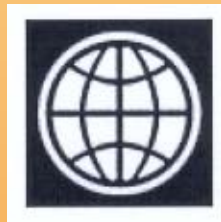




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Factors Affecting Demand for Fertilizer in Sub-Saharan Africa



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Valerie A. Kelly



The World Bank

Agriculture and Rural Development
Discussion Paper 23

Factors Affecting Demand for Fertilizer in Sub-Saharan Africa



Valerie A. Kelly

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Preface

Concerned by the low use of fertilizer in Sub-Saharan Africa compared to other developing regions, in 2004 the World Bank and the UK Department for International Development (DFID) jointly undertook an Africa Fertilizer Strategy Assessment, the objectives of which included:

- Identifying factors that have undermined demand for fertilizer in Sub-Saharan Africa;
- Identifying factors that have restricted the supply of fertilizer in Sub-Saharan Africa;
- Assessing lessons learned from past attempts to promote increased use of fertilizer in Sub-Saharan Africa; and
- Identifying entry points for supporting successful uptake of fertilizer by African farmers, particularly smallholders.

The Assessment generated a number of outputs. In addition to the “Africa Fertilizer Policy Toolkit,” a CD-based resource designed for use by policy makers and development agency staff, these included four ARD Discussion Papers—three that address specific fertilizer-related themes and one that summarizes the contributions made by participants in an e-forum about increasing fertilizer use in Africa that was conducted as part of the Assessment. The four ARD Discussion Papers include:

1. Alternative Approaches for Promoting Fertilizer Use in Africa

Eric W. Crawford, T. S. Jayne, and Valerie A. Kelly

This paper examines a number of financial, economic, social, and political arguments that have been made in favor of promoting increased fertilizer use in Africa. The cases for and against fertilizer subsidies are discussed in some detail.

2. Factors Affecting Demand for Fertilizer in Sub-Saharan Africa

Valerie A. Kelly

This paper provides a comprehensive overview of the current state of knowledge about the factors affecting farm-level demand for fertilizer in Sub-Saharan Africa. Technical, economic, and policy options for strengthening demand are reviewed.

3. Factors Affecting Supply of Fertilizer in Sub-Saharan Africa

D. I. Gregory and B. L. Bumb

This paper evaluates different strategies to make significant improvements in fertilizer supply to smallholder farmers in Sub-Saharan Africa. Use of supply

chain analysis is advocated as a means of identifying entry points where targeted interventions can shift the fertilizer supply curve to the right.

4. Increasing Fertilizer Use in Africa: What Have We Learned?
Colin Poulton, Jonathan Kydd, and Andrew Dorward

This paper summarizes the proceedings of an e-forum organized by Imperial College London and NR International on behalf of The World Bank and DFID as part of a wider Africa Fertilizer Strategy Assessment Exercise. The e-forum took place from February 15th to March 8th 2005.

Acknowledgments

The Africa Fertilizer Strategy Assessment was carried out by a team that included Michael Morris, Ron Kopicki, Derek Byerlee, Jeanette Sutherland, Neil MacPherson, and Karen Brooks McConnell (all of the World Bank), as well as Valerie A. Kelly (Michigan State University). Helpful comments and suggestions were received also from John McIntire and Jock Anderson (both of the World Bank).

Funding for the Assessment was provided by the World Bank and DFID, in part through the Agriculture and Rural Development (ARD)-DFID Partnership Program.

Many people at the World Bank, DFID, Michigan State University (MSU), the International Fertilizer Development Center (IFDC), Imperial College London, and other organizations contributed to the content and quality of the ARD Discussion Papers. While it is not possible to acknowledge all those who contributed, the authors would like to recognize a number of individuals who made particularly noteworthy contributions.

Alternative Approaches for Promoting Fertilizer Use in Africa—Research support was provided by Andrew Kizito, Megan McGlinchy, and Jones Govereh. Helpful comments were received from Duncan Boughton, other colleagues at MSU, and several anonymous reviewers.

Factors Affecting Demand for Fertilizer in Sub-Saharan Africa—Research support was provided by Andrew Kizito and Megan McGlinchy. Helpful comments were received from Eric Crawford, John Staatz, Sieglinde Snapp, Cynthia Donovan, Duncan Boughton, Guy Evers, Michael Morris, Derek Byerlee, and two anonymous reviewers.

Factors Affecting Supply of Fertilizer in Sub-Saharan Africa—Helpful comments were provided by informal reviewers from The World Bank and IFDC. Suggestions made by an anonymous referee also helped to improve the focus and contents of the paper. The paper was edited and prepared for publication by Marie Thompson (IFDC).

Increasing Fertilizer Use in Africa: What Have We Learned?—Bert Janssen contributed valuable comments on technical and economic issues relating to the soil science aspects of the paper.

The first two papers by MSU authors drew heavily on the findings of research carried out under the Food Security III Cooperative Agreement (GDG-A-00-000021-00) between MSU and USAID through the Bureau for Economic Growth, Agriculture, and Trade's Office of Agriculture and Food Security, with supplemental funding from the Africa Bureau's Office of Sustainable Development.

The third paper by IFDC authors drew heavily on both the Strategic Framework for African Agricultural Input Supply System Development (IFDC Technical Bulletin IFDC-T-63, 2000) funded by the United States Agency for International Development (USAID), the Government of the Netherlands, the International Fertilizer Industry Association (IFA) and support from the Economic Commission for Africa (ECA, and IFDC country assessments funded by USAID Africa Bureau).

Early drafts of the ARD Discussion Papers were reviewed by members of the World Bank team, as well as by Riika Rajalati (World Bank), Kees van der Meer (World Bank), Jean-Christophe Carret (World Bank), Jan Poulissse (FAO), Guy Evers (FAO), and Mike Wales (FAO).

The papers were edited by Shari Schlesinger. The publication process was managed by Melissa Williams (World Bank), with assistance from Marisa Baldwin (World Bank).

Acronyms and Abbreviations

AVP	Average value product
CA	Conservation farming
CARE	Cooperative for Assistance and Relief Everywhere, Inc (an NGO)
CLUSA	Cooperative League of the U.S.A.
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo International Maize and Wheat Improvement Center
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
FSR	Farming systems research
HEI	High external input
HIV/AIDS	Human Immunodeficiency Virus / Acquired Immunodeficiency Syndrome
IFDC	International Fertilizer Development Center
INTSORMIL	International Sorghum and Millet Collaborative Research Support Program
INRM	Integrated natural resource management
INSAH	Institut du Sahel (Sahel Institut)
I/O	Input/output price ratio
ISFM	Integrated soil fertility management
K	Potassium fertilizer
LEI	Low external input
LH	Land husbandry
MADIA	Managing agricultural development in Africa, World Bank program
MFC	Marginal factor cost
MIS	Market information system
MRR	Marginal rate of return
NRM	Natural resource management
N	Nitrogen fertilizer
NGO	Non-governmental organization
O/N	Output/nutrient ratio
P	Phosphate fertilizer
PADETS	Participatory Agricultural Development and Extension Training Service
PRs	Phosphate rock fertilizers

SCODP	Sustainable Community Oriented Development Program
SSA	Sub-Saharan Africa
SSP	Single Superphosphate fertilizer
SWC	Soil and water conservation
TSP	Triple Superphosphate fertilizer
VCR	Value/cost ratio
VMP	Value of the marginal product
WB	World Bank

Executive Summary

Background and Objectives

Although there has been some progress in agricultural productivity growth in Sub-Saharan African (SSA) during the past several decades, current growth lags far behind that in other regions of the world and is well below that required to meet SSA food security and poverty reduction goals. The slow growth is not surprising given SSA's less favorable agro-ecological conditions, lower investment in irrigation, and much lower use of fertilizer—only 9 kg of nutrients per ha compared to 73 in Latin America and 100–135 in Asia, where as much as 50% of the Green Revolution yield growth is attributed to fertilizer use.

The growing contrast between the role played by fertilizer in other regions and the very limited use of fertilizer in SSA has stimulated debate about the role of fertilizer in Africa, and what types of policies and programs are needed to realize its potential benefits. The objective of this paper is to provide a comprehensive overview of the current state of knowledge and the key debates concerning fertilizer demand in SSA. Technical, economic, and policy issues are addressed. The underlying assumption is that SSA needs to increase fertilizer consumption if it is to meet agricultural growth, poverty reduction, and environmental objectives. An important component of this assumption is that programs are needed to encourage economically sound and technically efficient fertilizer use, not simply increased use.

Determinants of Fertilizer Demand

The demand for fertilizer depends on (a) the price of the crop, (b) the price of fertilizer, (c) prices of other inputs that substitute for or complement fertilizer, and (d) the parameters of the fertilizer production function. In a world of perfect information and well-functioning markets, a farmer would demand the amount of fertilizer that maximizes financial returns—profit maximization occurs when the marginal cost of the last unit of fertilizer applied is equal to the value of the marginal returns. In reality, it is unlikely that African farmers are making profit-maximizing fertilizer decisions because they face significant information, liquidity, and risk constraints that limit effective demand for fertilizer; technical constraints that make it difficult to use fertilizer in combination with recommended crop management practices; and institutional constraints that limit the development of human capital and the performance of input and output markets. Two questions that most farmers will ask before making a fertilizer purchase are:

- Will fertilizer use be profitable (both absolutely and relative to alternative expenditures)?
- Can I acquire the desired amount of fertilizer and use it efficiently?

The profitability question relates to *incentives* and the acquisition and use question relates to *capacity* issues. In diagnosing the causes of weak effective demand for fertilizer it is useful to divide the discussion into these two broad categories.

How Good Are Fertilizer Incentives in SSA?

There has been a tendency to put forth three related hypotheses about the reasons for weak fertilizer demand in SSA:

- Because fertilizer response is weak (output/nutrient ratios <10 for cereals);
- Because price relationships are unfavorable (input/output price ratios >2);
- Because net returns are low (value/cost ratios <2);

A synthesis of studies addressing these three hypotheses suggests the following broad generalizations about incentives for fertilizer use in SSA:

- Maize and irrigated rice exhibit the strongest combination of incentives;
- Sorghum exhibits poor incentives compared to maize, but shows some potential;
- Millet incentives are generally poor;
- Among export crops, tea exhibits good indicators;
- Cotton has relatively poor yield response and mediocre profitability.

For most crops and zones, improvements in profitability could be realized by reducing SSA's input/output price ratios, which are among the most unfavorable in the world. For example, incentives derived from the favorable agronomic potential of fertilizer on maize in East and South Africa (where typical output/nutrient ratios are 17) is dampened by input/output price ratios that are considerably less favorable (5–7) than those in West Africa (2–4) and those in Latin America (1–3). Large gaps between reported minimum (often <2) and maximum value cost ratios (15 for East/South African maize) suggest that yield and price variability may also play an important role in reducing fertilizer incentives.

Improving Incentives

The programs and policies capable of improving incentives are of three types:

- Those that improve agronomic response.
- Those that protect farmers against low and volatile output prices.
- Those that reduce fertilizer costs.

Agronomic response: Improvements in agronomic response will come from investments in the physical environment, in research and technology development, and in improving farmers' management skills. Irrigation infrastructure, conservation farming, and soil and water conservation practices are examples of investments capable of improving the physical environment. There is much talk in SSA about increasing investment in irrigation infrastructure, and little debate about the need for governments to subsidize

costs because of the “public goods” nature of the investment. On the other hand, there is strong resistance by governments and donors to use subsidies to speed up adoption of conservation farming or soil and water conservation practices, despite the growing evidence that these practices have excellent potential to improve productivity and reduce poverty for the majority of SSA farmers, who are unlikely to gain access to land with controlled irrigation.

Investments in basic research and technology development need to increase; SSA spending per scientist has declined by 50% since the 1970s. Scientists need to develop cost-effective research methods that better link researchers, extension agents, and farmers. Fertilizer research is increasingly site-specific, increasingly aimed at “best bet” rather than maximizing recommendations, and, when conducted using participatory methods, it involves a wider range of stakeholders (farmers, extension, government, agricultural exporters and processors, NGOs) than previously. The potential for participatory methods to stimulate rapid diffusion of the complex soil fertility technologies and practices now being developed is not yet well established; extension remains a major challenge, even when stakeholders participate in the process.

Fertilizer’s agronomic potential is often unrealized because of poor land and crop husbandry practices at the farm level. The failure to transmit research results about increasing fertilizer use efficiency (fertilizer/crop rotation interactions, use of micro-doses, soil type/fertilizer interactions) to farmers is also a factor. Many “poor” management practices (late application or inadequate doses) often stem from farmers’ efforts to reduce risk. Response farming techniques and simulation models show promise for better risk management; but researchers need to transfer the lessons learned from these tools to many more farmers.

Output prices: Although price supports and subsidies can protect farmers against low and volatile output prices, these policy instruments tend to be expensive and difficult to manage. Government investments in transportation and communication generally reduce price volatility and price levels more slowly, but in a more sustainable manner than direct price interventions. Other options that show promise are cooperative action by farmers to strengthen their negotiating power, cereal banks and warehouse receipt systems allowing farmers to better the timing of their sales, market information systems that help both farmers and traders make more informed marketing decisions, and storage facilities that reduce losses and provide flexibility in the timing of sales. Developing new products (e.g., animal feed, enriched baby foods, and snacks) and output processing industries can increase demand for coarse grains (e.g., maize, millet, sorghum)—products which experience sharp price declines when production is good.

Fertilizer costs: Extremely high transportation costs associated with bottlenecks at ports and poor road infrastructure contribute to high fertilizer costs. Taxes and sector policies can also increase costs, particularly if policy changes are frequent and unpredictable. Government investments in transport infrastructure, reduced taxes for inputs, and consistent policies regarding input promotion programs will contribute to lower prices. Local production of fertilizer does not appear to be a viable economic option for most countries because current levels of demand are

too low for economies of scale to be realized. If neighboring countries worked to develop regional fertilizer markets, the benefits of local production relative to the costs might become more favorable. Various approaches to reducing farm-level risk can reduce costs and increase demand. Options range from simply selling inputs in smaller quantities to the introduction of weather insurance schemes now being tested on a limited scale.

Improving Capacity to Purchase Fertilizer

Purchases are constrained by low farm incomes (particularly for farmers who are not producing commercial crops), poor access to credit, and lack of market power that can be acquired through building strong farmer organizations for political advocacy and cooperative input/output marketing. Efforts to resolve the income problem include diversification into higher valued export crops and products that can substitute for imports (e.g., horticultural products). Both credit and market power constraints are being addressed in a number of cases through the development of farmer associations; the most successful experiences tend to include sizeable and sustained investments in farmer capacity building. In the past, interlinked markets successfully resolved credit problems for key SSA cropping systems (e.g., cotton in Francophone West Africa, coffee in Tanzania, sugar in Kenya). Recent efforts to liberalize the markets for these sectors have tended to weaken the output market links that ensured high rates of credit reimbursement. New approaches to reduce credit defaults are being developed. Some lending agencies have joined together to create borrower data bases (to reduce the risk of multiple loans to the same borrowers) and others have participated in warehouse receipt programs to collateralize crop output—both efforts increase lender costs but also have the potential to significantly reduce risks of borrower defaults.

Improving Capacity to Use Fertilizer

Potential demand can be increased through agricultural research but increases in *effective* demand require transmission of the knowledge about fertilizer to farmers, along with the skills to use it efficiently. The biggest challenge facing extension services at present is that of developing a strategy to (a) inform farmers about available technologies, and (b) increase farmers' capacity to evaluate, adopt, and adapt the most appropriate technologies for their situation from a pool of available ones. This approach contrasts sharply with SSA's traditional "one size fits all" approach to fertilizer recommendations. Although extension services are viewed as the means of transmitting agricultural knowledge and skills, the crux of the problem goes far beyond poor performance on the part of extension services. The review notes (a) weaknesses in the ability of researchers (both technical and social scientists) as a group to effectively communicate consistent, financially sound recommendations for extension; (b) an apparent lack of strategy for targeting fertilizer technologies and land husbandry knowledge and skills to appropriate agro-ecological and socio-economic situations; (c) limited effort to disseminate fertilizer technologies beyond farmers participating in research trials or contact farmers in extension programs; (d) poor or non-existent monitoring and evaluation of the diffusion process, which limits the ability of research and extension to work together on understanding the

process of adoption and adaptation; and (e) inconsistency in agricultural policies (credit, price, subsidy) that makes it difficult for farmers to assess benefits from year to year and sustain fertilizer adoption. An added challenge is the very low level of literacy in rural Africa, which significantly increases the costs of delivering extension messages.

The solutions to these problems of knowledge diffusion are not self-evident and they will often be location- and crop-specific. In addition, extension messages and methods may also need to differ according to gender, prevalence of HIV/AIDS, and access to markets and infrastructure.

Given budget constraints, more cost-effective collaboration between all the stakeholders in the agricultural transformation process (researchers, extension specialists, NGOs, farmers, input suppliers, banks, exporters and processors) will be needed. The relative importance of different actors will vary by the stage of input market development as will the role of the government. Increased funding for extension appears justified given recent declining trends, but more cost-effective programming of any additional funding will also be needed. There are many examples of “promising” approaches to improve knowledge transfer such as participatory technology development, use of simulation models to fine-tune recommendations, and outreach to the commercial sector to stimulate supply at an early stage in the adoption/diffusion process are but a few examples. Unfortunately, most of these “promises” remain just that, with little evidence of widespread application and impact on effective demand for fertilizer. In situations where lack of effective demand (rather than poor supply) seems to be the binding constraint, much more emphasis needs to be given to identifying successful approaches for diffusion of knowledge and skills.

Clarifying the Role of Fertilizer in the Overall Development Strategy

There is a need for clearer thinking about how fertilizer policy fits into a country’s overall development strategy and goals. Fertilizer’s traditional role as a productivity enhancing agricultural input is being expanded as donors and governments seek to use it as an instrument for achieving a wide range of diverse goals (i.e., GDP growth, poverty alleviation, soil fertility replenishment, soil conservation, food security, and safety net). Although increased use of fertilizer in combination with improved land husbandry practices has the potential to make a contribution in these diverse areas, the types of programs and policies one might implement to achieve these different goals have important implications for the spatial distribution and sequencing of fertilizer promotion efforts. Consider the different needs and outcomes that might be realized by programs to stimulate fertilizer demand for each of the following three categories of crops:

- High value or export crops with reliable markets (horticulture, cotton, tea);
- Fertilizer responsive crops (hybrid maize or irrigated rice) often with weak or risky markets;
- Crops with relatively weak fertilizer response and low output prices (millet, sorghum, and legumes), generally grown in more difficult environments

where integrated soil fertility management may be more appropriate than less complex seed/fertilizer technologies.

Production systems that include the first two types of crops are likely to need less intensive extension on the technical aspects of farming but more attention to the development of input acquisition and output marketing skills (topics that current extension services rarely address) whereas farmers producing crops of the third type will need assistance in improving their technical farming skills and ability to evaluate and adapt complex, integrated management practices to their individual situations.

Although fertilizer use intensity tends to be greatest on high value or export crops, estimates of fertilizer consumption by crop suggest that the largest share of fertilizer in SSA is now applied to cereal crops (40% on high-yielding maize and another 21% on other cereals and pulses). Efforts to expand fertilizer demand for these different situations are likely to have different productivity, economic growth, equity, and environmental implications. For example, promoting fertilizer and improved land husbandry among poor farmers in difficult agro-climates may have positive environmental consequences (reduced soil mining) and poverty alleviation implications (better food security), but it may not contribute as much to growth in GDP or to the development of viable fertilizer supply networks as would a program to expand irrigated agriculture or encourage farmers to increase the intensity of fertilizer use on irrigated crops.

Limited funds will force governments to make choices about which farmers and which crop sectors are given priority for fertilizer promotion programs; at the national as well as at the local level, these choices should be based on a well-defined overall strategy with clearly defined objectives that also take into account the need to develop effective input supply systems.

1. Introduction

Why a Paper on Fertilizer Demand in Sub-Saharan Africa?

Although there has been some progress in agricultural productivity growth in Sub-Saharan African (SSA) during the past several decades, current productivity growth lags far behind that in other regions of the world and is well below the growth required to meet food security and poverty reduction goals set forth in national and regional plans. A few statistics on cereal production illustrate the point. SSA cereal yields averaged 1.1 tons/ha in 2000 while those in Asia, Latin America, and the Middle East/North Africa averaged 3.7, 2.8, and 2.7 tons, respectively. SSA's average annual growth in cereal yields from 1980–2000 was only 0.7% whereas rates for other regions ranged from 1.2 to 2.3%. Growth in SSA cereal production per capita during this period was stagnant, whereas those in other regions increased from 0.90 to 2.3% (statistics from UN Millennium Project 2005). In short, Africa has not yet experienced its "Green Revolution."

Soil scientists are quick to point out that soils in Africa are inherently less fertile than in Asia where the Green Revolution took place (Townsend 1999; Voortman, Sonneveld, and Keyzer 2000; Weight and Kelly 1999). Low inherent fertility is exacerbated by less favorable climate (low, poorly distributed rainfall and high temperatures). The slow productivity growth is not surprising given SSA's less favorable agro-ecological conditions (described more fully in Appendix 1), plus lower investment in irrigation, and much lower use of fertilizer—only 9 kg of nutrients per ha compared to 73 in Latin America, 100 in South Asia, and 135 in East and Southeast Asia (FAO 2004a). A key challenge is determining what types of policies and programs are most likely to assist farmers realize the full potential of available technologies and production practices and at the same time protect the resource base for future generations.

There is ample evidence from experience outside Africa that increased use of inorganic fertilizers has been responsible for an important share of world-wide agricultural productivity growth. Some argue that fertilizer was as important as seed in the Green Revolution (Tomich, Kilby, and Johnson 1995), contributing as much as 50% of the yield growth in Asia (Hopper 1993). Others have found that one-third of the cereal production world-wide is due to the use of fertilizer and related factors of production (Bumb 1995, citing FAO). Research suggests that fertilizer could bring similar productivity gains to the continent. Pieri (1989), reporting on fertilizer research conducted from 1960–1985, confirmed that fertilizer, in combination with other intensification practices, had tripled average cotton yields in West Africa from 310 to 970 kg/ha. Research summarized more recently shows numerous cases of strong fertilizer response for maize in East and Southern Africa (Byerlee and Eicher 1997; Heisey and Mwangi 1997).

The growing contrast between the productivity role played by fertilizer in other regions of the world and the very limited use of fertilizer in SSA has stimulated a

great deal of debate about what the role of fertilizer should be in SSA, and what types of policies and programs will be most likely to help SSA farmers realize the benefits of fertilizers. The World Bank's Africa Fertilizer Strategy Review, to which this paper is contributing, is an effort to provide a comprehensive overview of the technical, economic, and policy issues of relevance to fertilizer policy design and implementation in SSA. The focus on fertilizer in this review is *not* meant to imply that fertilizer alone is the solution to African agricultural productivity problems. Sustained productivity growth in SSA will depend on farmers' capacity to effectively combine a broad range of land, crop, and animal husbandry practices with cost-effective use of modern inputs such as chemical fertilizers and improved crop varieties.

Recognizing the complexity of the agricultural production process, the World Bank Africa Region Environmental, Rural and Social Development Unit has nevertheless elected to focus attention on a single input—fertilizer—because there remains significant debate about the underlying technical and economic evidence on fertilizer potential in SSA and the types of policies, investments, and institutional changes needed to realize that potential. The underlying assumption of this paper (and others in this series) is that SSA needs to increase fertilizer consumption if it is to meet both agricultural productivity growth and environmental (particularly soil and water conservation) objectives. An important component of this assumption is that programs and policies to increase fertilizer consumption need to encourage economically sound and technically efficient use of this expensive input, taking into account the cost-effectiveness of fertilizer as well as alternative and complementary production inputs and practices.

This paper, which focuses on fertilizer demand issues, is one of three background papers commissioned by the World Bank's Africa Region. A second paper examines the financial, economic, social, and political arguments in favor of promoting increased fertilizer use (Crawford, Jayne, and Kelly 2005) and a third paper addresses supply-side constraints on fertilizer use and alternative approaches for improving fertilizer availability (IFDC 2005). These papers were written to serve as background for an e-forum (February/March 2005), organized to elicit "lessons learned" from experienced practitioners. Together, the background papers and e-forum synthesis (Poulton, Kydd, and Dorward 2005) provided a foundation for the subsequent development of a "policy maker's tool kit," prepared with the objective of guiding World Bank staff and others tasked with developing programs to promote agricultural productivity growth in Africa.

The terms of reference for this paper on fertilizer demand are:

...to provide a comprehensive overview of the factors that determine the strength of effective demand for fertilizer at the farm level. Where appropriate, it should include empirical data, especially with regard to physical response to fertilizer use in different contexts, as well as the profitability of fertilizer use in different contexts. The paper is intended to take readers to the "frontier of knowledge" with respect to economic, technical, and institutional factors that affect fertilizer demand in Africa.

It should identify public policies, initiatives, and investments that hold out the best opportunities to shift the fertilizer demand curve out (World Bank 2004).

Looking at “Demand” Through an Economist’s Eyes

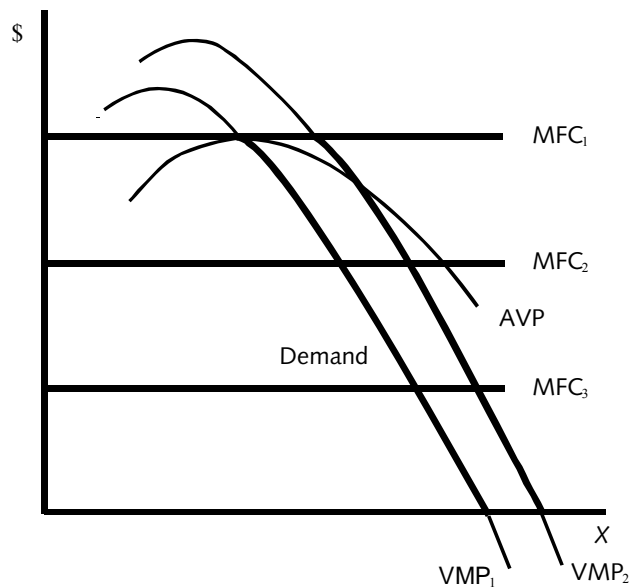
Conceptually, the paper approaches fertilizer from an economist’s market perspective whereby the intersection of the fertilizer demand and fertilizer supply functions determines consumption levels. In other words, consumption is the outcome of the conversion of fertilizer’s economic *potential* into farmers’ effective demand and the fulfillment of this demand through fertilizer supply and distribution systems (Desai 1988). In developing countries, fertilizer’s economic *potential*—determined by the prevailing fertilizer responses and prices—is almost always much larger than *actual use* (Desai 2002).¹

In this paper, we focus on the demand side of the equation. The fertilizer demand function is often referred to as a “derived” demand because it is determined to a large extent by the final demand for the crop produced. In general, the demand for fertilizer depends on (a) the price of the crop(s), (b) the price of fertilizer, (c) prices of other inputs that substitute for or complement fertilizer, and (d) the parameters of the production function that describe the technical transformation of the inputs into an output (i.e., the fertilizer response function) (Debertin 1986).

A profit maximizing decision process at the farm level is often assumed to shape the demand curve. In the case of a hypothetical production process with a single variable input, the farmer wanting to maximize profit would find the point at which the value of the marginal product (VMP= marginal physical product * output price) was equal to the marginal factor cost (MFC=cost of adding the last unit of input). This decision process is illustrated in Figure 1.1, which shows that as the MFC declines (all else equal) the profit maximizing quantity of input demanded increases. If the output price increases or technical change occurs (making fertilizer more productive), the VMP curve shifts upward from VMP1 to VMP2, increasing the demand for the input at any given level of MFC. This theoretical framework suggests that increased output prices or technological changes are the keys to shifting the fertilizer demand curve out and increasing demand.

Because of numerous underlying assumptions, this profit maximizing framework tends to be a theoretical concept that seldom matches perfectly with real farm decision making processes. The theory assumes that the farmer (a) seeks to maximize profits from fertilizer use, (b) knows the physical response curve, (c) is able to estimate output prices for the upcoming marketing season, and (d) faces no input purchase, production, or output marketing constraints or risk. Although all these assumptions are seldom met, the underlying concepts offer a useful framework for organizing the discussion of fertilizer demand *if* the implications of unmet assumptions are addressed. For example, risk considerations and resource constraints such as financial liquidity can influence fertilizer decisions, particularly for resource-poor farmers in SSA.

Figure 1.1 The Demand for Inputs to the Production Process



Source: Authors.

The demand paper has the following structure. Section 2 provides an overview of fertilizer consumption trends from 1961 to present. Section 3 presents a framework used for assessing the determinants of fertilizer demand. Section 4 provides an in-depth discussion of the technical and economic incentives that shape farmers' fertilizer demand and Section 5 reviews what is known about institutional factors that shape farmers' capacity to acquire and use fertilizer. Section 6 is a summary of key constraints to and opportunities for increasing fertilizer demand.

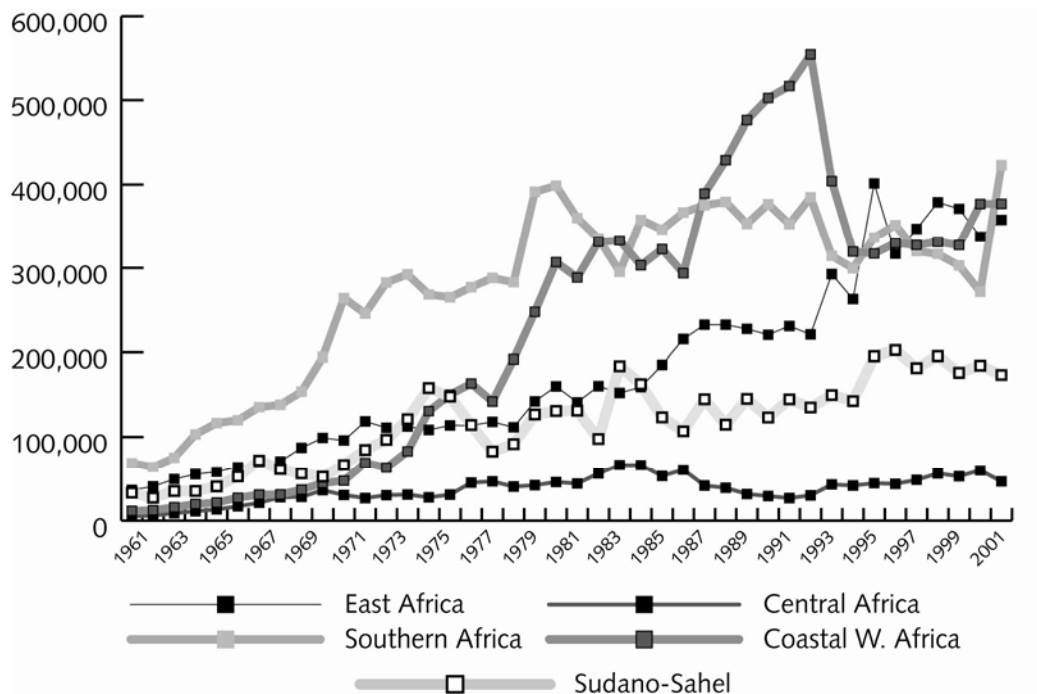
2. Fertilizer Consumption Trends in Africa

Fertilizer consumption trends expressed in terms of aggregate quantities consumed and intensity of use (i.e., kg per hectare of arable land and permanent crops) reflect both demand and supply decisions.

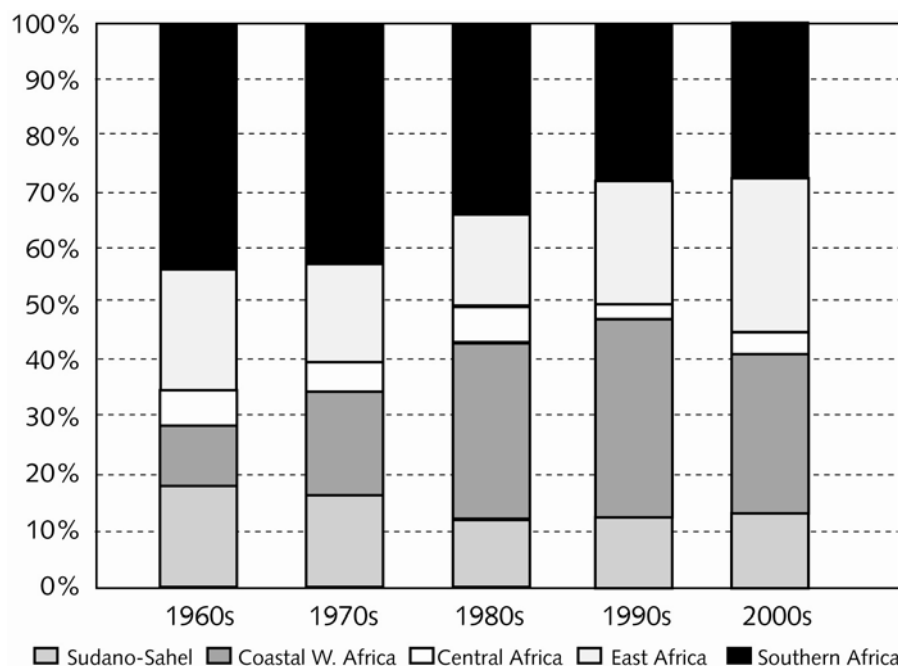
Quantities of Fertilizer Consumed

The entire African continent (including North African countries and South Africa) has consistently represented only 2–3% of world fertilizer consumption; the share for Sub-Saharan Africa (excluding South Africa) is generally less than 1%. Fertilizer consumption for SSA in general grew at an annual rate of 4% from 1961 to 2002; but growth rates declined from about 6% between 1961 and 1989 to only 1% from 1990 to 2002. Figure 2.1 graphs trends in aggregate fertilizer use for each of the five agro-ecological regions of SSA² and Figure 2.2 shows the share of SSA fertilizer used by region. Major policy reforms such as devaluations and subsidy removal (implemented during the 1980s and 1990s) tended to temporarily reduce consumption in individual countries. Because the timing of the implementation for these policies differed across countries, the regional trends are smoother than the county-specific trends. The Central African Region and the Sudano-Sahelian countries have generally consumed less fertilizer than

Figure 2.1 Total NPK Fertilizer Use in Sub-Saharan Africa, 1961–2002



Source: Compiled by author from FAOSTAT data.

Figure 2.2 Distribution of SSA Fertilizer Consumption Trends by Region

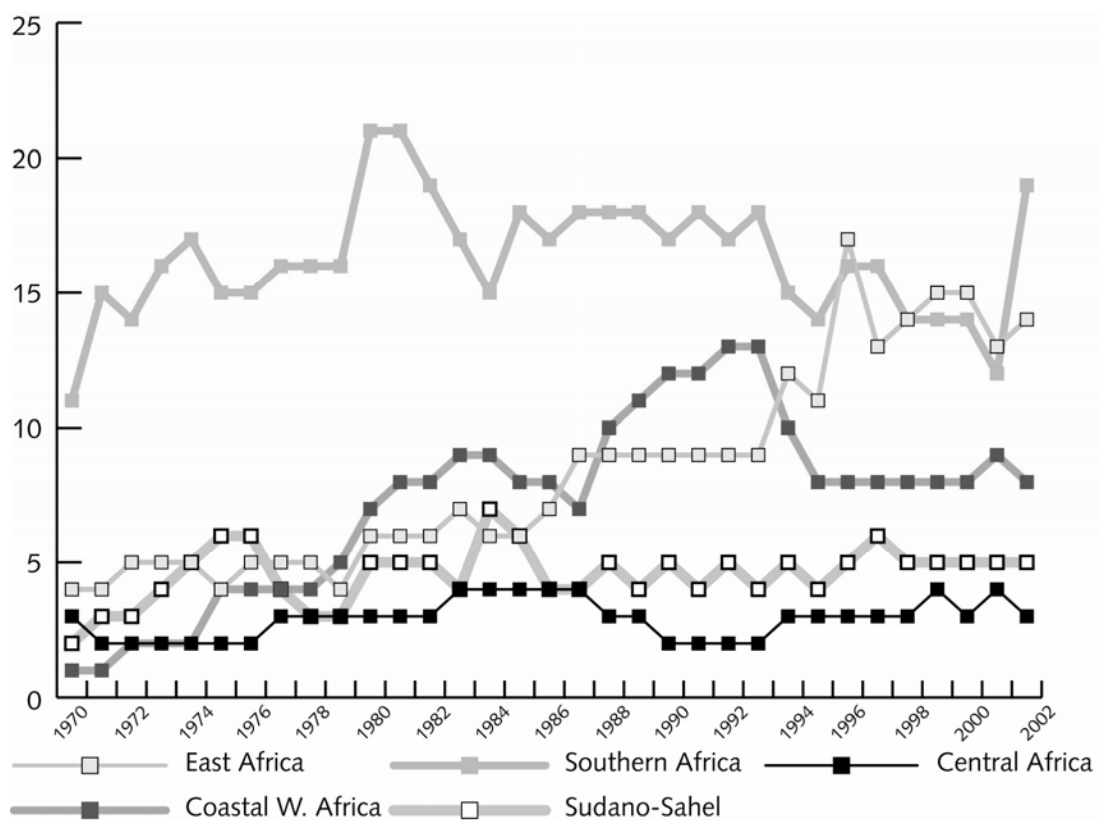
Source: Compiled by author from FAOSTAT data.

other regions while the southern and eastern African regions consumed more. Trends in Coastal West Africa are largely driven by Nigeria, which introduced multiple changes in distribution and marketing during the 1990s while maintaining high fertilizer subsidies until 1997. All regions except Central Africa and the Sudano-Sahel experienced some sustained growth in fertilizer consumption between the late 1970s and the 1990s. In the Sudano-Sahel, low rainfall limits response and expensive transport to land-locked countries raises costs (though not necessarily any more than is the case for land-locked countries in East and South Africa). In Central Africa, higher soil fertility coupled with lower population densities may lead to less perceived need for fertilizer.

These regional figures mask variability among SSA countries. For example, from 1998–2002, four countries accounted for 50% of all SSA fertilizer consumption: Nigeria (14.2%), Zimbabwe (12.4%), Ethiopia (12.2%), and Kenya (11.2%).³ Within each region there are also sharp differences in consumption. Cameroon accounted for 84% of Central Africa's 1998–2002 consumption, and Nigeria for 52% of the Coastal West African consumption. In the East Africa Region, 82% of the fertilizer consumption from 1998–2002 was in two countries: Ethiopia (43%) and Kenya (39%). During the same period, Zimbabwe consumed 48% of all the fertilizer in Southern Africa (excluding South Africa).

Intensity of Fertilizer Use

Figure 2.3 examines the intensity of fertilizer consumption by region from 1970 to 2002. Overall, the average intensity of fertilizer use throughout SSA increased from 4 kg/ha in 1970 to 10 kg/ha in 1996 from which period, the intensity has stabilized with the 2002 intensity being 10 kg/ha. This level has been far lower than that of South Africa (not included in Figure 1.4) whose average intensity has

Figure 2.3 SSA Intensity of Fertilizer Use: 1970–2002

Source: FAOSTAT data.

been 62 kg/ha with a low of 45 kg in 1970 and a peak of 99 kg/ha in 1981. Intensity has generally been highest in Southern (16 kg/ha average) and East (8 kg/ha average) Africa and lowest in the Sudano-Sahel (4 kg/ha) and Central (3 kg/ha) regions. Sustained growth in intensity is most apparent in East Africa.

Some of these regional averages are heavily influenced by individual country observations. For example during the 1991–1995 period, the sugar-producing Mauritius had an extraordinarily high rate (by SSA standards) of 259 kg/ha while Uganda had a very low rate of 0.20 kg/ha.

Fertilizer Use by Crop

It is difficult to find representative SSA statistics on fertilizer use by crop. FAO does not report this in their fertilizer data base because much of the fertilizer consumption data is based on trade statistics rather than tracking of fertilizer use within a country. The only multi-country analyses found on fertilizer use by crop were (1) a 1989 report of six countries covered in a World Bank study (Lele, Christiansen, and Kadiresen 1989), a study of 14 SSA countries believed to represent about 43% of SSA's fertilizer consumption during the early 1990s (cited by Gerner and Harris 1993), and a 2002 study that included 12 Africa countries jointly representing 70–75% of SSA fertilizer consumption during the late 1990s (FAO 2002). Table 2.1 summarizes the results from the most recent study.⁴ It shows that maize was the principal crop fertilized (40% of consumption in

countries covered), followed by other cereals (primarily teff, barley, and wheat in Ethiopia, but also some sorghum and millet elsewhere). Fruits, vegetables, and sugar cane combined represent another 15% of use. Rice, cotton, tobacco, and traditional tubers such as cassava and yams represent 2–3% each.⁵ Because the countries included differ across the three studies identified, it is difficult to draw conclusions about trends. In all studies, however, maize was the dominant crop fertilized. Fruits and vegetables appear to be increasing in importance as well as the diverse group of “other crops,” but more systematic analysis is required to confirm this.

Fertilizer intensity measured as average kg/hectare (not shown in table 2.1) does not follow exactly the same pattern across crops; intensity tends to be higher on tobacco, sugar, and cotton and lower on cereals (including maize) (Gerner and Harris 1993).

The conventional wisdom about fertilizer use in SSA is that much more goes to high value or export crops than to staple food crops. Although the data presented in Table 2.1 are limited in terms of geographic coverage, they suggest that an important share of fertilizer was being used on food crops, particularly maize and other cereals. The extent to which agricultural policies (e.g., input and output price subsidies) influence the share of fertilizer applied to different crops cannot be discerned from the data, but it cannot be excluded from consideration as several countries covered in the Table 2.1 summary had fertilizer subsidies in place during the period covered (e.g., Ethiopia in 1995 and Nigeria in 1996). Nevertheless, the relatively large share of fertilizer used on maize probably reflects some combination of (a) the relatively high fertilizer response of maize, (b) strong market demand for maize, which converts it from a traditional “food” crop to a “cash” crop, and, in some cases, and (c) subsidized prices. This suggests that in building fertilizer demand, traditional food crops should not be ignored. Given their importance as a share of total cultivated land, they will be particularly important crops for stimulating the use of fertilizer to address problems of nutrient mining (see section 4). If efforts to build fertilizer demand focus exclusively on export and niche crops, fertilizer’s potential contribution to improvements in soil nutrient content and organic matter will be limited to a very small share of SSA’s arable lands and the aggregate fertilizer demand will remain low, reducing opportunities for the supply system to realize economies of scale. Desai and Gandhi (1988) have argued that rapid expansion of fertilizer demand in Asia as well as in Africa requires substantial increases in the use of fertilizer on cereal and other food

Table 2.1 Fertilizer Use by Crop in the Late 1990s

Crop	Percent of Consumption
Maize	40
Other cereals and pulses	18
Fruits and vegetables	8
Sugar cane	7
Rice	3
Cotton	3
Tobacco	2
Traditional tubers	2
Other crops	19

Source: Compiled by authors from data in FAO 2002 covering 12 SSA countries.

crops; but this will only occur if those crops become more commercialized, which highlights the link between increasing fertilizer demand and strengthening output markets.

This broad-brush description of fertilizer consumption trends leads one to ask why such stark differences exist across countries, regions, and crops. The challenge is to understand the extent to which demand or supply is constraining in a particular situation and to identify corrective actions. The rest of this document provides guidance on analyzing the demand constraints while the companion report (IFDC 2005) focuses on the analysis of the supply side.

3. Farm-level Fertilizer Demand as a Function of Incentives and Capacity

In reality, it is extremely unlikely that African farmers are making profit-maximizing fertilizer demand decisions as described in the introduction because most farmers face significant economic constraints (e.g., high price risk and low incomes resulting in poor financial liquidity) that limit their effective demand for fertilizer, technical constraints that make it difficult to use fertilizer in combination with recommended crop management practices, and institutional constraints that limit the development of human capital and the performance of input and output markets. In diagnosing the causes of weak effective demand for fertilizer, it is necessary to use an analytical framework that goes beyond the simple arithmetic of profit maximization. We have found it useful to think of the determinants of fertilizer demand in terms of the financial incentives to purchase it and the capacity to acquire and use it (Reardon et al. 1995; Reardon et al. 1999a). These two broad categories of determinants are derived from the two questions that most farmers will ask before making a fertilizer purchase:

- Will fertilizer use be profitable (both absolutely and relative to alternative investments)?
- Can I acquire the desired amount of fertilizer and use it efficiently?

The profitability question relates to incentives and the acquisition and use question relates to capacity issues.

Incentives to Purchase Fertilizer

Incentives include factors that directly influence the profitability of the fertilizer such as fertilizer yield response and input and output prices. There is an important distinction between researchers' perceptions of incentives (which shape potential demand) and farmers' perceptions of the incentives (which shape effective demand). There is often a significant gap between the two because farmers' knowledge of or experience with fertilizers may lead him/her to perceive the yield response and profitability as substantially lower than that perceived by researchers and extension personnel. Narrowing this gap is one of the challenges faced by extension services promoting fertilizer.

Incentives are also shaped by relative returns, (i.e., the profitability of the expenditure relative to the returns expected from alternative farm and non-farm opportunities or "needs" such as education and health), and the risk of the expenditure, both in absolute terms and relative to the risk of alternative opportunities. Risks associated with fertilizer use in SSA are particularly important because variability in fertilizer response (production risk) and output prices (price risk) tends to be higher in Africa than elsewhere. Fertilizer response is highly variable across locations (due to climate and soil), across farmers (due

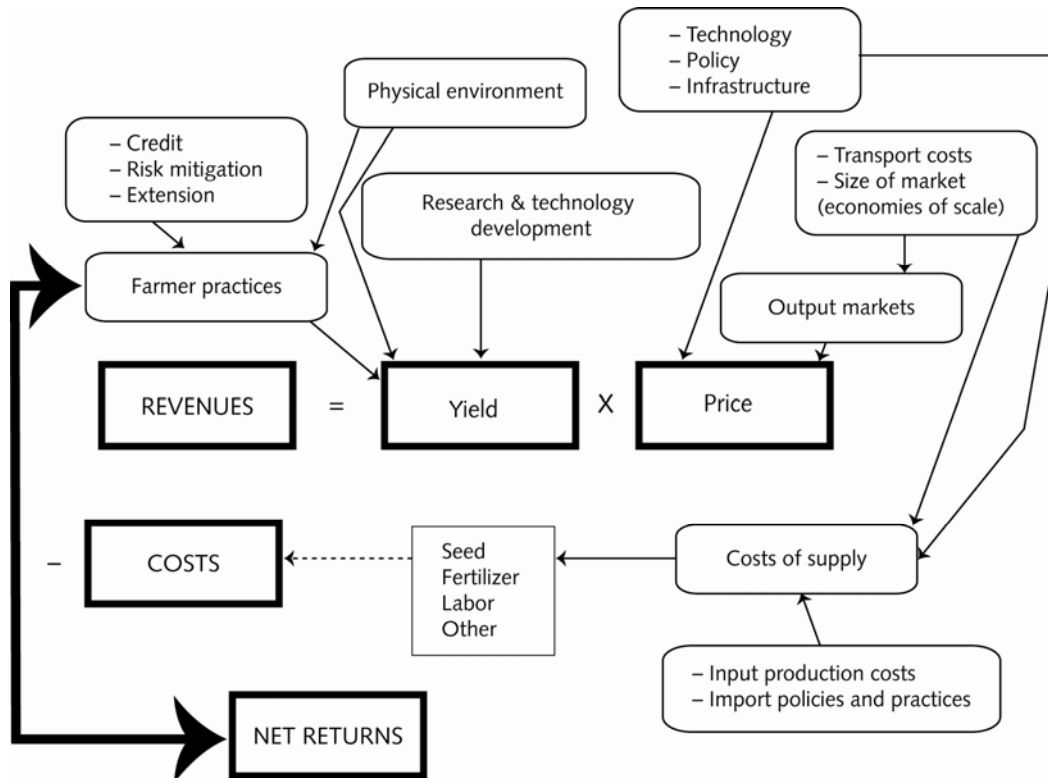
largely to different management practices), and across time (due to changes in climate and soil quality). Output prices are also variable and easily influenced by changes in aggregate national and regional production of key crops, international trade agreements, and policies to ensure urban food security. Because only a small portion of many crops ever enters a market (the bulk being consumed on farm), many agricultural markets in Sub-Saharan Africa are “thin,” meaning that a small change in total production can result in a large proportional change in marketed surplus. As a consequence, prices can be highly volatile, increasing output price risk. For example, at the period when maize production in Ghana was increasing rapidly due to the introduction of seed/fertilizer technologies, the output/fertilizer price ratio fluctuated by as much as 100% from season to season, compared to less than 10% fluctuations in the Punjab at a comparable stage of development (Byerlee 1994). Although fertilizer prices are usually known at the time of purchase, they too can be highly variable across time and space, making it important for researchers, extension agents and farmers to reevaluate fertilizer doses and profitability frequently.

Capacity to Acquire and Use Fertilizer

Capacity to use fertilizer depends on both human capital (health and nutritional status of the farm family, labor availability, education and skill levels) and financial capital (income, assets, and access to credit). Improvements in human capital are more likely to shift the demand curve out by moving farmers’ perceptions of agro-economic potential (and effective demand) closer to the true agro-economic potential. Improvements in financial capital will not shift the demand curve out but will move a farmer along the same demand curve to a higher quantity of fertilizer used. Both incentives and capacity are affected by broader factors such as technologies, institutions, and policies, by trends such as globalization, and by extension and demonstration programs that are designed to improve crop husbandry knowledge and induce farmers to purchase inputs and/or make more effective use of them.

Figure 3.1 is a schematic presentation of this framework. It illustrates some (not all) of the many factors that influence farmers’ incentives and capacity to use fertilizer while highlighting the central importance of financial considerations. Incentives are shaped largely by factors that affect output prices and input costs (e.g., policies, infrastructure, transport costs, market size) as well as investments in technology development that increase potential yields. Capacity is largely a function of credit availability, risk mitigation programs, and extension services that influence farmers’ production practices and actual yields. We use these two broad categories of determinants—incentives and capacity—to organize the discussion in the next two sections of the paper.

Figure 3.1 Conceptualizing Fertilizer Demand: A Function of Financial Incentives and Farmers' Capacity to Use and Acquire the Input



Source: Adapted from Crawford et al. 2003

4. Incentives Shaping Fertilizer Demand

Analytical Methods Used to Evaluate Fertilizer Incentives

Most of what we know about incentives for farmers to use fertilizer in SSA comes from agronomic and economic analyses of fertilizer trials conducted either at research stations or on-farm and from on-farm demonstrations using farmers' management practices.

Fertilizer trials are of different types. In some cases, researchers focus on quantifying the yield response of one key nutrient (N, P, or K) while other nutrients are applied at high levels that do not constrain the response of the focus nutrient. Other studies do not try to separate the response of the different nutrients, using multiple doses of commonly available compound fertilizers such as 15-15-15 or 17-17-17. This latter approach was popular during the 1970s when FAO provided support for fertilizer research in an ambitious program that covered many SSA countries. The key difference between on-station and on-farm trials is the ability of the researcher to control variables other than differences in fertilizer. The more variables that are controlled, the more certain the researcher can be that yield changes are due to changes in fertilizer. The disadvantage, however, is that by controlling so many variables researchers usually obtain much higher yield responses than would be the case on a typical farmers' field (Boughton et al. 1990 provide a good discussion of the trade offs between research station and on-farm trials).

On-farm demonstrations tend to be comparisons of farmers' practices with a single dose of fertilizer that has been identified as most promising through agronomic and economic analysis of fertilizer trial data. Although easy to implement, the weakness of the single-dose comparison plot is that the farmer does not have an opportunity to see for him/herself the incremental costs and benefits of moving from lower to successively higher doses of fertilizer.

The first step in evaluating incentives is to establish whether there are statistically significant differences in yield response among the various treatments represented in the trials or demonstrations. This is usually done by the agronomists having conducted the trials using analysis of variance and, data permitting, estimates of response functions. The next step involves the use of partial budgets to calculate the net returns to different fertilizer applications. A partial budget looks at only the costs and returns that have changed as a result of the fertilizer application. The calculations involved can be summarized as follows:

$$\text{Net Returns} = (Y * PO) - (F * PF) - \text{OTH}$$

Where Y = yield increase attributed to fertilizer use

P O = price of output

F = quantity of fertilizer used

PF = price of fertilizer

OTH = other costs of acquiring/applying fertilizer and harvesting additional yield

One then calculates a marginal rate of return (MRR) for each marginal increase in the fertilizer dose.⁶ The MRRs are then compared to a minimum acceptable MRR, which is identified by researchers in consultation with farmers using information about prevailing interest rates and returns to other economic activities. The treatment with the highest net benefit and an MRR higher than the minimum acceptable MRR becomes the tentative recommendation, subject to sensitivity and risk analysis. Using spreadsheets for the partial budgets makes it particularly easy to vary assumptions about yields and prices for sensitivity analysis.

The steps summarized above are the ones recommended by most economists for assessing the financial incentives to fertilizer use. Results represent a close approximation to the profit maximizing decision process that underpins the fertilizer demand function described in the introduction (section 1.B.). There are many good guidebooks on doing this type of analysis (Boughton et al. 1990; CIMMYT 1988; Crawford and Kamuanga 1988; Dillon and Hardaker 1993), so we do not go into the details.

Because agricultural scientists doing fertilizer research in Africa often focus their technical research on maximizing response or redressing problems of nutrient depletion in soils, economic considerations are often taken into account after a potential recommendation has been identified rather than using the partial budget procedure described above. The calculation of value/cost ratios is the most commonly used approach to evaluate the financial incentives for a farmer to use a fertilizer treatment that has been identified using non-economic criteria. A value/cost ratio (VCR) is based on an analysis of the change in returns and costs of the recommended fertilizer treatment vis a vis no fertilizer use or the farmer's current practice:

VCR = Value of additional yield obtained from fertilizer use/cost of fertilizer used

The point at which the value/cost ratio is equal to one is, in principle, the same as the profit maximizing point when the value of the marginal product divided by the marginal factor cost (mentioned in section 1.B) is equal to one. There are, however, two important differences: (a) the value/cost ratio is a measure of average rather than marginal change in profitability because it does not examine incremental changes in returns as doses increase; and (b) the costs included in a value/cost ratio are generally limited to the expenditure on fertilizer rather than the full range of costs (including labor) associated with fertilizer use. To account for these differences in calculation and the fact that farmers do not have perfect knowledge of crop prices and yield response, analysts have established "rules-of-thumb" for interpreting these ratios. Most consider a ratio equal to two as the minimum requirement for a farmer to adopt fertilizer and a ratio of three or four to be necessary when production or price risk is high.

A VCR is simple to calculate and can reliably identify fertilizer recommendations that are unlikely to be adopted by farmers (i.e., those with a $VCR < 2$). It is a poor tool for identifying the most profitable fertilizer dose and also for determining the likelihood of adoption when the VCR is greater than two (because it does not consider alternative uses of resources). In the partial budget analyses, alternatives to fertilizer use are taken into account when establishing the target marginal rate of return. Appendix 2 provides an illustration of how recommendations based on a VCR analysis might differ from those based on a more complete partial budget analysis. The illustration shows that in some cases a $VCR > 2$ can be associated with a fertilizer dose that has a negative marginal value product (i.e., the farmer is earning less money than he/she would if using a lower dose). Despite these shortcomings, the VCR's ease of calculation has made it the most commonly used indicator of financial incentives for fertilizer use found in the published literature.

How Good Are Fertilizer Incentives in SSA?

This is an extremely difficult question to address at the macro level because fertilizer response and input/output prices are best analyzed at the micro level for specific agro-ecological and market situations; it is also important to take into account the individual farmer's resource constraints and risk preferences. Because there has been a tendency to put forth broad hypotheses about the salient reasons for weak fertilizer demand in SSA, Yanggen et al. (1998) evaluated the extent to which empirical evidence was available to support three overlapping hypotheses about why fertilizer demand was low in SSA:

- Because fertilizer response is weak (measured using output/nutrient ratios)
- Because price relationships are unfavorable (measured using input/output price ratios)
- Because net returns are low (measured using value/cost ratios)

Table 4.1 reports typical,⁷ minimum, and maximum values for the three key indicators of incentives commonly reported in the fertilizer literature. An O/N (output/nutrient) ratio shows how many kg of additional output a farmer can obtain from a kilogram of fertilizing nutrient. Ratios of ten or higher are considered efficient for cereals; there do not appear to be any generally acceptable rules-of-thumb for other crops. An I/O (input/output price) ratio shows the number of kg of production a farmer needs to purchase one kilogram of fertilizer; the lower the ratio, the higher the incentive; I/O ratios less than 2 are generally considered attractive to farmers. Value/cost ratios are rudimentary indicators of potential profitability. Because MRRs, the economist's preferred measure of profitability, were seldom reported in the literature, Yanggen et al. (1998) relied on VCRs. The rule-of-thumb for VCRs is that they must be at least two before a farmer will consider fertilizer use; in high-risk production environments the minimum VCR for adoption may be 3 or 4.

Yanggen et al. (1998) report these indicators by crop and region (West versus East/Southern Africa). We cite Yanggen et al. (1998) extensively in this section because it provides the most thorough review of fertilizer response and financial incentives that we found.⁸ Before reviewing the key conclusions from this

synthesis, its limitations must be recognized. First, the indicators used should be considered rough estimates of relative incentives; they do not provide the type of solid analysis of absolute and relative profitability one obtains through the partial budget process. Second, it is not clear how representative the results are because so much of SSA fertilizer research is not published and accessible.⁹ Third, VCRs reported in the agronomic literature were usually based on “financial” prices, which may have reflected subsidies that no longer exist. Fourth, making comparisons between SSA and other regions of the world poses problems in terms of correctly matching similar agro-ecologies. To control for this problem, the inter-regional comparisons focused on rain-fed agriculture for all crops but rice, where there are results for both rain-fed and irrigated rice. Rainfall levels, soil types, and agro-ecological zones are shown when they were reported in the base documents.

		Yield Response (O/N Ratio)			Price Incentives (I/O Price Ratio)			Profit Incentives (V/C Ratio)		Observations on Patterns and Incentives
Crop	Region	Typical	Min	Max	Typical	Min	Max	Min	Max	
Maize	E/S Af.	17	2	52	5–7	3.9	13.9	1	15	Maize consumes about 25% of fertilizer used in SSA but a high percent of maize production receives no fertilizer at all.
	W. Af.	15	0	54	2–4	1.9	5.1	.69	26	
	L.A.	10	5	18	1–3	.01	7.1	1.2	5.3	
Cotton	E/S Af.	5.8	0	7	1.8	.07	4.6	.00	3.1	Accounts for about 17% of SSA fertilizer use; a very large percent of cultivated cotton area is fertilized.
	W. Af.	5	2	12	1.9	.09	3.7	.61	3.7	
Rice (irr.)	W. Af.	12	7	16	2	.2	4.5	1.6	3.97	Accounts for only 4% of SSA fertilizer consumption. Total SSA area in rice is small % of total cultivated area.
	Asia	11	7.7	33.6	2.5	1.4	5	1.5	3.1	
Sorghum	E/S Af.	10	4	21	6	3.2	9.3	1.5	2.6	Accounts for 8% of fertilizer used in SSA; very small portion of total sorghum area is fertilized.
	W. Af.	7	3	14	2–4	1.4	4.9	1	18	
	Asia	7	2.8	21	2	1.7	2.6			
Millet	W. Af.	7	2.8	21				.5	39	Accounts for 3% of fertilizer used in SSA; very small portion of total millet area is fertilized.
	Asia	20	3	27				<1		

Table 4.1 Fertilizer Incentives: Summary of Key Indicators by Crop and Region

		Yield Response (O/N Ratio)			Price Incentives (I/O Price Ratio)			Profit Incentives (V/C Ratio)		Observations on Patterns and Incentives
Crop	Region	Typical	Min	Max	Typical	Min	Max	Min	Max	
Ground-nuts	W. Af.	9	4	21	3	.3	4.2	1.5	5.8	Accounts for 1% of fertilizer used in SSA although a major cash crop in many countries.
	Asia	6.5	6	17	1	.7	1.2			
Coffee	E. Af.	8.5	5	10						Accounts for <1% of fertilizer used.
	W. Af.	4	2	6						
Tea	E. Af.	14	8	35						Accounts for <1% of fertilizer used.

Source: Yanggen et al. 1998.

Notes: Information on VCRs was sparse, and costs that were used in calculating ratios were poorly documented, hence no attempt was made to generalize about "typical" VCRs. Information about shares of fertilizer consumption is drawn from Gerner and Harris (1993). Three crops which use a large share of SSA fertilizer (wheat 14%; sugarcane 11%; and tobacco 5%) are not covered because they are important crops in only a few countries and very little information about "incentives" for these crops was found. The shares reported by Gerner and Harris (1993) differ from those reported in Table 1, section 1.C. of this report because of differences in time periods and countries covered.

Appendix 3 provides a crop by crop synthesis of our conclusions and supporting evidence about fertilizer incentives drawn from the Yanggen et al. (1998) document. The bullets below present an abbreviated synthesis that complements the information in Table 4.1.

- Among the cereal crops covered, maize (SSA's most important fertilizer consumer) and irrigated rice exhibit the strongest incentives.
 - O/N ratios and VCRs equal or exceed standard benchmarks for both crops
 - The maize ratios exceed those for Latin America, whereas the rice ratios are comparable to the Asian examples
 - Yields per hectare are high: 2–4 tons for maize and 4–6 tons for rice
 - On the down side, maize profitability is threatened by high yield variability (across sites and seasons) and by unfavorable I/O price ratios; both discourage fertilizer use for the vast majority of maize farmers
- Sorghum exhibits poor incentives compared to maize, but still showed some potential
 - O/N ratios were comparable to Asian examples (5–6 range)

- SSA sorghum yields tended to be less than one ton vs. one and one half tons elsewhere
- Using fertilizer in combination with crop residues, manure, or water and erosion control measures considerably increases sorghum response to fertilizer and is associated with higher yields (1.5 tons)
- Millet incentives were generally poor
 - Yields rarely exceeded one ton and were frequently <500 kg
 - O/N ratios tended to be lower in West Africa than in Asia
 - VCRs tended to be higher in West Africa than in Asia, but generally <2
 - Despite the generally poor incentives, millet is a crop that is grown in areas where maize and sorghum cannot grow so continued efforts to improve response will be important to a large share of SSA farmers
 - Response is best when fertilizer is used in combination with good land husbandry practices
- Among the export crops covered, only tea—a crop whose production is limited to a few areas in SSA—exhibits good indicators
- Cotton has relatively poor yield response and mediocre profitability

In sum, Yanggen et al. (1998) conclude that (a) high-productivity maize and rice technologies are available, but more adaptive research and improvements in extension programs are needed to adapt them to diverse smallholder production environments, (b) sorghum and millet technologies (millet more so than sorghum) are not yet highly productive so more basic research is required, with a focus on increasing fertilizer efficiency through complementary inputs and land husbandry practices, and (c) there is substantial room for improving fertilizer technologies for export crops, particularly cotton.

For all crops and zones covered in Table 4.1, improvements in profitability could be realized by reducing SSA's I/O price ratios, which are among the most unfavorable in the world. It is particularly important to note that while the agronomic potential of fertilizer on maize in East and Southern Africa is extremely good, the economic potential is constrained by price ratios that are less favorable (5–7) than those in West Africa (2–4) and those in Latin America (1–3).

Although the maximum VCRs shown are all very favorable, the minimums are all below the benchmark level of 2, suggesting that for each crop/zone examined there is a risk of unprofitable fertilizer use. The synthesis in Yanggen et al. (1998) offers some insights about fertilizer incentives in SSA for different crops and regions and the relative importance of agronomic versus price constraints. It also raises many questions about the quality of the data base on fertilizer response and profitability available for doing this type of analysis.

Improving Fertilizer Incentives

The preceding discussion synthesized information on fertilizer response, input prices and output prices that affect fertilizer profitability and demand incentives. The conceptual framework presented in Figure 3.1 stressed the centrality of these

three variables but also identified a wide range of indirect determinants of fertilizer profitability that shape these three key variables. A good understanding the role played by these indirect determinants of fertilizer demand is essential in the analysis and design of policies and investments to stimulate fertilizer demand. These indirect determinants include the physical environment, infrastructure, government tax and price policies, credit, and agricultural research (See figure 3.1). If financial analysis shows input use to be unprofitable or of low profitability, opportunities for increasing the profitability can be found by examining the various factors influencing yields, prices, and costs. In the following sections we discuss the most important indirect determinants shaping each of these direct determinants and identify public policies, initiatives, and investments that are discussed in the literature as options for improving fertilizer incentives. Before looking at each category of determinant in-depth, we discuss the issue of risk and uncertainty because improving fertilizer incentives in SSA is concerned, in large part, with reducing the risks and uncertainty inherent in fertilizer decision making. Reducing risks can change farmers' perceptions of fertilizer incentives so that they better approximate the full potential of fertilizer documented in the agronomic and soil science literature.

Risk and Uncertainty

We use the definitions for risk and uncertainty proposed by Hardaker, Huirne, and Anderson (1997) where uncertainty refers to imperfect knowledge and risk refers to uncertain consequences, particularly exposure to unfavorable consequences. In SSA two of the greatest areas of uncertainty are future rainfall patterns and output prices; these are also two of the greatest sources of farmers' exposure to risk with consequences for large losses of income or missed opportunities for increasing income. In addition, there is institutional risk associated with changes in government policies that influence farm production and profitability and personal risk associated with illness or death (a risk that has been increasing in SSA due to the spread of HIV/AIDS). The combination of production, price, government, and personal risk are generically referred to as *business risk*. A separate category of risk is *financial risk*, which is a function of the overall indebtedness of the farm and measured as the ratio of debt to total capital. For most SSA farmers, debt is limited to seasonal credit for agricultural inputs and short-term (1–5 years) credit for agricultural equipment and traction animals.

In our discussion of agronomic response below we will be addressing issues of *production risk* or low yields due to poor rainfall, inappropriate use of inputs, pests, etc. All these factors decrease fertilizer response and farmers' perceptions of it; this results in a farm-level demand curve for fertilizer lower than that suggested by agronomic research. In the section on prices, we talk about market risks or low net returns to agriculture due to unfavorable prices for purchased inputs or marketed output.

Agronomic Response

Figure 3.1 highlighted the important role that the physical environment, research and technology development, and farmer practices play in shaping crop yields; these are the same factors shaping fertilizer response.

Investing in the physical environment to improve fertilizer response. SSA cannot radically change the relatively poor natural endowment it inherited in terms of soil and climate, but governments can make investments and, through policy, encourage farmers to make investments to improve agronomic response in difficult environments and to take full advantage of fertilizer's potential in the better endowed regions such as the east and southern African highlands. There are two ways of doing this: (a) investments in irrigation, and (b) improved water and land management for rain-fed systems.

Irrigation: The Asian Green Revolution provides ample evidence of the important role played by irrigation in reducing the risk of fertilizer adoption, increasing crop yield response to fertilizer and stimulating growth in aggregate agricultural production (Desai 1988; Fan, Hazell, and Thorat 1999; Fan, Zhang, and Zhang 2002). Although irrigated agriculture is not well developed in SSA and the potential for expansion appears more limited than in Asia, there is strong evidence for (a) more fertilizer use under irrigated conditions, and (b) significantly enhanced fertilizer response when improved technologies (seed varieties and seeding methods, improved leveling of fields) are used in combination with fertilizer and irrigation in SSA (Bonneval, Kuper, and Tonneau 2001; Mariko and Chohin-Kuper 2001). Irrigation has the greatest potential to significantly increase yields/hectare by avoiding the risks associated with rain-fed agriculture and by increasing fertilizer efficiency. However, the downside of irrigation investments must be considered. Past experience with large-scale irrigation in SSA (and elsewhere) reveals sizable engineering and management challenges. Also, irrigation investments tend to benefit a relatively small share of farmers and land area, diminishing the aggregate impact of increased fertilizer use on economic indicators such as GDP and levels of poverty.¹⁰ Finally, irrigation investments tend to be very expensive, at least for the large scale projects. In short, investments in irrigation (both large and small scale) have the potential to significantly increase fertilizer response; but decisions to invest in irrigation must be based on careful analyses of the full range of costs and benefits to the irrigation project and not simply on the limited goal of increasing fertilizer response.

Improved water and land management: There are a variety of "schools" or "approaches" to improved water and land management that have been pursued in SSA during the recent past. Among the approaches most commonly mentioned in the SSA literature are practices such as natural resource management (NRM), integrated soil fertility management (ISFM), improved land husbandry (LH), conservation agriculture (CA), and soil and water conservation (SWC). While the emphasis differs from one school to another, the broad objectives tend to be similar: understand, manage, and improve land resources used for crop, livestock, and forestry production. Following research on soil nutrient depletion during the early 1990s (Stoorvogel and Smaling 1990; van der Pol 1992), which showed alarming rates of nutrient loss, attention focused on SWC, NRM, and ISFM as means of reducing nutrient losses, improving moisture retention, and increasing organic matter. Over time, there has been growing recognition of the need to look at land management from a broader land husbandry perspective. Good land husbandry involves the active management

of rainwater, vegetation, terrain, plant nutrients and soils, including their inherent biota. Farmers who improve land husbandry aim to better match land uses with management practices; they manage soil organic matter and create and maintain favorable soil structure, rather than merely preventing physical loss of water and soil (as is the case with most SWC and NRM approaches) (Bot and Benites 2001).

Most of the nutrient depletion studies argue that the high rate of nutrient mining in and of itself should justify government and/or donor intervention to increase fertilizer use so the mining can be stopped before the productivity of the soils declines to a level where reversal will no longer be possible.¹¹ Estimates of levels of fertilizer needed are usually much higher than what a typical smallholder farmer would be willing or able to use under rain-fed conditions. For example, 75 to 100 kg of fertilizer per ha are recommended in Mali and Zimbabwe to simply maintain current nutrient levels, with no information presented on the increased yield that might be attributed to the fertilizer (Henao and Baanante 1999). The dilemma with this line of reasoning is that it proposes a rationale for increasing fertilizer consumption without addressing the underlying need to increase fertilizer efficiency; without increases in efficiency there is unlikely to be a sustainable shifting out of the demand curve. Henao and Baanante (1999) confirm the potentially important role of management practices when they do sensitivity analyses showing that the amount of NPK needed to maintain nutrient balances would decline by about 45% if erosion and leaching were reduced and a larger share of crop residues were returned to the soil.

Research on natural resource management (NRM) and integrated soil fertility management (ISFM) practices tends to take a slower but possibly more sustainable approach to problems of soil degradation, using various mechanical and organic methods to increase soil quality to a level where small amounts of inorganic fertilizer can act as effective and efficient complements. Recent research suggests that this slower approach may not be as detrimental to mined soils and production as originally thought. For example, Gigou and Bredoum (2002) found that using ISFM it is possible to increase yields despite declining levels of soil N and soil organic carbon and Snapp (1998a, 1998b) showed that smallholder farmers in Malawi could successfully address P sustainability issues using biological approaches (maize/legume intercrops) either with or without mineral fertilizers; phosphorus recycling was much higher in the intercropped systems than for monoculture maize. Legume intercrops can also contribute to overall crop productivity by making N available to crops at the time they need it (Giller 2002; Sanginga 2003). Research on integrated soil fertility management practices has also identified numerous situations where the use of organic fertilizers to improve soil quality results in higher response for inorganic fertilizers than if they had been used alone (IFDC 2002; Place et al. 2003; Vanlauwe et al. 2002; Weight and Kelly 1999).

Recent research, particularly in the Sudano-Sahelian regions of SSA, has shown the yield increasing benefits of mechanical practices that increase soil moisture: for example, Kaboré and Reij (2004) writing about improvements in traditional planting holes in the Yatanga region of Burkina Faso and Sanders, Shapiro, and Ramaswamy (1996) reporting on a variety of techniques developed to improve

soil management and make fertilizer use more efficient in millet and sorghum production in West Africa. In most cases there is evidence that fertilizer efficiency increased with these practices or that farmers not using fertilizer began to use it. There is also evidence from aerial photos and satellite imagery in Mali and Burkina Faso that villages having benefited from extension programs in natural resource management (anti-erosion practices and improved forest management) show fewer signs of deteriorating vegetative cover than neighboring villages (i.e., less expansion to marginal lands and more intensification on existing plots) (Tappan and McGahuey 2004). There is some limited evidence that this intensification has been accompanied by increased fertilizer use (particularly on cash crops such as cotton), but the issue has not been studied adequately (Kelly 2003).

Conservation agriculture is a relatively new approach in SSA that is currently being tested in Zambia (Haagblade and Tembo 2003), Zimbabwe, Tanzania and Ghana. Although relatively new to SSA, CA has a well documented record of successfully improving land husbandry and crop productivity in Latin America (FAO 2001). CA widens the concept of better land husbandry, taking into account crop and animal husbandry and natural resources in a manner that creates a commercially viable and sustainable production system (Bot and Benites 2001). Rather than focus on soil and water conservation, CA attempts to minimize or avoid the soil-damaging effects associated with tillage-based crop production methods by developing zero-tillage production practices. Beneficial effects (summarized in Bot and Benites 2001) are increased infiltration of rainwater (Roth 1985), reduced soil erosion and increased groundwater levels (Derpsch 1997), less leaching of soil nutrients and farm chemicals (Becker 1997), and increased soil organic matter capable of turning agricultural land into a carbon sink (Schlesinger 1999).

In our view, arguments for maintaining nutrient balances through high doses of mineral fertilizers are not yet well substantiated due to poor data on yield and profitability and evidence from ISFM, CA, SWC, and NRM research that alternate technologies and practices are available. Although evidence from recent research is promising in terms of the availability of technical solutions for maintaining soil quality, evidence on adoption and scaling up of the results of ISFM, CA, SWC, NRM and other similar research approaches is weak. This makes it difficult to estimate the potential impact that these varied approaches might have on fertilizer demand and calls for more attention to issues of stimulating adoption of technologies capable of improving land husbandry while increasing fertilizer use efficiency.

Investing in research and technology development to improve fertilizer response.

There are three aspects of agronomic research on fertilizer that merit attention: (a) publication and reporting of fertilizer research results, (b) evolution of research methods and themes, and (c) funding.

Publication and reporting: Limited publication of fertilizer response research makes it difficult to find; and poor documentation of trial details makes it difficult to perform economic analyses and determine the trial's relevance for other sites and situations. Yanggen et al. (1998) describe a number of difficulties

encountered in finding reports of fertilizer research that were documented well enough to permit comparisons of information on yield response across sites and crops. Failure to differentiate between average and marginal response was frequent as was failure to mention seed varieties and describe complementary practices such as use of manure or pesticides. The tendency for economic analyses to be added after the fact rather than being considered an integral part of the fertilizer response analysis often results in trials that do not include enough different treatments and reports that do not contain the data necessary for marginal analyses of profitability. Such problems were encountered in Rwanda when fertilizer response data from before the 1994 war were reviewed and potentially profitable crop/dose combinations for 2000 were identified and mapped in an effort to provide user-friendly guidelines for extension workers throughout the country (Kelly and Murekezi 2000; Murekezi 2000). A similar review of past fertilizer response data was conducted for Zambia (Donovan et al. 2002). Both studies reported problems similar to those mentioned by Yanggen et al. (1998). Fertilizer response research is expensive and can take several years of work; poor documentation of methods and results limits the ability of other researchers to add value to the basic agronomic findings through economic analysis; and it limits the ability of extension services and NGOs to understand the results and adapt them to specific farming situations.

There have been recent efforts to standardize reporting on seed variety research in an attempt to speed up the variety registration process and harmonize the rules across countries (INSAH 2003). Economists and agronomists doing research on fertilizer and soil fertility issues might benefit from developing similar procedures for reporting their results at the national and regional levels. The advent of the internet has made sharing unpublished work much easier and quicker than it was in the past. Hopefully, recent efforts to facilitate the exchange of working papers on agriculture and food security topics through information portals¹² will encourage African research institutes and individual researchers to get their documents posted on-line and linked to some of these portals; this would increase regional and international collaboration on fertilizer research and reduce redundancy.

In our review we did identify some examples of reporting on fertilizer response that stood out from the others and could be used as models for improving the accessibility and the analysis of fertilizer response data (particularly the economic analysis). Pieri (1989), for example, synthesized an extensive body of fertilizer response data and measurements of changes in soil quality during long-term trials covering several decades of research in Francophone West Africa; the length of the trials permits an analysis of both the positive and negative impacts that fertilizer use can have on soil quality. During the 1990s, the Soil Fertility Initiative provided funding for a number of countries to develop soil fertility management plans. As part of this planning process, several countries did extensive reviews of available data on fertilizer response from research trials and on-farm demonstrations. These syntheses have improved access within each country to the results of several decades of fertilizer research; however, they still have fairly limited distribution and are not widely available outside the country of origin (See, for example, Henao et al. 1992 for Mali).

Choice of research methods and themes: Research methods in general have evolved over time in SSA and this has had an impact on fertilizer research. From the colonial period through the 1960s and 1970s agronomic research was generally conducted on research stations. In the case of fertilizer, it comprised multi-rate trials used to identify yield-maximizing doses of N, P, and K (separately or as complex fertilizers) that were used to develop farmer recommendations. Farmer involvement in the research was unusual and research-extension links were weak. Although fertilizer use grew during this period, a general dissatisfaction with farmers' slow pace of adopting new agricultural technologies moved researchers toward a farming systems research (FSR) approach during the 1980s. FSR took into account the complex settings in which farmers operated when selecting themes and conducting research (Gilvert, Norman, and Winch 1980; Norman 1980; Norman et al. 1995); it also did not lead to satisfaction (McCown 2001; Röling 1988). At present, there is a move to replace FSR with more participatory methods that are used in the thematic areas of integrated natural resource management (INRM) or integrated soil fertility management (Braun, Thiele, and Fernandez 2000; Farrington 1995a; Franzel and Scherr 2002; Pound et al. 2003; Reijntjes, Haverkort, and Waters-Bayer 1993). In describing the transition from FSR to INRM, Douthwaite et al. (2004) note that INRM represents a paradigm shift where "hard" reductionist science is being tempered by "softer" more holistic approaches in a move from classical agronomy to ecological sciences, from static analysis to systems' dynamics, from top-down to participatory approaches, and from factor-oriented management to integrated management. The view is that "research efforts should be directed at improving the capacity of agroecological systems to adapt to changes and to continuously supply a flow of products and services on which poor people depend..." in other words, improving farmers' capacity to adapt technologies to their own situations (Douthwaite et al. 2004; Snapp, Blackie, and Donovan 2003). Snapp, Blackie, and Donovan (2003) points out that the evolving market situation brought about by economic reforms in SSA calls for a shift from fine-tuning high-input recommendations for inorganic fertilizers (something the authors think has gone on too long and at a high cost in research dollars) to a focus on giving farmers information and skills that will help them to optimize economic and biological returns to small investments in technologies of relevance to both cereal and export crops.

An evolution in the key debates about soil fertility in general and fertilizer use in particular has also occurred. There has been a fair amount of debate on the strengths and weaknesses of organic versus inorganic fertilizers and their relative potential for resolving smallholders' production problems. Proponents of the low-external-input (LEI) school of thought have long been vocal in their support of low-cost, organic approaches for Africa's smallholders (Farrington 1995b; Jiggins, Reijntjes, and Lightfoot 1996; Pretty 1995) and saw little hope for increasing productivity and reducing degradation through the types of massive increases in the use of inorganic fertilizers proposed by Green Revolution advocates (Borlaug and Dowsell 1995; Quiñones, Borlaug, and Dowsell 1997). During the past decade, proponents of low-external-input (LEI) and high-external-input (HEI) approaches both appear to be moving toward more moderate views, but most projects and programs dealing with soil fertility issues

still tend to lean in one or the other direction.¹³ Today there seems to be general agreement on the need to increase both organic and inorganic fertilizer use in Africa,¹⁴ though the optimal amounts of each are increasingly viewed as site and farmer specific.

Recognition of organic/inorganic complementarities and the importance of promoting general improvements in land husbandry has led many agronomists to shift from factor-specific research on fertilizer alone to research that looks at inorganic fertilizers in combination with organic fertilizers (ISFM), a range of soil and water conservation (SWC) practices, natural resources management (NRM) practices or the introduction of conservation agriculture (CA)—the goals being to increase fertilizer efficiency, lower input costs, and maintain or improve soil quality (Bot and Benites 2001; Buresh, Sanchez, and Calhoun 1997; IFDC 2002; Palm, Myers, and Nandwa 1997; Place et al. 2003; Vanlauwe et al. 2002). These approaches also address the concern of many that fertilizer promotion alone—without attention to improved varieties (Sanders, Shapiro, and Ramaswamy 1996), irrigation (Desai 1988), farmer management practices (Murage et al. 2000), soil and water conservation practices (Kaboré and Reij 2004), and reduced tillage options (Bot and Beintes 2001)—would not achieve the agricultural production growth rates needed to stimulate general economic development and reduce poverty. Success in efforts to improve fertilizer efficiency will shift the entire demand curve out (See figure 1.1), resulting in an increase in demand at each level of fertilizer price; assuming no major constraints to adoption, this shift would normally result in a more dramatic increase in fertilizer demand than a simple move along an existing demand curve due to changes in fertilizer prices.

The implications of these paradigm shifts for fertilizer research are important. Trials providing the type of fertilizer response data needed to estimate fertilizer production functions and determine profit maximizing doses of fertilizer are becoming rare now and those dating from the 1960s and 1970s are of questionable relevance today given changes in climate and soil quality. Fertilizer research is increasingly site specific, increasingly aimed at “best bet” (See box 4.1 for an illustration) rather than maximizing recommendations, and, when conducted using participatory methods, theoretically involves a wider range of stakeholders (farmers, extension, government, agricultural exporters and processors, NGOs) than previously. For example, Dimes et al. (2003) report on collaborative links between researchers, NGOs and the commercial sector that led to traders located near farmer field schools being trained in fertilizer product knowledge, handling and storage, and inventory management practices during the research process. The underlying motivation for this broader participation in agronomic research and shift to “best bet” recommendations is the belief that innovation is a social process involving learning by doing in which innovations and institutions co-evolve; hence, research that does not involve the full network of actors from the start will fail to stimulate the co-evolution necessary for widespread adoption of innovative behavior (Douthwaite et al. 2004).

Box 4.1 Ranking Methods Used to Refine the Selection of “Best Bet” Technologies**Comparison of Three Technology Ranking Methods for Mother Trials: 1997/98–1999/2000**

Option	Agronomic	Economic	Farmer
Unfertilized maize	5	6	5
Maize + standard fertilizer dose	2	4	7
Maize + pigeon pea	3	2	2
Maize+pigeon pea+standard fertilizer dose	1	3	6
Groundnut+pigeon pea	6	5	3
Maize+tephrosia	4	7	4
Mucuna-maize rotation	7	1	1

“Mother” trials are conducted by researchers and completely randomized with four replications. The fertilizer doses were area-specific recommendations base on research reported in Benson (1997). Agronomic rankings are based on yield, economic rankings on marginal rates of return, and farmer rankings on their expressed preferences.

Comparison of Three Technologies Ranking Methods for Baby Trials: 1997/98–1999/2000

Option	Agronomic	Economic	Farmer
Unfertilized maize	3	4	4
Maize + pigeon pea	2	1	1
Groundnut+pigeon pea	4	2	2
Maize+tephrosia	1	3	3

“Baby” trials are either researcher- or farmer- managed; they are not replicated but conducted at multiple sites around a Mother trial on a subset of the trials included in the Mother trial.

Observations: For Mother trials the ranking based on agronomic criteria is different from that based on economic criteria because of different resource requirements, and input and output prices of maize and legumes. The rankings based on economic criteria and farmers’ preferences are the same for mucuna-maize rotation and maize-pigeon peas treatments but different for others because the marginal rate of return analysis does not consider resource constraints, access to input and output markets, risk and food security. For Baby trials, there is a high correspondence between rankings base on economic criteria and farmers’ preferences. This shows that baby trials achieve a better targeting of technologies that best fit farmers’ circumstances and which are likely to be selected first for adoption.

Source: Adapted from Twomlow, Ruskie, and Snapp 2001.

One is justified in asking whether these participatory approaches, combined with efforts to take into account the full complexity of the farming system, will succeed. The site-specific nature of the new approaches risks producing localized solutions that do not respond adequately to the pressing problems of poverty and food insecurity, which exist under a wide range of institutional and agroecological conditions across the continent. In our limited review of the

literature on participatory approaches to improved land and crop husbandry, the evidence suggests that stimulating rapid diffusion of complex technologies and practices remains a major challenge (IFDC 2002; Place et al. 2003; Pound et al. 2003; Snapp, Blackie, and Donovan 2003; Snapp and Heong 2003; Twomlow 2004). Evidence on whether improvements in fertilizer response through these approaches are likely to stimulate fertilizer demand is also limited. After an extensive review of the ISFM literature, Place et al. (2003, p. 374) found that the evidence was, at best, indirect and mixed:

A recent study of improved fallow and biomass transfer systems in western Kenya found that they were being used by 30–45% of those households who were not using fertilizer or manure (Place et al. 2002). However, they have not yet spurred an increase in the use of fertilizer. Likewise, some studies have suggested that in cash cropping systems organic inputs only replace fertilizer when fertilizer supply becomes problematic (Bosma et al. 1996; Mortimore 1998). Raynaut (1997) found evidence linking increased availability of mineral fertilizers for cash crops to increased use of organic nutrients on food crops. In Niger, Abdoulaye and Lowenberg-DeBoer (2000) showed that patterns of intensification exhibit a pattern of graduation from manure to mineral fertilizer use (Place et al. 2003).

Place et al. (2003) conclude that although information gaps remain concerning the extent to which benefits from organic systems are generating demand for fertilizer; the binding constraints to input market growth seem unlikely to be relieved by technical progress in ISFM.

The recognition that fertilizer response is better analyzed as one small part of an overall production system makes intuitive sense, particularly given that yield and profit maximizing recommendations resulting from multi-rate fertilizer trials using high fertilizer doses have not been adopted by SSA farmers (Okali, Sumburg, and Reddy 1994, Snapp, Blackie, and Donovan 2003). Nevertheless, it is difficult to assess the extent to which this move away from research on fertilizer *per se* is a response to the difficult policy environment faced by fertilizer in SSA since the early 1980s (no subsidies, little credit, and poor transport infrastructure compared to Asian countries at the time of the Green Revolution) or a result of agricultural scientists having gained a better understanding of how to respond to Africa's relatively difficult climate and soil endowment (poorer fertilizer response due to lower and more erratic rainfall, less irrigation, less fertilizer-responsive seed varieties, older and more degraded soils). Recent calls for a reconsideration of fertilizer subsidies in SSA suggests that not everyone is confident that SSA farmers (particularly the poorest ones) will be able to adopt even the small amounts of fertilizer being recommended by recent research without some improvement in price ratios supported by subsidies (Sachs 2003; UN Millennium Project 2005).

Investment in technology research: Good research requires funding. A quick overview of trends in agricultural research funding provides some insight into the current agricultural research context in SSA. Although studies showing that the benefits of agricultural research tend to be far greater than the costs are more numerous than those showing poor returns (see, for example, Alston et al. 2000;

Oehmke and Crawford 1996), investment in agricultural research by African governments is stagnant or declining. During the 1990s, 50% of SSA countries experienced negative growth in agricultural research spending and the average rate of growth for the region (South Africa and Nigeria excluded) was only 0.2% per year. Although the number of full-time equivalent researchers increased three-fold from the 1970s to present, spending per scientist declined by 50% during this same period, raising serious questions about resources available to the new scientists. Comparisons of research investment intensity across countries and regions are frequently based on research expenditures as a share of agricultural GDP. Although there is no firm benchmark for appropriate levels of research intensity, the World Bank often uses a level of 2%. Average research intensity in SSA has been declining from 0.95% in 1981 to 0.79% in 1995 and most recently to 0.70% in 2000; but it remains above the average intensity of 0.62% for all developing countries grouped together. It has been suggested that this intensity be increased to 1.5% by 2015 if SSA is to meet agricultural productivity and food security goals. We were unable to find any specific statistics on the share of African agricultural research budgets devoted to fertilizer research in general or fertilizer response studies in particular, but these declining rates of overall investment do not bode well for improvements in fertilizer research.¹⁵

Farmers' practices, complementary inputs, and risk. We have included this as a separate topic on determinants of fertilizer yield response given how important a role farmer practices play in shaping on-farm fertilizer response, but several of the key issues relating to farmers' practices have already been mentioned above. We have noted that to ensure appropriate application of recommendations it is important to include information on all complementary inputs used (seed varieties, pesticides, herbicides, manure, compost) so that extension agents will know how to advise farmers and farmers will know what they must do in addition to applying recommended doses of fertilizer. Given the current move toward more participatory research methods and improving capacity for "adaptive management," the challenge will be in working with farmers to make sure they understand how the vast array of management decisions they make (tillage, timing of weeding, timing of fertilizer applications, use of organic nutrients) is likely to affect fertilizer response and how that will vary under different rainfall situations. This presents a major challenge to both research and extension. Innovative research efforts involving adjustments in fertilizer recommendations to accommodate farmers' risk concerns and management practices include:

- A response farming technique that uses early rainfall events to decide on the amounts of fertilizer to apply in a given season and when, thereby reducing risk of applying a large amount of fertilizer that doesn't respond due to low rainfall (Piha 1993);¹⁶
- Simulation modeling to test fertilizer yield response over time under different weather conditions (Crawford, Howard, and Kelly 2000) and management strategies that involve tradeoffs with other investments such as hiring labor (Dimes et al. 2003; Rohrbach and Okwach 1998).

- A long-term study that showed grain yield and profitability could be increased by 50% or more in Zimbabwe by applying fertilizer to maize after a grain-legume rotation, or a maize-legume intercrop rather than to continuous maize (Waddington and Karigwindi 2001).
- Experimentation with fertilizer on different types of fields found that using fertilizer on compound rather than “bush” fields (the current practice) farmers can double fertilizer efficiency (IFDC 2002).
- The FERRIZ_Y model developed to derive soil fertility management strategies as a function of different goals (yield or profit maximization, cost reduction) for farmers in the irrigated rice zones of Mali permitted researchers to develop new, more efficient recommendations for farmers, thereby reducing risk and cost (Wopereis et al. 1999)

Although this type of research has potential for identifying practices that will significantly reduce risk and improve fertilizer efficiency, the extent to which the modeling results have been diffused to and adopted by farmers is not clear.

Prices

In the agricultural sector prices act as signals for the allocation of resources by farmers. In SSA input/output price ratios tend to be higher (more kg of output required to purchase one kilogram of fertilizer) and more variable than elsewhere (Byerlee 1994; Yanggen et al. 1998), making it difficult for farmers to use prices when making decisions about fertilizer use. Transmission of price signals is not easy when communications and transportation infrastructure is weak and institutions to support markets are poorly developed. This combination of factors increases marketing risks and costs, often resulting in sub-optimal production decisions by farmers. The framework presented in Figure 4.1 offered some insights about factors that shape input and output prices. Output prices can be influenced by technology (particularly availability of processing and storage technologies), communications infrastructure to stimulate the free flow of information on market prices and physical stocks, transportation infrastructure to stimulate movement of products from surplus to deficit zones, and characteristics of marketing firms such as size (which determines economies of scale) and efficiency (which shapes the size of the marketing margins). Input costs are affected by all of these factors plus input production costs and policies affecting import activities (exchange rates, capital to finance imports, import duties, and efficiency of ports).

During the Green Revolution in Asia, researchers put substantial effort into assessing the relative importance of farmers’ response to changes in both input and output prices. A review of literature synthesizing this research during the 1970s suggests that farmers’ demand for fertilizer and output supply were both more responsive to changes in output prices than to changes in fertilizer prices, with estimates of the price elasticity of fertilizer demand generally less than one but ranging from a negative 0.17 to a negative 2.03 due to variability across countries and differences in modeling specifications (Timmer 1974, 1976). David (1975) notes differences in estimates depending on the type of data (aggregate or household surveys) and the time span (long-run allowing adjustments in

technology and other variables, or short-run with only prices and fertilizer demand changing), but concludes that approximately one-third of the variation in fertilizer use in India was motivated by price and two-thirds by changes in technology and other non-price factors. Timmer (1976) raises questions about an underlying assumption of these models—that fertilizer and output prices are independent. Using the Asian experience as a point of reference, he argues that fertilizer use affects the food supply, thereby changing food prices, which affect fertilizer prices. The extent to which fertilizer and food prices are linked in SSA at this point in time is an empirical question. Given the low intensity of fertilizer use (particularly on food crops) and the lack of significant correlations between fertilizer use levels and aggregate production and yield statistics, the relationship is likely to be much weaker in SSA than elsewhere. Shields (1976) reviewed a variety of methods used for forecasting fertilizer demand during the 1970s and concluded that weaknesses in the data and conflicting results obtained from different modeling methods severely limited the usefulness of such estimates for policy makers.

Econometric methods have become more sophisticated since the 1970s; but it is still not clear that these models provide useful policy guidance—again because slight variations in the methods lead to important differences in the results, often with little effort by analysts to explain the differences and offer advice about which results are appropriate for a given policy decision. A few recent examples from SSA are illustrative. Analysis of Ethiopian farm survey data shows a fertilizer price elasticity of 0.09 and an output price elasticity of 0.16 (Abrar 2001). This finding is consistent with Asian findings about the relatively larger output price response. Abrar (2003) found, however, that if one does not assume perfect efficiency in estimating the profit function, the price elasticity of fertilizer moves to -0.38—a substantially larger impact than other estimates for Ethiopia such as those in the 0.03 to 0.10 range found by Croppenstedt and Mulat (1997), using farm survey data, and by Yao (1996), who used aggregate time series data. In the Abrar (2003) model that did not impose efficiency, the fertilizer price elasticity was larger than all the output price elasticities but wheat and several of the non-price elasticities such as access to extension and infrastructure.¹⁷ Recent analyses of the potential impact of changes in fertilizer price in Ghana found farmers more responsive to price than in Ethiopia; the authors estimated that a 10% subsidy would increase fertilizer demand by 22.4%, expand maize supply by 27%, and increase farmers' income by 30%. The corresponding cost of the subsidy was estimated at 6% of the farmers' revenue gains (Langyintuo, Foster, and Lowenberg-DeBoer 2001).

Adoption studies using binary dependent variables to differentiate between adopters and non-adopters and a variety of explanatory variables describing farm characteristics and the general physical and socio-economic environment, do not produce estimates of the price elasticity of fertilizer demand but they can provide some insights on the role of prices. INTSORMIL research in Niger found that the favorable movements in the fertilizer/output price ratio were associated with increased adoption, along with exposure to demonstration trials and two indicators of household financial liquidity (Sanders 2002; Tahirou and Sanders 2002).

Understanding farmers' responsiveness to price changes is extremely important given all the attention being paid to using fertilizer subsidies to stimulate demand. The identification, evaluation, and synthesis of results of studies having estimated fertilizer and output price elasticities for SSA would be a useful contribution to the debate on using price subsidies or other price policies to stimulate demand. Without a firm grasp on likely response, it is difficult to estimate the costs and benefits of a subsidy policy.

Reducing fertilizer costs. Input prices are largely determined by the characteristics of the input supply system, which is discussed in-depth by IFDC (2005) or by government policy (including subsidies), which is covered by Crawford, Jayne, and Kelly (2005). Hence, we limit our discussion here to a few observations on determinants of input costs and marketing options that hold promise for making inputs more financially accessible to farmers and refer the reader to the companion papers in this series for a more thorough discussion.

Improving import and domestic marketing efficiencies: Jayne et al. (2003) compared the fertilizer cost structures for Kenya, Ethiopia, and Zambia identifying policies and investments that could reduce costs. They found that domestic marketing costs represented 50% or more of farm-gate prices. These high costs were not due to unusually high margins; the sum of importer, wholesaler, and retailer profit margins generally accounted for less than 10% of total cost. Recommendations for cost reductions included improved efficiency at ports; improvements in port, rail, and road infrastructure; better coordination of inland transport of fertilizer, and reduced uncertainty about government's role in input distribution. Estimates of the farm-gate price reductions from implementing the full range of recommendations in each country ranged from 11 to 18%.

Cooperative action by farmers: Although the Jayne et al. (2003) recommendations call for government investment and policy reform, another way of reducing farm-gate costs is for farmers to realize price benefits from quantity discounts in purchasing and transport and from competitive bidding. This is usually accomplished by way of farmer associations or cooperatives. The results here have been mixed. Bingen, Serrano, and Howard (2003) argued that many programs focus too much on technology transfer and not enough on human capacity development that empowers farmers to work collectively on a broader range of activities, including training in skills needed to negotiate with traders, to manage credit, and to enforce contracts with members as well as with suppliers and buyers. Coulter et al. (1999) also stressed the importance of training and democratic processes. In addition they find that size needs to be limited (10–30 members seems optimal) and that cooperatives that focus on a specific crop or activity and are linked to a particular outcropping scheme offering input supply and output marketing services under contract have a better chance of succeeding.

Lowering costs through local fertilizer production: During the past decade there have been numerous studies to evaluate the cost and technical efficiency of phosphate rock versus imported phosphate fertilizers such as SSP and TSP for countries with important local phosphate deposits such as Mali, Senegal, Zimbabwe, Madagascar, and Burkina Faso. IFDC (1997) reported results of three country

studies designed to show the benefits of using rock phosphates as a capital investment on a broad scale to restore the P level of degraded soils and kick start agricultural productivity. All studies showed that higher analysis P was more profitable than phosphate rock. The constraints to making local phosphates more competitive with imports are many, but in most cases limitations in local infrastructure (high transport and energy costs) were factors.

A more recent agronomic study using data from a multi-factoral field experiment carried out over four years and in eight locations in Niger, Burkina Faso, and Togo drew similar conclusions:

...locally available high quality Rock Phosphate can only be an alternative to SSP at the farmers' level if it is much cheaper, properly conditioned to avoid negative farmer reactions to its powdery nature and most of all if its application is restricted to well-defined zones with low pH and high rainfall. (Buerkert, Bationo, and Piepho 2001: p.13).

A synthesis of world-wide research on rock phosphates remains optimistic about the potential in the long-run; but it too reports that there are many knowledge gaps that need to be filled before researchers can develop viable farm-level recommendations for use of local rock phosphates (italics added):

Advances in standard characterization, methods of evaluation and technologies for enhancing the agronomic effectiveness of PRs will help improve knowledge and management techniques for increasing adoption by farmers. With these scientific and technological advances, it would then be possible to identify specific management practices for effective and economic direct application of PRs ... However, specific technologies need to be developed in each case and more research is needed in order to obtain conclusive results. (FAO 2004b: p.125)

Reducing risks associated with high cost inputs: Risk adverse behavior on the part of SSA farmers has been found to account for fertilizer application rates at least 20% below economically optimal rates (Binswanger and Sillers 1983). An alternative to reducing the cost of fertilizer is to reduce the size of the financial risk associated with fertilizer purchase.

In the section on agronomic response we described a number of land husbandry practices that can increase fertilizer efficiency, reduce production risk and reduce the amount that a farmer needs to spend per hectare for fertilizer. There are also a number of marketing options for reducing cost and risk, particularly for farmers just beginning to experiment with fertilizer. There is strong evidence that selling fertilizer in small packages (as small as one kilogram) increases demand among resource-poor farmers (Kelly, Adesina, and Gordon 2003; Seward and Okello 1999; Wanzala 2003; Wanzala et al. 2001). For small-packs to succeed, however, quality control becomes an even more important issue than it is with sales of standard 50 kilogram sacks (Gisselquist and van der Meer 2001). Experience also shows that marketing promotion campaigns coupled with demonstrations on farmers' fields contributes to rapid testing and uptake of the small packs (Seward and Okello 1999). Due to the number of actors and transactions involved before fertilizer is broken up into very small bags, the cost per kg is extremely high. Demand could be significantly improved, if a lower

cost means of getting many small bags of fertilizer to the farmer's doorstep were found. Lack of access to complementary inputs such as improved seed, lime or manure also limits purchases of small quantities and/or their agronomic effectiveness; improved legume and cereal seed need to be bundled with small amounts of fertilizer to encourage adoption and optimal results. Small bags of fertilizer are also an opportunity to provide technical information to optimize use of these small amounts (Snapp personal communication).

Another avenue for reducing financial risk is rescheduling input credit payments following bad production seasons rather than forcing farmers sell productive assets to repay (Demeke et al. 1998).

Risk is not only a problem for farmers. A variety of agro-dealer programs now being supported by Rockefeller Foundation, International Fertilizer Development Center, the Citizens Network for Foreign Affairs and others are designed to reduce suppliers' risks thereby encouraging them to extend input distribution networks to under or un-served markets; the costs of credit guarantee funds and retailer training are covered 50% by the project and 50% by the participating suppliers. The hope is to make fertilizer accessible in areas where it was previously inaccessible and to reduce the costs in other areas (Kelly, Adesina, and Gordon 2003).

Protecting farmers against low and volatile output prices. Low output prices discourage farmers from producing surpluses for the market, thereby reducing demand for expensive productivity enhancing technologies. Volatile output prices across both seasons and years make it difficult for farmers to assess the potential benefits of fertilizer; this results in less than optimal use. Calling for higher output prices seems to be in conflict with the agricultural transformation framework that envisions crop prices declining as productivity improvements increase aggregate production. It is also difficult to argue for higher food prices on a continent where so many people are poorly nourished. Nevertheless, food price stabilization policies used by many SSA governments to please urban constituencies, which tend to be more politically vocal than rural, are viewed by some as a key factor in the slow adoption of improved cereal technologies on the continent (e.g., Sanders and Ahmed 1998; Sanders, Shapiro, and Ramaswamy 1996). Donor food aid interventions to further exacerbate the problem of low producer prices (Sanders 2003).

Price stabilization policies:¹⁸ Through the 1970s, the typical SSA response to price instability was direct market intervention for both food and export crops as well as for inputs such as fertilizer. The interventions often involved government parastatals purchasing and reselling or distributing food and supplying inputs to farmers at subsidized prices, coupled with official price controls and the imposition of various internal and external trade restrictions. Some of the most rapid growth in fertilizer consumption occurred in SSA while these policies were in place (e.g., 15% annual growth rates in West Africa, 12% in East Africa and 28% in Central Africa during the 1960s). In a number of cases, the combination of fixed support prices, input subsidies, and blanket consumer subsidies did succeed in raising food output significantly (e.g., countries such as Zimbabwe and Zambia during the 1980s and Kenya and Malawi during the 1970s) (Jayne et

al. 2004). These apparent successes were short-lived, however, because the fiscal burden eventually exceeded most governments' capacity to continue the support programs (Jayne and Jones 1997).

Beginning in the 1980s, donors and international lending agencies began promoting food marketing and price policy reform in SSA in an effort to stop the escalating costs of price stabilization and input subsidy policies. Recommendations for reform included the liberalization of food markets, with reductions in direct government purchasing and selling; investments in public goods such as marketing infrastructure and market information; business friendly improvements in commercial codes; and greater use of trade rather than government stocks to address supply imbalances. The impacts of these market reforms and how well they have been implemented continue to be the subject of considerable debate (e.g., Dorward et al. 2004; Gabre-Madhin, Barrett, and Dorroh 2003; Jayne et al. 2004; Jayne et al. 2002; Reardon et al. 1999b; Sachs 2001; World Bank 2000). Although views differ concerning progress made, there is general agreement that the post-reform environment in SSA continues to expose both farmers and consumers to significant food price instability and risk. This situation has led several governments (e.g., Zambia, Kenya, Zimbabwe, and Malawi) to reinstitute (or not seriously phase out) pre-reform stabilization policies such as the use of marketing boards and buffer stocks. Oygard et al. (2003) provide a long list of government policies in Malawi and Zambia that continue to influence market prices, including government cereal sales at below market prices to selected millers; sales of imported maize at subsidized prices; and prohibitions on maize exports. At present, there is a need for more careful analysis of the tradeoffs between government expenditure on price stabilization policies (which address the symptoms of price instability) and expenditure on investments capable of reducing the instability (e.g., irrigation infrastructure, research on drought tolerant crop varieties, market information systems, increased processing, and storage facilities).

*Improving market information:*¹⁹ Price flexibility, may be viewed in a positive light in that it reflects both supply and demand and seasonality in production, thereby providing producers with incentives to adapt their production to market requirements. For this to happen, markets must function well. Marketing costs include handling and transportation as well as transaction costs such as collecting information about opportunities at different markets. The higher the level of transaction costs between markets, the smaller the probability that exchange will take place. Good market information systems (MIS) can reduce the transactions costs associated with information collection and processing and permit price flexibility to play its anticipated role. A key to a successful MIS is that correct information on market conditions (i.e., prices, flows, stocks) must be available and, within reason, accessible to all. Farmers, assemblers, wholesalers, retailers, and processors all need reliable information to make good production and market decisions. Market information (particularly historical, time series) is also essential for good policy design and analysis.

Despite all the theoretical benefits of MIS, a FAO survey of 120 countries revealed that only 53 had some form of MIS, and among these 53, several offered quite limited services (Shepherd 1997). Many of these systems have been created

with donor support and are run by government services. A recent review of market information systems in Botswana, Ethiopia, Ghana, and Zimbabwe noted a number of shortcomings in these systems (Robbins 2000):

- A tendency to cater to the needs of the administration more than to the needs of farmers and traders;
- Too much dependency on donor funding;
- Poor dissemination of data (often due to poor communications infrastructure);
- Lack of programs to train stakeholders in how to use the information;
- Little effort to provide information that would stimulate regional trade;
- Misguided efforts to link African systems to commodity market data bases that have little relevance for Africa (with the exception of coffee and cocoa exchanges);
- Use of software that is not optimal for the task at hand (rapid dissemination of price information) and hardware that is costly and difficult to maintain without project support.

There have been efforts to address some of these problems in Mali where the operating costs of the MIS are now covered by a combination of government funds and receipts from specialized services offered to consultants and commercial banks (the latter covers 10% of the budget). Banks use the MIS data to value grain stocks pledged as collateral for loans (Sansoni 2002). In addition to weekly radio reports of price changes for principal crops and inputs, the data are posted on the internet. The Malian MIS has also been promoting regional exchange among MIS and commercial actors in West Africa by sponsoring an annual outlook conference.²⁰ Reviewing more than ten years of experience with MIS in Mali, Dembélé and Staatz (2004) have identified six essential factors for MIS success:

- Commitment of policy makers;
- Financial commitment over the medium term of external funding agencies;
- Developing thorough knowledge of the marketing systems of the country;
- Choice of the appropriate institutional “home” for managing the system;
- Development of the human capital for managing the system; and,
- Constant targeting of the information needs of the users, which is essential to the financial survival of the system.

The value of market outlook and information systems and institutions is self-evident to most; however, there has been very little effort to describe how well the potential benefits are being captured by African MIS, and what the trade-offs are in terms of alternative investments (Jayne et al. 2004). The relative contribution of MIS toward directly reducing price instability versus improving the environment for investments in storage, commodity and futures markets, and other risk reducing institutions is also a topic that needs more attention. The

answers to these questions will differ from country to country; hence national level research is needed.

Improved storage: If commodity storage is inadequate because of incomplete markets and a poor appreciation of the capacity of storage to reduce risk and stabilize prices, one option for encouraging more storage without introducing a complex and costly price stabilization scheme is a storage subsidy. This approach maintains (and may even encourage) private sector investment while contributing to price stabilization and risk reduction. Although potentially less costly than a price stabilization scheme, determining the appropriate level for the subsidies will not be easy and treasury costs could be substantial (Jayne et al. 2004).

Efforts to address storage issues have included: (a) village cereal banks whereby farmers store their grain in a community storage facility controlled by an association, which uses the stocks as collateral to obtain bank credit while the members wait for the output price to increase; and (b) warehouse receipt systems, which go beyond the village level to develop commercial storage, thereby permitting traders to assemble larger volumes, break bulk shipments into smaller sizes to meet local needs, and prepare products for reshipment. A farmer can place his grain in a warehouse and obtain a negotiable receipt, effectively turning stocks into secure collateral. In a country with many small producers, each of whom have difficulty physically and financially storing maize over the crop year, and have no access to credit; a warehousing system can enable them to more fully participate in the price-discovery process (Oygaard et al. 2003). We did not find any empirical examples of warehouse receipt systems for SSA, although there have been discussions about introducing one in Zambia.

*Market alternatives to direct price stabilization policies:*²¹ Commodity futures, options, and warehouse certificate programs, such as that described in the last paragraph, are often discussed as market alternatives to reduce food price instability (Coulter and Onumah 2002; Faruqee and Coleman 1996; Hess and Syroka 2002; Sarris 2000). Although these approaches do not require direct government intervention, they do require investments in public goods and are not without cost to governments. Several studies have examined the potential for commodity futures and options contracts to be used as instruments for managing food and export price risks in low-income countries (e.g., Gilbert 1985; McKinnon 1967; Myers 1993; Myers and Thompson 1993; Overdahl 1987; Rolfo 1980). Jayne et al. (2004) conclude that the constraints to using these options in SSA are significant at present. This suggests that such market alternatives hold little hope for improving incentives for fertilizer demand in the near term.

An alternative “market” approach to help farmers get better prices focuses on increasing demand for low-value crops and improving farmers negotiating skills. INTSORMIL in West Africa, recognizing the need to move beyond its initial mandate of technology development, has undertaken a range of activities to help farmers get better output prices: (a) training programs to improve farmer negotiating power with processors; (b) contract systems that provide farmers with advances (or loans) at harvest time so that they do not have to sell production when prices are at their lowest; (c) training farmers to improve

product quality and convincing processors to pay a premium for good quality; and (d) stimulating development of and demand for new, cereal-based products such as sorghum cookies and livestock feed.(Sanders 2003).

5. Capacity to Acquire and Use Fertilizers

Human Resources

Although the simple model of fertilizer demand presented in Figure 1.1 suggests that the demand curve is derived from the fertilizer response function, farmers' effective demand for fertilizer will be based on their perceptions of fertilizer response on their own farm—these perceptions can differ significantly from researcher perceptions of response. Perceptions of potential response will vary depending on exposure to extension, actual hands-on experience with fertilizer, risk preferences, general agroecological conditions, and farm-specific soil characteristics. For this reason, increases in fertilizer demand will depend on extension programs capable of teaching farmers about appropriate fertilizer doses; and supporting management practices so that farmers' perceptions of the response approximate the true agronomic and economic potential of the fertilizer.

There is good evidence that farmers' perceptions are influenced by levels of basic education (See Pickney 1994 for Kenya, Nkonya, Schroeder, and Norman 1997 for Tanzania, and Jha and Hojjati 1993 for Zambia); and exposure to extension (Jha and Hojjati 1993 for Zambia, Thompson 1987 for Nigeria, and Heisey and Mwangi 1997 for maize in East Africa). The extension variable tends to be more straightforward, with results on education suggesting that it often operates indirectly through cooperative membership and access to credit. Investments in education and extension in SSA have lagged behind those in other parts of the world (Lopez 2003). In addition, there are often important disparities in access to education and extension by region and gender (Gladwin 2002). Insufficient levels of investment are often compounded by inappropriate training methods and content, in primary and secondary education as well as in extension.

Africa's experience with various approaches to agricultural extension have been varied and, to date, not adequate to the task at hand. Our role here is not to provide a review of the strengths and weaknesses of different approaches as there are numerous evaluations of the World Bank's Training and Visit program (e.g., Anderson and Feder 2003 and Gautam 1999, cited in Eicher 2004), and the more recent FAO Farmer Field School approach emphasizing participatory methods (Feder, Murgai, and Quizon 2004 and Sones, Duveskog, and Minjauw 2003, cited in Eicher 2004); as well as the growing interest in private extension models using universities, NGOs, and out-grower schemes. Some countries, such as Mozambique, have been experimenting with multiple options in an effort to find the best solution (Eicher 2002; Gemo and Rivera 2002).

Our review of the literature suggests that the biggest challenge facing extension services in SSA at present is that of developing a strategy to (a) effectively inform farmers about available technologies that are generally appropriate to their

situation; and (b) increase farmers' capacity to evaluate, adopt, and adapt the most appropriate technologies for their situation from a pool of available ones.

This will require better integration of research and extension to ensure that extension is not still recommending high-input doses of fertilizer that are no longer profitable given prevailing prices. In Zimbabwe, Malawi, and Zambia official extension service recommendations for maize fertilization remained at their traditional high levels following the dissemination of research results in both countries showing that these recommendations were not profitable (Benson 1997; Dimes et al. 2002; Donovan et al. 2002; Snapp 1998b).

Africa's extension history has been one of developing simple, pan-territorial recommendations for all farmers in an effort to reduce the costs of both extension and input distribution. Emerging evidence from various types of research to improve land husbandry (section 4.C.) as well as growing evidence on the diminishing profitability of traditional high-input levels of fertilizer suggests that a major change in both the content and the method of extension will be required—a one-size-fits-all approach will not be adequate. There seems to be a minimum of three broad groups of production systems that call for quite different approaches in extension:

1. High-value and/or export crops with relatively sure output markets;
2. Lower value crops with high agronomic and economic potential for fertilizer (e.g., improved varieties of maize and irrigate rice);
3. Lower-value crops with poor agronomic and economic potential for fertilizer (e.g., millet, sorghum, legumes).

Cropping systems which include type (1) or type (2) crops are likely to need less intensive extension on the technical aspects of farming but more attention to the development of input acquisition and output marketing skills (something which current extension services rarely address); whereas type (3) systems will need to invest heavily in efforts to improve farmers technical farming skills and ability to evaluate, adopt, and adapt integrated management practices. In addition, extension messages and methods may also need to differ according to gender, prevalence of HIV/AIDS, and access to markets and infrastructure.

Another strategic issue involving extension and fertilizer demand is what type changes in demand should be targeted, more widespread adoption or increased intensity for farmers already applying some fertilizer? This is a question that must be answered at the country level or lower. Analyses in Zambia and Rwanda have both led to the conclusion that more widespread adoption will (a) increase the aggregate quantity demanded more quickly (Kelly et al. 2001 for Rwanda) and/or (b) result in both high returns to fertilizer expenditures and significant increases in income for farmers not presently using it (Deninger and Olinto 2000 for Zambia).

Investments to increase contacts between farmers and extension agents or to foster farmer-to-farmer learning are also needed. Sanders (2002) in speaking of INTSORMIL research in Sudano-Sahelian environments states that "we are convinced that the main determinant of technology introduction is for farmers to see it in the field in conditions similar to their own," this implies a substantial

expansion of demonstration efforts or programs providing farmers with access to testable samples of improved inputs and instructions on their use. Sanders (2002) observation is supported by evidence from the Sustainable Community Oriented Development Program (SCODP) experience in Kenya whereby very poor farmers began using fertilizer as the result of “awareness raising campaigns” conducted at local markets and churches; followed by well-supervised demonstration plots, and a reliable supply of fertilizer and improved seeds in very small, affordable packs (Kelly, Adesina, and Gordon 2003; Seward and Okelo 1999). There is also evidence from the flip side of the coin: The absence of a strong demonstration program in Rwanda appears to be holding back the expansion of fertilizer demand despite relatively promising analyses of fertilizer’s agronomic and economic potential and major improvements in fertilizer supply (Desai 2002; Kelly and Nyirimana 2002). By contrast, the Malawi Starter Pack Program gave all farmers an opportunity to test a “best bet” package of maize, legumes, and fertilizer; but lack of continuity from year to year in the recommendations and products delivered diminished the initial strength of the extension message (Snapp, Blackie, and Donovan 2003).

A recurrent theme in all the land husbandry literature reviewed (e.g., NRM, CA, ISFM, SWC) and discussions of participatory research approaches is the lack of solid evidence on diffusion of the technologies developed beyond the farmers participating in the SSA research programs (Snapp, Blackie, and Donovan 2003; Twomlow 2004) and the difficulties of evaluating the impacts of adoption/diffusion. Both researchers and extension services need to develop and employ improved methods for assessing technology diffusion and impacts (both economic and environmental) of fertilizer and accompanying land husbandry practices. The record to date is very poor, but without serious investments in monitoring and evaluation capable of contributing to improved extension performance, it is difficult to envision a diffusion of improved practices that will be rapid enough to address the critical problems of food security, poverty, and soil degradation. Happily, there have been some recent efforts to reflect on ways of going about this (See Duflo, Kremer, and Robinson 2004; Shiferaw, Freeman, and Swinton 2004) and other work of the Massachusetts Institute of Technology Poverty Action Lab at <http://www.povertyactionlab.com>).

Financial Resources²²

Financing problems are pervasive in SSA, affecting all sectors of the economy and all levels of the input sector. Prior to reforms, SSA governments ran a variety of input credit programs. In many countries, poor repayment rates led to huge government deficits that led, in turn, to donor “conditionalities” on government spending. It is generally agreed that agricultural input credit works best for input technologies with strong agronomic response and limited risk or high-valued crops with strong demand (both characteristics are often a function of public goods such as roads, markets, and irrigation infrastructure as well as technology research). Strong institutions for contract enforcement (social, political, or legal) also contribute to the success of agricultural credit programs. Agricultural credit’s poor track record in SSA may well be due, in part, to it having been offered to farmers for use on technical packages that were not profitable enough; this is becoming more apparent as fertilizer response data is increasingly subject

to financial analysis with results suggesting low or negative profitability for a number of long standing fertilizer recommendations (e.g., Benson 1997 for Malawi; Donovan et al. 2002 for Zambia).

Our earlier discussion of agronomic response suggests that there are two broad categories of fertilizer needs: one for export or irrigated crops, which tend to require higher doses and/or need to meet specific outgrower requirements, and one for ISFM technologies that call for relatively small amounts of fertilizer per hectare (often only 5–10 kg of nutrients). Sanders (2001) argues that many smallholders in Sudano-Sahelian regions of West Africa can often find financial resources to purchase the fertilizer needed for current seed/fertilizer and ISFM technologies drawing on off-farm income, migration remittance, or animal sales. He sees the more important constraint being the need for farmers to understand the yield increasing and income earning potential of various fertilizer technologies. On the other hand, the extremely large fertilizer expenditures required to obtain optimal results in irrigated rice production in the Office du Niger of Mali require expenditures equal to a large share of net farm income; hence, it is difficult for farmers to make these purchases without access to credit. In our view, sizeable amounts of credit will be necessary for the more fertilizer-intensive types of production situations but not necessarily for others. There has been substantial progress in the expansion of microfinance programs through out SSA, but they are poorly designed to address agricultural credit needs. Total amounts of loans tend to be small and the repayment is scheduled in multiple small paybacks that start immediately after the loan is received—a major constraint for expenditures on agricultural inputs which take three to six months before returns are realized.

The current agricultural credit problem in SSA is typically characterized as one of market failure due to imperfect information in the presence of risk (Dorward et al. 1998; Poulton, Dorward, and Kydd 1998; Kydd et al. 2002). Market failure occurs because it is costly to screen input credit applicants and institutions for contract enforcement are weak; moreover insurance is absent (for similar reasons) and farmers lack collateral for loans. The most common responses to this situation include: (a) a variety of small-scale, donor-funded NGO efforts to build farmer associations capable of accessing private sources of input credit, (b) interlinking market arrangements for export crops in various stages of transformation from pre-reform parastatals to post-reform competitive markets; and (c) government-run input credit programs. We review examples of each.

Credit through Building Farmer Associations

The logic behind the association-building approach is that collective action has the capacity to reduce farm-level transaction costs of both input and credit acquisition while simultaneously reducing transaction costs for potential input suppliers and output buyers. Cooperative movements in SSA during the early post-colonial period were often top-down, government-mandated organizations subject to elite capture and moral hazard. Although today's farmer associations are not immune to these problems, there has been an effort to foster the development of "bottom-up" (though arguably donor-led) associations characterized by self-selection and self-management (See Bingen, Serrano, and

Howard 2003). Reviews are available describing how NGOs like CARE and CLUSA have developed farmer capacity to organize and manage collective activities in Mozambique (Gordon 2000), Mali (Bingen 2003; Kelly 2000), and Zambia (Neubert and Sarda 2000). Other similar efforts to create associations able to deal with agricultural credit are the village savings and loan associations created with European donor assistance in the Office du Niger of Mali (Traoré and Spinat 2002), and the savings and loan associations being promoted by Sasakawa Global 2000 (Breth 1999; Galiba and Gléhouénu 1998).

The CARE and CLUSA programs tended to pay more attention than the savings and loan programs to developing farmer skills in a manner that would empower them to address a much broader array of problems than credit (e.g., political advocacy, technology transfer, and basic literacy and management skills). This heavy emphasis on capacity building appears to lead to more success in credit acquisition and repayment (Bingen, Serrano, and Howard 2003; Coulter et al. 1999; Kelly, Adesina, and Gordon 2003), but it is not infallible (Neubert and Sarda 2000). Given the “knowledge-intensive” nature of many of the improved land husbandry practices now being promoted as essential complements to fertilizer use, this type of farmer capacity building could have important spillovers in terms of increased capacity to understand and adapt these complex packages to diverse farming situations.

There is little doubt that viable associations can play an important role not only in helping farmers to access credit but also in reducing input and output marketing costs; yet, the long-time span (18–24 months) and the costs (several hundred U.S. dollars) reported by CLUSA for establishing a single, legally recognized organization have raised questions about scaling up these efforts (Heinemann 2002). CLUSA is conscious of the need to reduce costs and scale-up its activities – a concern reflected in (a) the creation of local capacity-building NGOs, (b) use of volunteer extension agents (paid honoraria by their associations), and (c) creation of Apex organizations to take on marketing and coordination functions across a group of smaller associations.

Interlinked Markets in Transition

Interlinked markets permit exporters or processors to use a farmer’s expected harvest as collateral for seasonal input credit. The system is mutually beneficial: farmers get credit for yield-increasing inputs while buyers can lock-in potential supply. Historically, credit repayment offered in the context of interlinked markets in SSA has experienced higher than average rates of repayment because the output markets were monopsonistic—farmers had no alternative outlet so they sold to their creditor. However, as competition for the targeted crop grows, opportunities diminish for linking input/output transactions capable of reducing credit risk and lowering input financing costs.

Examples of these interlinked markets that are now in transition are found in the cotton sector of francophone West Africa (Tefft 2000) Uganda and Zimbabwe (Gordon 2000; Gordon and Goodland 2000), Ghana and Tanzania (Poulton, Dorward, and Kydd 1998) and coffee in Tanzania (Winter-Nelson and Temu 2002).²³

The strength of credit provision through interlinked markets has been its ability to reduce credit defaults substantially, particularly strategic defaults. In some cases, there is also evidence that the costs of input acquisition are reduced when ordered in bulk (i.e., the case of the cotton sector in Mali). On the other hand, evidence of very low shares of world prices being paid to farmers participating in some vertically integrated production systems raises questions about the true costs and benefits of the system for farmers. The above cases suggest that the loss of linked markets tends to have a negative impact on input use and access to credit. To smooth the transition from monopsonistic interlinked markets to competitive interlinked markets, farmers associations must improve their management skills and ability to reduce strategic default and governments must develop more effective contract laws and enforcement procedures (See Dorward, Kydd, and Poulton 1998, for an in-depth discussion of these issues).

Government Credit

Government-run input credit programs make credit more accessible in situations where commercial banks find costs prohibitively high. However, the poor performance of government credit programs suggests a failure to address the underlying problems. Zambia's program has become a virtual giveaway due to low repayment rates of 30–40% (FSRP Zambia 2002). After years of very limited activity, Senegal's *Caisse Nationale de Crédit Agricole du Sénégal* substantially increased its input credit portfolio in 2000. Repayment rates have always been problematic (frequently only 50–60%); the increase in credit offered in 2000 simply raised the value of unpaid credit at the end of the season.²⁴

In Ethiopia, government-guaranteed credit was the driving force behind the Participatory Agricultural Development and Extension Training Service (PADETS), which followed the successful introduction of improved maize technologies by Sasakawa Global 2000 (Howard et al. 1999). Following years of very high (usually >98%) loan repayments,²⁵ two years of bumper cereal harvests led to an 80% drop in maize prices in early 2002, illustrating the need to combine technology promotion and credit programs with output market development activities, including improvements in transportation infrastructure to stimulate more trade between surplus and deficit zones (Gabre-Madhin 2003).

One argument for government-run credit programs is that they can increase aggregate demand for purchased inputs when there is a credit market failure, thereby boosting commercial interest in developing input supply networks. There is mounting evidence that these programs are not a cost-effective means of stimulating commercial input market development. Among the issues raised by analysts are the high costs of the programs (particularly in Zambia where defaults are high); heavy credit administration obligations placed on extension staff, making it difficult for them to perform normal extension activities (Ethiopia); and high levels of rent seeking associated with a tendency to favor politically well-placed suppliers (Zambia and Ethiopia), thereby constraining the development of lower cost, truly commercial input supply networks (See Donovan 1999; FSRP Zambia 2002; Jayne et al. 2003; Stepanek 1999).

Insurance

Looking beyond credit *per se* to institutions capable of reducing the risk associated with credit defaults due to crop failure brings us to the question of insurance and whether it could improve access to inputs by reducing financial risk. Experience has shown that crop insurance programs suffer because of adverse selection and moral hazard problems. Unequal access to information by participants in the insurance agreements leads to high transactions costs, further complicating the situation (Hazell, Pomareda, and Valdés 1986). Even in developed countries, crop insurance schemes tend to be difficult to implement and are frequently subsidized.

Some insurance experts are now recommending weather rather than crop insurance based on hedging through weather-based index insurance; the advantage is that the “trigger” that releases the insurance payment can be independently verified and is not subject to manipulation of farm losses. A weakness of the system is that it only insures against one type of crop failure, leaving much of production risk uncovered (i.e., animal damage and disease). Because this is a relatively new area of insurance, it is not likely to be available to African farmers soon, but the World Bank is supporting research on the topic (Jaffee et al. (2003) provide a short description of research in this area; Larson, Anderson, and Varangis (2004) provide a more in-depth discussion).

6. Conclusions²⁶

It seems appropriate to end this review where we began: with Figure 1.1 and the discussion of how the fertilizer demand curve is simply the marginal physical product of fertilizer multiplied by the output price for the crop being produced. This suggests that either increasing output price or fertilizer response will shift the demand curve outward; although the size of the price or productivity increase will determine how far out the demand curve moves. A shift in the demand curve is likely to elicit a greater increase in aggregate demand than a simple movement along the demand curve in response to a lower fertilizer price. Hence, we focus here on the key findings concerning agronomic response and output prices.

Effective demand for fertilizer is based on farmers' perceptions of fertilizer response, which may differ from the response observed by scientists. Hence, *potential* demand can be increased through agricultural research that identifies more fertilizer responsive crop varieties and land husbandry practices that increase fertilizer efficiency and reduce production risk. Increases in effective demand require transmission of the knowledge about fertilizer response to farmers, along with the skills to use it efficiently on their own farms. SSA's failure to translate the economic potential of fertilizer use (identified through research trials and financial analysis) into effective demand at the farm level appears to be a major constraint to increased fertilizer demand. Although extension services are viewed as the means of transmitting agricultural knowledge and skills, the crux of the problem goes far beyond poor performance on the part of extension services. We have noted (a) weaknesses in the ability of researchers (both technical and social scientists) as a group to effectively communicate consistent, financially sound recommendations for extension; (b) an apparent lack of strategy for targeting fertilizer technologies and land husbandry knowledge and skills to appropriate agroecological and socio-economic situations; (c) limited effort to diffuse fertilizer technologies beyond farmers participating in research trials or contact farmers in extension programs; (d) poor or non-existent monitoring and evaluation of the diffusion process permitting research and extension to work together on understanding the process of adoption and adaptation; and (e) inconsistency in agricultural policies (i.e., credit, price, subsidy) that makes it difficult for farmers to assess benefits from year to year and sustain fertilizer adoption.

The solutions to these problems of knowledge diffusion are not self-evident and they will often be country and location- or crop-specific. Given budget constraints, more cost-effective collaboration between all the stakeholders in the agricultural transformation process (researchers, extension specialists, NGOs, farmers, input suppliers, banks, exporters, and processors) will be needed. The relative importance of different actors will vary by the stage of input market development as will the role of the government. Increased funding for

agricultural research and extension appears justified given recent declining trends, but more cost-effective programming of any additional funding will also be needed. We reviewed many examples of promising participatory approaches to technology development, use of simulation models to fine-tune recommendations, outreach to the commercial sector to stimulate supply at an early stage in the adoption/diffusion process; but most of these “promises” remain just that, with little evidence of widespread use and impact on effective demand for fertilizer. In situations where lack of effective demand (rather than poor supply) seems to be the binding constraint, much more emphasis needs to be given to identifying successful approaches for diffusion of knowledge and skills.

Improving farmers’ perceptions of fertilizer profitability will increase effective demand, but so long as output price variability remains high in SSA, risk-averse behavior will keep farmers at a level of demand that is lower than what it would be in a more stable price environment. Hence, government, in collaboration with stakeholders, needs to identify the types of public goods and policies most likely to diminish the price variability in a given situation (this may be infrastructure development in some cases, storage in others, or food aid in yet others). Evidence from Asia, Latin America, and Africa, confirms that both output supply and input demand are more sensitive to changes in output prices than changes in input prices, suggesting that output market stabilization could make an important contribution to fertilizer demand. Fortunately, many of the policies and investments likely to reduce price risk in output markets are likely to contribute to lower prices and less risk in input markets (e.g., infrastructure and market information), providing even more incentive for farmers to increase fertilizer consumption.

In addition to a focus on diffusion of land husbandry knowledge and skills and output price stabilization to increase fertilizer demand, there appears to be a need for some strategic thinking about the reasons for increasing fertilizer demand in SSA. Fertilizer’s traditional role as a productivity enhancing agricultural input is being expanded as donors and governments seek to use it as an instrument for achieving a wide range of diverse goals (GDP growth, poverty alleviation, soil fertility replenishment, soil conservation, food security, and safety net). Although increased use of fertilizer in combination with improved land husbandry practices has the potential to make a contribution in these diverse areas, the types of programs and policies one might implement to achieve these different goals have important implications for the spatial distribution and sequencing of fertilizer promotion efforts. Consider the different outcomes that might be realized by programs to stimulate fertilizer demand for each of the following three key categories of crops:

- High value or export crops with reliable markets (e.g., horticulture, cotton, tea);
- Highly fertilizer responsive crops (e.g., improved varieties of maize or irrigated rice), often with weak or risky markets;
- Crops with relatively weak fertilizer response and low output prices (e.g., millet, sorghum, and legumes), generally grown in more difficult

agroecologies where ISFM may be more appropriate than less complex seed/fertilizer technologies.

Although fertilizer use intensity tends to be highest on high value or export crops, estimates of fertilizer consumption by crop suggest that the largest share of fertilizer in SSA is now applied to cereal crops (40% on high-yielding maize and another 21% on other cereals and pulses). Efforts to expand fertilizer demand for these different situations are likely to have different productivity, economic growth, equity, and environmental implications. For example, promoting fertilizer and improved land husbandry among poor farmers in difficult agroclimates may have positive environmental consequences (reduced soil mining) and poverty alleviation implications (better food security), but it may not contribute as much to growth in GDP or to the development of viable fertilizer supply networks as would a program to expand irrigated agriculture or encourage farmers to increase the intensity of fertilizer use on irrigated crops. Limited funds will force governments to make choices about which farmers and which crop sectors are given priority for fertilizer promotion programs; at the national as well as at the local level, these choices should be based on a well-defined overall strategy with clearly defined objectives that also take into account the need to develop effective input supply systems.

Appendix 1: Sources of Soil Fertility Problems in SSA

- Both climate and soils tend to be more constraining in Africa than elsewhere—these are among the most critical environmental factors that determine the sustainability of an agricultural system.
- African soils tend to be particularly poor in nutrients that can be absorbed by crops. While moderately fertile, well-drained soils, account for 33% of Asian soils, they represent only 19% of African soils (Brady 1990; Eswaran et al. 1997).
- Although organic matter levels are not inherently lower in the tropics and Africa than in the temperate zones (Greenland, Wild, and Adams 1992), the turnover (decomposition) rate of organic matter is often higher and the introduction of agriculture tends to accelerate decomposition and loss of soil organic matter (Weight and Kelly 1999).
- Another characteristic of African soils is their high level of diversity or variability, which makes it difficult to conduct agricultural research and design extension programs that have relevance for broad geographic areas and homogeneous groups of farmers.
- Africa's climate is such that water tends to be less available than elsewhere due to both rainfall levels and evaporation rates (Brady 1990). The high intensity of storms makes it difficult for crops to fully utilize rain water. The high intensity of both rain and winds, contributes to high levels of soil erosion (Lal 1990).
- Variability of rainfall affects the efficiency of nutrient uptake and influences farmers' fertilizer strategies (Bationo 1998; Brouwer and Bouma 1997).

Appendix 2: A Comparison of the VCR and MRR Approaches to Measuring Incentives

Both the approach recommended by economists (value of marginal product=marginal factor cost, subject to a target marginal rate of return) and the value/cost ratio approach often used by agricultural scientists ($VCR \geq 2, 3, \text{ or } 4$) examine fertilizer profitability, but the economist focuses on an analysis of marginal returns (to maximize profit) while the agricultural scientist tends to examine average returns (to ensure that returns exceed costs for yield maximizing doses identified). The table below (See table A-2.1) provides a simple example of how different decision rules can influence the net profits from a fertilizer application.

		Maize Yield	MPP	Maize Price	VMP	MFC	Profit	VCR	MRR
N		(Bu/ha)	N		N	N			
0		0							
20		16.50	0.89	4.00	3.56	1.00	45.98	3.30	230%
60		55.15	1.01	4.00	4.02	1.00	160.61	3.68	287%
120	(a)	110.74	0.76	4.00	3.10	1.00	322.94	3.69	271%
160	(b)	133.31	0.33	4.00	1.31	1.00	373.25	3.33	126%
180	(c)	136.94	0.03	4.00	0.15	1.00	367.78	3.04	-27%
200		134.00	-0.33	4.00	-1.32	1.00	336.00	2.68	-159%

Source: Adapted from Debertin, 1986, Table 3.1.

Notes: (a) A rule of maximizing returns subject to $MRR > 150\%$ would select a 120 kg dose. (b) A rule of maximizing profit ($MVP/MFC=1$) would select a dose greater than 160 and less than 180 kg. (c) A rule maximizing yields subject to the $VCR > 2$ would select the 180 kg dose. MPP=marginal physical product, VMP=value of marginal product (price * MPP), MFC=marginal factor cost (unit cost of fertilizer), VCR=value/cost ratio, MRR=marginal rate of return.

It is important to understand that the dose giving maximum yield will not be the same as the one giving maximum profit unless fertilizer is costless. At the point of maximum yield (i.e., 180 kg of N in the example below), the marginal factor cost is greater than the value of the marginal product; the farmer earns a profit, but it is less than he would with a lower dose. Using the $VCR > 2$ rule without controlling for positive marginal physical and marginal value product can lead to recommendations where the marginal value product is negative (e.g., 200 kg of N). As this VCR rule was generally applied by agronomists to confirm profitability of yield maximizing doses, it is unlikely that recommendations were made for cases where the marginal physical product was negative, but it is

possible that recommendations were made for cases where profit was not maximum (e.g., the case of 180 kg of N). The table also shows a marginal rate of return (MRR) for each treatment. If a farmer could get a return of 150% by purchasing and fattening an animal, the 126% MRR for the profit maximizing dose of fertilizer would not provide adequate incentive for the farmer to purchase fertilizer, despite the VCR of 3.33. A better choice for this farmer would be 120 kg/ha application rate with a MRR of 271%.

Appendix 3: Crop Level Synthesis of Fertilizer Incentives from Yanggen et al. (1998) Data

(1) Maize Response to Fertilizer

Maize exhibited the best overall response to fertilizer among the cereal crops examined, with an output/nutrient ratio generally in the 10–20 kilogram range and many examples of the ratio exceeding levels attained in other parts of the world.

Responses reported for East and Southern Africa generally exceed those reported for comparable agroecologies in Latin America and Asia. Only 19% of response ratios reported for East and Southern Africa were less than 7 while 38% of Latin American ratios were below this level. On the high side, 33% of the ratios in East and Southern Africa exceeded 25. Kenya, Malawi, and Tanzania had output/nutrient ratios >20 for improved varieties; Malawi and Zambia had ratios >10 for unimproved local varieties.

Response in West Africa was less robust than in East and Southern Africa. The high end of the response range was generally comparable to examples from Latin America and Asia (10–15 kg of output per kg of nutrient) with a few cases of ratios for response to nitrogen >20 for Ghana, Cameroon, and Nigeria; ratios for response to NPK were in the 10–20 range for Côte d'Ivoire, Gambia, Mali, and Nigeria. The lower ratios were, however, frequently less than 5 (particularly for unimproved varieties), illustrating that there is substantial down-side risk for maize/fertilizer technologies in West Africa.

Some of the maize documents reviewed examined complementary practices thought to enhance fertilizer response. For example, there was evidence that maize in West Africa responded well to fertilizer in the presence of complementary fertility practices (rotation with leguminous crops or manure application, for example). Maize grown in rotation with well-fertilized cotton appears to benefit from the residual effects of the cotton fertilizer. Maize yields in the cotton zone of southern Mali, for example, doubled between 1950 and 1980 (from 500 to 1000 kg/ha) (Pieri 1989).

(2) Sorghum Response to Fertilizer

Sorghum was less responsive to fertilizer than was maize, but comparable to sorghum response in other parts of the world such as India, where output/nutrient ratios of 5–6 were reported during the 1969–80 period.

East and Southern Africa exhibited the best response to NPK fertilizers; but examples were not abundant. Ratios ranged from 4–21 in Kenya, from 10–13 in Tanzania, and there was one example of an O/N ratio of 6 for Ethiopia. West African ratios did not exceed 15 and most examples were in the 4–6 range. Niger

and Senegal were the only countries reporting ratios >10; Mali and Nigeria had a few examples in the 8–9 range and there were eight examples with ratios <8 (Burkina Faso, Mali, Nigeria, Cameroon, Senegal, Ghana).

Few of the with-fertilizer yields for SSA exceeded 1500 kg/ha while most of the non-African examples did; those SSA yields that did exceed 1500 kg tend to be fertilizer used in combination with a leguminous rotation, an improved variety, or after a fallow. Because sorghum is often grown under difficult agroecological conditions (low rainfall and degraded soils), there are many examples of extremely low yields when no soil amendments were used (<200 kg/ha, for example, in some regions of Burkina Faso). Various fertility management techniques for increasing yields and fertilizer response in such areas have been studied. Yields on these soils responded to a combination of techniques such as tied ridges, NPK, and plowing; nevertheless, total production usually failed to pass 1 ton/ha. Physical response to NPK alone was about the same as that associated with tied ridges alone. Programming models for a Sudanian zone of Burkina Faso found that adding fertilizer to tied ridges increased net farm income by only 1%, suggesting that the financial incentives to increase fertilizer demand through the introduction of tied ridges will be limited.²⁷ See Sanders, Shapiro, and Ramaswamy (1996) and Shapiro and Sanders (1998) for more discussion of links between fertilizer use on sorghum/millet and soil management practices in West Africa.

(3) Millet Response to Fertilizer

Evidence was mixed on how SSA response compared with Asian response. SSA output/nutrient ratios were generally less than 10 for both local and improved varieties; data presented for Nigeria was a notable exception (lower limits were 3 and 7 but upper limits reached 11 and 21). The frequency of ratios <10 (largely from Sahelian climates) contrasted sharply with the Indian trial responses reported in Yanggen et al. (1998) which were in the 16–18 range for response of local varieties to nitrogen and in the 22–27 range for improved varieties. However, an 11-year average (1969–80) from a study of yields on farmers' fields in the Indian semi-arid tropics revealed a response of 3–4 kg of output per kilogram of nutrient—more comparable to those in Sahelian zones of SSA.

The levels of millet production per hectare (rarely exceeding 1000 kg/ha and frequently below 500 kg/ha)—both with and without fertility enhancing treatments—do not appear promising given the need to increase land productivity in SSA substantially. Although both maize and sorghum appear to have much greater potential, it is important to remember that millet is grown in difficult agroecological situations (low rainfall, high temperatures, and degraded soils) where maize and sorghum production may not be possible or as productive. Millet, for example, is able to access water from much lower in the subsoil than maize and sorghum. This means that if nitrates are leached beyond the effective depth of a sorghum root system (a common occurrence in the semi-arid tropics), millet plants may still be able to use these nitrates (Wetselaar and Norman 1960),

As with sorghum, many of the more recent millet trials have been designed explicitly to evaluate the productivity potential of various soil management practices used in combination with fertilizer in difficult agroecological situations. Programming models for production systems in the lower rainfall areas of the Sahelo-Sudan found no potential for profitable intensification of either sorghum or millet using fertilizer in combination with improved soil management practices; results for farmers in higher rainfall Sudanian zones were more promising (see Sanders, Shapiro, and Ramaswamy 1996; Shapiro and Sanders 1998).

(4) Rice Response to Fertilizer

The ratio of kg of output per kg of fertilizer for rice in SSA was generally in the 7–20 range; this parallels non-African developing country results. The average of all the SSA studies cited was 12, which is higher than the rule-of-thumb threshold of 10 and comparable to the average of 11.4 for Asian and Latin American examples.

Yields for fertilized rice in SSA approximated the non-African examples, generally falling in the 4000–6000 kg/ha range. This again was significantly better than maize which exhibited yields centered in the 2000–4000 kg/ha range, but showed more variability both on the high and low ends (again, a result of the rainfed conditions under which maize is grown).

Despite this apparent potential in terms of fertilizer response and land productivity, a key element to bear in mind is the extremely high costs of the irrigation systems where SSA irrigated rice is produced. With respect to the narrowly focused analysis of fertilizer response which is the subject of this section, our conclusion is that rice in SSA performs well. Because this good performance is in many cases dependent on production under highly subsidized irrigated conditions, any analysis comparing profitability of fertilizer use across crops will need to pay attention to both the private and the social profitability of irrigated rice production in general as a focus on only the profitability of fertilizer use will provide misleading policy recommendations.

(5) Groundnut Response to Fertilizer

Groundnut response to fertilizer was good (7–10 kg of output per kilogram of nutrient) compared with results reported for the Indian semi-arid tropics (6–7 kg). Lower responses were apparent primarily in highly degraded soils or where rainfall was <500 mm (reflected in many examples from Senegal that were for trials in zones with these characteristics). Large quantities of organic matter (10 tons of manure) used in combination with NPK increased yields on highly degraded soils, but the quantity of organic matter required to get this response is not realistic for typical farmers.

(6) Cotton Response to Fertilizer

Despite the strong link between fertilizer use and cotton in SSA (particularly in West Africa), well-documented examples of cotton response to fertilizer are difficult to find. Information summarized in Appendix 1 shows that cotton yields increased by more than 50% in 11 of the 18 trials reviewed. The high doses of

fertilizer used to obtain many of these yield increases result in relatively low output/nutrient ratios. For 64% of the trials with better than 50% yield increases, the output nutrient ratios were below 7. The low output/ nutrient ratios mean that the producer price for cotton must be relatively high if fertilizer use on cotton is to be economically attractive.

The best output/nutrient ratios were found in Mozambique (3 cases in 7–16 range), Chad (one case of 12), Mali, and Zambia (both 7). The Chad (Bebedjia) example cited is interesting not only for the high response but also because the soils are high in organic matter and better buffered than most SSA soils. Consequently, continuous application of large doses of nitrogen did not result in soil acidification as has occurred in some cotton production zones of Cote d'Ivoire and Senegal (Pieri 1989).

Our general conclusion concerning cotton response to fertilizer is that the physical response (kg per hectare and/or percent increase in yield) is generally strong enough for farmers to see a marked difference in production. However, exceptions exist; some cotton producing areas have less than ideal moisture and soil conditions. Response data presented in Appendix 1 (examples from Carr 1993) show that standard fertilizer recommendations are not appropriate for these zones and more site-specific recommendations for alternative approaches for increasing productivity in these areas are needed.

(7) Beverage (Coffee and Tea) Response to Fertilizer

Response data obtained for coffee and tea are limited, covering only Kenya and Cameroon. Many other countries produce coffee (Rwanda, Ethiopia, Cote d'Ivoire, Republique Centre Africaine), tea (Tanzania, Mali), and cocoa (Ghana, Cote d'Ivoire), so there is a need to improve the geographic coverage of the data in Yanggen et al. (1998). In general, the output/nutrient ratios are much higher for coffee and tea than for other crops examined. They rarely fall below 5 and are frequently greater than 10. Nitrogen is the most important nutrient for both crops. Recent research has shown, however, an increase in the number of cases where low levels of phosphate and potassium are beginning to compromise response to nitrogen (Carr 1993). This is yet another example of the important role that fertilizer research must play in monitoring and updating recommendations as soil conditions change.

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Endnotes

1. Desai (1988 and 2002) views fertilizer's *economic potential* as the amount of fertilizer that can be used profitably, based on an analysis of prevailing prices and response functions. Profitability may be benchmarked through a variety of indicators, but value/cost ratios of 2 or more are most frequently used.
2. We use the following definitions of agro-ecological zones: Coastal West Africa includes Benin, Côte d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone, and Togo; the Sudano-Sahel includes Burkina Faso, Cape Verde, Chad, Gambia, Mali, Mauritania, Niger, Senegal, Somalia, and Sudan; Central Africa includes Cameroon, Central African Republic, Congo (Brazzaville), Congo (Kinshasa, formerly Zaire), Equatorial Guinea, and Gabon; East Africa includes Burundi, Eritrea, Ethiopia, Kenya, Madagascar, Mauritius, Rwanda, and Uganda; Southern Africa includes Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe. Note that following FAO classification procedures, the country of South Africa is not included as part of SSA.
3. If we include South Africa in the SSA analysis, 62.5% of fertilizer consumption from 1998 to 2002 would have been covered by four countries: South Africa (38.7%), Nigeria (8.7%), Zimbabwe (7.6%), and Ethiopia (7.4 %).
4. Countries covered include: Ethiopia, Guinea, Kenya, Madagascar, Malawi, Mauritania, Nigeria, South Africa, Tanzania, Togo, Zambia, and Zimbabwe; years reported for each country varied but ranged from 1995–1999.
5. As only one West African cotton producing country was covered in the report, the share of cotton fertilizer is probably underestimated.
6. $MRR_{treatment1} = (\text{returns}_{t1} - \text{returns}_{t0}) / (\text{costs}_{t1} - \text{costs}_{t0})$, and so forth for each change in treatment.
7. "Typical" values are either median or modal values; this was done to diminish the influence of outliers.
8. The Yanggen et al. (1998) approach is similar to the one used by Lele, Christiansen, and Kadiresan (1989) to evaluate fertilizer incentives in the World Bank MADIA Study, but applied to a larger number of countries and crops.
9. There may also be a tendency for fertilizer research to be concentrated in higher potential zones, thus providing fewer observations for fertilizer response in more difficult environments. The recent expansion of research on integrated soil fertility management (discussed below) provides better evidence of fertilizer potential for these more difficult zones than some of the early fertilizer research summarize in Yanggen et al. (1998).
10. Recent modeling of the determinants of poverty reduction in India (Fan, Hazell, and Thorat 1999) and China (Fan, Zhang, and Zhang 2002) show that irrigation makes an important contribution to increases in agricultural productivity but very little contribution to poverty reduction.

11. For this review, we were unable to find evidence from empirical studies that soils have degraded to an irreversible level. There seems to be some evidence that, given farmers current practices, yields reach a very low level of productivity (200–500 kg of coarse grains per hectare) and stay there until farmers commence remedial action.

12. One example is <http://www.aec.msu.edu/agecon/fs2/test/index.cfm> the food security and food policy portal for Africa.

13. Snapp, Blackie, and Donovan (2003) provide an interesting description of the clash between ISFM and Sasakawa Global 2000 approaches during the third year of the Malawi Starter Pack program.

14. Because of the declining marginal increases from a single type of input, the additive effects of organic and inorganic nutrients have often been found to be superior in terms of overall yields and net financial returns. Bationo, Lompo, and Koala (1998) found this to be true for millet in Niger, and Rommelse (2001) for maize in Kenya; numerous other publications support these conclusions.

15. All statistics on SSA agricultural research investments in this paragraph came from Beintema and Stads (2004). Eicher (2004) also provides good background information and insights on this issue.

16. It can be argued that this is simply shifting the storage costs and risks to stockists; the intent here is not necessarily to limit purchases but to avoid fertilizer application when there is a high risk of crop loss. Fertilizer can be stored from one season to the next (with some deterioration in the value), but once applied, the risk of total loss is much greater.

17. It seems that the assumptions made about the nature of the “inefficiencies” imposed are extremely important here as they appear to be what is changing the elasticity.

18. This section draws heavily on Jayne et al. 2004.

19. This paragraph draws heavily on Shepherd 1997.

20. See http://www.aec.msu.edu/agecon/fs2/mali_pasidma/index.htm for copies of the outlook conference proceedings 1999 to 2003.

21. This paragraph draws heavily on Jayne et al. 2004.

22. This section draws heavily on Kelly, Adesina, and Gordon 2003.

23. Kelly (2003) provides brief summaries of the more detailed country-level publications on these interlinked markets.

24. Leo Sarr, World Bank, Senegal, personal communication, 2002.

25. Ethiopia, unlike most other SSA countries, has taken a very strong stand on repayment, with arrests or confiscation of assets where necessary (Demeke et al. 1998).

26. These conclusions are not meant to be prescriptive but rather to synthesize the key information presented in the document in a manner that stimulates reflection by participants in the E-Forum. It was anticipated that E-Forum participants, drawing on a combination of their own experiences and information provided in the background papers, would discuss and debate their views on what should be done to encourage SSA farmers to increase fertilizer use and to adopt the types of complementary land, crop, and animal husbandry practices that will increase fertilizer use efficiency.

27. Although not directly related to fertilizer response, it is interesting to note that income benefits were greater in a year of poor rains than one of good rains because output prices rose when aggregate production was reduced by poor weather.