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Article

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Classifying, Monitoring and Improving Soil Nutrient Stocks and Flows in African Agriculture

Nutrient stocks and budgets (positive minus negative flows) are quantifiable indicators of sustainability, and are applied in this paper to classify agro-ecosystems. Earlier work revealed that most agricultural systems in sub-Saharan Africa (SSA) can be labelled nonsustainable due to low nutrient stocks and negative nutrient budgets. To increase production and build sustainable agro-ecosystems in SSA, technologies that rank under "integrated nutrient management" (INM) should be adopted, to save nutrients from being lost, and to add new nutrient supplies to the system. An account is given of the socioeconomic factors at national and farm level, the interplay of which determines the actual adoption rate of INM. Based on an overview of what we do know and what we don't know, an INM research agenda is proposed that is based on the knowledge gaps.

INTRODUCTION

Today's environmental problems of pollution, degradation and depletion of natural resources have enhanced global awareness that the buoyancy of the world's agro-ecosystems is finite. Agenda 21, the legacy of the 1992 UN Conference of Environment and Development in Rio, describes a series of environmental issues to be addressed and avenues to be followed to move closer to "sustainable development" by the year 2000. Chapter 14 specifically deals with sustainable agriculture and rural development. Programme area J deals with "sustainable plant nutrition to increase food production", and singles out sub-Saharan Africa (SSA) as the subcontinent that is losing soil fertility at an alarming rate.

In SSA, where the agricultural sector generates the lion's share of Gross National Product (GNP), it is increasingly difficult to satisfy production and sustainability demands at the same time. Farmers are primarily concerned about the crop and animal production potential for the forthcoming season, because disappointing output has immediate financial and nutritional implications for their families. Longer-term processes that affect sustainability adversely, such as decreasing soil organic matter levels and nutrient reserves, however, are much less visible and may therefore seem less noteworthy to the farmer. Although SSA farmers are usually well aware of detrimental effects of, for example, decreasing fallow rates, they generally fail to invest in long-term soil fertility for reasons such as lack of land property rights, immediate cash needs, risk aversion and labor shortage.

Whereas soil research in SSA used to be focussed on soil fertility *per se*, it has of late clearly been given a spatio-temporal dimension. The vast majority of researchers have concluded that, on a per hectare per year basis (ha^{-1} yr^{-1}), negative nutrient flows or outputs exceed positive nutrient flows or inputs, rendering most agro-ecosystems nonsustainable (1–8). A FAO-initiated assessment of the nitrogen (N), phosphorus (P), and potassium (K) budget (positive flows minus negative flows) for 35 crops in 38 SSA countries gave a net negative budget ha^{-1} $yr^{-1}$of 22 kg N, 2.5 kg P, and 15 kg K in the period 1982–1984 (9, 10). In other words, soil fertility in SSA is at stake! Yields may still be good in places, but the soil nutrient stock is gradually being depleted to levels that can soon no longer sustain a still growing African population. In the Sahel and Sudan Savanna zones of West Africa, it seems we have come close to that point.

Fortunately, nutrient stocks and flows can be manipulated. When done judiciously, we talk of integrated nutrient management (INM). The extent to which a farm household adopts INM determines not just whether high farm output can be realized (production goal), but also whether production can remain high in the long run (sustainability goal). In this text, we first present a static classification of agro-ecosystems on the basis of their nutrient stocks and flows. Next, we list several components of INM-based farming systems that maintain or improve soil fertility. The latter basically pertains to farm management strategies that save nutrients from being lost from the system (e.g. erosion control, restitution of residues, recycling of manure within the farm) or interventions that add nutrients from outside (e.g. fallowing, mineral fertilizer application, biological N fixation). Mixtures also exist (e.g. agroforestry, zero-grazing). The likelihood of INM to be adopted is governed by the socioeconomic conditions at both the macro-level (e.g. market access, enabling environment) and at the micro-level (e.g. price ratios between inputs and outputs, efficient allocation of labor). Hence, it is imperative to know the existing socioeconomic boundaries at each system level and the required conditions to successfully campaign for INM.

Based on the foregoing, a research and development agenda is formulated to further study and promote the adoption of INM systems in SSA. Key to the INM agenda is the development and operationalization of a decision-support system for nutrient monitoring (NUTMON), ingredients of which were published

Table 1. Nutrient flows at different spatial scales (input = +; output = -; neutral = o).

	Country	Farm	Soil solution
1. mineral fertilizers			
a. *highly soluble*	o/+	+	+
b. *less soluble*	o/+	+	o
2. fodder			
a. *concentrates*	o/+	+	o
b. *roughage/grasses*	o	o/+	o
3. animal manure			
a. *dung*	o	o/+	o
b. *urine*	o	o	+
4. deposition			
a. *precipitation*	o/+	+	+
b. *dust*	o/+	+	o
5. biological N fixation			
a. *nonsymbiotic*	+	+	o
b. *symbiotic*	+	+	o
6. sedimentation	o/+	+	o
7. economic product			
a. *plant*	–/o	–	o
b. *animal*	–/o	–	o
8. crop residue removal			
a. *burning*	–	–	o
b. *fed to livestock*	o	o	o
c. *sold as mats/baskets*	o	–	o
9. water erosion	–/o	–	o
10. leaching	–	–	–
11. gaseous losses	–	–	–
12. nutrient uptake	o	o	–
13. desorption	o	o	+
14. sorption	o	o	–
15. mineralization	o	o	+
16. immobilization	o	o	–
17. weathering	o	o	+
18. chemical fixation and precipitation	o	o	–

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earlier (11). To turn NUTMON into an operational tool for all stakeholders in the field of land-use planning and sustainable agriculture, the INM agenda needs to be implemented at full force in different agro-ecological zones in SSA.

SPATIAL AND TEMPORAL AGRO-ECOSYSTEM BOUNDARIES

Nutrient flows occur at every spatial agro-ecosystem level. Examples are the mineralization of organic N and subsequent uptake by a plant root, application of animal manure from the farm stable to coffee stands, milk sold by a farmer to the factory, and national food imports. Three different spatial scales (country, farm, soil solution) are presented in Table 1. At each level, different processes determine the actual value of the nutrient budget. Concentrates purchased to feed stalled cattle, for example (2a in Table 1), may have been produced overseas, but may just as well have been produced within the country (+/o), whereas at a lower system level, they do enter the farm gate (+). Roughage (2b in Table 1) such as napier grass, is grown within the country (o), whereas it can be grown on the farm or purchased from a neighbor (o/+). Water erosion at farm level is a negative nutrient flow (–). The eroded material may end up in the ocean and be lost for good, but it may also become an input through sedimentation on floodplain farms in the lower reaches of the river basin (+). Table 1 shows that processes 12 to 18 are neutral at country and farm level (o), but all play a role at the soil solution level. The nutrient budget at this level is a reflection of the actual availability of nutrients to plants.

The nutrient budget concept also relates to different temporal scales. Agro-ecosystems that comprise long-fallows, for example, need not be balanced annually. A negative budget, in one or a few years, is acceptable as long as the following years are used for restoring soil fertility. When considering ecological and geological time scales, however, equilibrium situations as to nutrient budgets hardly exist as climate change, volcanism, and biodiversity development all have their more or less gradual impact on agro-ecosystems (12).

CLASSIFYING AGRO-ECOSYSTEMS ON THE BASIS OF NUTRIENT BUDGETS

At each agro-ecosystem level (country, catchment area, farm, plot, soil solution), a nutrient budget can be drawn up, with a sum of inputs that may exceed, equal or be lower than the sum of outputs. Table 2 lists the nutrient inputs, outputs and internal flows that can play a role at farm level, more or less summarizing the central column of Table 1. The following nutrient budget classification is meant to cover all possible nutrient surplus, equilibrium, and deficit situations.

Class I: Σ in - Σ out > 0

Net accumulation of nutrients is found in countries where mineral fertilizers (IN 1) and imported feedstuffs (IN 2a, 2b) are commonly used, and where atmospheric deposition (IN 3) is high due to air pollution. Table 3 shows how nutrient inputs grossly exceed nutrient outputs for agro-ecosystems in former West Germany (13). In SSA, positive nutrient budgets are largely restricted to within-farm movement of nutrients, such as the concentration of manure and household waste in home gardens and other fields close to the homestead (IN 2e, FL 2,3,5). Floodplains and irrigated land may receive more nutrients than they lose in the case of high-input rice or vegetable cultivation (IN 1,2,5), and in case they receive sediments from the upper reaches of the river basin (IN 5). In the vicinity of towns and agro-industrial sites, crops may receive substantial amounts of organic waste and compost originating from these nearby sources (IN 2c), which may rank them in Class I as well.

Table 2. Nutrient flows at farm level.

Nutrient inputs	
IN 1	Mineral fertilizers
IN 2	Organic inputs, subdivided into:
IN 2a	concentrates for livestock and fish
IN 2b	other organic feeds for livestock and fish
IN 2c	urban and agro-industrial waste
IN 2d	manure obtained from outside the farm
IN 2e	manure from farm livestock grazing outside the farm during part of the day
IN 2f	food for the farm family obtained from outside the farm
IN 3	Atmospheric deposition in rain and dust
IN 4	Biological nitrogen fixation in leguminous species (including free-living bacteria)
IN 5	Sedimentation as a result of (i) irrigation; (ii) natural flooding; or (iii) partial resedimentation of soil materials eroded from upper slopes
IN 6	Subsoil exploitation by trees and other perennial crops
Nutrient outputs	
OUT 1	Harvested crops, meat, milk, and fish, leaving the farm
OUT 2	Crop residues and manure leaving the farm
OUT 3	Leaching below the root zone
OUT 4	Gaseous losses (including denitrification, ammonia volatilization, and losses as a result of burning)
OUT 5	Runoff and erosion
OUT 6	Human faeces ending up in deep pit latrines
Internal flows	
FL 1	Crop residues fed to tethered farm animals or applied to certain plots
FL 2	Biomass from plots under pasture and fallow eaten by roaming farm animals
FL 3	Animal manure from within the farm applied to certain plots
FL 4	Crops, milk, meat and fish obtained from the farm, eaten by the farm family
FL 5	Food remnants and farmyard manure applied to certain plots

Table 3. Nitrogen budget (kg ha^{-1} yr^{-1}), for former West Germany (1986) and Tanzania (1982-1984).

	West Germany	Tanzania
Inputs		
Mineral fertilizers	126	2
Animal manure	47	1
Wet and dry deposition	30	3
Biological N fixation	12	4
Other	3	0
Total	218	10
Outputs		
Plant and animal production	51	17
Leaching, runoff, erosion	51	15
Gaseous losses	69	5
Total	171	37
Nitrogen budget	+47	–27

Class II: Σ in - Σ out = 0

The long-term equilibrium is typical of more or less "closed" systems, such as tropical rain forests and undisturbed savannas. Slight disturbances do not necessarily disrupt equilibria, as in the case of traditional long fallows. Where land is not scarce, the farmer leaves a plot as soon as its productivity dwindles, and subsequently shifts to a neighboring plot that has been idle during the previous years, gaining free fertility from atmospheric deposition (IN 3) and biological N fixation (IN 4). Any deficit in the nutrient budget of the cultivated plot is offset by gains from processes occurring during fallow periods. The nutrient pool may thus become fully replenished if fallow periods are long enough. Perennial agro-ecosystems dominated by high-input cash crops (IN 1; tea, coffee, oil palm) may be close to equilibrium for some nutrients, provided that management and input levels are high and losses through OUT 2–5 are minimized (e.g. mulching, cover crops, minimum tillage). Controlled grazing of improved pastures, preferably including leguminous species such as *Desmodium* (IN 4), may also lead to a Class II situation. The same holds for extensive grazing, as long as stocking rates are a reflection of the carrying capacity of the particular area.

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Class III: Σ in - Σ out < 0

Systems with negative nutrient budgets are widespread in SSA, ranging from the low-input food crop areas in the Sahel to the East African Highlands. FAO and World Bank statistics show that nearly 50% of the production increases in SSA realized during the past three decades resulted from area expansion, as opposed to 30% in Latin America and a mere 6% in East Asia. Meanwhile, fertilizer use in 1990 was 9 kg ha^{-1}, as opposed to 47 kg ha^{-1} in Latin America, and 190 kg ha^{-1} in East Asia. In Tanzania's arable land (Table 3), nitrogen outputs in crop and animal products alone (17 kg ha^{-1} yr^{-1}) amount up to almost twice the sum of all inputs (10 kg ha^{-1} yr^{-1}). At this stage, some further partitioning is necessary as some areas in SSA are still highly productive, yet they fall in Class III. This subclassification is restricted to the macronutrients N and P.

Class IIIa: plant available N and P > crop requirements

In Class IIIa the effects of nutrient depletion on yields are masked by the buffering effect of the soil's (still adequate) nutrient stocks. In areas that fall in this class, high agricultural production can be maintained for many years. A recently cleared Cambisol on the slopes of Mount Elgon in Western Kenya, for example, had a nitrogen stock of approximately 6000 kg N ha^{-1}. Assuming an annual mineralization rate of 3%, leaves the considerable amount of 180 kg N ha^{-1} available for plant uptake, and for offsetting negative nutrient budgets. Under continuous cultivation, some point in time will be reached, however, when organic matter and mineralized N can no longer buffer the production system, and the agro-ecosystem will be relegated to Class IIIb or IIIc.

Class IIIb: plant available N or P < crop requirements

This situation is reached as soon as the stocks of N and P are imbalanced. The Nitisol in Table 4 has a low P/N ratio. The table shows that the uptake of N and crop yields increased strongly on application of P fertilizer. Evidently, at a low P status only a fraction of the potentially available N is taken up by the crop. Although the N budget is negative, there is no point in adding N to the Nitisol as long as P is in short supply, as it will be lost anyway through one of the processes OUT 2–5 (Table 2). On applying P to this soil, the P/N balance may be restored and uptake of soil N by the crop (OUT 1) and yields may increase considerably, fulfilling a production target. The Vertisol in Table 4 has a high P/N ratio, but the same principle applies. Addition of fertilizer-N to this soil increases both the uptake of soil P and crop yields. Class IIIb is an important class, as soils with nutrient imbalances are widespread. The primary concern in this particular case should be balanced plant nutrition, followed by maintenance of the nutrient balance.

Table 4. Soil properties (0–20 cm layer), maize yield (kg ha^{-1}; 1990 data) and total aboveground nutrient uptake (N, P and K kg ha^{-1}) at different N and P fertilizer rates applied to three Kenyan soils.

	Nitisol	Vertisol	Arenosol
Soil properties			
org. C (g/kg)	27.0	27.3	6.3
N total (g/kg)	2.6	2.0	0.6
P-Olsen (mg/kg)	2.3	9.7	1.5
Exch. K (mmol/kg)	5.5	14.2	2.5
pH (H_2O)	5.2	7.9	7.2
sand (%)	25	25	88
silt (%)	32	10	6
clay (%)	43	65	6
Treatment	*Maize yields*		
N0 P0	2110	4570	2550
N0 P22	4860	4720	2270
N50 P0	2290	6300	2240
N50 P22	5250	7190	3730
	Nitrogen uptake		
N0 P0	42	63	26
N50 P0	50	109	36
N0 P22	79	70	47
N50 P22	79	114	59
	Phosphorus uptake		
N0 P0	5	24	3
N50 P0	6	35	4
N0 P22	12	23	11
N50 P22	11	38	12
	Potassium uptake		
N0 P0	30	95	26
N50 P0	36	126	30
N0 P22	58	106	34
N50 P22	58	133	51

Class IIIc: plant available N and P < crop requirements

As a result of both increasing population pressure and lack of yield increases per unit area, the vast majority of SSA agro-ecosystems falls in this class, which is characterized by negative nutrient budgets and, most importantly, low nutrient stocks. Table 4 shows the low levels of N and P in the Arenosol at the Kenyan Coast, and also demonstrates that substantial maize yield increases are only obtained when both nutrients are applied. Without nutrient inputs, there will be a further decline of the N and P stocks here, reducing both crop production potential as well as the number of options to build sustainable systems. In the vast millet, sorghum and groundnut growing areas of semiarid West Africa, for example, nutrient stocks are low and nutrient budgets are negative for at least N and P, because farmers apply very low amounts of nutrients from external sources (2–4). Prudencio, however, highlighted West-African farmers' survival strategies by making optimal use of farm-level spatial variation (14).

In general, however, due to lack of volcanic rejuvenation, most nonalluvial soils outside the Rift Valley zone are inherently poor and fragile. In the absence of external inputs and nutrient conservation, decreasing fallow rates lead to a further depletion of the already scarce nutrient reserves. At some stage, other soil properties (organic matter content, soil structure, soil biology) will also have deteriorated to the extent that whatever remains is virtually beyond repair.

INTEGRATED NUTRIENT MANAGEMENT: WHAT WE DO KNOW

Technologies

Researchers and farmers already know much about INM technologies. The first option to increase agricultural production is by intensifying production in fertile environments (Classes I, II and IIIa), such as inland valleys (Fr. *bas fonds*), home gardens (Fr. *champs de case*), labor-intensive horticultural areas in urban peripheries, and environments that are highly responsive to one particular input (Class IIIb), such as the P-deficient volcanic soils of the East African Highlands. Theoretically, long-fallows could then be maintained or reinstated in the more fragile environments (Class IIIc). Other options always boil down to INM, i.e. the manipulation of nutrient stocks and flows. A number of INM-based components of farming systems in Kenya and their characteristics are listed below.

Zero-grazing

- though both capital-intensive and labor-intensive, high milk (and meat) production, the socioeconomic importance of possessing livestock, and the possession of land titles together constitute a clear socioeconomic incentive;
- cross-bred dairy cattle are kept in zero-grazing units and fed fodder grasses, grown on the farm, and purchased concentrates; a large percentage of the nutrients involved are recycled as manure;
- if fodder grasses are planted on contour bunds, water erosion can be strongly reduced; similarly, the absence of free range saves nutrients as anti-erosion structures are not damaged, whereas manure does not reach the land in patches.

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Agroforestry

- trees potentially provide building poles, fuelwood, fodder, fruits, shade, etc.; species such as *Calliandra*, *Sesbania*, *Leucaena* (all leguminous species) and *Grevillea* are highly valued by farmers; in other words, the socioeconomic incentive is tangible;
- trees may increase biological N fixation, reduce leaching and water erosion, and add nutrients to the topsoil from layers not accessible to the roots of annual crops;
- interactions between agroforestry system components are still poorly quantified (presently one of the key research areas of the International Centre for Research on Agroforestry).

Soil conservation

- government policies and extension services have to play (and have played) a crucial role, as there is no direct socioeconomic incentive for the farmer;
- farmers collaboratively undertake soil conservation works at catchment level (hand-dug terraces, contour bunds, ploughed strips, grass strips, cover crops and mulching); labor availability is crucial for the success of soil conservation programs (15,16);
- few attempts have been made to turn data on annual soil loss per hectare into nutrient and productivity loss; physical data on land degradation are of little use to decision-makers unless transformed into units comparable with the cost of soil conservation.

Organic inputs

- there is a wide array of materials to be applied/recycled; farmers' perceptions on importance and type of organic inputs differ from place to place;
- synchronization of nutrient release from organic matter inputs with momentary crop nutrient demand is still poorly quantified (presently one of the key research areas of the Tropical Soil Biology and Fertility Programme).

Mineral fertilizers

- applying the right type and amount of mineral fertilizers at the right time, based on knowledge of inherent soil fertility and pH, may considerably raise production per unit area; the economic incentive is obvious, although abolishment of subsidies due to structural adjustment policies has recently reduced interest;
- if combined with nutrient-saving techniques such as manuring and erosion control, mineral fertilizers are used more efficiently.

We consider it important to group the options at hand into those that are merely saving nutrients, such as erosion control, restitution of residues, manuring, and those that are adding new supplies of nutrients to the system, such as fertilizer application, concentrates fed to livestock, sediments in floodwater, and inclusion of N-fixing species. Some options may have characteristics of both (e.g. agroforestry, zero-grazing). As each tract of agricultural land has its own agro-ecological potentials and limitations, the number of INM options to build sustainable agro-ecosystems is highly location-specific. In the East African Class IIIa and IIIb systems with reliable rainfall and deep soils, more options are available to safeguard productivity than in Sahelian Class IIIc systems with erratic rainfall and sandy or shallow soils. At farm household level, however, microclimate and soil fertility of individual plots can be considerably modified by the farmer. Individual households can be strikingly active and innovative, making use of indigenous knowledge to adjust their farming practices to the fast-changing agro-ecological and economic conditions.

The Need for an "Enabling Environment"

Government policy and implemented policy instruments largely determine the socioeconomic environment of rural farm households engaged in the agricultural production and marketing process. Adoption of technologies for implementation of INM practices is largely determined by these socioeconomic factors: short-term profitability of the technology, availability of appropriate credit facilities and inputs, extension services, marketing systems and price fluctuations, social acceptability, etc.

Although IMF-imposed structural adjustment policies currently restrict direct influence on the market (price regulation), other instruments to facilitate adoption of INM practices remain at the disposal of national governments, such as:

- giving priority to INM practices in the research and development agenda of National Agricultural Research Stations and Extension Services;
- providing necessary rural infrastructure to facilitate an efficient marketing process and increase market access;
- supporting and assisting the establishment of appropriate credit facilities;
- establishment of unambiguous land-tenure policies;
- stimulating investments in regional soil conservation projects;
- creating awareness of the long-term effects on soil nutrient mining.

Given the urgency of the situation, particularly on Class IIIc-land in the drier parts of West Africa, government-supported capital investments in nutrient stocks should be considered. In this context, mention should be made of a recent World Bank-initiated economic analysis of the feasibility of (rock) phosphates as a capital investment in SSA (17).

Economics of Technical Solutions

Cost-benefit analyses of technical options for INM require long-term estimations of the costs of lost nutrients and especially the foregone benefits of depleted soils. It is essential to differ between the short-term cost-benefit analysis, which a farm household makes when deciding to adopt a technology, and the long-term sustainability at farm household and at national levels.

For the short-term decision making the traditional cost-benefit analysis can explain most farm household behavior. The marginal costs of mineral fertilizers (IN 1), for example, are compared to the additional output realized in the crop or crop mixture. In general, addition of nutrients through mineral fertilizers considerably raises productivity per unit area. Applying the right type of fertilizer at the right time will induce more nutrients to be taken up by the crop (Table 4). The apparent effectiveness of mineral fertilizers is, however, not reflected in the average application levels. Whereas the availability of fertilizers was often restricted in the 1980s, it is currently the value-cost ratio that is the limiting factor. With the introduction of the structural adjustment policies, value-cost ratios of fertilizer use on maize in most West African countries declined seriously to values below 2, often regarded as a minimum value for adoption at farm household level (18).

The translation of the long-term sustainability effects in economic terms at farm household and at national levels is much more difficult to quantify. Interesting attempts have recently been made to estimate the future loss of production due to degradation (19–22), and to calculate the replacement cost of depleted nutrients (7). Much cited is the work by Stocking, who found that on a ha^{-1} yr^{-1} basis, the financial cost of water erosion (OUT 5) in Zimbabwe varied from USD 20 to USD 50 on arable land, and from USD 10 to USD 80 on grazing land (23). N and P losses from arable land were about three times the level of total fertilizer application in Zimbabwe, not including losses of nutrients dissolved in runoff water. Erosion thus has a massive hidden cost on the economy of Zimbabwe. From a policy viewpoint, there is a need to calculate the negative impact of unchecked

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erosion, i.e. the real on-site and off-site costs of degradation processes and, as a consequence, the potential benefits of conservation investments (21). In the East African Highlands, Kenya is ahead in the field of land adjudication, which is clearly reflected in the active interest in soil conservation (15, 24). Moreover, labor availability proved so crucial for soil conservation programs to succeed that a relatively high population density is even an asset rather than a liability (16).

Although all this knowledge is on the table, little has been turned into (inter)national policies. Contributions from agriculture to the national income are still merely based on the monetary value of commodities, and expressed in average *per capita* domestic product. Meanwhile, at farm household level, the short-term economic calculations will continue to determine (non-) adoption of INM practices. Inclusion of long-term sustainability aspects in assessing government policies and large-scale projects, however, is indispensable to change the socioeconomic environment of the farm household in favor of the much-needed implementation of INM practices.

INTEGRATED NUTRIENT MANAGEMENT: WHAT WE DON'T KNOW YET

Although much is known on INM technologies as such, few attempts have been made to systematically monitor and evaluate their impact on long-term soil productivity. Increased knowledge on the spatio-temporal dynamics of nutrient stocks and INM technologies at plot, farm and even district level or above are needed to institutionalize INM strategies by means of decision-support systems. Such systems not only compare technologies, but also indicate what it takes for a farm household to implement the technology under more or less enabling boundary conditions, or how a provincial administration could assist to overcome certain farm-level constraints. The ingredients for the technology side of such a decision-support system were published earlier as the NUTMON (NUTrient MONitoring) model (11).

The challenge of the INM agenda is to avoid reductionism, turning complex problems into models that provide a simplified simulation of reality. A complex multi-scale and multi-disciplinary topic such as INM is easily partitioned into well-researcheable bits and pieces, but it is more difficult to put the research results back into the subjective "reality" of different land use stakeholders. Next, interaction between different system levels is weakly developed, for example the impact of district and national policies on farm household decision making and vice versa, or the importance of spatial variability of natural resources at different land-use planning levels.

In our view, the INM agenda should in the first place focus on the farm household level, where all relevant decisions concerning nutrient management are taken. Modelling approaches can be used to structure complicated processes at farm level, but in a constant feed-back with real-world situations. Priority must be given to simple models that can be run in low-data environments. Based on the the above considerations, the INM agenda for SSA may take the following shape:

I. collect and monitor biophysical data and processes at plot and farm level to fill knowledge gaps on the nutrient flows mentioned in Table 2;
II. monitor objectives and strategies of farm households as regards relations between farm income, food security and INM;
III. monitor macro-level policies and how they fit the concept of "enabling environment" and their impact on the adoption of INM strategies at farm level;
IV. define and fill knowledge gaps on INM technologies and particularly on powerful combinations of technologies;
V. refine the NUTMON model (11) into a user-friendly decision-support system, accessible and digestible to all stakeholders in an area;
VI. develop scenarios to compare INM systems with "business as usual" systems, also including externalities, in order to sensitize the global community and convince development banks and donors that maintenance and improvement of soil productivity in SSA is everybody's business.

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