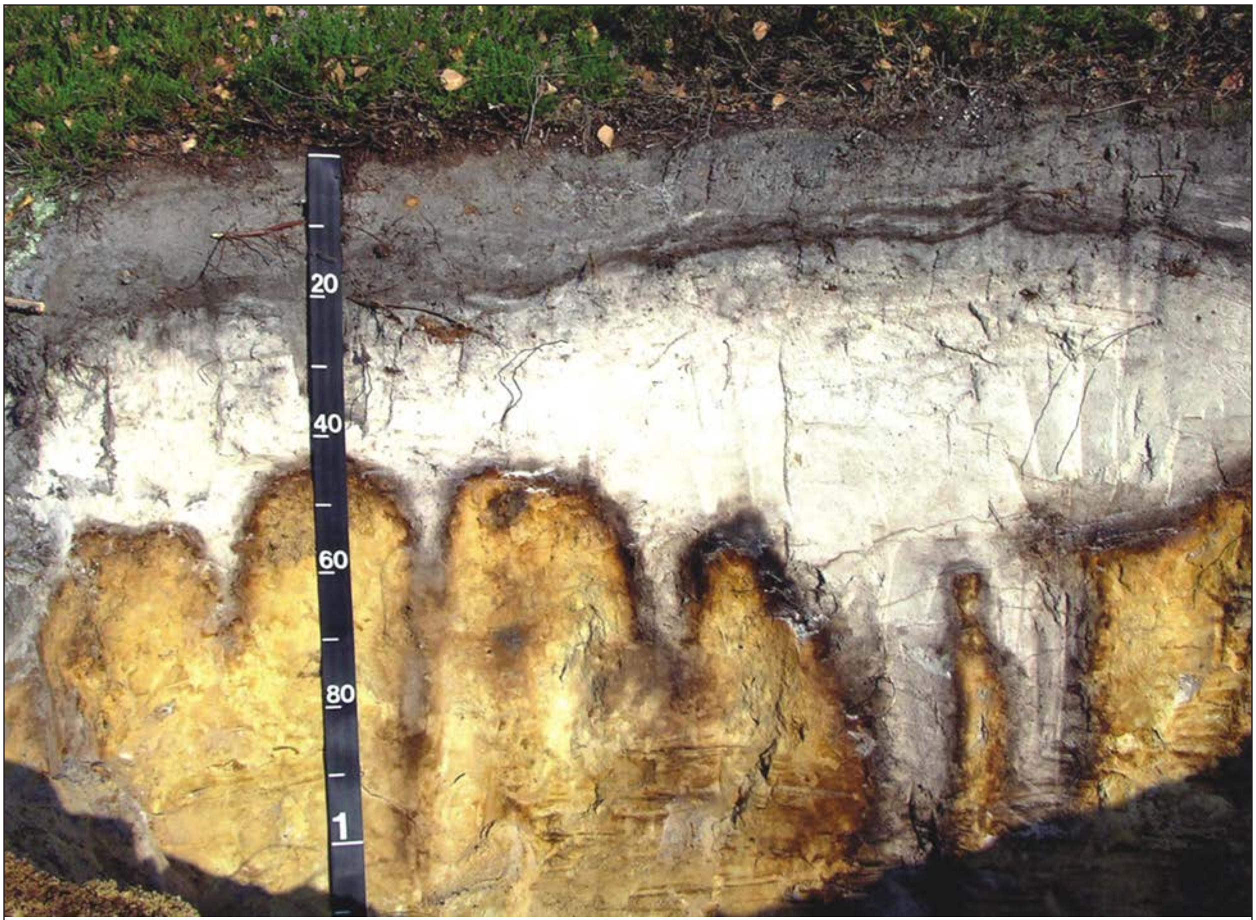

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Nutrient Budgeting in Tropical Agro Ecosystem-Modeling District Scale Soil Nutrient Balance in Western Zone of Tamil Nadu Using Nutmon-Toolbox

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Abstract: This study attempts to apply nutrient monitoring (NUTMON) methodology for carrying out nutrient audits, which includes calculation of nutrient balance at a regional 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. NUTMON is 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, atmospheric deposition and sedimentation and outputs of harvested crop produces, residues, leaching, denitrification and erosion losses. In the present investigation an attempt was made for nutrient budgeting at district scale in a semi-arid region of South India, using NUTMON methodology. Nutrient balance was worked out for Coimbatore district, which is the potential agricultural area in Western Zone of Tamil Nadu, India. The calculated nutrient balances were negative for N (−10.1 kg ha^{-1}) and K (−9.8 kg ha^{-1}) and positive for P (21.9 kg ha^{-1}). Soil nutrient pool has to offset the negative balance of N and K, there will be an expected mining of nutrient from the soil reserve in the study area. The management options to mitigate this mining by manipulating all inputs and outputs in a judicious way with an integrated system approach are also discussed.

Key words: Nutrient balance, inputs, outputs, fertilizers, manures, NUTMON

INTRODUCTION

Agricultural land use is always expected to supply the nation with enough quality food through rational soil management. The increase in food production must have to come from increased productivity, since horizontal expansion of cultivable area is not possible at this juncture of exploding population as that in India. However, at the same time soil nutrient depletion and other forms of degradation threatens the increase in productivity. Previously much research was focused on increasing the agricultural production but a gradual shift was made towards a long-term perspective considering both current and future production as well as the environmental impacts. In natural ecosystem, loss of nutrients (OUTPUTS) is generally compensated by nutrient gains (INPUTS). But as soon as land management and cropping pattern is changed by green revolution technologies the steady state of soil fertility can no longer be maintained.

Dwindling soil fertility has become an increasing and utmost urgent problem that has to be looked in right perspective in tropical agriculture. Soil fertility decline generally does not get the same public attention as droughts; pest infestation etc, since it is a gradual process and not associated with

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catastrophes and mass starvation it is largely invisible. The preservation and maintenance of fertility necessitate the investigation of nutrient element regime of the soil, which represent the life media for microbial activities as well as crop.

An interest on resource balances in agricultural science dates back to the early experiments of Boussingault, who in 1830s, set out to draw up balance sheets to show how far manure and other sources of nutrient supply (air, rain and soil) had satisfied the crop. Suggestions to use nutrient balances in nutrient management dates back more than 150 years, but have only become accepted in farmers practice in the last decades (Van Noordwijk, 1999). The first national level nutrient balance was carried out by Johnston and Cameroon for the UK in 1877 and is reflected by Powlson (1997), which showed a negative nutrient balance in UK. Stoorvogel and Smaling (1990) calculated the nutrient balance for 35 Sub-Saharan African countries and reported the seriousness of nutrient depletion on future food production. However, it has only been in the last decade, as concerns for soil fertility decline have increased and the limitations of standard chemical fertilizers have been recognized, thus the nutrient budgeting and balance analyses have come to the fore (De jager *et al*., 2001; Cuttle, 2002; Watson *et al*., 2002; Sheldrick *et al*., 2003).

Changes in soil fertility level should be monitored to provide early caveat on adverse trends and to identify the problem areas. Scientists in the recent past have reported that there is mining of N, P and K from soil reserves in almost all the agro-climatic zones across India without taking into account of the soil processes such as leaching, denitrification losses (Yadav *et al*., 2001; Swarup *et al*., 2001; Pal *et al*., 2001; Kumar *et al*., 2001). Smaling *et al*. (1993) have calculated nutrient balance at district scale for the Kisii district of Sub-Saharan Africa and reported an aggregated nutrient balance of −112 kg N, −3 kg P and −70 kg K ha^{-1} $year^{-1}$. This necessitates a regular monitoring of changes in soil fertility that occurs in the soil. For understanding the role of different process a budgetary approach offers good tool through analyzing the turnover of nutrients in the soil-plant system at different spatial scales. Keeping these facts in view, the present study was carried out to calculate nutrient budget of Coimbatore district of Tamil Nadu state of India, by using the decision support model NUTMON-Toolbox (Vlaming *et al*., 2001).

MATERIALS AND METHODS

Description of the Study Area-Site Characteristics

The study area Is the potential agricultural belt in the Western Agro-climatic Zone of Tamil Nadu in the southern part of India (Table 1). The data was collected during the period of 2002 to 2005. Usually dry climate prevails in most part of the district except western part, which has a semidry climate. The soils of this districts mostly belong to Alfisols and Vertisols and found best suited for crops *Oryza sativa* (rice), *Sorghum vulgare* (sorghum), *Zea mays* (maize), *Curcuma longa* (turmeric), *Saccharum officinarum* (sugarcane), *Musa* sp. (banana), *Arachis hypogaea* (groundnut), *Gossypium hirsutum* (cotton) and pulses. Somayanur, Pichanur, Peelamedu, Irugur, Palathurai, Periyanaickenpalayam, Noyyal, Chavadiparai, Dasarapatti, Palladam and Anaimalai series covers a major part of the soil series in the study area (Soil Atlas, 1998). The ground water level fluctuates annually between 3 to 15 m in wet areas and 15 to 35 m in dry areas. The main source of irrigation in the study area is by canals, tanks and wells. The major rivers flowing across the study area are Cauvery, Bhavani, Noyyal, Aliyar, Uppar, Palar and Nallar. Cropping pattern varies widely with the varieties of soils and facilities of irrigation. *Gossypium hirsutum* (cotton), pulses and millets are grown under rainfed condition in the black soils while in red soils, *Arachis hypogaea*, (groundnut) vegetables, pulses and millets are the main crops under irrigated conditions. *Oryza sativa* (rice), *Saccharum officinarum* (sugarcane), *Curcuma longa* (turmeric) and *Musa* sp.(banana) are grown where there is facilities for copious/assured irrigation.

Table 1: Characteristics of the study area

Site characteristics	
District	Coimbatore
Latitude/Longitude	10° 10'' and 11° 30'' N and between 76° 40'' and 77° 30'' E
Elevation (above mean sea level) (m)	427
Mean annual rainfall (mm)	600-700
Major soils	Alfisols, Vertisols

Source: Season and Crop reports, 2002

Soil characteristics	
Dominant soil series	Somayanur, Irugur, Palathurai
Texture	Clay to sandy clay loam
pH	6.8 to 8.3
Organic carbon (g kg^{-1})	4.6 to 6.1
Total N (g kg^{-1})	0.61 to 0.87
Total P (g kg^{-1})	0. 28 to 0.56
Total K (g kg^{-1})	2.6 to 3.8

A Brief Description of the Structure of Nutmon-Toolbox

NUTMON-Toolbox is a user friendly computerized software for monitoring nutrient flows and stock especially in tropical soils (Vlaming *et al*., 2001). This product consist of a structured questionnaire, a database and two simple static models (NUTCAL for calculation of nutrient flows and ECCAL for calculation of economic parameters). Finally, 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.

$$\text{Net soil nutrient balance} = \Sigma\ (\text{Nutrient INPUTS}) - \Sigma\ (\text{Nutrient OUTPUTS}) \qquad (1)$$

A detailed description of NUTMON-Toolbox is provided in Smaling *et al*., (1993), Van den Bosch *et al*. (1998 a and b), Vlaming *et al*.(2001) and Surendran and Murugappan (2006).

Calculating Inputs and Outputs

Modules

NUTMON-Toolbox module 1 was used to calculate the nutrient flows between the units and nutrient balances. This module includes 5 Inflows and 5 Outflows (Table 2). To determine nutrient input and output values a stepwise approach has been proposed in which the different determinants of IN 1-5 and OUT 1-5 are calculated, estimated or assumed (Smaling and Fresco, 1993).

Nutrient flows are quantified in three different ways *viz*., by using primary data, estimates and assumptions. Flows directly related to farm management were quantified by from the primary data. Flows quantified in this way are the use of chemical fertilizer (IN 1), organic inputs (IN 2), farm products (OUT 1) and other organic products (OUT 2), redistribution of household waste, crop residues and farmyard manure (FYM). The resulting data fall in the category of primary data. These flows are quantified using the following equation.

$$\text{Flows} = \Sigma_x \text{ wd Prod}_{x\,t} * \text{fr Prod}_x \qquad (2)$$

where,

$\text{wd Prod}_{x\,t}$ = Amount of product×in month t kg

frProd_x = Nutrient content in product×kg kg^{-1}

Table 2: NUTMON structural module

Input		Output	
IN 1	Mineral fertilizers	OUT 1	Harvested product
IN 2	Manure	OUT 2	Crop residues
IN 3	Atmospheric deposition	OUT 3	Leaching
IN 4	Biological N fixation	OUT 4	Gaseous losses
IN 5	Sedimentation	OUT 5	Erosion

Information on nutrient use applied through chemical fertilizers (IN 1) per tones of NPK was obtained from the FAI database (FAI, 2002). Manure production (IN 2) in each district was calculated by multiplying the per capita manure with livestock population (Murugappan, 2000). The quantity of manure produced by individual animal was calculated based on average body weight and by using the equation developed by Merck Vet. manual (1998). Removal of harvested produce (OUT 1) entails loss of nutrients and the quantity being determined by the average yield of the particular crop and its nutrient content. The average yield for all the crops cultivated in this district has been taken from the Season and Crop Reports (2001) published by the Government of Tamil Nadu and by using the average nutrient content of each crop (Tandon, 1997) OUT 1 (nutrients exported out of the farm in crop produces) was calculated. Nutrient export in crop residues (OUT 2) was calculated in a similar way by assuming that only 20% of the generated residue is being returned directly into field as a source of nutrients and the remaining 80% is being fed to the animals or burned as fuel (Tandon, 1992).

Transfer Function or Models Used

Atmospheric deposition (IN 3), biological N fixation (BNF, IN 4), leaching (OUT 3) and gaseous losses (OUT 4) were quantified fully on the basis of off-site knowledge using transfer functions and the resulting data are estimates. Due to lack of point data on wet and dry deposition (IN 3) at district level, the inbuilt transfer functions in NUTMON-Toolbox were used to calculate IN 3 as done by Smaling *et al*. (1993) where nutrient input was considered as a function of square root of average rainfall in mm $year^{-1}$. Inflow through atmospheric deposition (IN 3) in month t kg is calculated using the in-built regression equation of NUTMON-Toolbox, which is given in Eq. 2.

Nutrient from Atmospheric Deposition

$$(Area/10000)* (SQRT(PrecAnnual)) *(PrecMonth_t * Annual)* Reg.Coef \quad (3)$$

where,

Area = Area hectares
PrecAnnual = Precipitation mm $year^{-1}$
$PrecMonth_t$ = Precipitation mm $month^{-1}$
Reg. Coef = Regression coefficient for N, P and K

Non-symbiotic N fixation (IN 4b) is calculated using a function relating N fixation with mean annual precipitation. A small rainfall dependent contribution from non- symbiotic fixers was accounted as per the procedure of Stoorvogel and Smaling (1998). N input through Biological fixation (IN 4) is given as

$$= IN\ 4Non\text{-}Symb\ t\ p + IN\ 4Symb\ t\ p \quad (4)$$

Non-symbiotic N-fixation by crops in PPU p in month t kg is given in Eq. 4.

$$IN\ 4Non\text{-}Symb\ t\ p = (Area/10000)* (1/12) *2 + (PrecAnnual- 1350)*0.005) \quad (5)$$

The relative contribution of symbiotic and associative N fixation to that of free living organisms to the global total was taken as 70: 30 as assessed by Paul (1988). The amount of N fixed (IN 4) was calculated in the present study based on this assessment.

N contribution from groundwater (IN 5) is considered negligible in tropical conditions (Carolien Kroeze *et al*., 2003) and therefore, only P and K inputs from sedimentation was accounted in IN 5 based on the results of Abedin *et al.* (1991) and Handa (1998) who, respectively, calculated 1.5 kg P year^{-1} and 10 kg K year^{-1} as inputs from sediments.

Leaching of N and K (OUT 3) is assumed to be uniform for all soil-bound subsystems, whereas leaching of P is assumed to be zero. The percentages of leaching for both nutrients are calculated as a function of the clay percentage of the soil and the mean annual precipitation using transfer functions based on in built model (Smaling, 1993; Smaling *et al*., 1993).

For N

$$(\text{Mineralised } N_p/12) + \text{IN 1 MinFert } N_{p\,t} + \text{IN 1 MinOrg } N_{p\,t})*(2.1*10^{-2}*\text{PrecAnnual}-3.9) \quad (6)$$

For K

$$\text{frLeachK}_p *((\text{ExchK}_p * 1/12) + \text{IN 1 MinFert } K_{p\,t} + \text{IN 1 MinOrg } K_{p\,t}) \quad (7)$$

where,

IN 1 $\text{MinFert}_{p\,t}$	Inflow from fertilizers on PPU in month t
IN 1 $\text{MinOrg}_{p\,t}$	Inflow from organic manures on PPU in month t
FrLeach_p	Fraction of potassium leached from PPU p
ExchK_p	Exchangeable K in soil PPU p

The mineralization rate to calculate OUT 3 with respect to soil N was assessed in a column study. In this representative surface soil samples were collected from the study area and packed in the column of PVC pipes having a diameter of 10 cm and height of 45 cm. The soils in the column were maintained at field capacity level. Prior to incubation the soil was washed with distilled water and the moisture content was maintained at field capacity throughout the experimentation. The soil samples were extracted for NH_4 and NO_3–N using 2 M KCl as per the procedure of Bremner and Keeney (1985). The leachate was collected everyday and analyzed for NH_4 and NO_3–N immediately, until a static condition reached. Based on the released quantity of NH_4 and NO_3–N, the mineralisation rate of nitrogen was calculated. Total soil N was derived from collecting representative samples covering entire district and analyzed for its total N content. N mineralized (N_{min}) in 0-20 cm soil layer is calculated using Eq. 9.

$$N_{min} = 20 \times N_{tot} \times M \quad (8)$$

The percentage of gaseous loss (OUT 4) of N is assumed to be the same for each primary production compartment and is calculated as a function of the clay percentage of the soil and the mean annual precipitation using a transfer function (Smaling *et al*., 1993). Gaseous losses (OUT 4) are calculated by multiplying the loss percentage by fertilizer N, mineralized soil N and given in Eq. 10.

$$(\text{Soil N} + \text{Fertilizer N}) *-9.4+ 0.13 * \text{frclay}_p * 100 + 0.01 * \text{PrecAnnual} \quad (9)$$

Erosion (OUT 5) can occur in any of the primary production compartments. Soil loss (kg ha^{-1} year^{-1}), is estimated using the universal soil loss equation (Wischemeier and Smith, 1965). Soil loss is converted to nutrient loss (kg ha^{-1} $year^{-1}$), using the total N, P and K-content(%), of the soil and an enrichment factor.

$$(\text{Soil loss}_f * 1000 * \text{frSoil}_p * \text{EnrichFact} * \text{SoilFormFact} * (\text{Area}_p/\text{Area}_f) * \text{Cusle}_p \quad (10)$$

where,

Soil loss	Soil loss from FSU
FrSoil	Nutrient content in soil on PPU
EnrichFact	Enrichment factor
$Cusle_p$	USLE crop cover factor for PPU p

It is not easy to derive R factor from commonly collected meteorological data. On the basis of literature data this was set at 0.25% for the study area. The K factor also varies with types of soil and previous studies showed that K value ranged from 0.197 to 0.217 with 0.202 as an average. It has been found as 0.11 for chambal ravines (Pratap *et al*., 1978). But for major Indian soil types the value of K was 0.12 (Biswas and Mukherjee, 1982). Slope (S) and L were determined as per the procedure of Mitchell and Brubenzer (1980). The degree of land cover also varies and it was difficult to quantify in terms for the district. The value of C factor estimated for maize crop ranged from 0.266 to 2.528 based on the growing practices (Agnihotri *et al*., 1987). So from the previous studies an average C factor was estimated for the entire district as 1.4. Land management factor P was derived from Wenner (1981). The estimated average inherent soil fertility was used to translate soil loss data into N, P and K losses and by multiplying by an enrichment factor to arrive at OUT 5. Enrichment occurs because of the fact that the finest soil particles are the first to be dislodged during erosion and eroded soil material tends to contain more nutrients than the soil. In the present study the enrichment factor is set at 1.5 for N, P and K by assuming a ratio of 1: 1.5 for the nutrient content of the original soil to that of the eroded soil.

RESULTS AND DISCUSSION

Quantification of Inputs

The consumption of fertilizer in the study area has registered a spectacular growth i.e., 30 times (0.6 MT to 19 MT) during the last three decades owing to the adoption of green revolution technological packages. (FAI, 2002). The consumption of NPK fertilizers (IN 1) in Coimbatore district was 31,986, 10,793 and 22,715 tones; respectively (FAI, 2002). Animal manure enters the system after collection from livestock units in the farm itself (on-farm manure) or imported from nearby farms (off-farm manure). Available literature indicate that under Indian conditions only 40% of the total manure is used in agriculture and rest being used either as cooking fuel or wasted (Tandon, 1997; Matthew Redding, 1999). Therefore, out of the total potential nutrient generated from manures the quantity that enters into the farm as nutrients (IN 2) is given in Table 3.

Table 3 : Nutrient potential from manure in Western Zone of Tamil Nadu

Livestock units	Population (No.)	Dung/animal $year^{-1}$ (kg)	Nutrient potential (t) N	P	K
Cattle	419161	4453.0	7466	1867	5600
Sheep and goat	308376	277.4	642	171	385
Pig	21640	1058.5	126	115	115
Poultry	2683082	36.5	3917	1469	1998
Total			12151	3622	8098
Manure used as nutrient source (assuming 40% of total manure)			4839	1443	3223

The N, P and K deposition (IN 3) were derived from the inbuilt transfer functions in NUTMON-Toolbox. These values for Coimbatore were 3.39 N, 0.55 P, 2.21 K kg ha^{-1} $year^{-1}$, respectively. Land depositions of NH_3/NH_4 from the atmosphere provide about 10-20 kg N ha^{-1} $year^{-1}$ (Derwent *et al*., 1998). Sapek and Sapek (1993) reported that 17 kg of N and 0.5 kg of P ha^{-1} $year^{-1}$ were deposited in land from atmosphere. Abedin *et al*. (1991) and Handa (1998) have found that the annual inputs of K through atmospheric deposition exceeded 10 kg ha^{-1}. These results are in agreement with the observations made on nutrient deposition in the present study. Since the variations in climate within the study area are not considerable the quantified deposition data was extrapolated at the district level. Non-symbiotic N fixation calculated for Coimbatore was 572 t $year^{-1}$, respectively. Considering that the relative contribution of symbiotic and associative N fixation and non-symbiotic N fixation by free living organisms to the global total to be in the ratio of 70: 30, the amount of N fixed through symbiotic fixation was arrived for Coimbatore district (IN 4) as 1097 t $year^{-1}$.

Quantification of Outputs

Nutrients exported through harvested produce (OUT 1) and residues (OUT 2) in Coimbatore district has been calculated and presented in Table 4 and 5. Total losses of N through leaching (OUT3) for Coimbatore were found to be 8,095 t $year^{-1}$, respectively (28.41 kg N ha^{-1} $year^{-1}$, respectively). This calculated leaching loss of N from the system is similar to the value estimated by Bjornberg *et al*. (1996) (17-72 kg N ha^{-1} $year^{-1}$). As suggested by Dobermann *et al*. (1996) the leaching loss of P was assumed to be negligible, as most of the soils in the study area tend to retain/fix P. In fine textured soils, K leaching generally does not exceed 2 kg ha^{-1} $year^{-1}$(Tisdale *et al*., 1985). However, leaching

Table 4: Nutrient export through harvested produces of Coimbatore district

					Nutrient content (%)			Nutrient removal (t)		
Crop	Scientific name	Area	Productivity (kg ha^{-1})	Production (t ha^{-1})	N	P	K	N	P	K
Paddy	*Oryza sativa*	14.110	3.595	50725	1.12	0.34	0.81	568	173	410
Sorghum	*Sorghum vulgare*	80.284	318.000	25530	1.44	0.38	0.39	367	97	100
Maize	*Zea mays*	17.272	1.125	19431	1.62	0.41	0.47	315	80	91
Cumbu	*Pennisetum purpureum*	404.00	2.014	813	1.89	0.46	0.58	15	4	4
Pulses		30.191	450.000	13586	3.36	0.37	2.12	457	50	288
Turmeric	*Curcuma longa*	4.912	4.680	22988	1.12	0.46	1.06	258	106	244
Coconut	*Cocos nucifera*	91.799	1556.016	142841	1.80	0.11	1.20	2571	157	1714
Groundnut	*Arachis hypogaea*	22.485	1.504	33817	3.24	0.46	1.69	1096	156	571
Gingelly	*Sesamum indicum*	943.00	469.000	442	2.81	0.58	1.91	12	3	8
Sunflower	*Helianthus annuus*	78.00	1.263	98	2.56	0.35	4.12	3	0.34	4
Cotton	*Gossypium* sp.	7.852	322.000	2528	1.86	0.77	0.90	47	20	22
Tobacco	*Nicotiana tabacum*	964.000	1.496	1442	5.60	0.53	2.64	81	8	38
Fodder		1.374	2.650	3641	0.00	0.00	0.00	0.00	0.00	0.00
Ragi	*Eleusine corocana*	309.000	845.000	261	1.92	0.31	0.47	5	0.81	1
Castor	*Ricinus communis*	226.000	928.000	209	0.15	0.26	0.54	0.31	0.55	1
Niger	*Guizottia abyssiniaca*	226.000	259.000	58	0.68	0.24	0.46	0.40	0.14	0.27
Banana	*Musa* sp.	7.883	37.086	292349	1.81	0.42	1.30	5291	1228	3800
Tapioca	*Manihot utilissima*	1.767	14.000	24738	0.38	0.322	1.10	94	80	272
Onion	*Allium cepa*	3.941	17.654	69574	3.32	0.54	3.30	2310	376	2296
Brinjal	*Solanum melongena*	861.000	9.153	7881	2.10	0.32	2.90	165	25	228
Tomato	*Lycopersicon esculentum*	5.534	11.126	61571	4.80	0.48	3.10	2955	295	1908
Bhendi	*Hibiscus esculentus*	699.000	10.521	7354	3.30	0.61	2.55	243	45	187
Sugarcane	*Saccharum officinarum*	12.911	45.000	580995	0.42	0.18	0.65	2440	1046	3776
Beetroot	*Beta vulgaris*	479.000	18.000	8622	0.68	0.12	0.84	59	10	72
B.Gourd	*Momordica charantia*	535.000	15.000	8025	1.16	0.21	1.26	93	17	101
Greens		186.000	7.000	1302	1.12	0.26	1.30	15	3	17
Radish	*Raphanus sativus*	116.000	14.000	1624	0.90	0.11	2.60	15	2	42
Grapes	*Vitis vinifera*	379.000	32540.000	12333	0.50	0.42	4.60	8	0.96	22
Mango	*Mangifera indica*	3525.000	6443.000	22712	1.80	0.186	2.20	408	42	500
Total		312.245						19892	4026	16717

Table 5: Nutrient export through crop residues of Coimbatore district

					Nutrient content (%)			Nutrient removal (ton)		
Crop	Scientific name	Area	Productivity (kg ha^{-1})	Production (t ha^{-1})	N	P	K	N	P	K
Paddy	*Oryza sativa*	14.110	5.393	76.08800	0.84	0.13	0.78	639	99	593
Sorghum	*Sorghum vulgare*	80.284	477	38.29500	0.81	0.28	0.39	310	107	149
Maize	*Zea mays*	17.272	1.688	29.14700	0.76	0.13	0.47	222	38	137
Cumbu	*Pennisetum purpureum*	404.000	3.021	1.22000	0.80	0.24	0.58	10	3	7
Pulses		30.191	675	20.37900	2.01	0.21	1.82	410	43	370
Turmeric	*Curcuma longa*	4.912	7.020	34.48200	1.31	0.18	1.02	452	62	352
Coconut	*Cocos nucifera*	91799.000	10.125	9.29.465	0.23	0.04	0.48	2138	371	4461
Groundnut	*Arachis hypogaea*	22.485	2.256	50.72600	1.23	0.12	1.62	624	61	821
Gingelly	*Sesamum indicum*	943.000	704	663.00000	1.50	0.41	2.10	10	2	14
Sunflower	*Helianthus annuus*	78.000	1.895	148.00000	1.81	0.32	4.12	3	0.47	6
Cotton	*Gossypium* sp.	7.852	483	3.79300	1.88	0.90	0.90	71	34	34
Tobacco	*Nicotiana tabacum*	964.000	2.244	2.16300	1.68	0.36	2.72	36	8	58
Fodder		1.374	3.975	5.46200	1.33	0.14	1.38	73	8	75
Ragi	*Eleusine corocana*	309.000	1.268	392.00000	0.83	0.18	0.47	3	0.70	2
Castor	*Ricinus communis*	226.000	1.392	315.00000	0.30	0.60	0.54	1	1.89	1.70
Niger	*Guizottia abyssiniaca*	226.000	389	88.00000	0.48	0.16	0.46	0	0.14	0.40
Banana	*Musa* sp.	7.883	55.629	4.38.523	1.42	0.18	1.05	6227	789	4604
Tapioca	*Manihot utilissima*	1767.000	6.500	11.48600	1.48	0.21	1.12	170	24	128
Onion	*Allium cepa*	3.941	26481	1.04.362	0.88	0.22	1.30	918	229	1356
Brinjal	*Solanum melongena*	861.000	13729.5	11.821.00	4.20	0.46	4.60	496	54	543
Tomato	*Lycopersicon esculentum*	5.534	16689	92.357.00	3.20	0.28	2.80	2955	258	2586
Bhendi	*Hibiscus esculentus*	699.000	15781.5	11.031.00	4.10	0.32	1.80	452	35	198
Sugarcane	*Saccharum officinarum*	12.911	5	64.555.00	0.57	0.16	0.62	368	103	400
Beetroot	*Beta vulgaris*	479.000	9000	4.311.00	0.78	0.12	0.84	34	5	36
B.Gourd	*Momordica charantia*	535.000	7500	4.013.00	1.16	0.21	1.26	46	8	50
Greens		186.000	0	0.00000	1.12	0.26	1.30	0	0.00	0.00
Radish	*Raphanus sativus*	116.000	7500	870.00000	0.90	0.11	2.60	8	0.96	22
Grapes	*Vitis vinifera*	379.000	7500	2.843.00	0.90	0.42	4.60	26	11.94	130
Mango	*Mangifera indica*	3525.000	0					0	0.00	0.00
Total		312.245						16702	2357	17134
Total Removal								13361	1886	13707

of K on acid sandy soils in southern Nigeria accounted to 16 kg ha^{-1} $year^{-1}$ of soil derived K and 10 kg ha^{-1} $year^{-1}$ of surface applied K at an application rate of 60 kg ha^{-1} $year^{-1}$ (Omoti *et al*., 1983). Average K concentrations in soil water extracted by means of ceramic suction cups at 1 m depth were 0.6 mg K L^{-1} corresponding to a K leaching loss of 1.5 kg ha^{-1} $year^{-1}$ (Askegaard *et al*., 2000). The calculated K losses due to leaching in Coimbatore district was 1860 t $year^{-1}$.

N losses (OUT 4) calculated using the built-in multiple regression equation in NUTMON-Toolbox for Coimbatore districts were 693 t $year^{-1}$. The estimated soil losses using the universal soil loss equation for these districts were 355 t ha $^{-1}$ $year^{-1}$. The estimated soil loss clearly matched with the soil loss calculated on red and black soils of the study area by Santhanabosu and Sivanappan (1989) who reported losses to the tune of 0.236 to 585 t ha^{-1} $year^{-1}$.

Quantification of the Nutrient Balance

Quantification of the nutrient balance of Coimbatore district in western zone of Tamil Nadu revealed that the sum of the input factors (IN 1 to 5) minus output factors (OUT 1 to 5) produced a negative balance for N (−3160 t $year^{-1}$) and K (−3073 t $year^{-1}$) and a positive balance for P (+ 6423 t $year^{-1}$). (Table 6). The per hectare N and K balances were also negative (−10.1 N and −9.8 K kg ha^{-1} $year^{-1}$, respectively) whereas P registered a positive balance in cases (+21.9 kg ha^{-1} $year^{-1}$). 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 (Kumaraswamy, 2001). 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

Table 6: Soil nutrient balance of Coimbatore district. Western Zone of Tamil Nadu

In/Out ($t\,year^{-1}$)	IN 1	IN 2	IN 3	IN 4	IN 5	Total	OUT 1	OUT 2	OUT 3	OUT 4	OUT 5	Total	Balance	Balance ($kg\,ha^{-1}year^{-1}$)
N	31986	4839	1058	1097	0	38980	19892	13361	8095	693	98.5	42140	-3160	-10.1
P	10793	1443	171	0	429	12836	4026	1886	0	0	82.1	5984	6842	21.9
K	22715	3223	692	0	2860	29490	16717	13707	1860	0	279.0	32563	-3073	-9.8

contamination of surface and ground water causing accelerated eutrophication and poses risks of toxicity to aquatic life. Similarly, for the negative balance of N and K the reason being the sum of emissions was much higher than the imissions. 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 processes operate in the study area. 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 (Murugappan *et al*., 1999). 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 (Murugappan, 2000). The present study showed 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 resulting in soil fertility decline. 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.

Management Options

The major negative contributor is the outflow through harvested crop produce, which cannot be curtailed since the main aim of the farmers and policy makers is to enhance the productivity to feed the enormous population. Solutions to nutrient depletion and accumulation need to focus on economically feasible and socially acceptable technologies.

There is a wide range of management interventions (nutrient saving technologies *viz*., increasing the use efficiency, preventing/minimizing the losses) to influence soil nutrient balances. These nutrient saving technologies aims at an increased nutrient use efficiency. This can be achieved by synchronizing the requirements of crops and the type, quantity of and timing of fertilizer application (split doses) to the prevailing site-specific soil fertility. The split applications can be made to match the nutrient requirement of the crop with that of the nutrient availability in soil thereby increasing the efficiency of applied fertilizers.

The farmers in the study area have to be trained for efficient recycling of farm wastes, proper manure collection and storage methods so as to achieve a positive balance (Murugappan, 2000). Leaching and volatilization losses also depend on the mode of application and time of application in relation to rainfall etc. So to prevent the losses of nutrients from the system, the farmers should be trained in such a way to know about the whole system of their farm, nutrient inflows and outflows creating awareness about the activities which deplete their soil fertility and also training on efficient management techniques to mitigate them. So, a Participatory Technological Development Program has to be adopted in such areas (PTDP) to train the farmers (Murugappan, 2000). Introduction of green manures and legumes in the system is one of the technological options to replenish the soil nitrogen level without any external inputs.

Similarly to avoid the accumulation of P, farmers can skip the application of phosphatic fertilizers based on the soil test of their farm thereby reducing the input cost. Farmers can go for P maintenance dose to sustain the yield without reduction Therefore this nutrient balance studies as a whole should not be linked to the stocks, but also to, the growth of limitation by a particular nutrient. More precise fertilizer recommendations based on Site-Specific Nutrient Management (SSNM) with reference to local soil and crop conditions has to be evolved which is nothing but the so called precision agriculture usually applied in high tech western agriculture. But at present scenario, balanced fertilization with INM techniques should be adopted to sustain the agro-ecosystem and for this a participatory approach is needed. Finally to conclude one single technology does not solve nutrient related problems and solutions have to be sought in a suite of technologies through Integrated Nutrient Management (INM) /Best Management Practices (BMP).

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