



## Efficient nutrient recycling strategy through integrated nutrient management in hybrid napier within a coconut (*Cocos nucifera*)-based system

K NIHAD<sup>1</sup>, A A HARIS<sup>1\*</sup>, P SUBRAMANIAN<sup>2</sup>, JEENA MATHEW<sup>1</sup>, S INDHUJA<sup>1</sup>, S NEENU<sup>2</sup>,  
RAVI BHAT<sup>2</sup> and SANDHIP SHIL<sup>3</sup>

ICAR-Central Plantation Crops Research Institute, Regional Station, Kayamkulam, Kerala 690 533, India

Received: 9 May 2023; Accepted: 6 June 2023

### ABSTRACT

The present field experiment was conducted to investigate the impact of various combinations of organic inputs on the growth of fodder grass in a coconut [*Cocos nucifera* (L.)]-based mixed farming during 2013–17 at ICAR-Central Plantation Crops Research Institute, Regional Station, Kayamkulam, Kerala and refined in farmer's field during 2018–21. The experiment was conducted in randomized block design with seven treatments and three replications with one control [chemical fertilizer (CF) alone] and six organic recycling options with combination of a native strain of *Azospirillum* sp. [L8(3)] isolated from the coconut rhizosphere, [100% RDN through cow dung slurry (CDS), 100% RDN through coconut leaf vermicompost (CLVC), 100% RDN through CDS + CLVC (1:1), 100% RDN through CDS + CLVC (1:1) + *Azospirillum* sp., 75% RDN through CDS + CLVC (1:1) + *Azospirillum* sp. and 50% RDN through CDS + CLVC (1:1) + *Azospirillum* sp.]. Basal application of 15 tonnes of dried cow dung, 400 kg lime and 90:30:24 kg NPK/ha were supplied irrespective of the treatments. The plants supplied with 100% RDN through CF and CDS + CLVC + *Azospirillum* sp. recorded the higher yield during the first year, followed by a yield decline in subsequent years which may be due to the nitrogen-induced reduction in soil pH as evident from the soil analysis. The significantly higher fresh fodder yield (126.9 tonnes/ha/year), dry matter yield (22.7 tonnes/ha/year), neutral and acid detergent fibres, crude protein and plant nutrient uptake were recorded by plants supplied with 75% RDN through CDS + CLVC + *Azospirillum* sp. Technological refinement by adding additional lime (400 kg/ha) during second and third years resulted in 24.59% higher yield. This system of recycling resulted 50% reduction in external physical inputs during the first year and 90% reduction in subsequent two years.

**Keywords:** Coconut intercrop, Fodder grass, Liming, Nutrient recycling, Organic amendments

Coconut [*Cocos nucifera* (L.)] is one of the important plantation crops cultivated in the world, occupying an area of 12.56 million ha and producing an estimated 67698 million nuts. In India, coconut cultivation covers an area of about 2.17 million ha, mainly owned by small and marginal farmers (Annual report 2021–22). Due to the unique canopy and root structure of coconut palms, around 78% of the land area is available for companion crops. Mixed farming through diversified crops and livestock helps in achieving maximum system productivity ensuring profitability and sustainability (Danso-Abbeam *et al.* 2021). Crop animal interactions benefit small farmers and contribute to the sustainability in a mixed farming system (Devendra and Thomas 2002). For small-sized land holdings, fodder grasses

are preferred over legumes due to their higher productivity potential (Stur *et al.* 2013). However, only 4% of the cropped area in India is under fodder production, which has remained static for a long time (Singh *et al.* 2022). Hybrid Bajra Napier grass (Var. CO 3) is a widely accepted fodder grass that grows well in the coastal humid ecosystem of coconut plantations (Subramanian *et al.* 2007). To increase forage productivity, combining inorganic nitrogen with organic inputs as nutrients has been recommended (Obour *et al.* 2009). Diversity in agricultural production enhances nutrient recycling (Nowak *et al.* 2015). Nutrient recycling through adoption of integrated nutrient management in companion fodder crop under coconut based mixed farming system on long term perspective may augment system productivity; improve soil quality ensuring sustainability of the production system. However, information on recycling available organic amendments for sustainable productivity is limited. This study aims to evaluate the performance of fodder grass top dressed with various combinations of available organic inputs in a coconut-based mixed farming system during 2013–17. The best agronomic treatment was

<sup>1</sup>ICAR-Central Plantation Crops Research Institute, Regional Station, Kayamkulam, Kerala; <sup>2</sup>ICAR-Central Plantation Crops Research Institute, Kasaragod, Kerala; <sup>3</sup>ICAR-Central Plantation Crops Research Institute, Research Centre, Mohitnagar, West Bengal. \*Corresponding author email: [abdulharis.a@icar.gov.in](mailto:abdulharis.a@icar.gov.in).

further refined in a farmer-participatory approach during 2018–21. The results of this study will provide a practical approach to bridge the demand-supply gap of fodder in the country while reducing external inputs, particularly nitrogen fertilizers, in the coconut-based mixed farming system. This approach has potential to bring down the demand for chemical fertilizers, thereby reducing import and saving foreign exchange for the country.

## MATERIALS AND METHODS

The experiment was conducted at the Indian Council for Agricultural Research-Central Plantation Crops Research Institute (ICAR-CPCRI), Regional Station, Kayamkulam (9° 8' N; 76°30' E and 3.05 m amsl) in a coconut plantation during the period of August 2013 to July 2017. Subsequently, the best-performing treatment was assessed and refined in a farmer participatory research mode under similar soil conditions from August 2018 to July 2021. The soil of the experimental site is sandy loam of the order Entisol with pH of 5.7, 0.15% organic carbon, 397.3 kg/ha of available N, 53.1 kg/ha P<sub>2</sub>O<sub>5</sub>, 122.3 kg/ha K, 0.022% Ca, 24.6 ppm Mg, 1.12 ppm Mn, 13.4 ppm Fe, 1.39 ppm Cu and 2.2 ppm Zn. The study was carried out under the natural environmental conditions of the region with an average maximum and minimum temperature of 32.3°C and 24.2°C, respectively, and an annual mean rainfall of 2469.3 mm. The relative humidity of 92.2% (FN); 78.6% (AN), and mean evaporation of 3.53 mm/day were recorded during the study period.

*Description of imposed treatments:* The experiment was laid out in a randomized block design with six treatments and one control (chemical fertilizers) in three replications in the interspaces of coconut trees, leaving a basin area of a 2 m radius from the bole region of the palm. Hybrid bajra napier var. CO 3 was planted at a spacing of 60 cm × 60 cm with a net cropped area of 60% of the gross area. All treatments received a basal dose of lime (400 kg/ha), 15 tonnes of dried cow dung, and 90:30:24 kg NPK per ha of intercrop (based on the recommendation of 150:50:40 kg NPK per ha of pure crop) at the time of planting. The treatments included T<sub>1</sub>- 100% recommended dose of nitrogen (RDN) through chemical fertilizers; T<sub>2</sub>-100% RDN through cow dung slurry (CDS); T<sub>3</sub>-100% RDN through coconut leaf vermicompost (CLVC); T<sub>4</sub>-100% RDN through CDS + CLVC (1:1); T<sub>5</sub>- 100% RDN through CDS+CLVC (1:1) + *Azospirillum* sp. L8(3); T<sub>6</sub>-75% RDN through CDS + CLVC (1:1) + *Azospirillum* sp. L8(3); T<sub>7</sub>- 50% RDN through CDS + CLVC (1:1) + *Azospirillum* sp. L8(3). Chemical nutrients were supplied as urea (N), rock phosphate (P<sub>2</sub>O<sub>5</sub>), and potassium chloride (K<sub>2</sub>O). CDS and CLVC, recycled from the coconut-based integrated farming system unit, were used as organic amendments. The nitrogen requirement per ha of the intercropped area after each harvest was fixed at 90 kg/ha. CLVC prepared following the in-house developed technology was utilized (Gopal *et al.* 2009). The average NPK content of CDS and CLVC was estimated to be 0.9:0.3:0.2 and 1.7:0.22:0.18,

respectively. Top dressing of nutrients was done as six equal doses of 90 kg N/ha sourced from different inputs in all treatments. The treatments with organic manures (T<sub>2</sub> to T<sub>7</sub>) were supplied in two equal splits (immediately after harvest and 15 days later). *Azospirillum* sp. L8(3) isolated from the coconut rhizosphere was supplied uniformly (3.5 kg/ha/year) in T<sub>5</sub>, T<sub>6</sub>, and T<sub>7</sub> treatments along with organic manures during September-October. The treatment supplied with 75% RDN through CDS + CLVC (1:1) + *Azospirillum* sp. L8(3) which was found to be superior was further assessed and refined in a farmer participatory research mode from August 2018 to July 2021 in a 1 ha coconut garden having similar soil conditions. The practice adopted by the farmer (top dressing with cow dung slurry alone) was followed in A<sub>1</sub>. The treatment A<sub>2</sub> and A<sub>3</sub> were top-dressed uniformly with 75% RDN through CDS + CLVC (1:1) + *Azospirillum* sp. L8(3). During the second and third years of the study, an additional dose of lime (400 kg/ha/year) was supplied to the plants in the refined treatment (A3) for maintaining the soil pH at around 6.5. The yield of fodder grass was recorded randomly from a 3 m<sup>2</sup> area with 12 replications and was extrapolated into per hectare basis.

*Measurement of growth parameters, yield attributes and yields:* Biometric observations such as plant height (cm), leaf length (cm), and fresh weight of the fodder, were recorded at bimonthly intervals from the four selected clumps after removing the border effect during I, II, and III years of the experiment. Plant and soil nutrients were estimated according to Jackson (1973) and soil microbial count was measured following the procedure outlined by Allen (1959). The available form of micronutrients were analyzed by extracting them with 0.1 N HCl (Ogunwale and Udo 1978). The estimation of dietary fibres in the fodder was done using the Van Soest *et al.* (1991) method. The mean values of growth and yield parameters were recorded in each replication during every harvest, and year-wise mean values were documented to facilitate analysis and interpretation of the results.

*Statistical analysis:* Statistical analysis was conducted using SAS 9.3. Replicated measures analysis of variance (ANOVA) was employed to compare the differences in parameters among treatments. To determine specific differences between means, Duncan's Multiple Range Test (DMRT) was used. The Kruskal-Wallis Chi-squared test was utilized to compare the means between the farmer's practice, the best treatment, and the refined treatments (Cleophas and Zwinderman 2016).

## RESULTS AND DISCUSSION

*Crop growth and yield:* The study aimed to determine the growth and yield of hybrid bajra napier (Var. CO 3) grown in coastal sandy loam soils under coconut canopy using different nutrient sources from the system as topdressing. Results showed that the nutrient source significantly affected the growth and yield of the fodder grass. The use of CLVC in combination with CDS and *Azospirillum* sp. resulted in higher nutrient use efficiency, as indicated by plant growth

characters and yield. Plants supplied with 75% RDN through CDS and CLVC with *Azospirillum* sp. had steady growth throughout the years, with mean plant height significantly higher in treatments supplied with 100% CLVC alone and with *Azospirillum* sp., but not significantly different from 75% CLVC and *Azospirillum* sp. The best performing treatment was 75% recommended dose of nitrogen (RDN) provided through CDS and CLVC (1:1 ratio) with *Azospirillum* sp., showing consistent increase in yield and yield parameters over the years, indicating better nitrogen recycling capability. The plants supplied with 100% RDN [through inorganic nitrogen alone and CDS + CLVC + *Azospirillum* sp.] recorded higher yields and canopy height during the first year, but declined in subsequent years due to the nitrogen-induced reduction in soil pH (Tian and Niu 2015). The plants supplied with CDS alone recorded lower fodder yield throughout the years, possibly due to loss of nitrogen through the high rate of ammonia volatilization. The treatment with 75% RDN through CLVC + CDS + *Azospirillum* sp. had higher dry matter accumulation, neutral detergent fibre, acid detergent fibre and crude protein, indicating its improved efficiency and suitability as cattle feed. This treatment was comparable to that of the fodder grass produced using inorganic supplements (Table 1). The findings of this study highlight the importance of selecting the right nutrient source to achieve optimal growth and yield of fodder grass under coconut canopy.

During the first year of study in the farmer's field under refined technology, the fodder grass under A<sub>1</sub> (existing field) recorded an average yield of 66.16±6.90 t/ha where as the plants supplied with 75% RDN through organics and *Azospirillum* sp. yielded fodder of 89.62±7.08 t/ha. During the second and third years of the study the plants under farmer's practice recorded a yield of 85.48±7.42 t/ha and 80.25±6.32 t/ha, respectively. The treatment without application of lime (A<sub>2</sub>) in second and third year recorded an average yield of 116.77±7.44 t/ha and 135.97±8.57 t/ha where as with the application of lime, a higher average yield of 153.75±6.93 t/ha and 183.19±9.33 t/ha was recorded. The higher yield might be due to the regulated soil pH which was maintained at 6.5±0.19 during the period of study (2018–2021).

**Soil nutrient status:** The study revealed that the source of organic amendments significantly influenced the soil nutrient and microbial population (Table 2). Treatments receiving CLVC showed higher plant phosphorus levels, suggesting better P absorption. Overall, the phosphate-solubilizing bacteria and phosphorus content in the soil were sufficient and higher in the organic treatments supplied with CLVC. The potassium content of the fodder was also higher in plants treated with CLVC, whereas the soil potassium content was insufficient (54.6 kg/ha) at the start of the experiment and was depleted to less than 20 kg/ha after three consecutive years of growing fodder grass. Since potassium is a vital nutrient for both the main crop (coconut) and the intercrop, and its supply through the organics was minimal, the soil was showing drastic decline in potassium status. The higher

Table 1 Effect of top dressing on Hybrid Napier with organic residues on growth, yield, quality parameters and canopy height, yield and soil pH over the years

Treatment	Leaf length (cm)	Fodder yield (t/ha)	TDM (t/ha)	NDF (%)	ADF (%)	CP (%)	Plant canopy height (cm)			Yield (Fresh weight basis) (t/ha)			Soil pH		
							I	II	III	I	II	III	I	II	III
T <sub>1</sub>	111.2a	103.61b	14.47d	64.93a	37.37b	8.66ab	187.7a	165.9cd	164.3d	100.4ab	115.9c	94.6d	6.3b	5.5bc	5.3bc
T <sub>2</sub>	106.5b	97.53c	14.61d	60.53d	31.43f	6.51c	155.4b	165.6cd	160.6de	80.9d	111.6c	100.0cd	6.6a	5.6b	5.1c
T <sub>3</sub>	119.1a	111.48b	16.79cd	62.33c	33.33e	6.27c	165.9ab	187.1a	183.6b	93.0bc	126.2b	115.2bc	6.8a	5.8b	5.2c
T <sub>4</sub>	116.6a	100.70b	15.96cd	63.77b	35.07d	6.36c	151.8c	174.6bc	185.8b	83.69d	126.3b	92.2d	6.6a	5.7b	5.5b
T <sub>5</sub>	110.9a	114.49b	18.15bc	64.83a	37.10b	8.08b	171.1ab	186.2a	181.3bc	102.5a	123.3b	117.7b	6.6a	5.7b	5.6ab
T <sub>6</sub>	117.0a	126.89a	22.66a	65.40a	38.23a	9.33a	178.0a	186.4a	194.8a	103.4a	139.5a	137.8a	6.7a	6.0a	5.8a
T <sub>7</sub>	114.3a	115.19ab	19.80b	64.83a	36.17c	6.94c	141.8c	170.4c	181.9bc	90.2cd	128.6b	126.9ab	6.7a	6.1a	5.9a
LSD (P=0.05)	9.5	11.99	2.48	1.06	0.83	1.10	12.7	6.3	6.5	9.3	10.6	9.2	0.2	0.2	0.2

Means (N=3) separation within columns by 5% DMRT; Values of treatment followed by the same letter are not significantly different at P< 0.05. Treatment details are given under Materials and Methods.

Table 2 Effect of top dressing on Hybrid Napier with organic residues on soil nutrient status and microbial population

Treatment	OC (%)	N	P	K	Ca	Mg	Fe	Mn	Zn	Bacteria ( $\times 10^8$ )	Actinomycetes ( $\times 10^5$ )	Fungi ( $\times 10^6$ )
T <sub>1</sub>	0.68*	72.3*	83.8b	17.7a	119.9b	44.3c	11.8a	2.7b	2.40a	16.02d	26.60b	14.36a
T <sub>2</sub>	0.72*	76.0*	77.8b	13.9b	178.3b	51.0c	8.5c	2.7b	1.19c	23.63bc	41.69a	7.12cd
T <sub>3</sub>	0.59*	68.7*	77.8b	13.3b	239.8a	67.4a	13.1a	4.3a	1.98b	25.43b	40.82a	5.37d
T <sub>4</sub>	0.65*	65.7*	72.9c	14.1b	170.2b	57.7b	9.4b	3.7b	1.64b	52.75a	37.54a	5.31d
T <sub>5</sub>	0.62*	70.3*	76.5c	16.2a	309.1a	65.6a	11.0a	5.2a	1.62b	21.20c	29.82b	9.64bc
T <sub>6</sub>	0.71*	73.3*	94.5a	13.2b	256.3a	66.2a	11.0a	5.3a	1.70b	26.65b	29.82b	12.35ab
T <sub>7</sub>	0.62*	67.0*	80.4b	10.7c	261.3a	56.4b	8.7c	3.3b	1.73b	53.88a	37.93a	7.82c
LSD (P=0.05)	NS	NS	6.07	3.08	100.2	7.71	2.09	1.35	0.41	3.94	7.18	2.27

Means (N=3) separation within columns by 5% DMRT. Values of treatment followed by the same letter are not significantly different at  $P < 0.05$ ; \* Non-significant. Treatment details are given under Materials and Methods.

potassium content in plant tissues (Fig 1) and its depletion in soil indicates the potassium-exhaustive nature of the intercrop. Coconut also shows luxury consumption for potassium, which it stores in excess quantity in the stem. In addition to crop removal, the available potassium in coastal sandy loam soil is subject to leaching, especially in high rainfall region of coastal humid tropics. One of the significant observations of the experiment is that the system requires additional application of potassium fertilizer for balancing the depletion of potassium reserve in the soil and associated residual acidity. Fodder grass supplied with CLVC showed higher calcium content, and calcium depletion was lower in soils recycled with CLVC (Fig 2). However, the depletion of calcium from the soil and higher plant uptake suggests the need for external lime application. The study also found that the magnesium and zinc content were higher in plants supplied with CLVC. The higher magnesium content of plant tissues and increased depletion from soil suggest a high requirement of mineral nutrition for the crop. The plant tissues nourished with 100% RDN through combinations with CLVC had higher manganese, copper, and zinc content, which was at par with 75% RDN, favouring organic recycling in coconut-based farming systems for quality herbage production.

The management of soil nutrients has been shown to have a significant impact on microbial diversity and richness, which is crucial for maintaining soil and crop health (Lupatini *et al.* 2017). The results from our study revealed a general increase in microbial communities such as heterotrophic bacteria, actinomycetes, and free-living nitrogen fixers in the third year compared to the previous year, possibly due to the improvement in soil organic carbon in the intercropped soil that received a basal dose of organic manure (cow dung). Our findings support previous research that suggests organic soil amendments increase microbial diversity, richness, and community structure (Chen *et al.* 2020). T<sub>1</sub>, which received 100% N through chemical fertilization, had a significantly lower population count of bacterial heterotrophs compared to all other treatments that received split application of

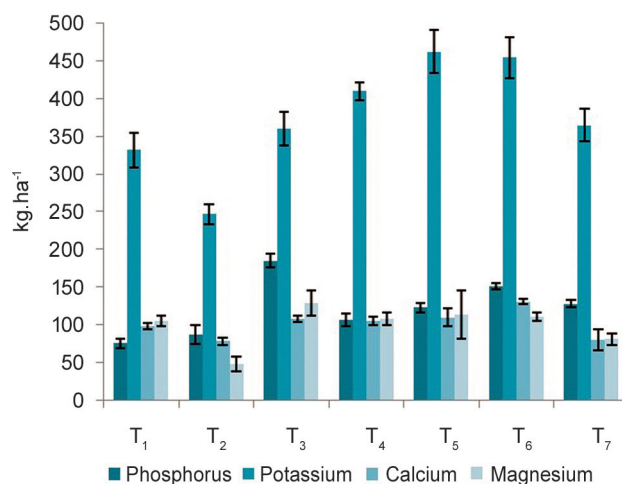


Fig 1 Effect of top dressing in Hybrid Napier with organic residues on nutrient uptake of phosphorus, potassium, calcium and magnesium. Error bars indicate standard error ( $\pm$ SE) at different levels of treatment means (N=3) at  $P < 0.05$  for phosphorus (LSD=14.90), potassium (Non significant), calcium (LSD=15.00) and magnesium (LSD= 26.50).

organics. Greater bacterial richness and diversity have been reported in organic management due to the restricted use of chemical fertilizers, which provides better substrates for microbial enrichment (Yang *et al.* 2019). The populations of actinomycetes were consistently higher in treatments that received either vermicompost or both vermicompost and cow dung slurry treatments (T<sub>2</sub>, T<sub>3</sub>, T<sub>4</sub>, and T<sub>7</sub>), which is in line with previous research indicating the preponderance of heterotrophic bacteria and filamentous actinomycetes in cow dung manure and coconut leaf vermicompost (Gopal *et al.* 2009, Gopal *et al.* 2017).

Significant dominance in filamentous fungal populations was observed in T<sub>1</sub> when compared to other treatments, which could be attributed to the shift to fungal abundance in acidic soil (Rousk *et al.* 2009). In contrast, the application of organics and *Azospirillum* sp. in other treatments could have induced a change due to their suppressive effects on

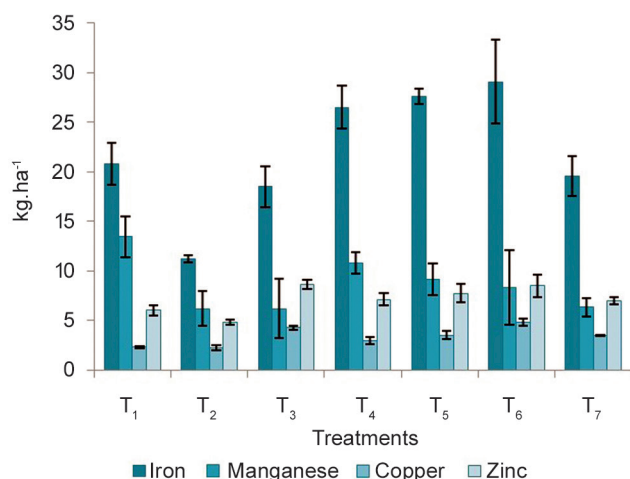


Fig 2 Effect of top dressing with organic residues on nutrient uptake of micronutrients. Error bars indicate standard error ( $\pm$ SE) at different levels of treatment means ( $N=3$ ) at  $p < 0.05$  for iron (Non significant), manganese (LSD=4.10), copper (LSD=0.80) and zinc (LSD= 1.20).

certain fungal communities (López-Reyes *et al.* 2017). Our study also found a slight but significant dominance of inorganic phosphate-solubilizing bacteria in the treatment with chemical topdressing application, likely due to the rapid mineralization of phosphatic fertilizers caused by organic manure decomposition and increased microbial acid phosphatase activity (Ali *et al.* 2019). Coconut leaf vermicompost showed higher populations of plant beneficial bacterial communities such as fluorescent pseudomonads and free-living  $N_2$  fixers, supporting the population trend of respective microbial communities in different treatments (Gopal *et al.* 2009). Application of plant growth-promoting microbes increases the nutrient-supplying capacity of soil, thereby promoting the growth of plants with limited inherent supply of nutrients (Nihad and Jessykutty 2010).

The study found that the best treatment for intercropping hybrid bajra napier in a coconut garden was 75% RDN through cow dung slurry, coconut leaf vermicompost, and *Azospirillum* sp. This treatment, along with a basal dose of 90:30:24 NPK through fertilizers resulted in an average yield increase of 24.59%. The study concluded that the integrated nutrient management schedule was cost-effective and led to a productivity (herbage yield) of 126.9 t/ha (average of three years) and higher dry matter yield (22.7 tonnes/ha/year), NDF, ADF, crude protein, and plant nutrient uptake, and lower dry matter digestibility and dry matter intake. The available soil nutrients and general and function-specific microbial communities were lower in the soils top-dressed with chemical fertilizer alone. The plants supplied with 100% RDN (through chemical fertilizer and organic inputs) recorded higher yields during the first year, followed by a declining trend in subsequent years due to the nitrogen-induced reduction in soil pH. Therefore, technology refinement through farmer participatory research (2018–2021) with an additional liming of 400 kg/ha/year resulted in an average yield of 142.18 tonnes/ha which is

24.59% higher than the average experimental yield (126.9 tonnes/ha).

In conclusion, the field experiment at ICAR-Central Plantation Crops Research Institute, Regional Station, Kayamkulam, has shown that various combinations of organic inputs can have a positive impact on the growth of fodder grass in a coconut-based mixed farming system. The study demonstrated that supplying plants with 75% RDN through the recycling of organic inputs such as cow dung slurry (3750 l/ha), coconut leaf vermicompost (2 tonnes/ha) after every cutting (6 times a year), in two equal splits at fortnightly intervals, along with *Azospirillum* sp. L8(3) (3.5 kg/ha/year) in a cost effective manner with a productivity of 126.9 tonnes/ha from 60% intercropped area. The refinement in farmer's field revealed that an additional lime application (400 kg/ha of intercrop) in the second and third years, resulted in the highest average yield of 142.18 tonnes/ha and up to 90% reduction in external physical inputs. Correction of soil acidity is vital for maintaining the fresh fodder yield in nutrient recycling with organics. The results also indicate that soil potassium status is diminishing (less than 20 ppm) and hence being a nutrient required by the main as well as the intercrop, potassium needs to be supplemented for maintaining soil health and system productivity. This approach shows great potential for reducing the reliance on external inputs in coconut-based mixed farming systems.

#### ACKNOWLEDGEMENT

The authors are grateful to Indian Council of Agricultural Research-Central Plantation Crops Research Institute for the financial support under the institute project 1000763057: Cropping/farming approaches for improving soil health and system productivity in coconut, arecanut and cocoa.

#### REFERENCES

- Ali W, Nadeem M, Ashiq W, Zaeem M, Gilani S, Rajabi-Khamesh S, Pham TH, Kavanagh V, Thomas R and Cheema M. 2019. The effects of organic and inorganic phosphorus amendments on the biochemical attributes and active microbial population of agriculture podzols following silage corn cultivation in boreal climate. *Scientific Reports* **9**: 17297. <https://doi.org/10.1038/s41598-019-53906-8>
- Allen O N. 1959. *Experiments in Soil Bacteriology*, 3rd edn. Burgess publishing Co. Minneapolis, USA .
- Annual report 2021–22. Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi.
- Chen Q, Ding J, Zhu D, Hu H, Delgado-Baquerizo M, Ma Y, He J and Zhu Y. 2020. Rare microbial taxa as the major drivers of ecosystem multi functionality in long-term fertilized soils. *Soil Biology and Biochemistry* **141**: 107686.
- Cleophas T J and Zwinderman A H. 2016. *Clinical data analysis on a pocket calculator*, 2nd edn. Springer International Publishing, Switzerland.
- Danso-Abbeam G, Dagunga G, Ehiakpor D S, Ogundeji A A, Setsoafia E D and Awuni J A. 2021. Crop-livestock diversification in the mixed farming systems: implication on food security in Northern Ghana. *Agriculture and Food Security* **10** (35): 1–14.

- Devendra C and Thomas D. 2002. Crop–animal interactions in mixed farming systems in Asia. *Agricultural Systems* **71**: 27–40.
- Gopal M, Gupta A, Sunil E and Thomas G V. 2009. Amplification of plant beneficial microbial communities during the conversion of coconut leaf substrate to vermicompost by *Eudrilus* sp. *Current Microbiology* **59**: 15–20.
- Gopal M, Bhute S S, Gupta A, Prabhu S R, Thomas G V, Whitman W B and Jangid K. 2017. Changes in structure and function of bacterial communities during coconut leaf vermicomposting. *Antonie van Leeuwenhoek* **110**(10): 1339–55.
- Jackson M L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Private Limited, New Delhi, India.
- Lopez-Reyes L, Moises G, Carcano-Montiel, Tapia-Lopez, Lilia, Guadalupe, Medina-de la Rosa and Tapia-Hernandez RA. 2017. Antifungal and growth-promoting activity of *Azospirillum brasilense* in *Zea mays* L. ssp. *mexicana*. *Archives of Phytopathology and Plant Protection* **50**: 727–43. doi:10.1080/03235408.2017.1372247
- Lupatini M, Korthals G W, de Hollander M, Janssens T K S and Kuramae E E. 2017. Soil microbiome is more heterogeneous in organic than in conventional farming system. *Frontiers in Microbiology* **7**: 2064.
- Nihad K and Jessykutty P C. 2010. Long term effect of organic manures and microbial inoculants on nutrient uptake and yield of *Plumbago rosea* when grown as an intercrop in coconut garden. *Journal of Medicinal and Aromatic Plant Sciences* **32**(3): 257–61.
- Nowak B, Nesme T, David C and Pellerin S. 2015. Nutrient recycling in organic farming is related to diversity in farm types at the local level. *Agriculture, Ecosystems and Environment* **204**: 17–26.
- Obour A K, Silveira M L, Adjei M, Vendramini J M and Rechcigl J E. 2009. Cattle manure application strategies effects on Bahia grass yield, nutritive value, and phosphorus recovery. *Agronomy Journal* **101**(5): 1099–1107.
- Ogunwale J A, Udo E J. 1978. *A Laboratory Manual for Soil and Plant Analysis*. Agronomy Department, University of Ibadan, Nigeria.
- Rousk J, Brookes P C and Bååth E. 2009. Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. *Applied and Environmental Microbiology* **75** (6): 1589–96.
- Singh D N, Bohra J S, Tyagi V, Singh T, Banjara T R and Gupta G. 2022. A review of India's fodder production status and opportunities. *Grass and Forage Science* **77**(1): 1–10.
- Stur W, Khanh T T and Duncan A. 2013. Transformation of small-holder beef cattle production in Vietnam. *International Journal of Agricultural Sustainability* **11**(4): 363–81.
- Subramanian P, Dhanapal R, Palaniswami C and Sebastian J. 2007. Feasibility studies on growing hybrid bajra napier fodder grass intercrop in coconut under coastal littoral sandy soil. *Journal of Plantation Crops* **35**(1): 19–22.
- Tian D and Niu S. 2015. A global analysis of soil acidification caused by nitrogen addition. *Environmental Research Letters* **10**(2): 024019.
- Van Soest P J, Robertson J B and Lewis B A. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* **74**(10): 3583–97.
- Yang Y, Ashworth A J, DeBruyn J M, Willett C, Durso L M, Cook K, Moore Jr P A and Owens P R. 2019. Soil bacterial biodiversity is driven by long-term pasture management, poultry litter, and cattle manure inputs. *Peer Journal* **7**: e7839.