic viability when compared to conventional mono-cropping with 100% inorganic fertilizers.

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CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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