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Pragmatic Approaches to Manage Soil Fertility in Sustainable Agriculture

[1]U. Surendran and [2]V. Murugappan
[1]Research and Development Center, E.I.D Parry (I) Ltd., Pettavaithalai,
Trichy District-639112, Tamil Nadu, India
[2]Center for Soil and Crop Management Studies,
Tamil Nadu Agricultural University, Coimbatore-641003, India

Abstract: An attempt was made for carrying out nutrient audits, which includes the calculation of nutrient balance at micro (plot/field), meso (farm) and macro (district) level and evaluation of trends in nutrient mining/enrichment. A nutrient budget is an account of inputs and outputs of nutrients in an agricultural system. NUTrient MONitoring (NUTMON) is a multiscale approach that assesses the stocks and flows of N, P and K in a well defined geographical unit based on the inputs and outputs. The calculated nutrient balances at crop activity level indicated a negative balance for cereals and pulses while positive for most of the horticultural crops. Similarly the results showed a negative balance for N and K and positive for P at farm level. Soil nutrient pool has to offset the negative balance of N and K hence there will be an expected mining of nutrient from the soil reserve in the study area. The management options/policy interventions to mitigate this mining by manipulating all inputs and outputs in a judicious way with an integrated system approach are also discussed. A strategy was worked out for deriving the fertilizer prescription rate using Decision Support System for Integrated Fertilizer Recommendation (DSSIFER) for the soil fertility status of the individual PPU of all the selected farms. By assuming DSSIFER prescribed fertilizers are applied to the individual PPUs, nutrient balance was generated with NUTMON-Toolbox and the results tend to be positive. NUTMON-Toolbox coupled with the system's approach for fertilizer optimization, DSSIFER and Agro ecological zoning would serve the purpose of gaining insight into long-term effects of farm management on enhancing soil fertility and productivity.

Key words: Fertilizers, inputs, NUTMON, nutrient balance, outputs, DSSIFER

INTRODUCTION

Agricultural land use is always expected to supply the nation with enough quantity food. Thus, intensification is necessitated in agriculture. Continuous intensive agriculture without adequate attention on rational soil management poses serious threat to the sustainability of agro-ecosystems. One of the consequences of irrational soil management under intensive cropping is the decline in soil fertility, i.e., the levels of nutrient replenishments are low to redress the process of nutrient depletion. This nutrient mining does not get the same public attention as droughts, pest infestation etc., since it is a gradual process and not associated with catastrophes and mass starvation and therefore largely invisible (Smaling, 1993). Also, pertinent is that many soil test methods do not readily reveal nutrient mining because the available fraction extracted is buffered well by supply from other nutrient pools, as is often seen with K availability in some high CEC soils. Prognoses for the effect of soil nutrient depletion on future agricultural production are even more difficult to establish.

The change in soil nutrient stocks over time has to be measured in order to quantify the extent of nutrient mining and also to provide an early caveat on adverse trends in nutrient inflows and outflows from the farm. Hence, a quantitative knowledge on the depletion of plant nutrients from soil is essential to understand the status of soil degradation and to devise optimum nutrient management strategies. Such a quantitative knowledge forms the basis and is essential for any management programme aimed to ensure sustainability in agro-production systems. Restoration of soil fertility can no longer be regarded as an issue connected with the use of organic and inorganic nutrient sources only. It requires a long-term perspective and a holistic approach. The holistic approach should take care of the nutrient stocks within a farm; their flow

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Corresponding Author: U. Surendran, Research and Development Center, E.I.D Parry (I) Ltd., Pettavaithalai,
Trichy District-639112, Tamil Nadu, India Tel: 91-9940120952

Table 1: Compound growth rate in yield for major crops

Year	Rice	Millets	Pulses	Oil seeds	Cotton	Coconut	Sugarcane
1971-80	0.46	3.59	1.67	0.81	3.82	8.89	2.35
1981-90	6.00	3.99	2.90	2.24	4.47	-5.62	1.51
1991-00	0.79	0.86	- 0.21	0.37	- 0.30	-2.75	-0.67

between various activities within the farm and nutrient balance at farm level that is arrived by matching nutrient inflows into the farm and nutrient exports out of the farm (Vlaming *et al*., 2001). Such a knowledge intensive management plan requires participatory research and development focus rather than a purely technical focus. The outcome from it will be useful to agricultural policy makers and also to the farmers to design policy interventions to mitigate undesirable trends, if any.

Crop yields harvested with the present level of fertilizer recommendations and the yields harvested in many fertilizer response experiments with higher levels than the present level have unequivocally revealed that the fertilizer optima calculated in present day research are erroneous and in many cases sub-optimal. Further, the boundary lines for the application of fertilizer management technologies is mostly administrative boundary (sometimes fewer parameter) based rather than science based and is the major cause for technology failures and degradation of resource base.

The compound growth rate in yield in major crops is either declining or negative (Table 1). It is the experience of the researchers that with newer crop varieties these yield barriers cannot be broken. The logical conclusion is that the soil resource base is degraded below a critical level that newer crop varieties or hybrids are not able to yield beyond a level, which is primarily determined by the level of native soil fertility. The amount of fertilizer used is also sub-optimal (and imbalanced too) at the site of application and therefore the expected yield increase is not realized.

This study envisages a wholesome approach in five phases covering all the above aspects in order to ensure real optimum character to these fertilizer optima and sustainability to agro-production systems that are vital to break the crop yield barrier.

Phase I: Farm level nutrient budgeting: Farm level nutrient budgeting is an essential component in any programme that aims towards sustainability in agriculture. It must be the base level information for farm or region or national level policies to promote INM (Integrated Nutrient Management) programmes. The first phase deals with the farm level nutrient budgeting using nutrient monitoring approach. Nutrient monitoring is a method that quantifies a system's nutrient inflows and outflows resulting in nutrient balance. Nutrient balance can be determined at spatial scales ranging from field level to continental scale. The nutrient balance studies at the level of individual activities within a farming system serve as a useful indicator and variable tool, providing insight into causes and magnitudes of losses of nutrients from the system and so helping to target interventions in places where undesirable trends are witnessed.

When this nutrient monitoring is applied to a system, where different management practices are being introduced, it can be used to assess the effects of these management practices on soil nutrient stocks and flows (Sharma, 2008; Stoorvogel *et al*., 1993; Smaling *et al*., 1993). Larger scale estimates of nutrient balance and budgeting have become increasingly influential in policy discussion related to soil fertility management and sustainable agriculture (World Bank, 1996). Nutrient monitoring has been a valuable tool for scientists to summarize and facilitate the policy makers to understand the nutrient cycling in agroecosystems and used as regulatory policy instruments (De Walle and Sevenstar, 1998).

Murugappan *et al*. (1999) have observed that irrespective of whether K is added or not, mining of soil K occurred with continuous intensive cropping due to a luxury consumption which would limit crop yields due to severe K deficiency and render the land chemically degraded. Unchecked nutrient depletion or accumulation has major implication on sustainability of agricultural systems and future world food supplies (Syers, 1997). Nutrient deficits occur in many Sub-Saharan African countries (SSA) (Stoorvogel and Smaling, 1990; Smaling, 1993) while nutrient surpluses are found in industrialized countries. Nutrient budgets can be used as an agro-environmental indicator and awareness raiser of nutrient (mis) use and nutrient use (in) efficiency (OECD, 2001). Nutrient balances/audits can provide an early indication of potential problems arising from a nutrient surplus (inputs > outputs) leading to accumulation of nutrients or a deficit (inputs < outputs) leading to depletion of soil nutrient reserves there by increasing the risk of toxicities or deficiencies, respectively, both of which reduce crop yields (Cuttle, 2002).

Approaches to nutrient budgeting: Budgets are the outcome of a simple nutrient accounting process, which detail all the inputs and outputs to a given or defined system over a fixed period of time. Recently many computerized decision support models for working out the nutrient balance were developed, viz., NUTrient MONitoring (NUTMON), NUtrient MAnagement Support System (NUMASS), MINeral Accounting system (MINAS), N CYCLE, OVERSEER, Ythan Nutrient budgeting tool etc., of-which NUTMON-Toolbox is a user friendly computerized software (developed by

Wageningen University, The Netherlands) for monitoring nutrient flows and stock especially in tropical soils (Vlaming *et al.*, 2001).

Farm level nutrient budgeting is done using this software based on nutrient stocks (where the nutrients are held in the farm) and flows (nutrient flow from one activity to another) with in a farm in order to assess whether the present farm practices ensure a positive nutrient balance or a negative one. In this phase the sustainability of the farm is assessed and the causes for the negative trends are identified which form the basis for making policy interventions to correct the negative trends.

Employing the computer software NUTMON-Toolbox and its calibration and validation enables quick assessment of nutrient balances at different scales, viz., farm, district and national levels. These nutrient balances are valuable information for farm management and policy makers. One is able to identify the source where the nutrients are held within a farm and their flows between different farm activities, viz., Primary Production Units (PPUs) (crops), Secondary Production Units (SPUs) (cattle, goat, poultry etc.) and Redistribution Units (RUs) (manure heap, crop). Thus the calibrated and validated NUTMON-Toolbox is a powerful tool in the hands of Scientists and Research Scholars who work in the field of INM to sustain crop yields and agro-production systems.

Structure and usefulness of NUTMON-Toolbox: The concept is based on five nutrient inputs (mineral fertilizer, organic manure, atmospheric deposition, biological nitrogen fixation, sedimentation) and five outputs (harvested products, crop residues, leaching, gaseous losses and erosion) and basically scale-independent. NUTMON is fed by a number of basic data and by nutrient input and output data. Basic data include the hectarage of the arable land and the spatial patterns of land use systems, i.e., the combination of prevailing soils and climate on the one hand and cropping and livestock systems on the other hand. Nutrient input and output data are reflections of the processes IN 1-5 and OUT 1-5. Each process has certain value and the nutrient balance is given by Σ IN- Σ OUT.

To determine nutrient input (IN 1-5) and output (OUT 1-5) values, a step-wise approach was followed viz., calculation, estimation or assumption. Some steps relate to data that were easily measured or obtained from farmer itself, for example fertilizer type and quantity and also the yield and hectarage of crops, but others related to more complex processes, for example amount of crop residues per land use system and data on denitrification and leaching losses. Some data needed continuous recording, for example quantity and frequency of irrigation and wet atmospheric precipitation, if any, while others were required irregularly, for example physical properties of soil etc.

On-farm nutrient flow: ways and means: The nutrient input flows in the experimental farm were identified as mineral fertilizers (IN 1), on-farm and off-farm (purchased) manures (IN 2), atmospheric deposition (IN 3) and biological N fixation (IN 4). Nutrient output flows were identified as crop uptake (OUT 1), removal in crop residues (OUT 2), leaching (OUT 3) and gaseous (volatilization) loss (OUT 4) (Fig. 1).

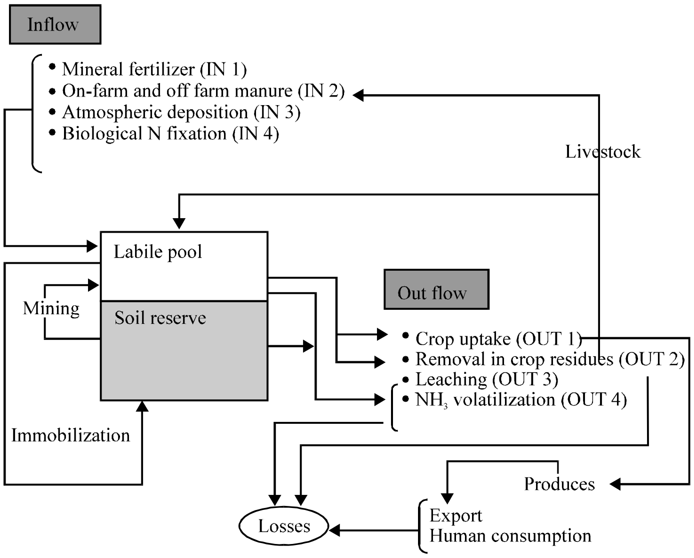

Fig. 1: Concept of On farm nutrient management and conservation of soil fertility

Table 2: NUTMON-Toolbox generated nutrient balance for the experimental farm

	Inputs (kg)				Outputs (kg)					
Nutrient	IN 1	IN 2	IN 3	IN 4	OUT 1	OUT 2	OUT 3	OUT 4	Partial balance (kg)	Full balance (kg)
Nitrogen	491.5	40.7	0.0	0.0	447.7	12.8	56.0	0.4	+71.8	+15.3
Phosphorus	72.8	12.7	0.0	0.0	88.8	6.4	0.0	0.0	-9.6	-9.6
Potassium	462.9	33.2	0.0	0.0	625.9	25.4	2.7	0.0	-155.2	-157.8

Table 3: NUTMON -Toolbox generated nutrient balance for the irrigated medium farm in Nathegoundenpudur

	Inputs (kg)				Outputs (kg)				Partial balance	Full balance	Partial balance	Full balance
Unit	IN 1	IN 2	IN 3	IN 4	OUT 1	OUT 2	OUT 3	OUT 4	(kg)	(kg)	(kg ha^{-1})	(kg ha^{-1})
Nitrogen												
PPU 1 Sorghum (8094 m^2)	42.0	0.6	2.8	0.0	15.3	3.2	6.0	0.0	24.1	20.9	29.8	25.8
PPU 2 Banana (4047 m^2)	59.0	22.5	1.4	0.0	60.3	33.3	8.4	0.0	-11.8	-18.8	-29.2	-46.5
PPU 3 Onion+Chillies (2023 m^2)	60.0	0.2	0.2	0.0	30.1	10.2	5.7	0.0	19.9	14.4	98.4	71.2
PPU 4 Maize (6070 m^2)	31.5	0.0	1.1	0.0	32.9	5.4	3.2	0.0	-6.8	-8.9	-11.2	-14.7
PPU 5 Turmeric (8094 m^2)	30.5	44.9	2.2	0.0	71.5	17.7	7.2	0.0	-13.8	-18.8	-17.0	-23.2
PPU 6 Blackgram (2023 m^2)	0.0	0.0	0.1	2.3	15.3	3.2	6.0	0.0	-4.6	-2.3	-22.7	-11.4
Phosphorus												
PPU 1 Sorghum (8094 m^2)	0.0	0.2	0.5	0.0	5.8	1.4	0.0	0.0	-7.0	-6.5	-8.6	-8.0
PPU 2 Banana (4047 m^2)	7.4	2.5	0.2	0.0	13.4	6.1	0.0	0.0	-9.6	-9.4	-23.7	-23.2
PPU 3 Onion+Chillies (2023 m^2)	21.0	0.0	0.0	0.0	5.1	2.1	0.0	0.0	13.8	13.8	68.2	68.2
PPU 4 Maize (6070 m^2)	9.0	0.0	0.2	0.0	8.0	0.9	0.0	0.0	0.1	0.3	0.2	0.5
PPU 5 Turmeric (8094 m^2)	22.5	10.6	0.4	0.0	9.8	2.4	0.0	0.0	20.9	21.3	25.8	26.3
PPU 6 Blackgram (2023 m^2)	4.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	3.2	3.2	15.8	15.8
Potassium												
PPU 1 Sorghum (8094 m^2)	0.0	0.2	1.8	0.0	3.9	10.1	0.1	0.0	-13.8	-12.1	-17.0	-14.9
PPU 2 Banana (4047 m^2)	60.1	3.0	0.9	0.0	41.6	21.1	0.5	0.0	-4.6	-4.2	-11.4	-10.4
PPU 3 Onion+Chillies (2023 m^2)	0.0	0.0	0.1	0.0	34.9	12.4	0.0	0.0	-47.3	-47.2	-233.8	-233.3
PPU 4 Maize (6070 m^2)	17.3	0.0	0.7	0.0	15.9	2.9	0.4	0.0	-1.5	-1.2	-2.5	-2.0
PPU 5 Turmeric (8094 m^2)	14.8	28.0	1.4	0.0	55.7	13.7	0.3	0.0	-26.6	-25.5	-32.9	-31.5
PPU 6 Blackgram (2023 m^2)	0.0	0.0	0.1	0.0	2.5	0.0	0.0	0.0	-2.5	-2.4	-12.4	-11.9

A major portion of the crop residues was returned to the farm as on-farm manure through livestock feeding. A small portion was recycled directly into the farm. A major portion of nutrients was exported out of the farm in harvested produces, which were meant either for human consumption or sale. It was also assumed that considerable amount of N and a small amount of K were leached out of the profile.

Presentation of nutrient budgets-case studies: Murugappan and Jagadeeswaran (2003) made an attempt for nutrient monitoring in a farm at Govanur village in Coimbatore district of South India, using NUTMON-Toolbox (NUTrient Monitoring Toolbox). The nutrient balance was expressed as the sum of inputs, (IN 1 + IN 2 + IN 3 + IN 4) minus the sum of outputs (OUT 1 + OUT 2 + OUT 3 + OUT 4), i.e., Σ IN-ΣOUT. The results indicated that N balance for the farm as a whole was positive (+15.3 kg) whereas these balances were negative for P (-9.6 kg) and K (-157.8 kg) (Table 2). It indicated that the usage of nitrogen fertilizers is sufficient enough to contribute for the crop uptake. The negative P and K balances might be attributed to the sub-optimal use of these fertilizers. Also, luxury consumption of K by the crops contributed to its negative balance.

Nutrient balance studies for the major nutrients viz., N, P and K were also monitored at different spatial scales viz., field (crop activity), farm and district levels in the Coimbatore and Erode districts of Western agro-climatic zone of Tamil Nadu by employing NUTMON-Toolbox (Surendran, 2005; Surendran and Murugappan, 2007). Eight irrigated and eight rainfed farms were considered in the study. The following are the results at different special scales.

At crop activity level: The nutrient balances at individual crop activity (primary production units -PPUs) level in a irrigated farm located at Nathegoundenpudur, Coimbatore district are presented as a example in Table 3. The results indicated that the calculated N and K balances were negative for banana, turmeric and maize, whereas for most of the crops the P balance was positive.

Flow diagram representing the various units within this farm is given in Fig. 2. The flow of nutrients to the farm from external sources was mainly through mineral fertilizers (IN 1) and on-farm and off-farm manures (IN 2) to banana (PPU 2), onion + chillies (PPU 3) and turmeric (PPU 5). The volume of flow to these PPUs was large as compared to the flows to other PPUs viz., pulses (PPU 6), maize (PPU 4) and sorghum (PPU 1). Similarly, the nutrients exported out of the farm (EXT) from PPUs that

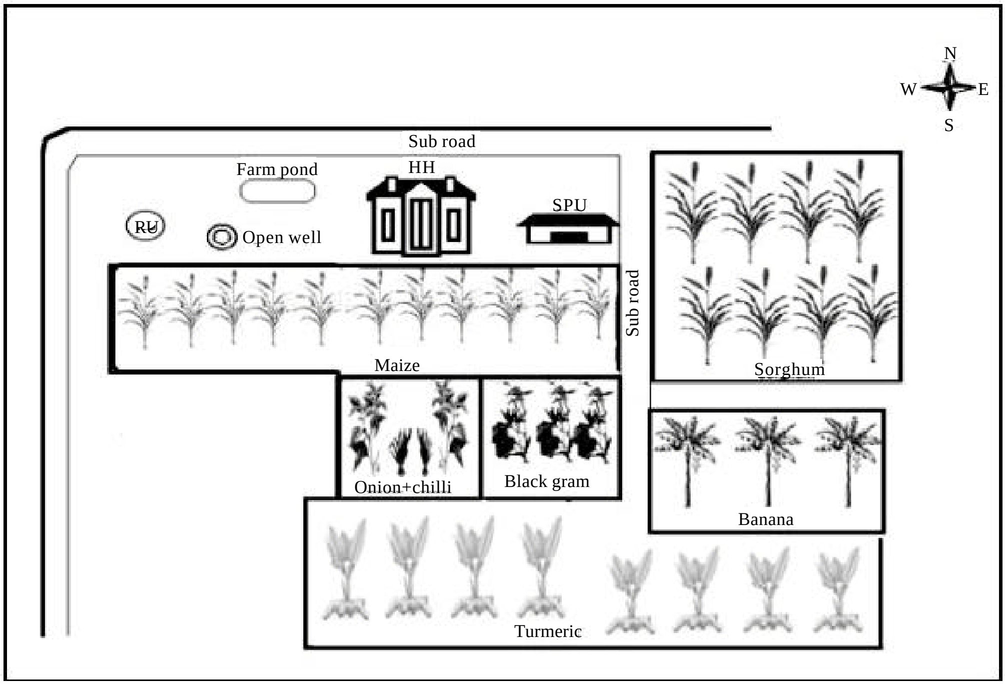

Fig. 2: Various units in the irrigated medium farm at Nathegoundenpudur

Table 4: NUTMON Toolbox generated nutrient balances at farm level

	Coimbatore district					Erode district					
Nutrient	Marginal	Small	Medium	Large	Mean	Marginal	Small	Medium	Large	Mean	Mean
Irrigated farms											
N	-48.6	25.2	-5.1	-27.4	-14.0	32.7	-47.0	62.6	-7.0	10.3	-1.8
P	-46.5	23.3	15.5	25.1	4.4	10.5	2.9	37.1	7.0	14.4	9.4
K	-126.7	-0.4	-31.3	-74.4	-58.2	-10.9	-94.6	-16.4	-18.5	-35.1	-46.7
Rainfed farms											
N	-1.8	-18.2	16.0	-22.0	-6.5	22.1	5.3	11.8	-18.5	5.2	-0.7
P	0.7	-2.5	-2.4	-1.7	-1.5	-0.2	-4.4	-4.4	-5.0	-3.5	-2.5
K	-3.5	-13.8	-9.0	-31.0	-14.3	-4.6	-2.7	-2.2	-37.6	-11.8	-13.1

occurred through the STOCK was large with maize (PPU 4), turmeric (PPU 5), onion + chillies intercropping (PPU 3) and blackgram (PPU 6). In the case of banana (PPU 5) and sorghum (PPU 1) nutrients were directly exported out of the farm (EXT) without going into the STOCK. The volume of flow of nutrients exported (EXT) from the STOCK was the largest in the farm and occurred through human consumption and sale of produce. Some quantity of nutrients has come into the STOCK as seed materials and stored in the farm. Similarly some quantity of nutrient flow occurred to the PPUs (viz., sorghum, onion and blackgram) from stock as planting materials.

The Secondary Production Units (SPUs) in the farm are tropical lactating cow (SPU 1, SPU 2) from which, nutrient flow occurred mainly to turmeric (PPU 5) and banana (PPU 2) through the compost heap (Redistribution Unit-RU 1). Also, through a portion of the residue from onion + chillies intercropping (PPU 3) and from external source as mineral fertilizers (viz., urea and SSP) nutrient flow occurred to compost heap (RU 1).

At farm level: The mean farm level N balances for Coimbatore and Erode districts were negative for both irrigated and rainfed situations (Table 4) (-1.8 and -0.7 kg/ha/year, respectively). The P balance was positive for irrigated farms (9.4 kg/ha/year) and negative for rainfed farms (-2.5 kg/ha/year). The average K balance was most negative in both irrigated and rainfed conditions (-46.7 and -13.1 kg/ha/year, respectively). The intensity of negative balance was high in Coimbatore district as compared to Erode district (-10.2, 1.4 and -36.3 kg N, P and K/ha/year in Coimbatore district and 7.8, 5.4 and -23.4 kg N, P and K/ha/year in Erode district).

Table 5: Nutrient balance at district scale for Western zone of Tamil Nadu

	INPUTS ($t\ year^{-1}$)						OUTPUTS ($t\ year^{-1}$)						Nutrient balance	Balance
Nutrients	IN1	IN2	IN3	IN4	IN5	Total	OUT 1	OUT 2	OUT 3	OUT 4	OUT 5	Total	($t\ year^{-1}$)	(kg/ha/year)
Soil nutrient balance of Coimbatore district														
N	31986	4839	1058	1097	0	38980	19892	13361	8095	693	98.5	42140	-3160	-10.10
P	10793	1443	171	0	429	12836	4016	1886	0	0	82.1	5984	6423	20.50
K	22715	3223	692	0	2860	29490	16717	13707	1860	0	279.0	32563	-3073	-9.80
Soil nutrient balance of Erode district														
N	36732	6315	1132	2100	0	46279	18876	18816	8964	556	100.0	47312	- 1033	- 3.27
P	11406	1790	186	0	473	13855	5665	3527	0	0	83.0	9275	4580	14.50
K	13422	4330	746	0	3154	21652	18760	19063	2054	0	286.0	40163	- 17811	- 58.60

The observed N balances was highly positive (62.0 kg ha^{-1}) in a medium farm and highly negative (-48.6 kg ha^{-1}) in a marginal farm. P balance was positive in almost all the selected irrigated farms. The positive balance was of high magnitude in a medium farm (37.1 kg ha^{-1}). Full and partial K balances were negative at all farms irrespective of the farm size. The highest negative balance of K was noticed in a marginal farm (-126.7 kg ha^{-1}). In rainfed farms most of the crops exhibited a negative N, P and K balances and this negative balance was of high magnitude with hedge lucerne, fodder sorghum, sorghum etc. P and K balances were found to be negative in all the selected rainfed farms of both the districts. K balance was found to be highly negative (-57.0 kg ha^{-1}) in a medium farm (Table 3).

These results indicated the need for critically reviewing the existing fertilizer recommendations for agricultural crops in general and sugarcane in particular. Other possible management to mitigate negative nutrient balances range from nutrient addition technologies (i.e., nutrient additions through mineral or organic sources, crop rotation etc.) to nutrient saving technologies (i.e., practices that aim to increase nutrient use efficiency viz., time and method of application, use of slow/controlled release fertilizers, use of urease/ nitrification inhibitors, use of N fixing and P solubilizing bio-fertilizers etc.). However, one single technology cannot solve nutrient related problems and hence solutions have to be sought from basket of technology options that should be economically feasible for the targeted farmers.

Nutrient balance at district level: At district scale the per hectare N and K balances were negative (-10.1 and -3.3 kg N/ha/year and -9.8 and -58.6 kg K/ha/year, respectively for Coimbatore and Erode districts), whereas P exhibited a positive balance in both cases (20.5 and 14.5 kg/ha/yea, respectively) (Table 5). The positive balance of P is the result the accumulation of P over years due to P fertilizer application and also the losses were low since the soils in the study area tends to fix P. The positive balance of P will result in an increased risk of nutrient emissions to the environment causing nutrient toxicity. The enhancement of P in soil reserves may lead to the contamination of surface and ground water causing accelerated eutrophication and poses risks of toxicity to aquatic life (CAST, 1996).

The negative balance of N and K implies that a net depletion of these nutrients from the soil reserves occurs. N is mobile in the soil system and is also lost from the system by leaching, volatilization of NH_3 in soils whose pH is more than neutral and denitrification in soils where submergence is a practice. All the three channels operate in the study area. While comparing the districts it was found that the high negative K balance in Erode district is mainly due to existing cropping system in which K depleting crops like turmeric, tapioca, banana, maize and paddy are grown. In the case of K, removal of harvested product (OUT 1 and 2) proved to be the strongest negative contributor followed by leaching which occurs in the study area since the soil characteristics are conducive for leaching. Yet the wider negative balance obtained may be due to suboptimal use of inputs in the study area. Continued nutrient mining process goes at the expense of soil nutrient from the mineral and organic matter reserves limits the crop yield and renders the land chemically degraded (Surendran and Murugappan, 2006; Murugappan, 2000). We can undoubtedly infer that the current practice of cropping system and nutrient management are exhaustive in terms of N and K withdrawals and cause greater drain of these nutrients from soil reserves. This process unchecked might lead to an irreversible loss of soil fertility and eventually jeopardize the production in the years to come and leaving the soils unfertile for the posterity. Declining soil fertility also prevents income generation of the rural community and triggers the migration of the rural population into urban centers in search of income and food at the expense of social security. A nutrient audit model described in this study can effectively play a role in assessing the problems and helps developing strategies and practices that can be used to make useful policy interventions.

Phase II: Estimation of realistic fertilizer optima: In any fertilizer optimization research, unknown or surprise nutrient deficiencies other than those nutrients studied are not identified and removed before conducting field experiments. This is the major source of variation that imparts sub-optimal character to the recommendations. In a multi-step systematic approach in the first step, the existence of such nutrient deficiencies is identified in any benchmark soil for which the fertilizer optima is calculated based on nutrient sorption curves. In the second step, by a 'green house nutrient survey' study the existence of these deficiencies is confirmed by quantitative measurements on biomass produced by sorghum seedlings grown under corrected and uncorrected situations. In the third step, optimum nutrient treatments are described based on the results of steps 1 and 2 and the field experiment with the test crop is conducted. Based on the response data, fertilizer optima are calculated and fertilizer calibrations are constructed and in the fourth step, these are validated in multi-location on-farm trials.

Case study: Using the systematic approach, Murugappan and Jagadeeswaran (2003) optimized the fertilizer requirement for rice. Nutrient sorption studies were performed in two soil types viz., Kalathur and Irugur soil series for P, K, S, Zn, Cu, Mn and B. Using these sorption curves and critical levels of nutrients, an Optimum Nutrient Treatment (ONT) was defined for both the soil types (Table 6). These ONT was validated using a green house experiment. The results indicate that the two experimental soils were found to be deficient in N, P, K and Zn. In the third phase, a treatment structure was formulated based on the ONT. In this structure the ONT formed the central treatment. In each case of N, P and K there were three more levels viz., a zero level, one below and one above the ONT. The grain yield data from the field experiment exhibited that there was significant response for all the nutrient studied. Fertilizer optimization was done for the rice response data using Quadratic Polynomial Surface (QPS), Mitscherlich-Bray (M and B) function and fertilizer prescription function for specified yield target (FP). These standardized fertilizer amounts by different approaches were compared with blanket fertilizer recommendation (Table 7). The results revealed that the grain yields obtained were markedly higher than that of the existing blanket recommendation. The N, P and K optima for rice by different approaches were greater than the blanket recommendation. This implies that the existing recommendations were old and evolved probably during late sixties or early seventies with the advent of Green Revolution. Though many of these recommendations for agricultural crops have been updated later by field research, these were not given effect for adoption leaving the older ones to persist which are sub-optimal in the present situation of changed crop varieties planted on depleted soil resource.

Table 6: Optimum Nutrient Treatment (ONT) for the experimental soils

Nutrient	Kalathur series	Irugur series
N	50 mg kg^{-1}	50 mg kg^{-1}
P	12 mg kg^{-1}	10 mg kg^{-1}
K	0.045 mg 100 g^{-1}	0.07 mg 100 g^{-1}
Zn	3.25 mg kg^{-1}	1.75 mg kg^{-1}

Table 7: Fertilizer amounts (kg ha^{-1}) for rice by different approaches in comparison to blanket recommendation

	ADT 36			CO 43		
Approach	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Blanket recommendation	120	38	38	150	50	50
Quadratic polynomial surface (QPS) function for maximum profit	175	54	50	165	63	65
Mitscherlich-Bray (M and B) function for initial soil test values and yield corresponding to maximum profit in QPS function	171	117	47	173	95	79
Fertilizer prescription function for initial soil test values yield and corresponding to maximum profit in QPS function	152	45	41	161	47	36

Since, the nutrient balance studies in Coimbatore and Erode districts of Tamil Nadu proved beyond doubt that the nutrient balance tends to be negative at crop activity, farm and district scales, to ensure balanced fertilization, redefining of the existing fertilizer recommendation is necessary. This systematic approach is a valid procedure for calculating fertilizer optima because unknown nutrient deficiencies are identified and eliminated pre-hand in a systematic way before the conduct of field experiments that are meant for calculating fertilizer optima for a crop and a benchmark soil. Fertilizer calibrations constructed using the data of field experiments in this approach showed high validity. This is a foolproof method that is now available with the researchers who are working in the area of fertilizer optimization. This procedure must form part of soil fertility evaluation research in any country.

Phase III. Construction of a Decision Support System (DSS): The DSSIFER (Decision Support System for Integrated Fertilizer Recommendation) is a agricultural decision-making software, which helps to generate site specific balanced fertilizer recommendations for almost all crops grown in Tamil Nadu. Based on the validated fertilizer optima and fertilizer calibrations from the studies

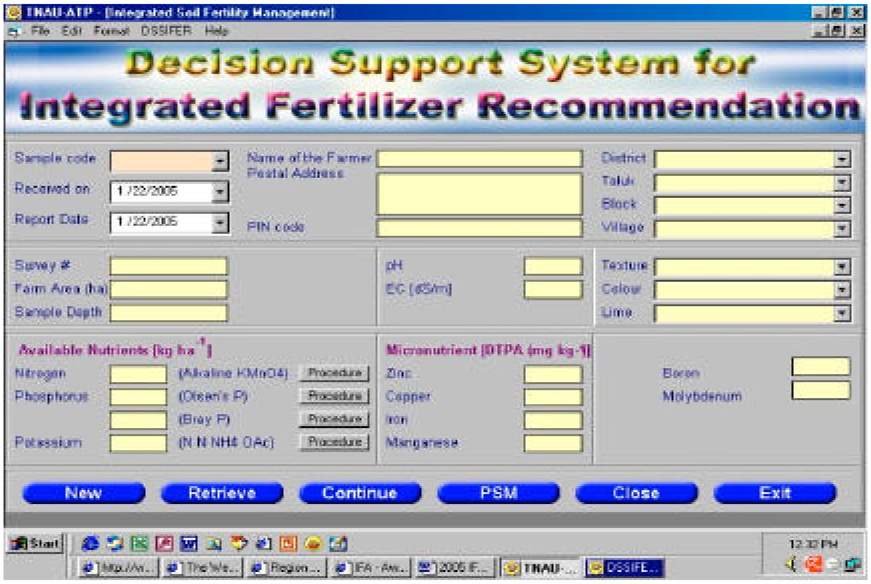

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Fig. 3: Screen capture of DSSIFER

conducted by employing the systematic approach a computerized DSSIFER was constructed as a tool for promoting balanced fertilization (Fig. 3). Besides, fertilizer calibrations available with Tamil Nadu agricultural University and the Department of Agriculture were also included as the basis for calculating fertilizer amounts for crops that are not covered in the studies with systematic approach. DSSIFER is a model product for transfer of technology and it aims to increase fertilizer use efficiency and maintain soil fertility for sustainable crop production. DSSIFER, a user friendly computerized product, is useful in decision making in soil fertility management (Murugappan, 2004).

With soil available macro and micronutrient levels, which are the input data for generating site-specific fertilizer recommendation, this software verifies the availability of soil test calibration for that site specific situation from among the 28 site-specific situations for which fertilizer prescription functions for specific yield target are already stored in the database. If available, the software asks for a yield target and calculates the fertilizer requirements (for each site specific situation a predetermined range of yield target within which the soil test calibration will safely work is also provided in the database). If not available, the software then checks for the site specific situation from among Mitscherlich-Bray functions stored in the database for 24 situations and calculates N, P and K recommendations, respectively, for 87.5, 93.75 and 93.75% yield sufficiency. If the situation for which fertilizer recommendation is to be generated is not available in both the above data base, then the software generates recommendation for this situation from general blanket recommendation as 25% extra if the soil analyzes low or 25% less if the soil analyzes high or the blanket amount itself if the soil analyzes medium nutrient availability status.

The DSSIFER uses critical level of Zn, Cu, Mn, Fe and B as the database to compute micronutrients recommendation for the crops. If the soil analyzes below the critical limit then the software generates recommendation on crop needs of micronutrient fertilizers. In both cases of macro and micronutrient recommendations, besides the fertilizer amounts, the time and method of application is also printed in the output.

Besides calculating the fertilizer requirements, DSSIFER software also generates recommendations on saline alkali soil reclamation using the soil analysis input of pH and EC. Also from the irrigation water analysis it checks its quality and gives out its suitability for irrigation in the output with recommendation for the safe use of poor quality water.

Phase IV: Frequent review and updating of DSSIFER: The presently followed fertilizer recommendations are mostly based on the outcome of research conducted during initial years of Green Revolution and therefore

Table 8: Nutrient balances at farm and district level after adopting DSSIFER generated integrated nutrient management strategy

	Mean farm level nutrient balance			District level nutrient balance		
Nutrient	Coimbatore	Erode	Mean	Coimbatore	Erode	Mean
N	25.9	33.3	29.6	63.9	19.6	41.8
P	13.9	15.4	14.7	71.2	38.9	55.1
K	10.5	10.2	10.4	37.7	2.1	19.9

they are obsolete. Recommendations, which have emanated from most of the recent research, have not been officially promoted. Through an Interactive Workshop to Re-look into Fertilizer Recommendation in Tamil Nadu these valuable research results were documented (Murugappan, 2004). This document Revised Fertilizer Recommendations for Crops in Tamil Nadu was presented in the Annual Scientific Workshop 2004 and with its approval released officially for adoption by farmers.

Assessment of the performance of DSSIFER software: Nutrient balances were computed using the NUTMON-Toolbox by replacing the farmer's practice of fertilization with DSSIFER generated crop and site-specific fertilizer recommendations and the farmer's crop yield with the yield targets fixed in DSSIFER. The results revealed that the nutrient balances were positive at both farm and district levels. The mean N, P and K balances were 29.6, 14.7 and 10.4 kg/ha/year at farm level and 41.8, 55.1 and 19.9 kg/ha/year at district level (Table 8). Thus, fertilizer programme generated by DSSIFER is not only balanced but also ensures sustainability of the agro-production systems.

Phase V: Defining recommendation domains to increase input use efficiency: Agro-ecological zoning within the major agro-climatic zones, which are the presently followed recommendation domains, is an essential component in attempts to increase fertilizer use efficiency. Soil's response to management within an agro-ecological zone is more uniform as compared that of an agro-climatic zone because only climatic parameters are used to earmark boundaries for the latter. Superimposing soil fertility information (as fertility capability classes -FCC), Length of Growing Period (LGP) and moisture index as layers on a digitized map of a region on a GIS platform provides agro-ecological units each of which is uniform with respect to response to fertilizer management. This would also help to increase the use efficiency of fertilizers. This zoning was done for the Western Agro-climatic Zone of Tamil Nadu and linked to DSSIFER to ensure spatial application. Database on Village Level Fertility Indices (VLFIs) that are available with the Tamil Nadu Soil Testing Service was created in DSSIFER and DSSIFER is now so designed that by a click of a village name on the digitized map fertilizer recommendation specific to the village will be generated based on VLFI.

Defining and evaluation of agro-ecological units as a basis for nutrient management and fertilizer recommendations were done in Western zone of Tamil Nadu (Murugappan, 2004). The taluk wise soil maps of the study area were digitized and the district, taluk and village boundaries were superimposed over it in a GIS platform. Irugur (15%) and Palladam (14%) soil series dominated the study area. Based on the surface and subsurface texture, 6 Fertility Capability Classes (FCC) were delineated. The study area was dominated by the FCC class Loam over loam (74%). Utilizing the taluk wise historical weather data, the two districts were classified into 4 Moisture Index (MI) zones in which the major area was under C1 Dry Sub Humid (70%). The study area was found to have four LGP (Length of Growing Period) zones among which two were dominant viz., 60 to 90 days (52%) and 90 to 120 days (40%).

The Agro-ecological sub-zones were derived based on criteria that appear to have direct influence on the interactions of applied inputs and closely related fertility management practices, viz., soil texture, soil moisture balance, rainfall and PET (Potential Evapo-Transpiration). The FCC, MI and LGP maps were superimposed to derive 21 Agro-Ecological sub-zones in the study area. Among them, the first six zones occupy about 80% of the study area. Baring the 5.5% area occupied by forests/hill/habitation, the rest of the 74.5% of area belong to loam over loam FCC unit (Fig. 4).

Environmental benefits of this approach: On-farm nutrient budget reveals the state of art of farm management and helps to evolve environmentally sound policy interventions to mitigate negative trends in nutrient budgets.

Fertilizer optima evolved by Systematic Approach are realistic and of ground water and eutrophication of water bodies by P are eliminated. Besides, soil degradation due to K mining is prevented (sub-optimal fertilization induces K mining).

The DSSIFER based fertilization ensures balanced nutrient use and thereby the risk of soil degradation due to nutrient mining and fertility depletion is prevented. The risk of NO_3^- leaching to ground water, eutrophication of water bodies by P are eliminated and soil degradation due to K mining is prevented.

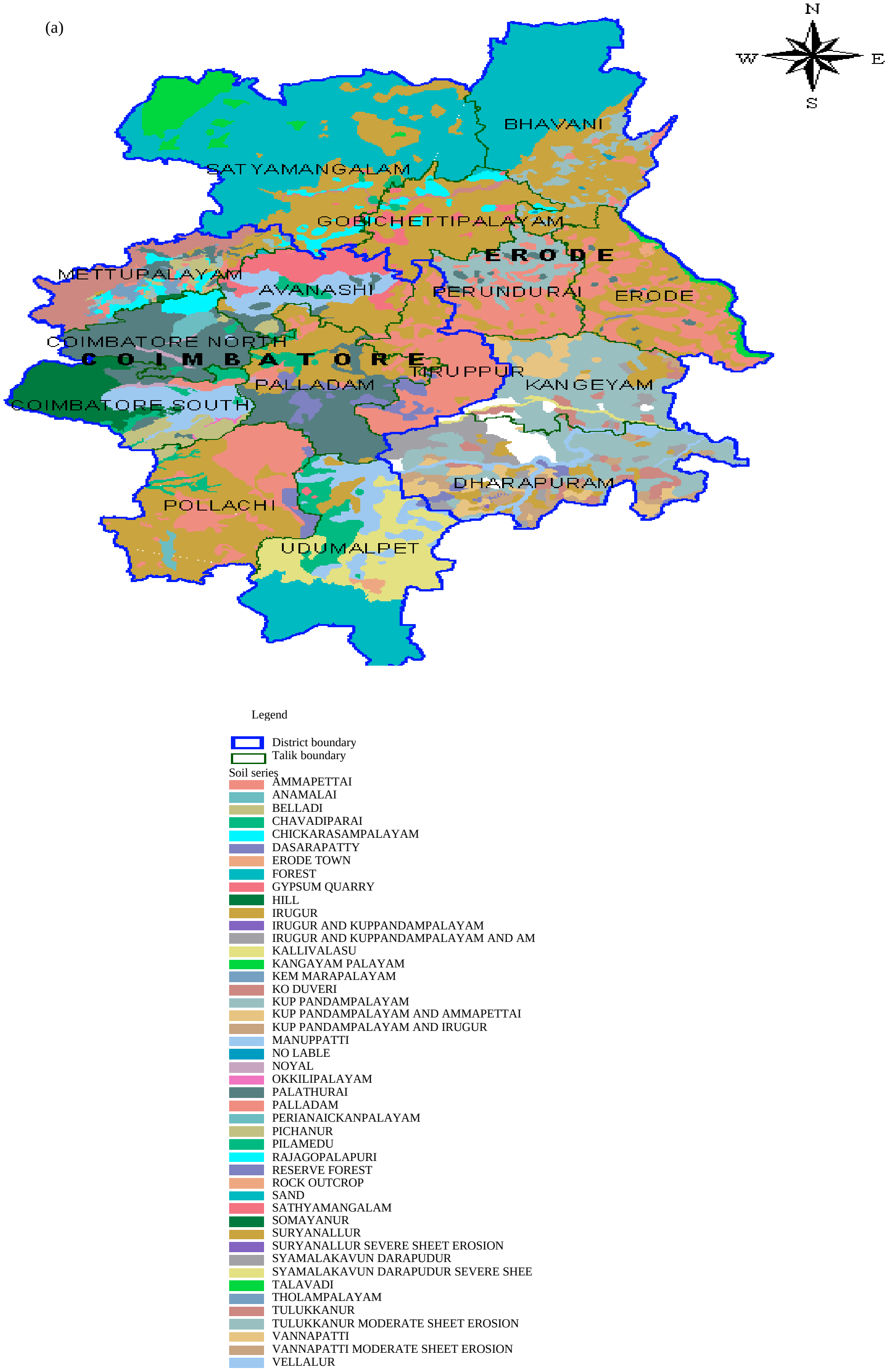
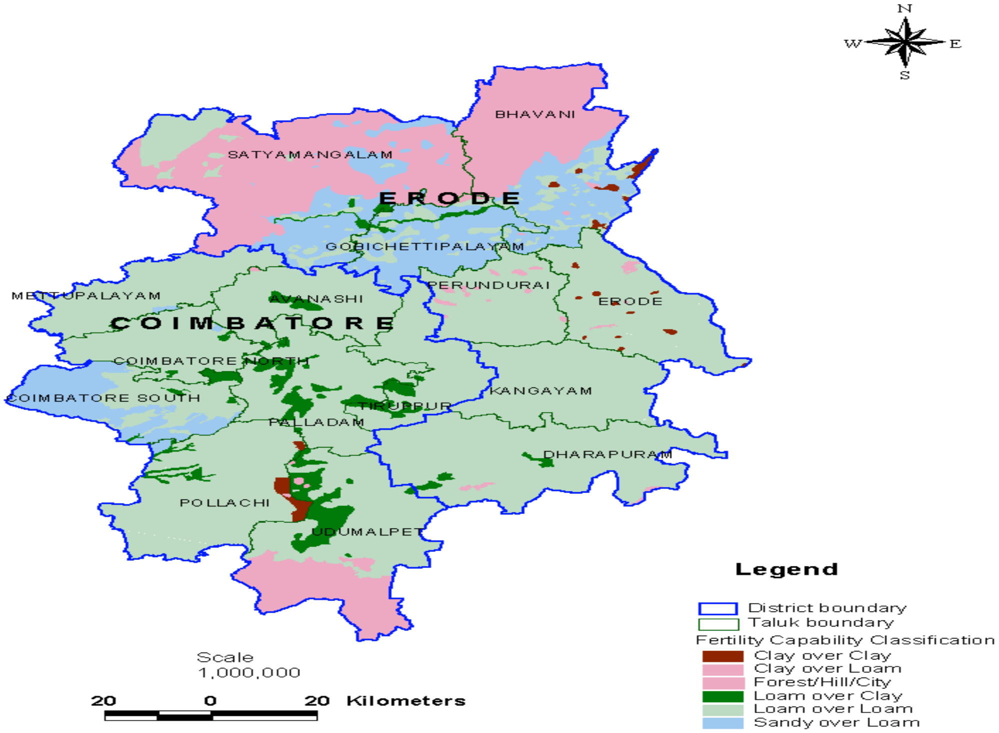
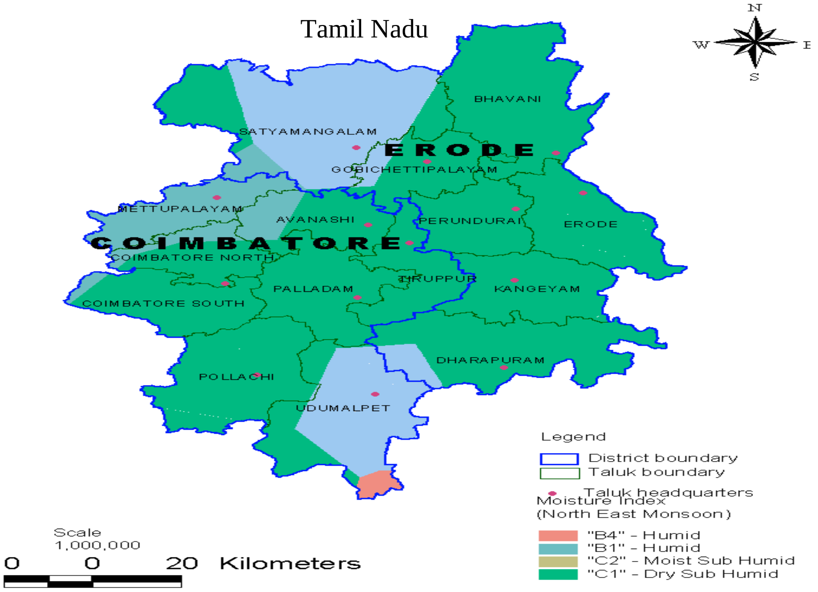


Fig. 4: Continued



(c)

Fig. 4: Continued



(e)

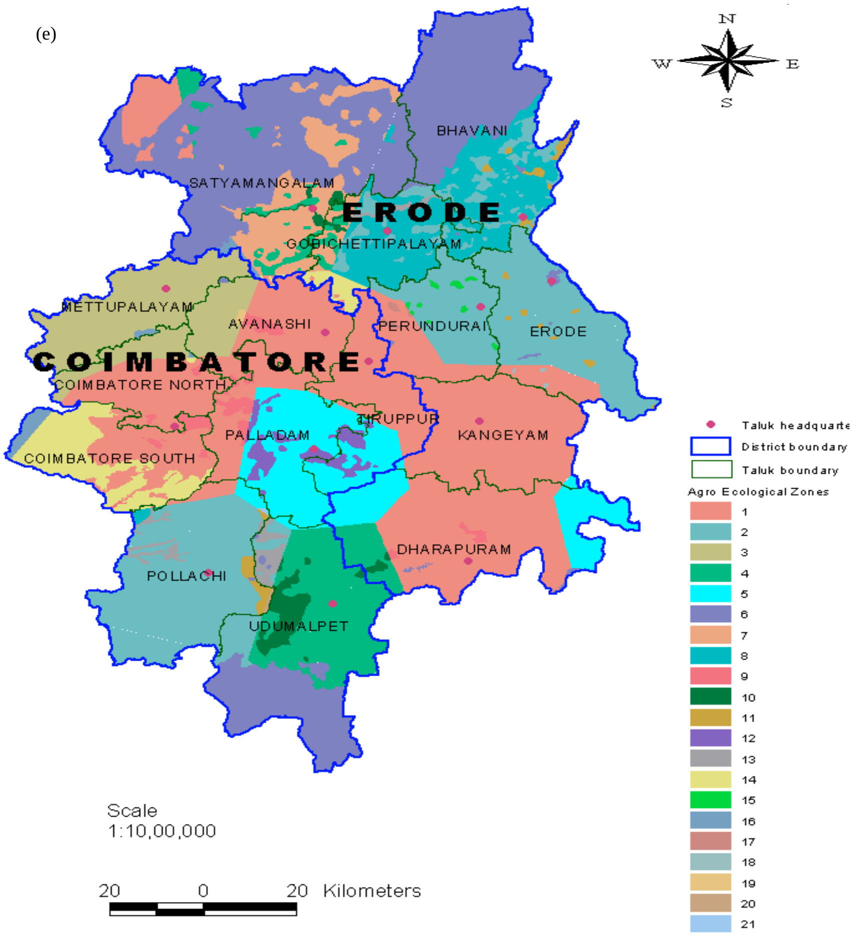


Fig. 4: (a) Soil, (b) FCC, (c) LGP, (d) MI maps and (e) agro ecological zones map of Coimbatore and Erode district

CONCLUSION

Nutrient monitoring allows study of a farm in an integrative, holistic way, capturing a real and complex farm situation, in due consideration of the effects of different activities on the farm, on the nutrient stocks and flows and the economic performance of the farm. Analytical tools, such as the Nutrient Audit models/NUTMON-Toolbox can play a pivotal role in assessing the problem and paves way to develop sustainable nutrient management policies, strategies and practices. However, nutrient balance as such is an incomplete indicator for sustainability and interpretation of a balance is difficult because it is not directly related to soil nutrient stocks. Hence NUTMON-Toolbox coupled with the system's approach for fertilizer optimization, DSSIFER and Agro ecological zoning would serve the purpose of gaining insight into long-term effects of farm management on enhancing soil fertility and productivity.

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