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BUDGETING PLANT NUTRIENTS FOR OPTIMUM CROP YIELDS AND SOIL FERTILITY MANAGEMENT

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ABSTRACT

A nutrient budget takes into account all the nutrient inputs on a farm and all those removed from the land. The most obvious source of nutrients in this situation is fertilizer, but this is only part of the picture. Other inputs come with rainfall, in supplements brought on to the farm and in effluent - either farm or dairy factory - spread on the land. In addition, nutrients can be moved around the farm - from an area used for growing silage to the area used to feed it out, from paddock to raceway, and within paddocks in dung and urine patches. In this paper, nutrient budget is discussed as a useful management tool that quantifies the amount of nutrients imported to and exported from a system. Nutrient budget is an important tool for effective crop yields and soil management. The paper therefore recommends among others that nutrient budgeting is a way of helping land owners choose and implement best management practices (BMPs) that will reduce the likelihood of nutrient surpluses, while maintaining soil productivity. Having a balanced nutrient budget for an agricultural production will help to avoid unnecessary production costs and greatly reduce pollution potential from surplus nutrients.

Key Words: Budgeting, Nutrients, Crop Yields and Soil Management

Introduction

A nutrient budget quantifies the amount of nutrients imported to and exported from a system. The budget is considered balanced, if inputs and outputs are equal (Turner, 1995). Nutrient budgets can be calculated at any scale, such as a farm, a county, a watershed, a state, or a country. The availability of data, as well as the scale of the unit of interest, will determine which nutrient balance approach is most appropriate. Nutrient budgets offer insight into the balance between crop inputs and outputs. In short, they compare nutrients you apply to the soil to nutrients taken up by crops (Smalling *et al.,* 1993).

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An accurate nutrient budget is an important tool to provide an early indication of potential problems arising from (i) a nutrient surplus (inputs>outputs), leading to an accumulation of nutrients and increased risk of loss or (ii) a deficit (outputs>inputs), depleting nutrient reserves and increasing the risk of deficiencies and reduced crop yields. They also provide regulatory authorities with a readily-determined, comparative indicator of environmental impact. Overall, nutrient budgets help ensure that farming practices are conducted in an efficient, economic, and environmentally sustainable manner (Harris, 1998).

A nutrient budget isn't as exact as a financial statement. An assortment of variables affects each tract of land. For example, some areas may have had too much manure applied over time or it may have been unevenly distributed. Previous flooding could throw things off, too. It's normal to incorporate limits and assumptions when compiling your budget including the average nutrient removal coefficient values if you don't have them specific to your field (Stocking, 1996).

The Need for Nutrient Budgets

Agricultural intensification without adequate restoration of soil fertility may threaten the sustainability of agriculture. Quantitative estimation of plant nutrient depletion from soils is useful for comprehending the state of soil degradation and for devising corrective measures (Harris, 1995). Nutrient-balance exercises serve as instruments to provide indicators of the sustainability of agricultural systems. Nutrient-balance studies have used a variety of approaches and methods for different situations. However, the information has remained scattered in several publications. A recently concluded FAO-commissioned project, 'Scaling soil nutrient balances', and scientific interactions (FAO, 2003) have thrown further light on the critical issues concerning nutrient-balance assessment approaches. They may also help bridge methodological gaps. Further methodological refinements are feasible through making them more spatially explicit (accounting for spatial variation of soils and climate) and through improving the procedures for calculating nutrient flow and quantifying soil nutrient stocks (David and Ruthven, 1993; Brown and Kane, 1995).

Considerations When Developing Nutrient Budgets

Developing a sound nutrient budget requires accurate nutrient input, transformation (cycling), and output data. These data can come from actual measured parameters, previously published values, or data sets collected and compiled by various state or federal agencies. Budget components not readily described by available data are often estimated or generated using scientifically-based assumptions. The accuracy of nutrient budgets is limited by the estimations and assumptions used to generate data needed to calculate the budget. In any budgeting process, land managers should acknowledge that there are factors outside their control that can impact the fates of nutrient pools. For example, annual rainfall patterns can affect N balance from year to year.

Developing nutrient budgets at a small scale (farm) and large scale (state or national) is usually easy and straightforward because data are often readily available at these scales. In contrast, it is much more difficult to develop a nutrient budget at intermediate scales, especially at the watershed scale. Accurate data are often not available at the watershed scale because much of the statistical data used in the budget is collected according to geographic and municipal boundaries rather than watershed boundaries. In addition, farms and urban areas coexist within many watersheds, allowing nutrient flows from both systems to intermingle. Therefore, determining accurate nutrient budgets at smaller scales (farm, community) is important when making nutrient management decisions at the watershed scale. Accurately determining various budgets is important to encourage BMP adoption at the appropriate scale in the watershed.

Components of a Nutrient Budget

Soil test: This component is complementary to the budget and lets you know what nutrients are already available to crops and helps you plan input purchases. It is a critical best management practice (BMP) in the 4R strategy.

1. **Yield history:** By examining the historical yields of crops take from specific fields, you can calculate nutrient removal over time. Yield history may also help better predict the amount of uptake that will occur with similar crops planted in the future.
2. **Previous applications:** Knowing what's been applied to the field in years past will offer insight into what may already be in the ground or what nutrients may no longer be present.
3. **Water:** Consider what kind of water has been applied to the field. Does irrigation water contain dissolved nutrients such as nitrogen (N), sulfur (S), or chloride (Cl)? If so, it should be counted as input.
4. **What's around you?:** Consider water sources that could run into your field. Is there a manufacturing facility nearby? What makes up these water sources can impact how you plant.

Types of Nutrient Budgets

A. Farm and field level studies

A farm and field level nutrient budget only accounts for nutrient imports and exports relative to farm or other similar unit boundaries using data that can be collected easily at the unit level. These nutrient inputs and outputs (e.g., animal feed, fertilizers, crop, manure, and animal products) can be readily tracked.

At a relatively small scale nutrient budgeting has been used as a means to assess the level of nutrient sources and flows, opportunities for improved use efficiency and scope for possible interventions. Such studies have been carried out at a variety of scales from patch and plot to farm level. For example, detailed plot-level studies have been carried out in Zimbabwe

(FSRU, 1996) and Niger (Brouwer *et al.,* 1993), where differences in nutrient flows over small areas were examined. Such studies highlight just how varied nutrient availability is within the field, and how farmers' management of nutrients and crops, is attuned to this (Carter and Murwira, 1995; Scoones *et al.*, 1996 for Zimbabwe; De SteenhuijsenPiters, 1995 for Northern Cameroon).

In southern Ethiopia, for example, comparison of onset (false banana) plots close to homesteads with intensively managed maize gardens and outfields reveals important differences in patterns of fertility management, types of nutrient cycling and levels of nitrogen and phosphorous balance at plot level (Eyasu*et al.*, 1998). Similarly, the banana fields in the *kibanja* homegarden in Bukoba district, Tanzania, directly and indirectly receive nutrients from the common *rweya* grasslands further away (Baijukya and De SteenhuijsenPiters, 1998). Other studies take the farm, rather than the plot or field, as the basic unit of analysis and calculate inputs and outputs accordingly. For example, a study in the Lake Zone in Tanzania estimated all inputs and outputs for an average type of narrow valley farming system (Budelman *et al.*, 1995).

A comparable approach has been used in Kenya (Shepherd *et al.*, 1995), and in northern Nigeria (Harris, 1998). While all these studies recognised that farms are made up of different sub-components, with different landscape positions, soil types and management regimes, the farm unit as a production and management unit was taken for the purposes of diagnostic assessment of soil fertility issues. Ultimately, the purpose of the study guides the scale of analysis and the data collection strategy, although the level of detail at which such studies are undertaken is always the result of a trade-off between cost and measurement intensity. All farm, field and plot level studies reviewed here have been geared towards identifying possible interventions for improving the efficiency of nutrient management.

For example, in Kenya a range of agroforestry interventions were identified for testing (Shepherd *et al.,* 1995); in Ethiopia testing of different manuring and composting techniques was proposed (FARM-Africa, 1996); and in Tanzania improved manure management techniques linked to home gardening were suggested by nutrient budget studies (Budelman *et al.,* 1995). In Mali, for instance, farmers were fully involved in the process of resource flow diagramming and analysis, leading to a range of interventions designed and implemented by farmers, including improved management of cut and carry livestock systems, composting, and contour ploughing (Defoer *et al.,* 1996).

In Zimbabwe and Ethiopia, a similar process has evolved where farmer research groups lead a process of problem identification, analysis and experimentation, which is supported by more detailed nutrient budgeting and soil sampling (FSRU, 1996; FARM Africa, 1996). The purpose of involvement by the farmer in such diagnosis is two-fold: first to provide information and understanding regarding local conditions and farmer strategy and, second, to support a longer term process of experimentation, research and adaptation firmly located at farm level. Such examples provide valuable material for the development of farmer-led analysis and action to improve soil fertility management (Deugd *et al.*, 1998).

B. Landscape and village territory studies

The influence of scale on nutrient balance analysis is also highlighted by those studies which take a watershed, village or 'terroir' approach, including arable, fallow and grazing areas. In a study in northern Burkina Faso, for instance, field level budgets were negative due to the export of crops for consumption or sale, but, at a village level, nutrient budgets were positive due to the import of manure from surrounding rangelands (Krogh, 1995). In the agro-pastoral settings typical of many African farming systems, the relationship between crop and range land is key. For this reason, many studies attempt to calculate the area of rangeland required to support the livestock which will provide enough manure to balance the nutrient off take from crop harvests and other outputs from cropped areas. This requires looking beyond the farm and field to the broader landscape or village territory. A number of studies of this sort have been undertaken, including work in Mali (Breman and Traore, 1987; Van Duivenbooden and Gosseye, 1990; Van Keulen and Breman, 1990; Van der Pol, 1992; Toulmin 1992), Niger (Powell and Williams, 1993; Williams *et al.*, 1995; Powell et al., 1995), Burkina Faso (Quilfen and Milleville, 1983; Prudencio, 1993); Nigeria (Powell and Mohammed- Saleem, 1987; Bourn and Wint, 1994); and Zimbabwe (Swift *et al.*, 1989). Ratios of the area of rangeland needed to supply sufficient livestock feed and so manure for one hectare of crop land are hugely variable, ranging from effectively zero in sites such as the Kano Close Settled Zone (Harris, 1995) to up to 45ha in much more extensive systems (Toulmin, 1992; Turner, 1995).

In addition, as with other scales of analysis, spatial and temporal variability are key to such nutrient flows and budget calculations. At a village or landscape level, the spatial relationship between the relatively dry top lands and the relatively wet bottomlands is often central to the agroecology of a farming system. This is influenced by nutrient flows and erosion dynamics at a landscape level, whereby some areas may be nutrient sources and others nutrient sinks or transition zones (Scoones, 1991). Thus losses through erosion in one part of the landscape provide benefits elsewhere, making the extrapolation of results from measurements at one site highly problematic (Stocking, 1996). Too often, budget analyses assume uniform patterns of soil loss across a landscape, which, if added up, result in large negative losses from erosion, ignoring the likelihood of considerable redistribution of soil and nutrients within the landscape (Böjo and Cassells, 1996, for Ethiopia).

Farmers may consciously manipulate erosion and run-off processes, increasing rates of loss in some areas as a means of concentrating moisture and nutrients in desired places. Temporal dynamics may also have major influences on balance results. In many agropastoral settings, temporal variation in livestock populations and related manure production (Williams *et al.,* 1995) or migration, and so farm-level labour or cash availability (David and Ruthven, 1993), can have significant impacts on levels of manure input, amounts of fertiliser purchased, and areas of land left fallow over time. Thus the negative balances in certain years may be compensated by higher level of inputs in other years. Nutrient budget dynamics need to be examined over several years as, for example, when drought causes a collapse in livestock numbers, after which a number of years are required for herd size to recover. However, despite acknowledging such spatial and temporal dimensions, most studies retain a snap-shot view which offers an average ratio of crop: rangeland, one that may have little meaning in the real world (Turner, 1995).

C. District national and continental scales

Many similar problems arise when the scale is enlarged yet further to a district, national or continental scale. A number of district level studies have emerged recently which make use of data from farm and village level analyses and attempt to extrapolate to a wider scale. For example, one such study from Kisii district, Kenya found consistently negative balances for all major nutrients at the aggregate district level (Smaling *et al.,* 1993). Similar results have been found in Mali, where aggregate nutrient losses are reported for all districts, except the cotton growing zone where imports of inorganic fertilisers compensate for harvest exports and other losses (Van der Pol and Traore, 1993; Powell and Coulibaly, 1995).

At national and regional levels a similarly gloomy story emerges: unless significant inputs of external inputs in the form of inorganic fertilisers are supplied, negative balances of nutrients are inevitable (McIntire and Powell, 1995). For Africa as a whole, the low level of inputs (including fertiliser) relative to outputs results in a consistently negative balance (Stoorvogel and Smaling, 1990; Stoorvogel *et al.,* 1993). These larger scale estimates have become increasingly influential in policy discussions around soil fertility management and the prospects for sustainable agriculture in Africa (IFPRI, 1995; FAO, 1996; World Bank, 1996) and numerous other government and agency documents on this subject). Almost all conclude that, because of aggregate deficits of nutrients, interventions must focus on increasing nutrient inputs through processes of nutrient 'recapitalisation', often involving major fertiliser programmes.

But, as discussed earlier, given the issues of spatial and temporal variability raised by studies carried out at smaller scales (indeed, the very studies on which these larger-scale assessments are based), we must ask: how reliable a guide for policy decisions are these aggregate nutrient balance estimates? It may be the case that "scale-inherent simplifications were inevitable" (Smaling *et al.*, 1993, 237), but what are the implications of these acknowledged weaknesses? And finally, a more fundamental puzzle: if things are so bad at an aggregate level (and apparently have been for some time - agriculture after all has been practised in many areas of Africa for centuries, without external inputs of chemical fertiliser), how is it that farming persists at all? In the next sections, we will first look at the way nutrient budget and balance studies at these different scales have been used in recent policy debates. We will then go on to review some of the conceptual, methodological and practical dilemmas raised by the use of nutrient budget and balance studies at different scales. We return in the final section to a discussion of why farmer participation in the soil nutrient debate is critically important if the insights raised by nutrient budgets and balances are to be translated into improved practice at farm level.

There are three main types of nutrient budgets that have also been recognized: **farm-gate**, **soil surface**, and **soil system**.

i. A **farm-gate** nutrient budget only accounts for nutrient imports and exports relative to farm (or other similar unit) boundaries using data that can be collected easily at the unit level. These nutrient inputs and outputs (e.g., animal feed, fertilizers, crop, manure, and animal products) can be readily tracked.
ii. A **soil surface** nutrient budget accounts for all nutrients that enter the soil surface and leave the soil through crop uptake. In the case of N, the total amount of manure or fertilizer N applied would be adjusted to account for ammonia volatilization, since

this N would not enter the soil surface. In addition, the soil surface budget includes estimates of nutrient inputs such as biological N-fixation and atmospheric deposition.

iii. A **soil system** budget is the most comprehensive type of nutrient budget because all nutrient inputs and outputs in a given area of interest are included in the budget The soil system budget requires the use of assumptions and estimations to account for nutrient transformations in the soil (e.g., immobilization, mineralization) and nutrient export from the system (e.g., losses through runoff, leaching, volatilization, and denitrification). Because a soil system budget relies on assumptions and estimates, more uncertainty is associated with this type of budget compared with farm-gate or soil surface budgets. The reliability of a soil system budget improves as more direct measurements of inputs, transformations, and losses are included.

Conclusion and Recommendations

A nutrient budget is a useful management tool that quantifies the amount of nutrients imported to and exported from a system. A nutrient budget takes into account all the nutrient inputs on a farm and all those removed from the land. The most obvious source of nutrients in this situation is fertilizer, but this is only part of the picture. Other inputs come with rainfall, in supplements brought on to the farm and in effluent - either farm or dairy factory - spread on the land. In addition, nutrients can be moved around the farm - from an area used for growing silage to the area used to feed it out, from paddock to raceway, and within paddocks in dung and urine patches.

1. Nutrient budgeting is a way of helping land owners choose and implement BMPs that reduce the likelihood of nutrient surpluses, while maintaining soil or increasing agricultural production or urban aesthetics.
2. Having a balanced nutrient budget for an agricultural or urban system can help to avoid unnecessary production costs and greatly reduces pollution potential from surplus nutrients.

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