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# Research on soil fertility in Southern Africa: Ten awkward questions

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**Abstract:** By raising important, sometimes ignored questions about research on soil fertility management in the subsistence, risk-prone maize-based cropping systems of sub-Saharan Africa, this paper seeks to improve the quality of problem definition, spatial and temporal extrapolation, and farmer participation, as well as promoting careful consideration of the factors governing adoption, links with policies, and longer-term and off-site consequences of changes in management practices. The article is targeted to Southern Africa, but the issues and their treatment are relevant to smallholder maize cropping and related research throughout the developing world.

**AGROVOC Descriptors:** Africa; Africa South of Sahara; Southern Africa; Soil fertility; Soil conservation; Soil management; Maize; Zea mays; Crop management; Cropping systems; Farming systems; Small farms; Technological changes; Innovation adoption; Development policies; Research projects

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## Introduction

Success in agricultural research calls for a unique blend of unconstrained creativity and painstaking discipline — creativity in designing technical options intended to be attractive to farm families, tempered by discipline in assessing their performance and attractiveness. Research on soil fertility management is especially difficult, in part because of:

- The many combinations of technical options available (inorganic fertilizers, crop residues, numerous species of green manures, animal manures, intercrops, rotations, agroforestry systems, improved germplasm, etc.).
- The variability in performance of these technical options under different soil and weather conditions.
- The complex ways in which technical options can impinge on existing farming practices.
- The possible importance of their long-term and off-site consequences.
- The complexity of identifying potential areas for extrapolation of research results.
- The importance of policies and institutional arrangements in shaping the farm-level cost-benefit equation that drives adoption.

Research on soil fertility management in maize systems may be difficult, but it is also supremely important for sustainable food security, particularly in sub-Saharan Africa. Adoption of improved maize germplasm has accounted for a little over half of the 1% annual growth in maize yields in sub-Saharan Africa since 1970; improved productivity and sustainability in maize systems must come increasingly from improved soil management practices that fit the infrastructural and institutional circumstances of many African farming systems: low population densities, seasonal labor bottlenecks, poor infrastructure (which increases the cost of external inputs), and price instability (Byerlee et al. 1994).

Given the complexity of research on soil fertility management, many researchers concentrate their efforts on a small subset of the important questions, but neglect the more awkward ones. Specific examples include issues relating to problem definition, spatial and temporal extrapolation, farmer participation, factors governing adoption, links with policies, and longer-term and off-site consequences of change.

This paper raises several of these awkward questions without trying to provide any definitive answers. By raising them, however, we hope to stimulate discussion among reseachers about themes which may have been ignored and new ones that contribute to understanding and solving important soil fertility problems in Southern African maize systems.

## Question 1 - Are soil fertility problems in maize systems well defined?

New soil fertility management practices should aim to solve important problems. But how well defined are the problems? Soil fertility problems are normally multi-dimensional (Harrington 1996), involving:

- The biophysical processes that underpin soil fertility in maize systems.
- The direct causes of the problems (which result from the above processes).
- Problem incidence.
- The consequences of problems.
- The pace of change with which these consequences are felt.

Given the exemplary work of the International Fertilizer Development Center (IFDC), the Tropical Soil Biology and Fertility Program (TSBF), the International Center for Research in Agroforestry (ICRAF), national agricultural research systems, and

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other research organizations (Woomer and Swift 1994), one might assume that the *biophysical processes* associated with soil degradation and low soil fertility in Southern African maize systems were well understood, especially relative to soil fertility depletion (Smaling and Braun 1996) and the requirements for recapitalizing soil fertility, particularly for phosphate (Sanchez 1996). In addition, there has been considerable work aimed at understanding water and nutrient cycling and improving synchrony — the capacity of soils to provide nutrients to plants at the time when they are most needed. Despite the work to date, however, we cannot presume to have a total or even satisfactory grasp of the many biophysical processes that underlie soil fertility problems in maize based agriculture in Southern Africa. Even in Asia, where considerably more research resources have gone into elucidating the processes that drive soil degradation and yield stagnation in intensive rice systems (Cassman et al. 1994), those processes have only recently been satisfactorily described, and the underlying causes of declining yields in rice-wheat systems in the Indo-Gangetic Plains remain poorly understood, despite intense study (Hobbs and Morris 1996).

As we ask about important unknowns regarding soil biophysical processes in maize systems in Southern Africa, it may be useful to subdivide process issues into two types:

- Degradation; for example, the on-going loss of organic matter and nutrients in lands with relatively high proportions of clay.
- Management of low fertility soils; for instance, farming on shallow, granitic sands where there may simply be *no degradation processes* at work.

*Problem incidence* refers to the simple questions: "Which biophysical problems are found on which soils, and where are these soils located?" Simple though they may be, these queries have important implications for technology targeting, the selection of representative sites, site characterization, the georeferencing of experimental locations, the pooling of data across sites, and priority-setting in technology design. Have the questions of problem incidence been answered to everyone's satisfaction? Is it generally known which problems are concentrated on which soils? Are trials georeferenced? Are data pooled across sites in a way that draws on suitable soil characteristics?

*Consequences* of soil-related problems may be found not only on-site (near-term productivity or longer-term resource quality and system sustainability; e.g., the build-up of *Striga*), but off-site as well (downstream or off-site economic, environmental or ecological effects of land degradation). Off-site consequences of land degradation can be more important than on-site consequences (Anderson and Thampapillai 1990). For example, erosion on sloping hillsides in Indonesia often does not affect the productivity of hillside maize systems, but the resulting siltation can ruin downstream irrigation infrastructure. What are the major off-site economic, environmental, or ecological consequences of land degradation in maize systems in Southern Africa?

*Pace of change* is also important — problems may be more significant if they unfold swiftly. What is the pace of change for major problems of soil degradation in maize systems in Southern Africa?

Finally, it is important to understand the underlying, *non-biophysical causes* of problems to develop viable solutions (Tripp and Woolley 1989). In sub-Saharan Africa, soil fertility problems have been traced to increasing land scarcity, shortened fallow periods, periodic labor shortages, and low use of inorganic fertilizers. The latter factor in turn derives from unfavorable grain/fertilizer price ratios, driven by poor infrastructure, unsuitable input and product pricing policies, and uneven performance of private sector companies (Mwangi 1997). Have the important cause and effect relationships been fully worked out for soil fertility problems in Southern Africa? Do they change over sub-regions? Farmers are particularly skilled at helping unravel cause and effect relationships among complex system interactions (Lightfoot et al. 1989). Has their experience been tapped?

## Question 2 - Does the current "menu" of technical options include promising farmer-developed practices?

There is a tendency in on-farm research for scientists to choose (often rather casually) a small number of technical practices which they subsequently assess in considerable detail. It can be awkward to ask whether the right practices were chosen to begin with. Sometimes, important farmer-developed options are overlooked. There is a fair literature on multiple sources of innovation (e.g., Bebbington 1989) which teaches us that farmers frequently can contribute innovative new practices to the pool of technical options being assessed. The numerous examples include:

- Farmer-developed methods for inserting *mucuna* in maize systems in Southern Veracruz, Mexico (Buckles 1993).
- Farmer-developed surface-seeding practices for establishing wheat after rice in Bangladesh (Hobbs and Morris 1996) and Thailand (Connell 1992).
- Farmer-developed methods of transplanting maize to enable a conversion of a two-crop per year to a three-crop per year system in the Red River Delta of Northern Vietnam (Tinh et al. 1992).
- Farmer-developed land management systems for flood-prone areas of the lower Indo-Gangetic Plains (John et al. 1993).
- Farmer-developed methods of dealing with erosion in Central Kenya (Tiffen et al. 1994).

In Southern Africa, it would be unusual indeed if farmers had no insights into soil management nor options for regenerating soils that have lost their fertility. What are farmers' strategies for regenerating soils? What conditions govern the success of these strategies? Have these approaches been considered in a research program? For soils that may not necessarily be undergoing degradation but that are of low inherent fertility, what are farmers' management practices? Is the Soil Fertility Network research agenda adequately rich in options for and developed by farmers?

## Question 3 - What have been farmers' experiences in using new practices suggested?

Not only can farmers help provide new technical prototypes and options; they are frequently good sources of insights on technical options already under study. Often farmers will have previous experience with a technology and thus possess a reasonable understanding of its performance under different circumstances.

In the Soil Fertility Network agenda, the following technical interventions are among those emphasized in research: legume green manures to foster regeneration of exhausted soils; groundnut cropping patterns in long-term trials; crop sequences involving legumes, maize, and sunflower; soybean-maize rotations; cattle manure x inorganic N; overcoming limiting nutrients on the Kalahari sands; and many, many more. Local farmers must surely have some knowledge of these practices. Have systematic efforts been made to tap farmers' past experiences with new practices being developed within the Network? How has such information been incorporated into Network findings?

## Question 4 - Which new soil fertility management practices are best suited to which soil types?

In our first question, the issue of *problem* incidence was raised: "Which biophysical problems are found on which soils, and where are these soils located?" A similar question can be asked regarding the targeting of *solutions* to these problems: "Which soil management practices are best suited to which soils, and where are these soils located?" Clearly, for example, research to identify the nutrients that limit maize productivity in Kalahari sands is most relevant to those soils. Are there differential responses by soil type for other aspects of fertility management in maize based production systems? As suggested earlier, how does this affect site selection, data analysis, and synthesis of results? Which data can sensibly be shared over which sites? What are the potential extrapolation areas for different technologies? Are test sites georeferenced? Are they and their soils characterized? Are the results of soil analyses used in answering some of the above questions? Should the Soil Fertility Network organize a database on soil fertility management practices by soil type?

## Question 5 - How can new practices be adapted most efficiently to the conditions of different systems?

Soil variability is only one factor that affects the cross-site synthesis of research results and the adaptation of prototype practices to farmers' circumstances. Indeed, adapting prototype practices to defined farming systems is a classic area for farmer participation in research. Much of the literature on participatory experimentation — farmer involvement in technology adaptation — deals with crop improvement. Examples include farmer participation in selecting advanced lines of common bean in Colombia (Ashby et al. 1987) and Rwanda (Sperling and Scheidegger 1995), and farmer participation in selecting rice varieties in Nepal (Sthapit et al. 1996). However, farmers and researchers have also worked together to tailor crop and system prototype technologies. Here we can cite the use of vining legumes to rehabilitate *Imperata* infested lands in the Philippines (Lightfoot et al. 1988) or the use of grassy strips with farmer-selected trees for erosion control in hillside maize systems in Southern Philippines (Fujisaka 1989). In fact, a whole new literature has grown up around participatory adaptive experimentation (e.g., ILEIA 1989).

Have researchers in the Soil Fertility Network worked with farmers to tailor prototype technologies studied by the Network to the needs and circumstances of different farming systems? This would require, of course, a characterization of the major farming systems in the target area. Is there a need to strengthen the capacity of Network members to engage in participatory experimentation for technology adaptation? Is there a need to re-examine the balance between researcher-managed strategic research vs. participatory adaptive research?

## Question 6 - How do the new practices perform under drought?

The attractiveness of new soil management practices to farmers will, in part, depend on how these practices perform under drought conditions; Southern Africa is, after all, a region noted for rainfall variability and weather-related risk. Other things being equal, soil management practices that perform poorly under drought conditions are likely to be less attractive to farmers. First, however, what is meant by the term "drought"? To be useful, the concept itself must be described more precisely. For instance, does it refer to:

- Late onset of rains?
- Early end of rains?
- Erratic dry spells during the rainy season?
- Concentration of rains in fewer events?
- Reduced average seasonal rainfall?

Most importantly, what climatic scenarios are of most concern to farmers?

Maize itself is especially susceptible to drought-occasioned yield losses during flowering and grain filling, crop development phases which occur from mid-season to late in the season (Westgate 1997). Unreliable rainfall during seedling establishment early in the season has also been cited as a major cause of yield reductions and even crop losses in maize (Bänziger et al. 1997). In the absence of a rich dataset (one that features multiple long-term experiments that extend over a large number of years and that suitably reflect variation in weather patterns), stability of performance of soil management practices best can be assessed through modeling. An example of modeling to assess the riskiness of a given technology option is offered in the following section. Note, however, that fruitful simulations from validated models also require input — specifically, data from trials accompanied by a minimum dataset (Table 1) (though these need not come from long-term trials).

### Simulation models and risk management - an example

To demonstrate the use of simulation models in assessing yield variability under different weather conditions, an example is maize response to fertilizer at Chitedze, Malawi. Crop production practices are those as described by Thornton et al. (1995) in their evaluation of the CERES-maize model in Malawi. The CERES-Maize and SOYGRO models are used — these are available in the whole system decision support package known as DSSAT (v3.1). One simulation experiment involved a single-season maize crop with an array of urea applications (0, 60, 120, 180 kg N/ha).[2] Annual simulated maize yields for the single season nil fertilizer treatment are depicted in Figure 1. Seasonal rainfall varied from 588 mm in 1990-91 to 1052 mm in 1986-87, with an average of 878 mm. Simulated yields in varied from 1.5 t/ha in 1989-90 to 2.6 t/ha in 1988-89, with an average of 1.9 t/ha.

There was no significant relationship between total *seasonal* rainfall and yield for any treatment. This is not surprising — simplistic empirical models which attempt to predict yield from total growing season rainfall without accounting for distribution are rarely accurate. This is illustrated in Figure 2, where above-ground dry matter accumulation is compared for two seasons (1987-88 and 1989-90) with similar total seasonal rainfall (808 mm). In 1989-90 there was substantial early season rainfall, leading to waterlogging and lower yields (1.5 t/ha). In contrast, rainfall was more evenly distributed in 1987-88 leading to higher yields (2.1 t/ha).

**Table 1. The minimum dataset for simulation of cropping systems.**

| Measurement | Depth increment (cm) | Timing |
|---|---|---|
| Maximum temperature | Surface | Daily |
| Minimum temperature | Surface | Daily |
| Solar radiation or Sun hours | Surface | Daily |
| Rainfall | Surface | Daily |
| Organic C | 0-5, 5-10, 10-20, 20-40, 40-60, 60-80, 80+ | Sowing |
| Organic N | 0-5, 5-10, 10-20, 20-40, 40-60, 60-80, 80+ | Sowing |
| Ammonium/Nitrate-N | 0-5, 5-10, 10-20, 20-40, 40-60, 60-80, 80+ | Sowing, harvest |
| Ammonium/Nitrate-N | 0-5, 5-10, 10-20 | Tasseling, anthesis and harvest |
| Total P | 0-5, 5-10, 10-20, 20-40 | Sowing |
| Extractable P | 0-5, 5-10, 10-20, 20-40 | Sowing |
| pH | 0-5, 5-10, 10-20, 20-40, 40-60, 60-80, 80+ | Harvest |
| Crop residues | Surface, 0-5, 5-10, 10-20 | Sowing, harvest |
| Total aboveground biomass | | Tasseling, anthesis and harvest |
| Tillage | Record depth and type | Record date |
| Irrigation | Record method | Record date |
| Fertilizer | Record depth and type | Record date |
| Germination (50% of plants) | | Record date |
| Anthesis (50% of plants) | | Record date |
| Maturity (50% of plants) | | Record date |
| Grain yield | | Record |
| Grain N | | Record |
| Grain number @ harvest | | Record |

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[2] The fertilizer applications in this simulation were in multiples of 30 kg N/ha at approximately weekly intervals. The initial application was two weeks after planting. Historical weather records (1984-91) from Chitedze Research Station were used in the seasonal analysis, with the crop being grown under identical soil conditions for each of seven seasons. These eight-year weather data were used to generate a theoretical weather dataset for a twenty-year analysis. In the simulation, the mineral N content of the top 50 cm of sandy-loam soil at the time of planting each year was 44 kg/ha (assuming a bulk density of 1.3 g/cm$^3$) with a volumetric water content of 0.11 cm$^3$/cm$^3$). A 500 kg/ha residue cover with a N content of 0.53% was also incorporated at that time. This analysis produces a range of yields for each fertilizer treatment solely dependent on the different weather conditions for each season. In all simulations a plant population of 37,000 plants/ha was used, planted on 20 November each year. The maize cultivar was a local traditional variety. The model does not take into account the impact of weed populations and pest damage on yield. It also assumes that phosphorus is non-limiting.

One way to quickly assess the relative performance of each treatment in response to the same weather conditions is through a cumulative probability function plot. The output for each treatment (in this case yield for each year) is ordered from lowest to highest and plotted against equal increments of cumulative probability. It is evident from Figure 3 that the local maize cultivar with no fertilizer is unlikely to attain a grain yield greater than 2.6 t/ha under the specified range of climatic and management conditions. Under these conditions, this cultivar has a 50% probability of yielding at or below 1.9 t/ha.

Note that the above results are based on a climate dataset of relatively short duration. When we ran the same nil fertilizer treatment with a theoretical twenty-year weather dataset, the simulation output included two years of complete crop failure. When we plotted each of the four treatments as cumulative probabilities (Figure 4), the maximum attainable yield with the local cultivar using the actual recorded weather at Chitedze for 1984-1991 was 3.2 t/ha. When we used the full twenty-year dataset we obtained a similar yield.

Modeling can also be used to simulate and thereby forecast the likely longer-term effects on crop yields

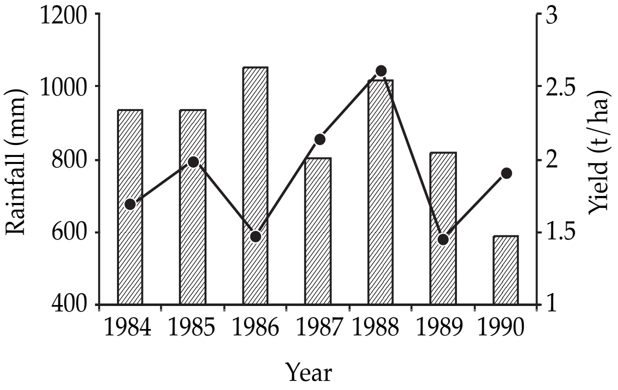

**Figure 1. Seasonal rainfall (bars) and simulated maize grain yield (points) for a local cultivar grown at Chitedze, Malawi (nil fertilizer), using the CERES-Maize model.**

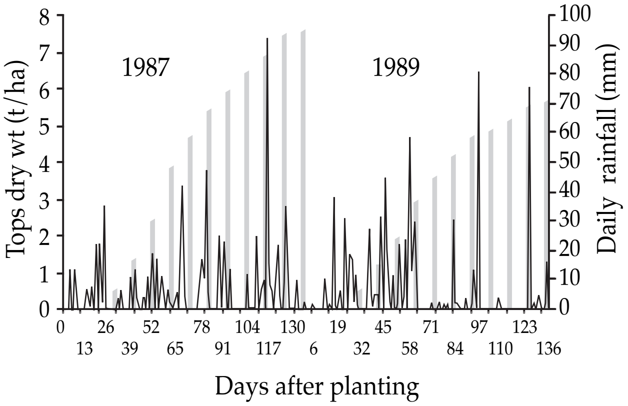

**Figure 2. Daily rainfall (lines) and simulated accumulation of aboveground maize biomass (shaded) for a local cultivar grown at Chitedze, Malawi (nil fertilizer), in 1987-88 and 1989-90.**

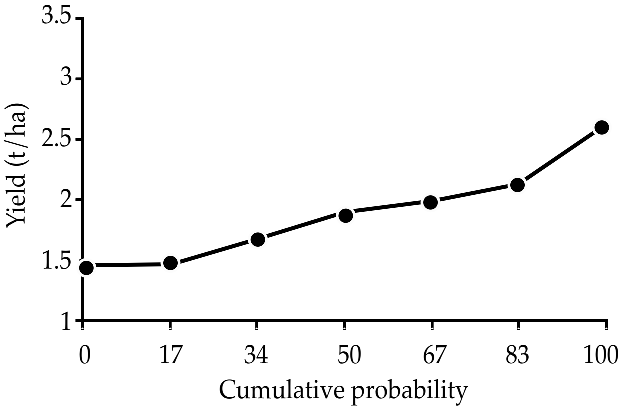

**Figure 3. Distribution of simulated maize yields for a local cultivar grown at Chitedze, Malawi, for seven single seasons (1984-85 to 1990-91) under identical initial conditions.**

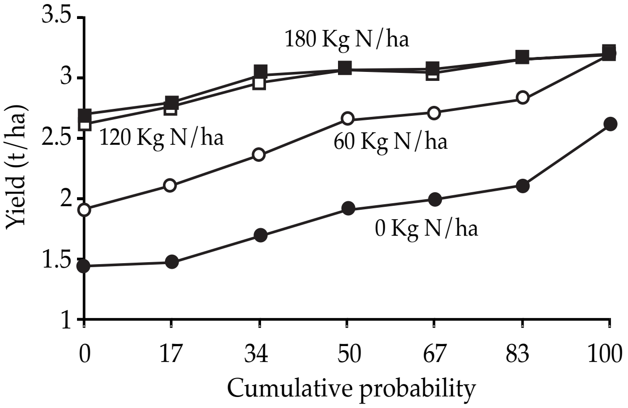

**Figure 4. Distributions of simulated maize yields for a local cultivar grown at Chitedze, Malawi, for seven single seasons (1984-85 to 1990-91) under identical initial conditions and several fertilizer N additions in the form of urea.**

and soil quality indicators of introducing new rotations or the use of green manure cover crops or manures. (For lack of space, examples are not provided here.)

## Question 7 - How do the new practices mesh with farmers' risk management strategies?

Farm families that survive or even thrive in a drought-prone, risky environment understandably have developed strategies to deal with climatic variation. For Southern African families who rely on maize systems for income and employment, risk management strategies might feature (Scoones et al. 1996):

- Staggered maize planting.
- Early maturing maize varieties.
- Maize seed soaking.
- Crop diversification.
- Crop sequences or rotations that foster moisture conservation.
- Landscape management (e.g., varying the relative intensity of use of low-lying lands vs. hillsides).
- Use of cattle husbandry or off-farm or non-agricultural employment as alternative sources of income, etc.

To these options may soon be added another important one — drought- and low-N tolerant maize varieties (Edmeades et al. 1997).

How well do new soil management practices mesh with these risk management strategies? Might recommended intercrops or undersown legumes rob moisture from maize during a drought, further reducing grain production badly needed for subsistence? Are the high labor inputs needed for green manure management feasible if farm family survival during drought periods depends on livestock management or off-farm employment? How can reseachers and farmers work together to answer these questions?

Note that new maize technology (modern varieties and fertilizer) can sometimes be risk efficient (Ames et al. 1993; Smale et al. 1994). Can organic-based technologies do as well?

## Question 8 - How well understood are the factors governing adoption of new soil management practices?

Good performance under drought conditions and a good fit with farmers' risk management strategies are crucial to the attractiveness of new technology for farm families. But other factors — particular those that influence the near- and longer-term costs and benefits of adoption — may be equally important.

Information on factors governing adoption can be generated during farmer participatory adaptive experimentation (see Question 5). At times, however, dedicated adoption studies are needed (see CIMMYT Economics Program 1993 for a summary of methods useful in conducting adoption research). In addition, there is no substitute for a sound economic analysis — and a sound farmer assessment — of practices being proposed for widespread dissemination. Whatever the source or type, information on factors governing adoption can be exceedingly useful, as the following examples show.

- Farmers in Western Kenya began using improved fallows that feature direct seeding of *Sesbania* in place of maize on their least productive maize lands, even though the yield increase in the following maize crop was only about 25%. Farmers quickly realized that the savings in crop labor offset foregone maize yields and used the practice to reclaim depleted land. Understandably, adopting households were those with access to off-farm income or with low labor to land ratios (Swinkels et al. 1996), and an awareness of this helped in targeting the technology.
- In West Africa, researchers have found that adoption of *Mucuna* in maize systems has been greatest where soil fertility is declining and inorganic fertilizers are not subsidized, where noxious weeds (like *Imperata*) severely affect maize production, and where farmers have good contact with development organizations that facilitate access to *Mucuna* seed (Vissoh et al. 1997). Knowledge of these factors has guided subsequent dissemination efforts involving *Mucuna*.

What is known about factors that govern the adoption of soil management practices for Southern Africa? What is the cost-benefit equation for the major technical options — both near-term and longer-term? Are inorganic fertilizer, lime, or other soil amendments really profitable to farmers when realistic transport costs, interest rates and product prices are included in the analysis?[3] What are the hidden costs of adoption?

For example, is it possible that open grazing by livestock during the dry season constrains green manure growth or use of crop residues as a source of organic matter source? Is the fencing of land a hidden cost of adopting these practices? Should farmers plow immediately after harvest to incorporate green manure biomass and so avoid it being eaten by roaming cattle? Is it feasible for most farmers to plow in such a manner? Participatory research with farmers, economic analysis of trials, and adoption studies can help answer these important questions.

## Question 9 - What mechanisms are in place to accelerate and improve the quality of adoption by informing the policy debate?

Policymakers typically have multiple objectives, only one of which may be to improve the productivity and sustainability of maize systems. Policy decisions *will* be made, whether or not the information base to support these decisions is complete. Decisions, once taken, can have unexpected or unintended consequences for agricultural production in general, and maize system productivity in particular.

Agricultural scientists and research managers may not necessarily be the best people to determine or influence policy, but they have a very important role in helping inform the policy debate. What mechanisms are in place for agricultural scientists or research managers to provide essential information to policymakers?

The adoption of improved technologies that depend on the use of purchased inputs, such as seed and fertilizer, is strongly conditioned by the policy environment with respect to input supply and prices. To foster adoption, the following are said to be needed:

- A cost-effective mix of price policy, credit, input supply, and extension, (with special attention to the economics of fertilizer use, the availability of fertilizer, price policies and credit, pricing environment and distribution costs, the privatization of supply, and infrastructure development) (Mwangi 1997).
- Mechanisms for ensuring that such programs are sustainable over the long term, given the short-term nature of most maize production campaigns (Byerlee et al. 1994).

The adoption of improved soil management technologies that depend on organic as well as inorganic inputs will be conditioned by other dimensions of the policy environment; these include participatory extension to foster farmer learning of knowledge intensive technologies, access to green manure seeds of good quality, improved markets for grain legumes, and policies that encourage use of crop residues and green manures as soil amendments or mulch (for example, support for fencing off land).

Information on factors governing adoption of productivity enhancing, resource conserving practices needs to be packaged and made available to local, regional and national level policymakers. Are there mechanisms in place to do so?

## Question 10 - Will adoption of improved soil management practices materially contribute to the regeneration of the soil resource base? Over what time frame? With what other longer-term or off-site effects?

The Soil Fertility Network has several objectives, among them: to help rehabilitate exhausted soils and to foster improved productivity of maize systems through improved soil fertility. Rehabilitation of exhausted soils and improvement

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[3] See Perrin and Anderson 1979 - or updated versions - for methods of partial budget economic analysis of agronomic experiments.

of soil fertility does not happen overnight. Some might assert that the objectives of soil rehabilitation and substantial improvement of soil fertility are inherently unattainable, even if farmers were to fully adopt the best recommended soil fertility management practices.

Several types of studies can help elicit information relative to this issue, including long-term experiments, farmer monitoring, or chronosequence studies (Triomphe 1996). Does the Soil Fertility Network manage such research?

Rather than wait years or decades for this information to emerge, models can be used to simulate the long-term consequences for soil fertility of the introduction of different soil management practices. Several (APSIM, CENTURY, SOCRATES) serve the purpose. Have modeling approaches been used to explore the longer-term consequences of adoption for the productivity and sustainability of maize systems? Are data gathered in trials that can be used to validate these models? Should the Soil Fertility Network strengthen its skills in this area? Note, again, that fruitful simulations from validated models require input in the form of data from trials accompanied by a minimum dataset (Table 1).

Finally, as noted in an earlier section (Question 1), off-site consequences of land degradation are important worldwide. These off-site consequences often relate to water quantity or quality for downstream users (e.g., siltation of irrigation infrastructure or pollution of water for urban consumers from erosion in the uplands). What are possible off-site consequences of the introduction of new soil fertility management practices and, if there are any, how should they be assessed?

## Conclusion

We began this paper by pointing out that agricultural research is complex and that success in research calls for a unique blend of creativity and discipline. The participants in the Soil Fertility Network are to be complimented on both counts. We recognize that much excellent work has been done and, by asking the above questions, hope to strengthen this excellence.

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