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Modeling Based Fertilizer Prescription Using Nutmon-Toolbox and Dssat for Soils of Semi Arid Tropics in India

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Abstract: Mining of nutrients from soil is a major problem causing soil degradation and threatening long-term food production in developing countries. In this study an attempt was made for carrying out nutrient audits, which includes the calculation of nutrient balance at micro (plot/field) and meso (farm) 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 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. The nutrient budgeting study in an irrigated farm at Coimbatore district revealed that the nutrient management practices are not appropriate and sustainable. Soil nutrient pool has to offset the negative balance of N and K, hence there is an 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 suggested. Besides, N management option utilizing DSSAT for the experimental soil and to the benchmark soil has been carried out as an example.

Key words: Nutrient balance % Inputs % Outputs % Fertilizers % NUTMON % Nutrient mining

INTRODUCTION

Nutrient stocks in soil are dynamic and linked to the systems resource flows and capture. In a natural ecosystem the stock is at “equilibrium” *i.e.,* losses (OUTPUTS) are compensated by nutrient gains (INPUTS) representing a conceptual closed nutrient cycle. Even in subsistence farming systems, with some nutrient inputs by manure and household waste the soil fertility level was stable. But as soon as changes occur in the land management practices and cropping pattern as in the case due to green revolution technological packages, the steady state of fertility can no longer be maintained.

Soil fertility management is a lasting challenge for researchers to achieve sustainable development in agricultural production systems, since harvest of arable crops exhausts soils of their nutrient reserves. In the traditional system of agriculture, soils were regularly supplied with organic manures to make up for nutrients that were mined by the crops. However, nutrient mining occurs in intensive cropping to meet the rising needs of food for the exploding population without adequate attention on appropriate and balanced use of nutrient inputs [1]. In urgency for higher production, no serious attention has been given to long-term soil health. The policy of attaining higher production without giving due emphasis to sustainability and soil health can be clearly visualized from the declining annual compound yield growth rate (CGR) of 1.31 during 2001 from 2.56 during 1991 in Indian agriculture [2]. It is the experience of the researchers that with newer crop varieties these yield barriers could not be broken. The logical conclusion is that the soil resource base is degraded below a critical level and newer crop varieties or hybrids are not able to yield beyond a level, which is primarily determined by the level of native soil fertility.

Nutrient Budgeting-Why?: Decline in soil fertility seldom gets the same public attention as floods and droughts, since it is a gradual process and not associated with catastrophes and mass starvation. The change in soil nutrient stocks over time in a given farm has to be measured in order to quantify the extent of nutrient mining and also to provide an early warning on adverse trends in

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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 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. 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.

Stoorvogel *et al*. [3] and Smaling [4] calculated the nutrient balance for 35 Sub-Saharan African countries and reported the seriousness of nutrient depletion on future food production. Nutrient balances have been monitored by number of authors in European Union and they found that N, P and K budgets are in the range of deficit to surplus [5, 6]. However, it has only been in the last decade, as concerns for soil fertility decline have increased and the limitations of chemical fertilizers have been recognized, the nutrient budgeting and balance analyses have come to the fore front [7-11].

In India, Murugappan *et al*. [1] 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. 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 [12-15]. However, a budgetary approach in which nutrient inflows and outflows in a given farm are understood and compared by employing NUTMON-Toolbox [16] to provide insight into causes and magnitudes of losses of nutrients from the system is lacking in these works. There is a need for such an approach in Indian agriculture where negative annual yield growths are witnessed. This study describes such an approach that will certainly help to target interventions in places where undesirable trends to limit crop yields are witnessed.

MATERIALS AND METHODS

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 [16]. 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 [16]. 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.

$$\text{Net soil nutrient balance} = E\,(\textit{Nutrient INPUTS}) - E\,(\textit{Nutrient OUTPUTS}) \quad (1)$$

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. A detailed description of NUTMON-Toolbox is provided in Smaling *et al*. [17], Van den Bosch *et al*. [18], Vlaming *et al*.[16], De Jager *et al*. [20] and Surendran and Murugappan [21].

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. Complete database for crops that are not included in the Toolbox but are grown in the study area had been generated afresh.

Table 1: CERES - Maize MDS requirements

INPUTS	Daily Weather	Solar radiation
	Site Cultivar Management	Max.& Min. Temperature
		Precipitation
		Latitude and Longitude
		Variety name/genotype
		Planting date
		Population / Row spacing
		Seedling age
		Seeding depth (If needed)

Description of DSSAT and its crop models: Decision Support Systems (DSS) are interactive computer software that help decision makers utilize data and models to solve unstructured problems. DSSAT (Decision Support System for Agro Technology Transfer) was designed through an international collaboration by IBSNAT (International Benchmark Site Network on Agrotechnology Transfer) for users to easily create experiments to simulate on computers outcomes of the complex interaction between various agricultural practices, soil and weather conditions and to suggest appropriate site specific technologies [22]. This integrated system model allows one to predict the behaviour of the system for a given set of conditions. This integrated system model allows one to predict the behavior of the system for a given set of conditions. CERES models were combined into a single module to simulate rice, maize, barley, sorghum and millet. CERES-Maize is a module of DSSAT v3.5 and the modules in DSSAT are described briefly in Jones and Kiniry, 1986. Genotypic coefficients (Genotypic coefficients-Carbohydrate partitioning, fractions of stem reserves at flowering, development rate for vegetative and reproductive phases) may be determined in controlled environments/ field condition. For this a software package referred to as the Genotype coefficient calculator (GENCALC) has been used. This software enables users of the latest IBSNAT versions of CERES-Maize models to estimate genotype coefficients from field data sets. The coefficients of genotype are estimated iteratively by running the CERES-Maize model with approximate coefficients, comparing the model output (e.g., dates of predicted phenological events such as, germination, flowering *etc*.) to actual data and then altering the genotype coefficient until the predicted and measured values match [23]. In this study, genetic coefficients of the cv. COH(M) 4 were derived from the data of field experiment.

The field experiment was conducted in farmers' holding at Nathegoundenpudhoor village, of Coimbatore district with maize cv. COH (M)-4 as test crop. The soil of the experimental site belonged to Somayanur series and according to USDA soil taxonomy it could be classified as fine loamy, mixed isohyperthermic, calcareous, Udic Haplustalf. The experiment was conducted in randomized block design with fifteen treatments and three replications. The treatments consists of four levels of nitrogen *viz*., 0, 135.0, 168.5 and 202.5 kg N haG^{1}, five levels of phosphorus *viz*., 0, 62.5, 78.1, 93.7 and 125.0 kg P_2O_5 haG^{1}, five levels of potassium *viz*., 0,50.0, 62.5, 75.0 and 100.0 kg K_2O haG^{1}, two levels of Zn (0,12.5 kg haG^{1}), two levels of FYM (0,12.5 t haG^{1}) and two levels of biofertilizer (0, 2 kg ha$^{-1)}$) and a control.

The 25 per cent of the recommended levels of N as urea and full dose of P, K and Zn as single super phosphate, muriate of potash and $ZnSO_4$, respectively along with FYM and *Azospirillum* (2 kg haG^{1}) were applied as basal at the time of sowing. The remaining N was split and top dressed as 50 per cent on 25 DAS and 25 per cent on 40 DAS.

Data for model calibration: The minimum data set requirements (MDS) are given in Table 1. By following the procedures described in IBSNAT [24] the Minimum Data Set (MDS) required for CERES-Maize model calibration was collected from the field experiment.

For the calibration of CERES-MAIZE model in DSSAT software, soil profile data for Somayanur series, were fed into the 'soil sol' file and thus the soil database for model calibration was created in DSSAT software.

Daily weather data on minimum and maximum temperature, rainfall and solar radiation were collected from Tamil Nadu Agricultural University Meteorological Observatory for the year of experimentation *viz*., 2002-2003 and weather database was created in the weather file in DSSAT software. The experimental input file on crop management 'FILEX' was created in DSSAT. The conditions prevailed in the experimentation, *viz*., soil, weather and management formed the database for calibration of CERES-Maize model with the test genotype [COH(M) 4] in the experiment.

RESULTS

Description of the selected farm: This irrigated farm lies in Nathegoundenpudur village in Thondamuthur block of Coimbatore district of Tamil Nadu. The farm has a cultivable area of 2.8 ha. The soil of the farm is well drained and taxonomically belongs to Somayanur series [25]. The soil of the farm have the characteristics of to sandy clay loam with a pH of 7.2, OC of 4.6 g kg^{-1} and Total N, P and K of 0.91, 0.8 and 4.8 g kg^{-1}. The source of irrigation is mainly wells, situated in the farm itself. Farms are conceptualized as a set of dynamic units, which depending on management, form the source and /or destination of nutrient flows and economic flows. They are Farm Section Unit (FSU), Primary Production Unit (PPU) / crop activities, Secondary Production Unit (SPU) / livestock activities, Redistribution Unit (RU)/ manure heap, House Hold (HH), Stock and Outside (EXT).

This farm comprises of six primary production units within three farm section units. They are sorghum (PPU 1), banana (PPU 2), onion + chillies intercropping (PPU 3), maize (PPU 4), turmeric (PPU 5) and blackgram (PPU 6). Crop activities (PPUs), livestock activities (SPU), manure pit (RUs), household (HH) and irrigation source are depicted in Fig. 1.

On-farm nutrient flow: ways and means: The identified nutrient flows into the selected farms are mineral fertilizer (IN 1) on-farm and off-farm manure (IN 2), atmospheric deposition (IN 3) and biological fixation (IN 4). Nutrients for the farm were mainly through chemical fertilizers and organic manures that are met from external sources besides on-farm generated manures. The farmers besides using on-farm manure also purchases manure off-farm and import 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 / burning. Outflows in the farm 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: The quantified nutrient balance at the crop activity level (PPUs) using NUTMON-Toolbox are presented in Table 2. The full balance was highly positive with onion + chillies intercropping (PPU 3) for N and P (71.2 and 68.2 kg ha^{-1}). The lowest positive N balance of 25.8 kg ha- was observed with sorghum (PPU 1). However, the N balance was negative with banana (PPU 6) and turmeric (PPU 5). Similar to N, the highest negative P balance (-23.2 kg ha^{-1}) was recorded with banana (PPU 2).

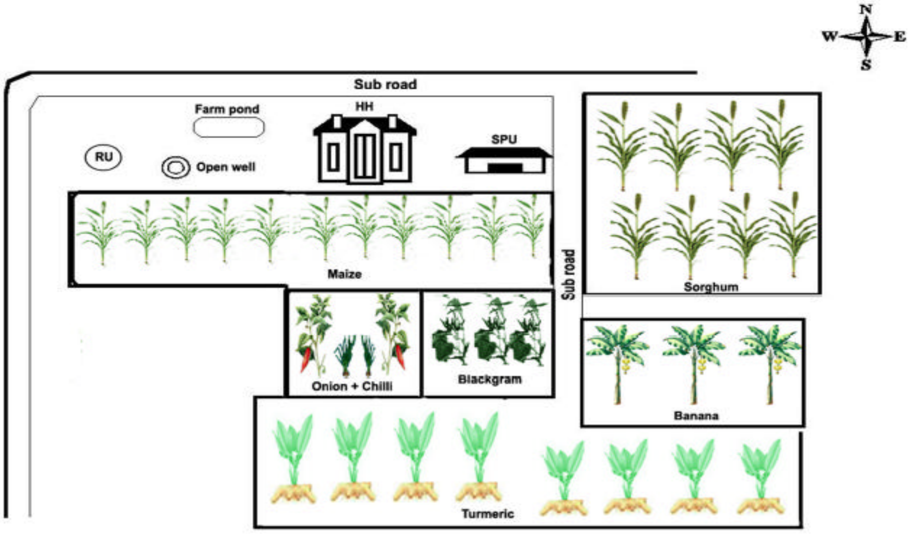

Fig. 1: Farm sketch indicating crop activities in Nathegoundenpudur

Table 2: NUTMON Toolbox generated NPK balance at Crop activity (PPU) levels of the irrigated farm

Crop activity (PPU)	N balance	P balance	K balance
Medium farm - Nathegoundenpudur			
PPU 1 Sorghum (8094 m^2)	25.8	-8.0	-14.9
PPU 2 Banana (4047 m^2)	-46.5	-23.2	-10.4
PPU 3 Onion+Chillies (2023 m^2)	71.2	68.2	-233.3
PPU 4 Maize (6070 m^2)	-14.7	0.5	-2.0
PPU 5 Turmeric (8094 m^2)	-23.2	26.3	-31.5
PPU 6 Blackgram (2023 m^2)	-11.4	15.8	-11.9

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

Flows	Inputs (kg)				Outputs (kg)				Partial balance	Full balance	Partial balance	Full balance
Nutrient	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	256.3	2.6	7.8	2.3	164.8	83.3	30.7	2.0	10.8	-11.8	4.7	-5.1
Phosphorus	83.0	0.5	1.3	0.0	29.3	19.8	0.0	0.0	34.4	35.7	15.0	15.5
Potassium	103.3	1.8	5.2	0.0	123.4	57.3	1.4	0.0	-75.6	-75.7	-32.9	-31.3

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

Among the three nutrients, full K balance was negative and high (–233.3 kg ha^{-1}) in onions + chillies intercropping (PPU 3). All the crops showed signs of negative balance with K. Similar trend of results was also observed with partial NPK balances.

Nutrient balance at farm level: For the farm as a whole the nutrient balance was expressed as the sum of inputs minus the sum of outputs covering all FSUs, SPUs and 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 experimental farm as a whole in Nathegoundenpudur showed that the full balances were positive for P and negative for N and K, while the partial balance was positive for N and P and negative for K (Table 3).

DISCUSSION

Nutrient balance at crop activity (PPU) level: In the case of millets, N, P and K balances were negative due to mismatch between nutrient input and output/export. Economic constraints with these farmers would necessitate adoption of technology at sub-optimal level which leads to less concern with these farmers about sustainability issues like appropriate nutrient management to sustain agricultural production systems [26, 27].

But in the case of black gram, N and K balances were negative and P balance was positive. Black gram usually receives P through foliar nutrition and therefore depletion of soil P reserve by it may not be exhaustive. Negative balances for N and K, suggest for updating the existing fertilizer recommendation since K is omitted in the presently followed state recommendation [28].

Negative balances for all the three nutrients were seen with banana, implying that the amount of fertilizer applied to banana was sub-optimal and other managements like manure addition, recycling of wastes, use of bio-fertilizers *etc*., were insufficient to match the gap between nutrient export out of the farm and input into the farm.

Nutrient balance study results also revealed that adequate attention was given by the farmers in nutrient management in crops where the prices for the produce are remunerative. This was evident from the results obtained with turmeric where N and K balances were marginally negative and P balance was marginally positive. However, even in these cases, the negative trend in nutrient balance has to be arrested by properly fine tuning the fertilizer recommendation or making adjustments with other nutrient inputs like on-farm manuring / vermicomposting / green manuring, crop residue recycling *etc* [29].

Among the crop activities, there was only one inter-cropping component *viz*., onion + chillies in which case the N and P balances were positive and this indicate that inter-cropping systems receive adequate attention on N and P management but not in K management. Adequate attention on K management in such inter-cropping system is essential because both the companion crops remove large quantities of K from the soil. If this trend of negative K balance is left unchecked, the continuing K mining would deplete soil K to a level below the critical level at which yield will be limited.

Nutrient balance at farm level: This negative N balance at farm level was due to the high outflow of N through harvested produces, crop residues, losses from manures, leaching and gaseous losses. Leaching and gaseous losses of N in the irrigated farms were high (10.8 to 46.8 kg) which is in agreement with the findings of Kroeze *et al.* [30]. 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 and growing and insitu incorporation of green manure crop during fallow period to contain leaching losses that occur in considerable amounts in the selected farm and production and application of on-farm organic manures to recycle nutrients in crop produces / residues to improve soil fertility are the possible options to mitigate the negative N balance [31]. 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). Kumaraswamy [32] was of the view that in soils

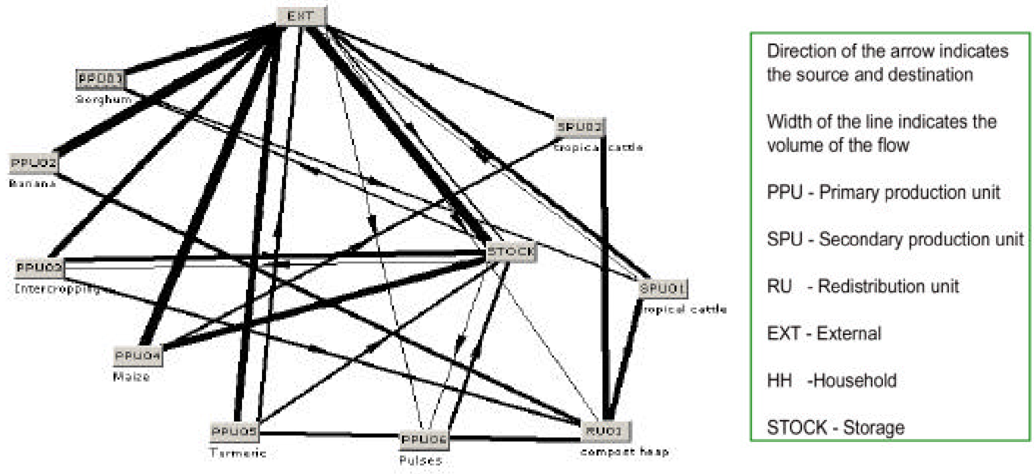

Fig. 2: NUTMON-Toolbox generated nutrient flows between various units of the farm at Nathegoundenpudur

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 [33].

This negative K balances was due to major outflow of nutrients from the farm through removal in harvested produce (OUT 1) and crop residues (OUT 2). K removal in crop produce and crop residues far exceeded the K fertilizer addition. Crop uptake of K is usually as much as N uptake and sometimes, as in the case of tubers, vegetables *etc*., higher than N uptake. But the amount of K replenished through fertilizer K recommendation by the crops is always very low in magnitude as compared to that of N [28]. Besides the soil fertility sustainability issue, the sub-optimal K application to crops reduces the potential profitability from them and the likelihood of recouping farmers' investment on crop production. With total dependency in India on imports for K fertilizer, such concern on economics will permit to stretch K imports to fulfill the crop requirements.

Further, the farmers in the study area do not regularly and effectively recycle the residues from crops like sugarcane, turmeric, coconut *etc*., which contain appreciable amounts of K. This was a major cause for the observed negative balance in farm level K budget [34]. Increasing the rate of K fertilizer addition at an economically optimal level, import of off-farm manure sources (IN 2) into the farm and effective recycling of farm wastes are the possible management options to maintain a positive K balance at farm level.

The nutrient stocks and flows diagram (Fig. 2) for the irrigated farm in Coimbatore district gave a clear picture about the stocks of nutrients in the farm at different sources and the flows that occurred between different units. A careful analysis of the diagram helps to formulate policy interventions for effecting optimal flow of nutrients between different units within the farm. For example, the flow of nutrients from on-farm manure to various crop activities was not uniform. In this farm most flow occurred to turmeric and banana. Nutrient flow to manure heap occurred *via* the secondary production units *viz*., cattle and / or goat. But the nutrient flow to manure heap *via* crop residues was also minimal. Therefore, there is a need to re-look into the nutrient management programme to ensure that recycling of the farm wastes is done with high accuracy to avoid nutrient losses *via* residues that are not used for feeding the cattle or in the manure preparation activity in the farm. Also, burning of residues should also be avoided and thereby these residues can be profitably used in manure making.

Strategy: 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. However, fertilizer being the major input, a strategy was worked out for maize a PPU in the farm under study using the DSSAT.

Model Calibration: The genotypic coefficients are estimated iteratively by running the model with approximate coefficients and by comparing the model outputs to actual data. The coefficients were adjusted until the predicted and observed values closely match. The Minimum Data Set (MDS) recorded from the field

Table 4: Genetic coefficients calculated using GENCALC for maize cv. COH (M)-4

VAR#	VAR-NAME	P1	P2	P5	G2	G3	PHINT
TN0003	COHM4	220.00	2.10	871.00	654.00	7.358	38.90

VAR#	Identification code or number for a specific cultivar
VAR-NAME	Name of cultivar
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8oC) during which the plant is not responsive to changes in photoperiod.
P2	Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours).
P5	Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8oC).
G2	Maximum possible number of kernels per plant
G3	Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day).
PHINT	Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances

Table 5: Comparison of CERES - maize model prediction with measured variables from the field experiment

	N3		N2		N1		Control	
Variable	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured
Flowering date (DAP)	56	57	56	57	56	57	56	57
Physiological maturity (DAP)	102	102	102	102	102	102	102	102
Grain yield (kg ha-1;dry)	6570	6554	6479	6403	6318	6290	2507	2507
Wt. per grain (g; dry)	0.2502	0.25	0.2502	0.24	0.2502	0.23	0.2475	0.22
Grain number (Grain/m2)	2625	2621	2589	2668	2525	2735	974	1140
Grains/ear	416.7	420.0	411.0	427.0	400.7	438.0	154.5	182.0
Maximum LAI (m2/m2)	4.02	4.65	3.97	4.35	3.89	3.88	2.68	3.26
Biomass (kg ha-1) at harvest	15950	16005	15540	15629	14776	15385	7902	5912
Stalk (kg ha-1) at harvest	9380	9451	9061	9226	8459	9095	5395	3405

experiment for the treatment that received N, P and K at 150 % of the state recommendation were used to create the experimental file (MZX file), an average file (MZA file) and time file (MZT file). Using MZX, MZA and MZT files, the Gencalc programme was run and the genetic coefficients required for maize hybrid COH (M) 4 were obtained (Table 4). These calculated genotypic coefficients were used for predicting the growth variables in maize in rest of the N levels. Using the above 3 input files (*viz*., MZA, MZX and MZT) the model was run and the predicted values of phenological, growth and yield variables of hybrid maize

(COH (M) 4) under different N levels were generated. The predicted values with respect to phenological dates, grain yield and weight per grain showed good agreement with the measured values (Table 5).

Optimization of N using validated CERES-maize: Utilizing the calibrated CERES-maize model in the present investigation, an attempt was made to optimize N requirement of COH (M) 4 maize cultivar for the Somayanur soil series in which the field experiment was conducted. This was done by varying the levels of applied fertilizer N from 0 to 300 kg ha^{-1} in the 'input file' of the DSSAT software. By using the calibrated CERES-maize model the yield was predicted for different N levels. These predicted yields were related to the input N levels in a quadratic polynomial surface functions.

A perusal of the R^2 values for these functions revealed that there was a significant relationship exists between maize yield and applied fertilizer nitrogen (0.9987**). Utilizing these function, N optimum corresponding to maximum yield (physical optima) as well as profit (economic optima) was calculated by equating the first order derivative, respectively, to zero as well as to price ratio of N input to grain yield of maize (Table 6). The N optima generated utilizing DSSAT was to the tune of 186 kg N ha^{-1}.

Technology transfer: The calibrated CERES-maize model has been used to optimize the N requirement for maize cultivar COH (M) 4 for dominant benchmark soils (Irugur soil series) of the western zone of Tamil Nadu, a major maize growing tract. It was accomplished by

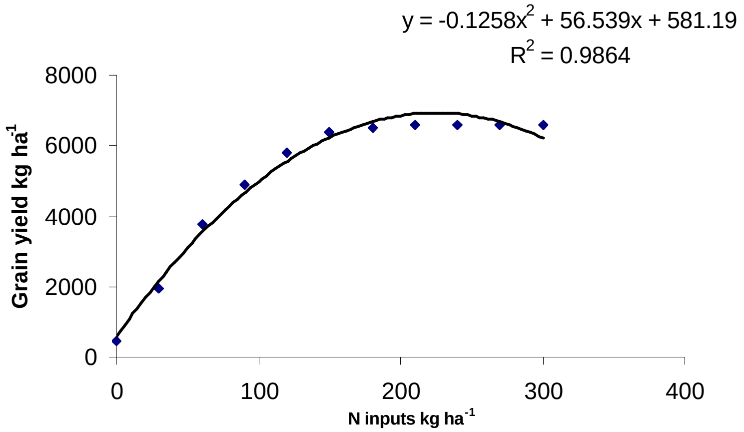

Fig. 3: Response of maize to N in quadratic polynomial surface for Irugur series

Table 6: Response function in quadratic polynomial surface for maize in Somayanur soil series in Western zone of Tamil Nadu

Response function	y = -0.1154x2 + 43.122x + 2511
R2	0.9987
Physical optima for N (kg ha-1)	186
*Economic optima for N (kg ha-1)	180

Table 7: Response function in quadratic polynomial surface for maize in bench mark soils (Irugur soil series) in Western zone of Tamil Nadu

Response function	y = -0.1258x2 + 56.539x + 581.19
R2	0.9864
Physical optima for N (kg ha-1)	225
*Economic optima for N (kg ha-1)	219

*Economics were calculated using a price of per kg of N as Rs.8.67 and one kg of maize as Rs.6.00.

varying the quantum of applied fertilizer N from zero to 300 kg ha^{-1} in the 'input file' of the DSSAT software. By using the calibrated CERES-maize model the yield was predicted for all the N levels. These predicted yields were related to the input N levels in a quadratic polynomial surface functions. Utilizing these function, N optimum corresponding to maximum yield (physical optima) as well as profit (economic optima) was calculated by equating the first order derivative, respectively, to zero as well as to price ratio of N input to grain yield of maize (Fig. 3). The N optima generated utilizing DSSAT revealed that these optima (225 kg N ha^{-1}). were of high magnitude as compared to the existing state recommendation of 135 kg N ha^{-1} (Table 7) and this is in accordance with the points made in discussion.

CONCLUSIONS

Thus in the present investigation, nutrient monitoring with NUTMON-Toolbox at different spatial scales (*viz*., micro (crop activity) 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. NUTMON-Toolbox serves as a tool to identify the depletion of nutrients and to suggest the management options. Besides, N management option utilizing DSSAT for the experimental soil and to the benchmark soil showed that the fertilizer recommendation to the crops is always very low in magnitude and this can be increased to economically optimal level for sustaining the soil health.

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REFERENCES

1. Murugappan, V., P. Santhy, D. Selvi, P. Muthuvel and M. Dhashinsmoorthy, 1999. Land degradation due to potassium mining under high intensive cropping in semi arid tropics. Fert. News, 44(5): 75-77.
2. Yadav, J.S.P., 2002. Agricultural Resource Management in India-The Challenges. J. Agrl. Res. Manage, 1(2): 61-69.
3. Stoorvogel, J.J., E.M.A. Smaling and B.H. Janssen, 1993. Calculating soil nutrient balances at different scales I. Supranational scale, Fert. Res. 35: 227-235.
4. Smaling, E.M.A., 1998 Nutrient Balances as indicators of Productivity and sustainability in Sub-Saharan African agriculture, Agric. Ecosyst. and Environ. **71(1, 2, 3) (Special issue), p283.**
5. Brouwer, F. and P. Hellegers, 1997. N flows at farm level across European union agriculture. In: Romstad, E., Simonson, J.and Vatn, A. (Eds.), Controlling Mineral Emissions in Europe. CAB International, Wallingford.
6. OECD, 2001. OECD National soil surface nitrogen balances-Environmental indicators for Agriculture, Explanatory notes. OECD Secretariat.
7. De Jager, A., D. Onduru, M.S. Van Wijk, J. Vlaming and G.N. Gachimbi, 2001. Assessing sustainability of low external input farm management systems with the nutrient monitoring approach; a case study in Kenya. Agric. Syst, 69: 99-118.
8. Cuttle, S.P., 2002. Nutrient budgets as a tool for researchers and Farmers. In: Powell *et al*. (Eds), U.K Organic Research; Proceedings of the COR conference 26-28th and A bery stwyth. pp: 169-172.
9. Watson, C.A., H. Bengtsson, M. Ebbesvik, A.K Loes, A. Myrbeck, E. Salomon, J. Schroder and E.A. Stockdale, 2002. A review of farm scale nutrient budgets for organic farms as a tool for management of soil fertility. Soil Use and Manage, 18: 264-273.
10. Bekunda, M. and G. Manzi, 2003. Use of the partial nutrient budget as an Indicator of nutrient depletion in the highlands of south western Uganda. Nut. Cycl. Agroecosyst. 67(2): 187-195.
11. Sheldrick, W.F., J. Keith syers and J. Lingard, 2003. Soil Nutrient audits for China to estimate nutrient balances and output / Input Relationships. Agric. Ecosyst. and Environ. 94: 341-354.
12. Yadav, R.L., B.S. Dwivedi, V.K. Singh and A.K. Shukla, 2001. Nutrient mining and Apparent balances in different agroclimatic zones of Uttar Pradesh. Fert News, 46(4): 13-18.
13. Swarup, A., K.S. Reddy and A.K. Tripathi, 2001. Nutrient mining in Agroclimatic zones of Madhya Pradesh. Fert. News, 46(4): 33-38.
14. Pal, S.S., B. Gangwar, M.L. Jat and B.S. Mahapatra, 2001. Nutrient mining in Agro climatic zones of Uttranchal. Fert. News, 46(4): 93-102.
15. Kumar, V., R. Anil, S R.P. Narwal and M.S. Kuhad, 2001. Nutrient mining in Agro climatic zones of Haryana. Fert. News, 46(4): 81-92.
16. Vlaming, J., H. Van den Bosch, M.S. Van Wijk, A. De Jager A. Bannink and H. Van Keulen, 2001. Monitoring nutrient flows and economic performance in tropical forming systems (NUTMON). Alterra, Green World Research and Agricultural Economics Research Institute, LEI, The Netherlands.
17. Smaling, E.M.A., J.J. Stoorvogel and P.N. Windmiejer, 1993. Calculating soil nutrient balances in Africa at differnet scales II. District scale. Fert. Res., 35: 237-250.
18. Van den Bosch, H., A. Dejager and J. Vlaming, 1998a. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) II. Tool development. Agric. Ecosyst. Environ., 71: 54-64.
19. Van den Bosch. H., S. Maobe, N. Ogaro, J.G. Gitari and J. Vlaming, 1998b. Monitoring nutrient flows and economic performance in African systems (NUTMON) III. Monitoring nutrient flows and Balances in three districts in Kenya, Agric. Ecosyst. Environ., 71: 65-82.
20. De Jager, A., D. Onduru, and C. Walaga, 2004. Facilitated learning in soil fertility management: assessing potentials of low-external-Input technologies in east African Farming Systems. Agric. Syst, 79: 205-223.
21. Surendran, U. and V. Murugappan, 2006. A micro and meso level modeling study for assessing sustainability in semi arid tropical agro ecosystem using NUTMON-Toolbox. J. Sust. Agri., 29: 151-179.
22. Jones, C.A. and J.R. Kiniry. 1986. CERES-maize: A simulation model of Maize growth and development. Texas AandM University press, college station, Texas.
23. Uehara, G. and G.Y. Tsuji, 1993. The IBSNAT Project. In: Penning de Vries, F.W.T., P. Teng and K. Metesean (Eds.) Systems Approaches for Agricultural development. Kluwer Publishers, Dodrecht.

24. IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer). 1990. Decision Support System for Agrotechnology Transfer v 2.1. (DSSAT 2.1). Dept. of Agronomy and Soil science, University of Hawaii, Honululu, Hawaii, USA.In: Tsuji, G.Y., Hoogenboom, G and Thornton, K.K (Eds.) 1998. Understanding options for agricultural production. Kluwer Academic Publishers, The Netherlands.
25. Soil Atlas, 1998. Soil survey and land use organization, Department of Agriculture, Government of Tamil Nadu, Coimbatore, India.
26. Mutert, E., 1996. Plant nutrient balance in Asia and pacific region; Facts and consequences for agricultural production. APO-FFTC Seminar on Appropriate use of fertilizers. pp 730-112.
27. Ramisch, J., 1999 Is it in the balance? Evaluating soil nutrient budgets for an agro-pastoral village of southern Mali. Managing Africa's Soils No.9. London, IIED Drylands Programme.
28. CPG, 1999. The Crop Production Guide, Published jointly by Tamil Nadu Agricultural University and State Department of Agriculture, Tamil Nadu, India.
29. Jagadeeswaran, R., 2002. Monitoring on farm nutrient management for sustainable soil fertility management. Ph.D thesis submitted to Tamil Nadu Agricultural University, Coimbatore, India.
30. Kroeze, C., R. Aerts, D. Van Breemen, K. Van Dam and Van der Hoek. 2003. Uncertainties in the fate of nitrogen I; An overview of sources of uncertainity illustrated with a Dutch case study. Nut. Cyc. Agroecosyst. 66: 43-69.
31. Vos, J. and P.E.L. Van Der Putten, 2000. Nutrient cycling in a cropping system with potato, spring wheat, sugar beet, oats and nitrogen catch crops. I. Input and off take of nitrogen, phosphorus and potassium. Nut. Cycl.Agroecosyst. 56: 87-97.
32. Kumaraswamy, S., 2001 Organic farming Principles and Practices. Kisanworld 28(3): 15-16. Chennai.
33. Debnath, N.C. and R.K. Basak, 1986. Effect of rock phosphate and basic slag on available P in acid soils in relation to soil characteristics, seasons and moisture regimes. J. Ind. Soc. Soil Sci., 34: 464-470.
34. Murugappan V., 2000 Integrated Nutrient Management-The concept and overview. In:, Kannaiyan, S., Thiyagarajan, T.M., Mathan, K.K., Savithri, P., Selvakumari, G. and Murugappan, V. (Eds) Integrated Nutrient Management. Tamil Nadu Agricultural University and Tamil Nadu Department of Agriculture, Coimbatore, India.