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Modeling based Nutrient Recommendation with NUTMON –Toolbox for Sustenance of Soil Fertility in humid tropical Kerala – A farm level study

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Abstract

In the present study, an attempt was made to carry out nutrient audits, which include the calculation of nutrient balance at the micro (plot/field) and meso (farm) levels and the evaluation of trends in nutrient mining / enrichment by employing the NUTrientMONitoring (NUTMON) Toolbox.NUTMONis a multiscale approach that assess the stocks and flows of N, P and K in an well defined geographical unit based on the inputs *viz.,* mineral fertilizers, manures, meteorological data, atmospheric deposition, sedimentation and outputs of harvested crop produces, residues, leaching, denitrification and erosion losses. The nutrient budgeting study was carried out for 2 farms in Palakkad district, Kerala by adopting the standard procedures and calculations (*viz.*,1. Organic 2. Integrated nutrient management). The calculated nutrient balances at crop activity level indicate a negative balance for nitrogen, phosphorus and potassium in crops like paddy, coconut, arecanut and banana. The farm with integrated nutrient management had N balance as negative, whereas P and K balance was positive. The farm with organic nutrient management had a negative balance for N, P and K. The results indicate that nutrient management practices are not appropriate and sustainable. The management options to mitigate this mining by manipulating all inputs and outputs in a judicious way with an integrated system approach are suggested. A strategy was worked out for deriving the nutrient prescription rate using results of site specific soil test for the individual crops of the selected farms. By assuming prescribed nutrients are applied to the individual PPUs, nutrient balance was simulated with NUTMON-Toolbox and the results tend to be positive for N, P and K.

Keywords: *Nutrient balance, Inputs, Outputs, Fertilizers, nutrient mining,NUTMON*

Introduction

The agricultural scenario of the Kerala state is unique, characterized by diversity of crops and multiplicity of cropping situations.In the humid tropical region of Kerala, agriculture plays a significant role in the livelihood of the local population. The diverse and intensive agricultural practices in this region, however, pose challenges to soil fertility and sustainability. Continuous cultivation, combined with inadequate nutrient management, leads to soil degradation, nutrient depletion, and reduced agricultural productivity. Traditional methods of nutrient management often fail to address the specific needs of different soil types and crops, resulting in inefficient use of fertilizers and negative environmental impacts.Low fertile lateritic

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soils, the nature of topography with undulating terrain, coupled with high intensity rainfall, leads to top fertile soil loss through severe erosion and nutrient lost through leaching might have been one of the contributing factors for low productivity. There are several possible reasons for this low productivity, however at this juncture the low yield of crops associated with high cost of production is a great concern in Kerala's agriculture. The first predominant cause of soil degradation in these high rainfall zone regions undoubtedly is water erosion. On an average 15-18 t $ha^{-1}$of top fertile soil is eroded in Kerala ultimately resulting in low fertility status besides having other implications like low crop productivity, ground water recharge etc., (State of Environment Report, Kerala, 2007). Soil nutrient depletion is a pressing concern directly linked to food insecurity, particularly in low- and middle-income countries across Africa, Asia, and Latin America (Bouwman et al., 2017). In these regions, prevalent agricultural practices often involve intensification without adequate fertilizer application, leading to nutrient mining.

To assess the environmental performance of agricultural systems, several tools have been developed over the past decades, such as life cycle assessment. However, the impact of agriculture on soil nutrients is often excluded from these analyses. Instead, tools like nutrient balance calculations (also known as nutrient budget) are used, estimating the difference between nutrient inputs and outputs within predefined spatial and temporal boundaries (Surendran et al., 2016).However, such studies on calculating the nutrient balances as inflow and outflow *viz.*, loss of nutrients through soil erosion and leaching loss are very limited in Kerala region and have not been linked as nutrient balance studies earlier. Hence, with this background the present study was carried out to give solutions by identifying the root cause and assessing the nutrient inflows and outflows from the system i.e. at field level and farm level using Decision Support Systems.

MATERIALS AND METHODS

Study sites

The study area is located (10º 19′ and 11º 15′ N latitudes and east longitudes 76º 01′ and 76º 55′ E longitudes)in Palakkad district of Kerala in southern part of India. It is the largest district in Kerala, having a total geographical area of 4 4 80 km^2. The site characteristics of the study is presented in Table 1. The district experiences two types of climates. Ottappalam, Alathur and Mannnarkad taluks experience a climate similar to that of other districts in Kerala; whereas Palakkad and Chittur taluks experience a dry climate similar to that in Tamil Nadu. The major cultivated crops in Palakkad district are rice, coconut, banana, rubber, arecanut, brinjal, tomato, gourds, pumpkin, groundnut, sugarcane, sweet potato, tapioca, maize, ragi, sorghum, redgram, blackgram, greengram, horse gram, black pepper, nutmeg, cardamom, tea, coffee, cotton etc. Length of growing period varies from 105 to 252 days.

Table 1. Characteristics of the study area

Site Characteristics	
District	Palakkad
Latitude/Longitude	10º 19′ and 11º 15′ N and between 76º 01′ and 76º 55′.
Mean annual Rainfall (mm)	2300-2500
Major soils	Laterite soils
Major soil orders	Ultisols, Entisols, Vertisols and Alfisols
Major crops grown	Rice, coconut, banana, rubber, arecanut, brinjal, tomato, gourds, pumpkin, groundnut, sugarcane, sweet potato, tapioca, maize, ragi, sorghum, red gram, black gram, green gram, horse gram, black pepper, nutmeg, cardamom, tea, coffee, cotton

Soil Characteristics

Dominant Soil series	Mannur, Anuppur, Agali, Thirunarayanapuram, Karakurissi, Bhavajinagar, U thrampallam
Texture	Clay to sandy loam
pH	Strongly to medium acidic
Organic carbon (g kg^{-1})	4 .6 to 6.1
P (kg ha^{-1})	15 to 92
K (kg ha^{-1})	90 to 715

Model Description

Structure of NUTMON -Toolbox

NUTMON-Toolbox is user-friendly computerized software for monitoring nutrient flows and stock especially in tropical soils (Smaling, 1998; Vlaming et al. 2001;Surendran and Murugappan, 2007; Surendran and Murugappan,2010). The toolbox consists of a structured questionnaire, a database, and two simple static models (NUTCAL for calculation of nutrient flows and ECCAL for calculation of economic parameters). A user-interface facilitates data entry and extraction of data from the database to produce inputs for the both models (Vlaming et al. 2001). The tool calculates flows and balances of the macronutrients (N, P and K) and economic performance of the farm through independent assessment of major inputs and outputs using the following equation.

Net soil nutrient balance = (Nutrient INPUTS) - (Nutrient OUTPUTS) … (1)

There is a set of five inputs (IN 1-5: mineral fertilizer, organic inputs, atmospheric deposition, biological nitrogen fixation and sedimentation), five outputs (OUT 1-5: farm products, other organic outputs, leaching, gaseous losses, erosion), and six internal flows (consumption of external feeds, household waste and human excreta, crop residues, grazing, animal manure, and home consumption of farm products). Nutrient flows are quantified in three different ways in NUTMON *viz*., by using primary data, estimates and assumptions. Farm inventory and farm monitoring regarding nutrient flows into and out of the farm was done using the available questionnaires through farmer participatory analysis. Initally, farms need to be conceptualized as a set of dynamic units, which depending on management, form the source and /or destination of nutrient flows and economic flows. The conceptual framework consisted of four major components, which are i) Farm Section Unit (FSU). - Areas within the farm with relatively homogeneous properties ii) Primary Production Unit (PPU) / crop activities — Crop activities in a piece of land with different possible activities such as one or more crops (annual or perennial), a pasture, a fallow and located in one or more FSUs iii) Secondary Production Unit (SPU) / livestock activities — Group of animals within the farm that are treated by the farm household as a single group in terms of feeding, herding and confinement and iv) Redistribution Unit (RU) — Nutrient storage activities. Location within the farm where nutrients gather and from which they are redistributed, such as manure heaps and compost pits. Based on this concept, the selected farms were conceptualized and the farm inventory and farm monitoring regarding nutrient flows into and out of the farm was done using the available questionnaires through farmer participatory analysis.Collected data were fed into the data processing module and the nutrient balance for the individual crop activity (micro) and farm (meso) as a whole were computed using the NUTMON-Toolbox. Additional information that was needed for the calculations but that cannot be given by the farmer; *viz*., nutrient contents of crops and other livestock products had been analyzed and stored in background database. Soil sampling and analysis provided information on the current nutrient status of soils

RESULTS AND DISCUSSION

Description of the selected farms

The farms selected for the study are located at Perumatty and Melarkode area in Palakkad district of Kerala. Among the two farms in one farm, the nutrient management is exclusively organic and devoid of any chemical fertilizers, hereafter referred as organic farm (OF). In other farm, the nutrient management is by integrating both organic manures and chemical fertilizers, hereafter referred as integrated nutrient management farm (INMF). The area of the INMF and OF farm is of 1.4 and 1.0 ha, respectively. Both the farms are irrigated through the well located within the farm. The OF farm comprises of three farm section units (FSUs) and INMF has four FSUs and is divided based on the homogenous soil properties, slope and crops grown in the farm (Table 2).

Table 2 . Characteristics of Farm Section Units

Farms	Farm Section Units (FSU)	Slope Characteristics	Soil Properties	Other Terrain Features	Primary Production Units (PPUs) / Crops
Organic Farm (OF)	FSU 1	Flat to gentle slope	Sandy loam, well-drained	Low erosion risk, uniform terrain, Near to the Road and have the household building	Coconut (PPU 1)
	FSU 2	Moderate slope	Sandy loam, well-drained	Minor undulations, moderate erosion potential	Banana (PPU 2)
	FSU 3	Gentle slope	Clay loam, good moisture retention	Some variation in terrain, low erosion	Coconut (PPU 3), Arecanut (PPU 4), Paddy (PPU 5)
Integrated Nutrient Management Farm (INMF)	FSU 1	Flat to gentle slope	Sandy loam, well-drained	Low erosion risk, uniform terrain, Near to the Road and have the household building	Coconut (PPU 1), Banana (PPU 2)
	FSU 2	Moderate slope	Loamy soil, moderately drained	Slightly uneven terrain, minor erosion	Coconut (PPU 3), Banana (PPU 4)
	FSU 3	Gentle slope	Clay loam, good water retention	Slight undulations, minimal erosion	Banana (PPU 5), Coconut (PPU 6)
	FSU 4	Slight to moderate slope	Sandy loam, well-drained	Moderate erosion risk, varied terrain	Coconut (PPU 7), Banana (PPU 8)

In the case OF, the nutrients for the farm were mainly through organic manures that are met from external sources besides on-farm generated manures. The farmer, besides using on-farm manure, also purchased manure off-farm and imported it into the farm. This was included as IN 2a and IN 2b. Besides, a part of crop residue was also directly recycled into the farm by incorporation. In the case of INMF, the nutrients were mainly from chemical fertilizers from external sources and organic manures from both on and off- farm sources. Outflows in the farms included crop uptake (OUT 1), removal in crop residue (OUT 2), leaching (OUT 3), gaseous loss (OUT 4) and erosion losses (OUT 5).

Nutrient balance at crop activity (PPU) level in OF and INMF

In the Organic Farm (OF), the nutrient balances at the Primary Production Unit (PPU) level, covering all the FSUs, were generated using the NUTMON Toolbox and are presented in Table 3. All crop activities (PPUs) exhibited a negative balance for nitrogen (N) and phosphorus (P), except for banana (PPU 2), which showed a positive balance of 13.4 kg ha^{-1} for N and 5.7 kg ha^{-1} for P, respectively. Regarding potassium (K), all crop activities also demonstrated a negative balance, with the highest deficit observed in paddy (PPU 5) at –545.2 kg ha^{-1}. In summary, none of the crop activities in the OF exhibited a positive balance for all three nutrients. For the Integrated Nutrient Management Farm (INMF), the nutrient balances at the PPU level displayed a mixed trend (Fig. 1). In all coconut and banana fields (PPUs 1 to 8), the N balances were negative, indicating insufficient nitrogen management under this system. Similarly, banana crops in all relevant PPUs (PPU 2, 4, 5, and 8) also recorded negative balances.

Table 3. NUTMON Toolbox generated NPK balance at Crop activity (PPU) levels of the Organic farm (OF)

Crop activity (PPU)	N balance	P balance	K balance
		kg ha^{-1}.	
PPU 1 Coconut	-123.0	-16.4	-161.5
PPU 2 Banana	13.0	5.7	-1.2
PPU 3 Areca (betel) nut	-9.8	-0.8	-18.1
PPU 4 Coconut	-269.4	-41.6	-328.5
PPU 5 Paddy /Rice	-128.6	-65.7	-545.4

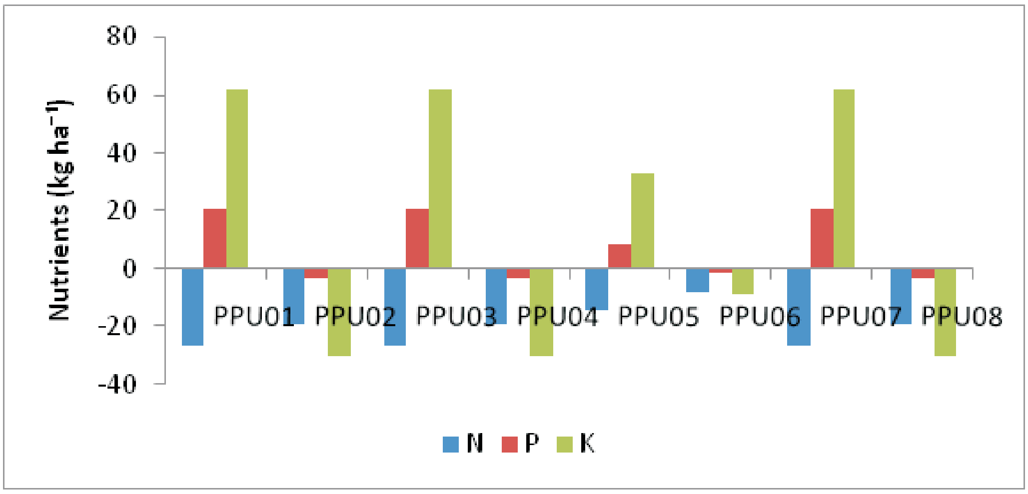

Fig.1. NUTMON Toolbox generated NPK balance at Crop activity (PPU) levels of the INM farm

For coconut the phosphorous and potassium balances were positive, while the nitrogen balance was negative. This indicates that the current nutrient application practices are sub-optimaland other management strategies like manure addition, recycling of wastes, use of bio-fertilizers etc., were insufficient to match the gap between nutrient export from the farm and nutrient inputs. The nutrient management practices adopted in the case of coconut, resulted in built-up of P and K fertility of soils. In general, nutrient balances in perennial crops crop like coconut was positive as compared to annuals where, negative nutrient balances were observed. These suggest that the recycling of the wastes from the coconut plot and application of both organic and inorganic nutrients might have resulted in the built up of soil fertility. Additionally, these findings indicate that the market prices for crop produce do not significantly influence nutrient management practices on this farm. For instance, while banana cultivation is more profitable than coconut, the nutrient application is still inadequate to meet the requirements of banana crops.

Nutrient balance at farm level

At the farm level, the nutrient balance was calculated as the difference between the total inputs and outputs across all farm section units (FSUs), Primary Production Units (PPUs), Secondary Production Units (SPUs), and Redistribution Units (RUs). There has been a slight variation in the nutrient balance of the farm than the individual PPUs. NUTMON-Toolbox generated nutrient balance for the INMF as a whole showed that the full balances were positive for P and K and negative for N (Table 3).

In contrast, the organic farm (OF) exhibited a negative balance for all three nutrients (Table 4).Farm level nutrient balance in these two farms revealed that the sustainability of the soil fertility is not being managed efficiently. Even though the negative balance at field level (crop activity) was larger than that at farm level, the nutrients were still within the farm ecosystem that were eventually tied up in pools without any linkage with farm nutrient flow channels. Therefore, any profitable farm management plan should aim to link them in the flow channels or otherwise undetected economic loss in farm management would occur. Similar turnover of nutrients from plots to livestock activity and vice-versa was reported earlier (Surendran and Murugappan, 2010;Surendran et al., 2016).

The negative nitrogen (N) balance at the farm level was primarily due to high N outflows through harvested produce, crop residues, losses from manure, leaching, and gaseous emissions. Leaching and gaseous losses of N in the irrigated farms were high which is in agreement with the findings of Leipet al. (2011). A review and upward revision of existing fertilizer application rates to crops, use of slow-release N fertilizers or use of urease / nitrification inhibitors to improve N use efficiency are some of the strategies to mitigate this negative balance. Additionally, growing and incorporating green manure crops during fallow periods can help reduce significant leaching losses observed on the farm. Producing and applying on-farm organic manures to recycle nutrients from crop residues will also enhance soil fertility (Vos and Van Der Putten, 2000). The difference in full and partial balance of N might be due to the contribution of N from Nitrogen fixation. Full and partial balances of P were positive. This positive balance was mainly due to the optimal use of P fertilizers and absence of pathways of losses of P other than crop uptake (OUT 1) and loss in crop residues (OUT 2). It is suggested that in soils with such buildup of P, fresh P inputs through fertilizers can be omitted or a maintenance dose of P can be applied to effect saving on cost of P fertilizer. Use of P solubilizing (Phosphobacteria) and mobilizing (VAM) microorganisms as biofertilizers will improve the utilization of native soil P in such situations of P fertility buildup in soil (Surendran and Vani, 2013).

Table 3. NUTMON -Toolbox generated nutrient balance for the integrated nutrient management farm in Kerala

Flows / Nutrient	Inputs (kg)				Outputs (kg)					Partial balance (kg ha^{-1})	Full balance (kg ha^{-1})
	IN 1	IN 2	IN 3	IN 4	OUT 1	OUT 2	OUT 3	OUT4	OUT5		
Nitrogen	193.5	105.1	24.3	39.9	303.4	0.0	158.6	56.1	18.8	-3.4	-122.9
Phosphorus	90.0	26.3	4.0	0.0	52.6	0.0	0.0	0.0	10.6	44.9	40.3
Potassium	450.0	99.4	16.0	0.0	337.6	0.0	5.6	0.0	87.4	149.6	95.2

*Partial balance = (IN1-2)– (OUT1-2) **Full balance = (IN 1-5) -(OUT1-5)

Table 4. NUTMON -Toolbox generated nutrient balance for the organic nutrient management farm in Kerala

Flows / Nutrient	Inputs (kg)				Outputs (kg)					Partial balance (kg ha^{-1})	Full balance (kg ha^{-1})
	IN 1	IN 2	IN 3	IN 4	OUT 1	OUT 2	OUT 3	OUT 4	OUT 5		
Nitrogen	0.0	103.5	15.0	12.2	451.5	0.0	47.0	16.6	126.6	**-183.0**	**-268.7**
Phosphorus	0.0	25.9	2.5	0.0	75.1	0.0	0.0	0.0	71.2	**-25.9**	**-62.0**
Potassium	0.0	68.0	9.8	0.0	518.1	0.0	0.4	0.0	587.2	**-236.7**	**-540.4**

*Partial balance = (IN1-2)– (OUT1-2) **Full balance = (IN 1-5) -(OUT1-5)

The K balance was negative due to very minimal use of external inputs as minerals fertilizers and off-farm manures. Apart from this, huge quantities of nutrients were exported out of the farm through harvested produce and leaching losses. Such soil mining of K was also reported earlier, and they found that irrespective of whether K is added or not, mining of soil K occurred in continuous and intensive cropping due to luxury consumption (Murugappan et al., 1999; Surendran et al., 2016). This negative balance necessitates bringing into farms plant nutrients in amounts equivalent to that of the quantity exported out the farm as crop produces.The mining of K is also accelerated under imbalanced fertilizer N use which stimulates crop growth and ultimately increases the crop uptake of K. The issue of how long these negative K balances can be permitted to continue without serious consequences on soil K supply and on crop yield requires further study. The solution lies in applying optimal amounts of potassium (K) fertilizer as part of a balanced fertilization plan, alongside improved management of crop residues to recycle the K removed from the soil.

Strategy for Nutrient Use

Nutrient depletion is the result of a net imbalance, between incoming and outgoing nutrients in farm inputs and outputs. Because many aspects of farm management, influence these processes, there is a need for a `basket of technology options′, addressing the various causes of depletion. Implementing an optimal nutrient use strategy requires balanced fertilization that considers soil nutrient status and crop-specific needs. However, fertilizer being the major input, a strategy was worked out for each PPU of individual farm under study by combining both organic and inorganic nutrients along with soil and water conservation measures and the results were simulated using the NUTMON tool box. The nutrient recommendation derived based on the site specific soil analysis for the crops grown at both these farms by combining organic and chemical fertilizers made the farm balance positive. The nutrient prescription for most of the crops revealed that the presently followed state recommendation is sub-optimal and an upward revision is the need of the hour to make the crop production profitable and sustainable. NUTMON-Toolbox generated nutrient balance was positive for all the three nutrients when the nutrient management programme is based on the site specific nutrient management (Fig. 2).

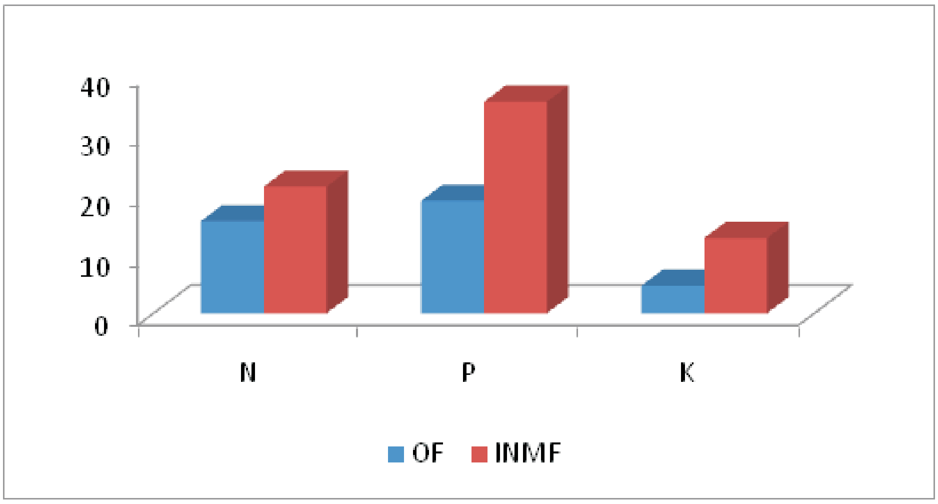

Fig.2. NUTMON Toolbox generated NPK balance at INMF and OF farms

Conclusions

In this investigation, nutrient monitoring with NUTMON-Toolbox at different spatial scales (*viz*., micro (plot) and meso (farm) levels) exhibited a trend of depletion of N and K from soil reserve whereas P was positive indicating the need for carefully redefining N and K management strategies. However, the site and crop specific simulated nutrient recommendations, combined with soil and water conservation practices, transformed the negative balance of N and K in to positive ones. Decision Support Systems (DSS) *viz*., NUTMON serves as a tool to identify the depletion of nutrients and helps to suggest the management options using a systematic approach.

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