Staff Paper

Farmers' Demand for Fertilizer in Sub-Saharan Africa

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IN SUB-SAHARAN AFRICA

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List of Acronyms

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

AFRICAN FARMERS' DEMAND FOR FERTILIZER

Valerie Kelly[1]

1. Introduction

A. 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 were 3.7, 2.8, and 2.7 tons, respectively. SSA's average annual growth in cereal yields from 1980-2000 was only 0.7% while rates for other regions ranged from 1.2 to 2.3%. Growth in SSA cereal production per capita during this period was stagnant, while that 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 (Weight and Kelly 1999; Townsend 1999, Voortman, Sonneveld, and Keyzer 2000). 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 agroecological 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 while also protecting 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).

[1] The author would like to acknowledge the very helpful research support provided by Andrew Kizito and Megan McGlinchy, and comments from Eric Crawford, John Staatz, Sieglinde Snapp, Cynthia Donovan, Duncan Boughton, Guy Evers, Michael Morris, Derek Byerlee, and two anonymous reviewers.

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 WB 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).

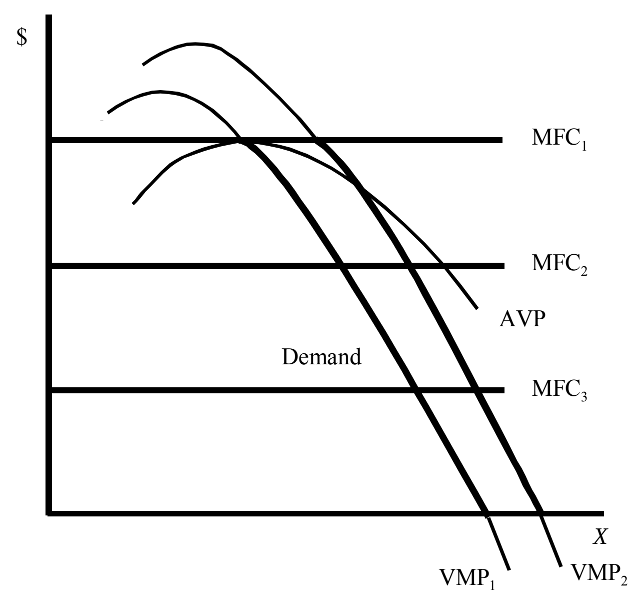
B. Looking at “Demand” Through an Economist’s Eyes

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).[2]

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 (1) the price of the crop(s), (2) the price of fertilizer, (3) prices of other inputs that substitute for or complement fertilizer, and (4) 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, which shows that as the MFC

Figure 1. The Demand for Inputs to the Production Process



[2] Desai 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.

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.

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

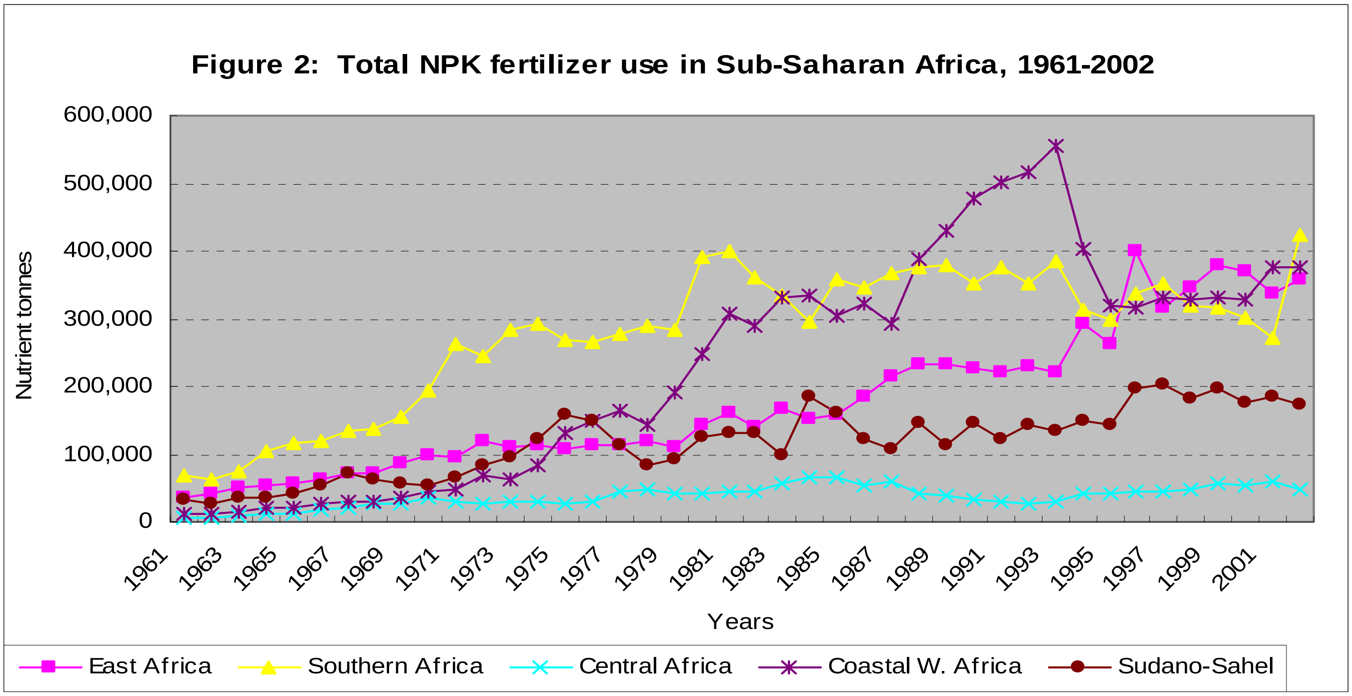
Fertilizer consumption trends expressed in terms of aggregate quantities consumed and intensity of use (kg per hectare of arable land and permanent crops) reflect both demand and supply decisions.

A. Quantities of Fertilizer Consumed

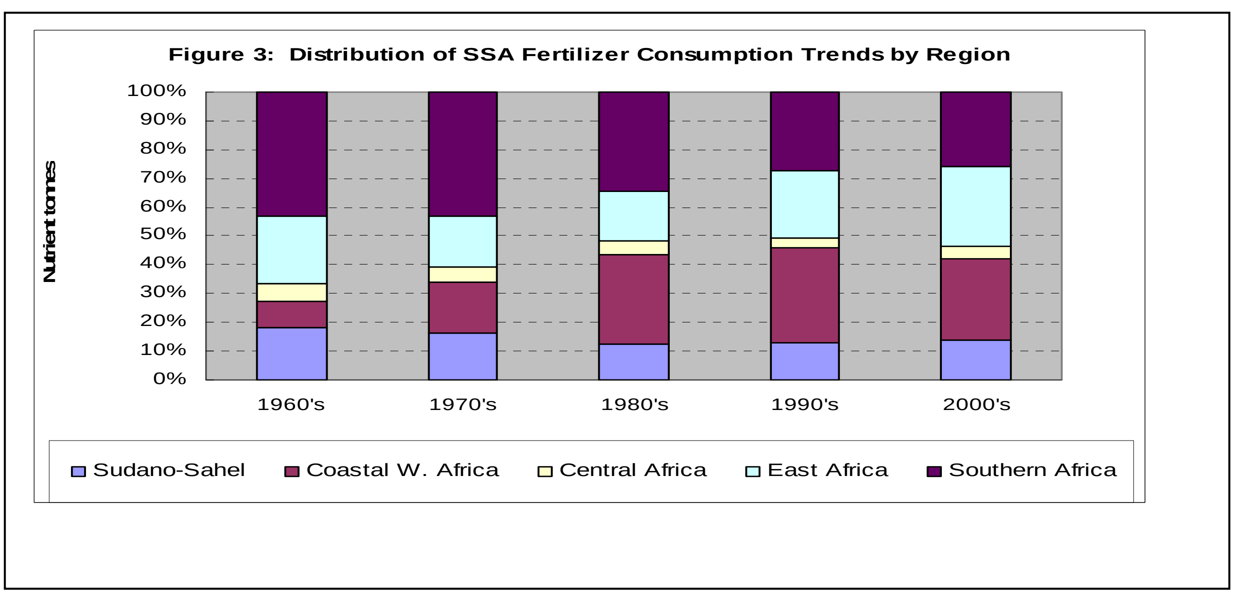
The entire African continent (including North African countries and South Africa) has consistently represented only 2-3% of world fertilizer consumption; the share for Sub-Saharan Africa (excluding South Africa) is generally less than 1%. Fertilizer consumption for SSA in general grew at an annual rate 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 graphs trends in aggregate fertilizer use for each of the five agro-ecological regions of SSA[3] and Figure 3 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

[3]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.

smoother than the county-specific trends. The Central African Region and the Sudano-Sahelian countries have generally consumed less fertilizer than 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 Southern Africa). In Central Africa, higher soil fertility coupled with lower population densities may lead to less perceived need for fertilizer.

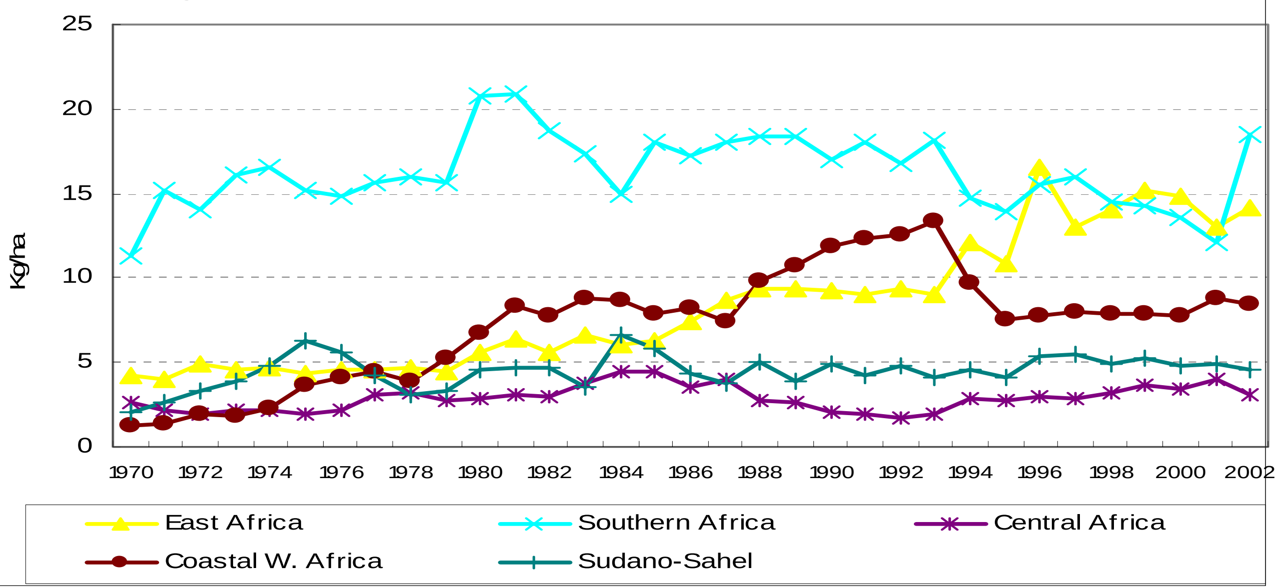


These regional figures mask variability among SSA countries. For example, from 1998-2002, four countries accounted for 50% of all SSA fertilizer consumption: Nigeria (14.2%), Zimbabwe (12.4%), Ethiopia (12.2%), and Kenya (11.2%).[4] Within each region there are also sharp differences in consumption. 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).

B. Intensity of Fertilizer Use

Figure 4 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 4) whose average intensity has 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.

Figure 4: SSA Intensity of Fertilizer Use: 1970-2002



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.

[4] 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 %).

C. 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 1 summarizes the results from the most recent study.[5] 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.[6] 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.

Table 1. Fertilizer use by crop in late 1990s

Crop	% 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.

Fertilizer intensity measured as average kg/hectare (not shown in Table 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 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 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 (1) the relatively high fertilizer response of maize, (2) strong market demand for maize, which converts it from a traditional "food" crop to a "cash" crop, and, in

[5] 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.

[6] As there was only one West African cotton producing country covered in the report, the share of cotton fertilizer is probably underestimated.

some cases, and (3) 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 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.

A. 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.

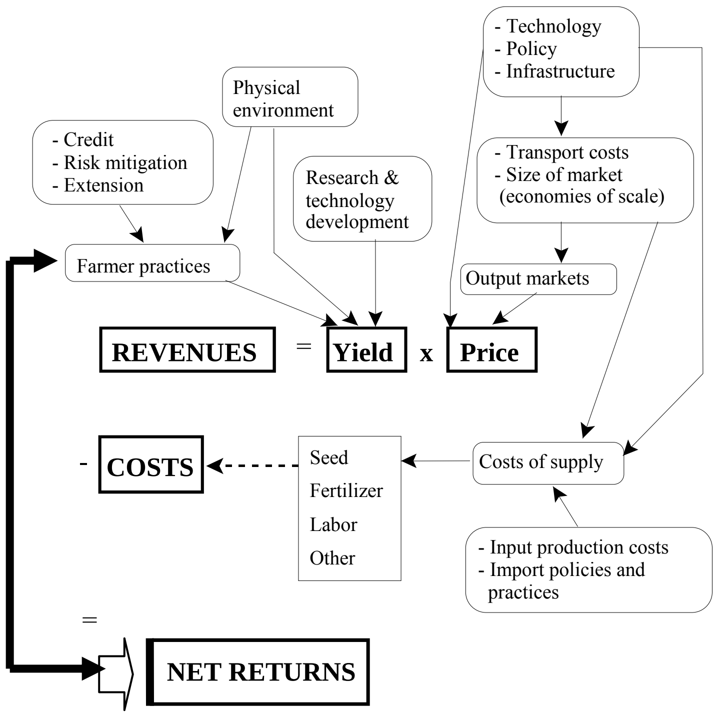
Incentives are also shaped by relative returns, i.e., the profitability of the expenditure relative to the returns expected from alternative farm and nonfarm opportunities (or "needs" such as education and health), and the risk of the expenditure, both in absolute terms and relative to the risk of alternative 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.

B. 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 5 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 5. Conceptualizing Fertilizer Demand: A Function of Financial Incentives and Farmers' Capacity to Use and Acquire the Input



4. Incentives Shaping Fertilizer Demand

A. 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:

Net Returns = (Y * PO) – (F * PF) - 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.[7] 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 (CIMMYT 1988; Crawford and Kamuanga 1988; Boughton et al. 1990; 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

[7] $MRR_{treatment1}$ = (returns $_{t1}$ – returns $_{t0}$) / (costs $_{t1}$ – costs $_{t0}$), and so forth for each change in treatment.

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: (1) 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 (2) 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 <u>un</u>likely 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.

<u>B. How Good Are Fertilizer Incentives in SSA?</u>

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 agroecological 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 2 reports typical,[8] 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

Table 2. 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	
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		
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 used in calculating ratios 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.

[8] "Typical" values are either median or modal values; this was done to diminish the influence of outliers.

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.[9] 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.[10] 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 agroecologies. To control for this problem, the inter-regional comparisons focused on rainfed agriculture for all crops but rice, where there are results for both rainfed and irrigated rice. Rainfall levels, soil types, and agroecological zones are shown when they were reported in the base documents.

Appendix 3 provides a full copy of the detailed response tables reported in Yanggen et al. (1998) and Appendix 4 is 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 2.

- 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, while 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

[9] 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.

[10] 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).

- 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 (1) 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, (2) 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 (3) there is substantial room for improving fertilizer technologies for export crops, particularly cotton.

For all crops and zones covered in Table 2, 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.

C. Improving Fertilizer Incentives

The preceeding discussion synthesized information on fertilizer response, input prices and output prices that affect fertilizer profitability and demand incentives. The conceptual framework presented in Figure 5 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 5). 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.

(1) 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.

(2) Agronomic Response

Figure 5 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.

(a) 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: (1) investments in irrigation, and (2) improved water and land management for rainfed 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 (1) more fertilizer use under irrigated conditions, and (2) 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 (Mariko, and Chohin-Kuper 2001; Bonneval, Kuper, and Tonneau 2001). Irrigation has the greatest potential to significantly increase yields/hectare by avoiding the risks associated with rainfed 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.[11] 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 (van der Pol 1992; Stoorvogel and Smaling 1990), 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

[11] 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.

possible.[12] Estimates of levels of fertilizer needed are usually much higher than what a typical smallholder farmer would be willing or able to use under rainfed 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 (Sanginga 2003; Giller 2002). 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 (Place et al. 2003; Vanlauwe et al. 2002; Weight and Kelly 1999; IFDC 2002).

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).

[12] 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.

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.

(b) Investing in research and technology development to improve fertilizer response

There are three aspects of agronomic research on fertilizer that merit attention: publication and reporting of fertilizer research results, evolution of research methods and themes, and 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 portals[13] 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 (Norman 1980; Norman et al. 1995; Gilbert, Norman, and Winch 1980); it also did not lead to satisfaction (Röling 1988; McCown 2001). 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 (Pound et al. 2003; Braun, Thiele, and Fernandez 2000; Farrington 1995a; Franzel and Scherr 2002; 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

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

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 (Pretty 1995; Farrington 1995b; Jiggins, Reijntjes, and Lightfoot 1996) 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 Dowswell 1995; Quiñones, Borlaug, and Dowswell 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.[14] Today there seems to be general agreement on the need to increase both organic and inorganic fertilizer use in Africa,[15] 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 (Palm, Myers, and Nandwa 1997; Buresh, Sanchez, and Calhoun 1997; Vanlauwe et al. 2002; Place et al. 2003; IFDC 2002; Bot and Benites 2001). These approaches also addresses 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 (Figure 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

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[14] 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.

[15] 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.

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 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).

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Box 1: Ranking methods used to refine the selection of “best bet” technologies

Comparison of three technology ranking methods for Mother trials: 1997/98-1999/200

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” trails 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 (Snapp, Blackie, and Donovan 2003; Snapp and Heong 2003; Twomlow 2004; Pound et al. 2003; Place et al. 2003; IFDC 2002). The 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, page 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, Sumberg, 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 (UN Millennium Project 2005; Sachs 2003).

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, Oehmke and Crawford 1996; Alston et al. 2000), 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.[16]

(c) 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);[17]
- Simulation modeling to test fertilizer yield response over time under different weather conditions (Crawford, Howard, and Kelly 2000) and management strategies that involve

[16] 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.

[17] 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 it the value), but once applied, the risk of total loss is much greater.

tradeoffs with other investments such as hiring labor (Rohrbach and Okwach 1998; Dimes et al. 2003).

- 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.

(3) 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 (Yanggen et al. 1998; Byerlee 1994), 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 5 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, efficiency of ports, etc.).

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.[18] 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 nonadopters 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.

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[18] 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.

(a) 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. While 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 via farmer associations or cooperatives. The results here have been mixed. Bingen, Serrano, and Howard (2003) argue 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 stress 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) reports 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, page 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, page 125)

Reducing risks associated with high cost inputs. Risk averse 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; Wanzala 2003; Wanzala et al. 2001; Seward and Okello 1999). 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).

(b) 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, Shapiro, and Ramaswamy 1996; Sanders and Ahmed 1998). Donor food aid interventions to further exacerbate the problem of low producer prices (Sanders 2003).

Price stabilization policies.[19] 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., Reardon et al. 1999b; World Bank 2000; Sachs 2001; Jayne et al. 2002; Dorward et al. 2004; Gabre-Madhin, Barrett, and Dorooh 2003; Jayne et al. 2004). Although views differ concerning progress made, there is general agreement that the post-reform

[19] This section drawn heavily on Jayne et al. 2004.

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.[20] Price flexibility can 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 (prices, flows, stocks, etc.) 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

[20] This paragraph draws heavily on Shepherd 1997.

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.[21] Reviewing more than ten years of experience with MIS in Mali, Dembélé and Staatz (2004) have identified six essential factors for MIS success:

- the commitment of policy makers;
- the financial commitment over the medium term of external funding agencies;
- developing thorough knowledge of the marketing systems of the country;
- the choice of the appropriate institutional “home” for managing the system;
- the development of the human capital for managing the system;
- the 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. While 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 include (1) 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 (2) 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 (Oygard et al. 2003). We did not find any empirical

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

examples of warehouse receipt systems for SSA (although there have been discussions about introducing one in Zambia).

Market alternatives to direct price stabilization policies.[22] 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 (Faruqee and Coleman 1996; Sarris 2000; Coulter and Onumah 2002; Hess and Syroka 2004). Although these approaches do not require direct government intervention, they do require investments in public goods and are therefore 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., McKinnon 1967; Rolfo 1980; Gilbert 1985; Overdahl 1987; Myers 1993; Myers and Thompson 1993). 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: (1) training programs to improve farmer negotiating power with processors, (2) 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, (3) training farmers to improve product quality and convincing processors to pay a premium for good quality, and (4) stimulating development of and demand for new, cereal-based products (sorghum cookies, livestock feed, etc.) (Sanders 2003).

5. Capacity to Acquire and Use Fertilizers

A. Human Resources

Although the simple model of fertilizer demand presented in Figure 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 straight forward, 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

[22] This paragraph draws heavily on Jayne et al. 2004.

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., Gautam 1999 and Anderson and Feder 2003, cited in Eicher 2004) and the more recent FAO Farmer Field School approach emphasizing participatory methods (Sones, Duveskog, and Minjauw 2003 and Feder, Murgai, and Quizon 2004, 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 (Gemo and Rivera 2002; Eicher 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 (1) effectively inform farmers about available technologies that are generally appropriate to their situation, and (2) 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 (Dimes et al. 2002; Donovan et al. 2002; Benson 1997; 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 (improved varieties of maize and irrigate rice)
3) Lower-value crops with poor agronomic and economic potential for fertilizer (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) while 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 (1) increase the aggregate quantity demanded more quickly (Kelly et al. 2001 for Rwanda) and/or (2) 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' 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 (Kelly and Nyirimana 2002; Desai 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 (Twomlow 2004; Snapp, Blackie, and Donovan 2003) 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 Shiferaw, Freeman, and Swinton 2004; Duflo, Kremer, and Robinson 2004; and other work of the Massachusetts Institute of Technology Poverty Action Lab at http://www.povertyactionlab.com).

B. Financial Resources[23]

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 an expenditure 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: (1) a variety of small-scale, donor-funded NGO efforts to build farmer associations capable of accessing private sources of input credit, (2) interlinking market arrangements for export crops in various stages of transformation from pre-reform parastatals to post-reform competitive markets, and (3) government-run input credit programs. We review examples of each.

[23] This section draws heavily on Kelly, Adesina, and Gordon 2003.

(1) 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. While 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 (Kelly 2000; Bingen 2003), 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 Gléhouénou 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 (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 (Kelly, Adesina, and Gordon 2003; Bingen, Serrano, and Howard 2003; Coulter et al. 1999), 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 (1) the creation of local capacity-building NGOs, (2) use of volunteer extension agents (paid honoraria by their associations), and (3) creation of Apex organizations to take on marketing and coordination functions across a group of smaller associations.

(2) 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).[24]

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).

(3) 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 National 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.[25]

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,[26] 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

[24] Kelly (2003) provides brief summaries of the more detailed country-level publications on these interlinked markets.
[25] Leo Sarr, World Bank, Senegal, personal communication, 2002.
[26] 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).

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 Jayne et al. 2003; FSRP Zambia 2002; Stepanek 1999; Donovan 1999).

(4) 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 (animal damage, disease, etc.). 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. Conclusions[27]

It seems appropriate to end this review where we began: with Figure 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

[27] 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.

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 (1) weaknesses in the ability of researchers (both technical and social scientists) as a group to effectively communicate consistent, financially sound recommendations for extension, (2) an apparent lack of strategy for targeting fertilizer technologies and land husbandry knowledge and skills to appropriate agroecological and socio-economic situations, (3) limited effort to diffuse fertilizer technologies beyond farmers participating in research trials or contact farmers in extension programs, (4) 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 (5) inconsistency in agricultural policies (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, 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, safety net, etc.). While 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 (horticulture, cotton, tea);
- Highly fertilizer responsive crops (improved varieties of 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 agroecologies where ISFM may be more appropriate than less complex seed/fertilizer technologies.

While 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.

REFERENCES CITED

Abdoulaye, T., and J. Lowenberg-DeBoer. 2000. Intensification of Sahelian Systems: Evidence from Niger. *Agricultural Systems* 64: 67-81.

Abrar, S. 2001. *Duality, Choice of Functional Form and Peasant Supply Response in Ethiopia*. CREDIT Research Paper No. 01/20. UK: University of Nottingham.

Abrar, S. 2003. *Estimating Supply Response in the Presence of Technical Inefficiency Using the Profit Function: An Application to Ethiopian Agriculture*. Discussion Papers in Economics #03/04. UK: University of Leicester.

Alston, J.M., C. Chan-Kang, M.C. Marra, P.G. Pardey, and T.J. Wyatt. 2000. *A Meta-Analysis of Rates of Return to Agricultural R&D: Ex Pede Herculem?* IFPRI Research Report 113. Washington, D.C.: International Food Policy Research Institute.

Anderson, Jock, and Gershon Feder. 2003. Agricultural Extension: Good Intentions and Hard Realities. *World Bank Research Observer* 19.

Bationo, A. 1998. Water Use Efficiency Review. Niamey, Niger: ICRISAT. Unpublished report.

Bationo, A., F. Lompo, and S. Koala. 1998. Research on Nutrient Flows and Balances in West Africa: State-of-the-art. *Agriculture, Ecosystems and Environment* 71.1-3: 19-35.

Becker, H. 1997. Research Gives Clues to Reduce Herbidide Leaching. U.S. Agricultural Research Service Press Release.

Beintema, N., and G_J Stads. 2004. *Investing in Sub-Saharan African Agricultural Research: Recent Trends*. IFPRI 2020 Africa Conference Brief 8. Washington, D.C.: IFPRI.

Benson, T.D. 1997. Spatial and Temporal Variation in Fertilizer Recommendations for Maize Grown by Smallholders in Malawi. In *Maize Commodity Team Annual Report 1995/1996*, ed. T. Benson. Lilongwe, Malawi: Department of Agricultural Research, Ministry of Agriculture and Irrigation, Chitedze Research Station.

Bingen, J. 2003. The Upper Niger River Valley Union and Associated Farmers' Enterprises (UGOA): A Case Study of a Farmer Cooperative Alliance for Agricultural Input Supply in Mali. Unpublished report for CLUSA.

Bingen, J., A. Serrano, and J. Howard. 2003. Linking Farmers to Markets: Different Approaches to Human Capital Development. *Food Policy* 28: 405-419.

Bingswanger, H., and D.A. Sillers. 1983. Technological Priorities for Farming in Sub-Saharan Africa. *World Bank Research Observer* 3: 81-98.

Bonneval, P., M. Kuper, and J-P Tonneau, eds. 2001. *L'Office du Niger, grenier à riz du Mali*. Montpellier/Paris: CIRAD/Karthala.

Borlaug, N., and C. Dowswell. 1995. Mobilising Science and Technology to Get Agriculture Moving in Africa. *Development Policy Review* 13: 115-129.

Bosma, R., K. Bengaly, M. Traore, and A. Roeleveld. 1996. *L'elevage en voie d'intensification: Synthese de la recherché sur les ruminants dans les exploitations agricoles mixtes au Mali-Suc*. Amsterdam: Royal Institute of the Tropics (KIT).

Bot, A., and J. Benites. 2001. *Conservation Agriculture. Case Studies in Latin America and Africa*. Rome: FAO.

Boughton, D., E. Crawford, M. Krause, and B. de Frahan. 1990. *Economic Analysis of On-farm Trials: A Review of Approaches and Implications for Research Program Design*. MSU Department of Agricultural Economics Staff Paper No. 90-78. East Lansing: Michigan State University.

Brady, N. 1990. *The Nature and Properties of Soils*. 10th ed. New York: MacMillan Publishers.

Braun, A., G. Thiele, and M. Fernandez. 2000. *Farmer Field Schools and Local Agricultural Research Committees: Complementary Platforms for Integrated Decision-making in Sustainable Agriculture*. AGREN Network Paper No. 105. UK: ODI.

Breth, Steven A., ed. 1999. *Microfinance in Africa*. Mexico City: Sasakawa African Association.

Brouwer, J., and J. Bouma. 1997. *Soil and Crop Growth Variability in the Sahel: Highlights of Research (1990-95) at ICRISAT Sahelian Center*. Information Bulletin No. 49. Netherlands: ICRISAT, Patencheru, Andra Pradesh, India and Agricultural University of Wageningen.

Buerkert, A., A. Bationo, and H.P. Piepho. 2001. Efficient Phosphorous Application Strategies for Increased Crop Production in Sub-Saharan West Africa. *Field Crop Research* 72: 1-15.

Bumb, B. 1995. *Global Fertilizer Perspective, 1980-2000: The Challenges in Structural Transformation*. Technical Bulletin T-42. Muscle Shoals, Alabama: International Fertilizer Development Center.

Buresh, R.J., P. Sanchez, and F. Calhoun, eds. 1997. *Replenishing Soil Fertility in Africa*. Special Publication 51. Madison, WI: Soil Science Society of America, Inc. and American Society of Agronomy, Inc.

Byerlee, D. 1994. Technology Transfer Systems for Improved Crop Management: Lessons for the Future. In *Agricultural Technology: Policy Issues for the International Community*, ed. J.R. Anderson. Wallingford, UK: CAB International.

Byerlee, D., and C.K. Eicher, eds. 1997. *Africa's Emerging Maize Revolution*. Boulder, CO: Lynne Rienner Publishers.

Carr, S. 1993. *Improving Cash Crops in Africa: Factors Influencing the Productivity of Cotton, Coffee, and Tea Grown by Smallholders*. World Bank Technical Paper No. 216. Washington, D.C.: World Bank.

CIMMYT. 1988. *From Agronomic Data to Farmer Recommendations: An Economics Training Manual*. Mexico: CIMMYT.

Coulter, J., A. Goodland, A. Tallontire, and R. Stringfellow. 1999. *Marrying Farmer Cooperation and Contract Farming for Service Provision in Liberalising Sub-Saharan Africa*. ODI Natural Resource Perspectives Number 48. London: Overseas Development Institute.

Coulter, J., and G. Onumah. 2002. The Role of Warehouse Receipt Systems in Enhanced Commodity Marketing and Rural Livelihoods in Africa. *Food Policy* 27: 319-337.

Crawford, E., and M. Kamuanga. 1988. *Economic Analysis of Agronomic Trials for the Formulation of Farmer Recommendations*. MSU Department of Agricultural Economics Reprint Paper No. 6. East Lansing: Michigan State University.

Crawford, E.W., J. A. Howard, and V.A. Kelly. 2000. *Financial and Risk Analysis of Maize Technology in Ethiopia, Based on CERES-Maize Model Results*. MSU Department of Agricultural Economics Staff Paper No. 00-47. East Lansing: Michigan State University.

Crawford, E., T. Jayne, and V. Kelly. 2005. Why Promote Increased Use of Fertilizer in Africa. Draft paper prepared for the World Bank Africa Region, Environmental, Rural and Social Development Unit as part of a project that supports its Africa Fertilizer Strategy Review.

Crawford, E., V. Kelly, T. Jayne, and J. Howard. 2003. Input Use and Market Development in Sub-Saharan Africa: An Overview. *Food Policy* 28:4: 277-292.

Croppenstedt, A., and D. Mulat. 1997. An Empirical Study of Cereal Crop Production and Technical Efficiency of Private Farmers in Ethiopia: A Mixed Fixed-random Coefficients Approach. *Applied Economics* 29: 1217-26.

David, C. 1975. A Model of Fertilizer Demand of Asian Rice Farms: A Micro-macro Analysis. Ph.D. dissertation, Stanford University**.**

Debertin, D. 1986. *Agricultural Production Economics*. New York: McMillan Publishing Company.

Dembélé, N. N., and John Staatz. 2004. *Lessons from the Malian MIS Experience*. MSU Department of Agricultural Economics Staff Paper No. 04-29. East Lansing: Michigan State University.

Demeke, M., V. Kelly, T.S. Jayne, A. Said, J.C. LeVallée, and H. Chen. 1998. *Agricultural Market Performance and Determinants of Fertilizer Use in Ethiopia*. Working Paper No. 10. Ethiopia: Grain Market Research Project, Ministry of Economic Development and Cooperation.

Deninger, K., and P. Olinto. 2000. *Why Liberalization Alone Has Not Improved Agricultural Productivity in Zambia*. Policy Research Working Paper 2302. Washington, D.C.: World Bank.

Derpsch, R. 1997. *Importancia de la Siembra Directa para obtener la Sustentabilitdad de la Producción Agrícola*. Argentina: V Congreso Nacional de Siembra Directa de AAPRESID, Mar del Plata.

Desai, G. 1988. Policy for Rapid Growth in the Use of Modern Agricultural Inputs. In *Agricultural Price Policy for Developing Countries*, eds. J. Mellor and R. Ahmed. Baltimore, MD: Johns Hopkins University Press.

Desai, G. 2002. Key Issues in Achieving Sustainable Rapid Growth of Fertilizer Use in Rwanda. Bethesda, MD: Abt Associates. Consulting report.

Desai, G., and V. Gandhi. 1988. Fertilizer Consumption in Sub-Saharan Africa: An Analysis of Growth and Profile of Use. Paper presented at the IFPRI/IFDC workshop on Fertilizer Policy in Tropical Africa, 5-7 April, Lome, Togo.

Dillon, J., and B. Hardaker, 1993. *Farm Management Research for Small Farmer Development*. FAO Farm Systems Management Series No. 6. Rome: FAO.

Dimes, J., L.J. Muza, G. Malunga, and S. Snapp. 2002. Trade-offs Between Investments in Nitrogen and Weeding: On-farm Experimentation and Simulation Analysis in Malawi and Zimbabwe. Paper presented at the 7th Eastern and Southern Africa Regional Maize Conference and Symposium on Low-Nitrogen and Drought Tolerant Maize, February 11-15, Nairobi, Kenya.

Dimes, J., S. Twomlow, J. Rusike, B. Gerard, R. Tabo, A. Freeman, and J.D.H. Keatinge. 2003. Increasing Research Impacts Through Low-cost Soil Fertility Management Options for Africa's Drought-prone Areas. Paper presented to the International Symposium for Sustainable Dry Land Agricultural Systems, ICRISAT Sahelian Center, December 2-5, Niamey, Niger.

Donovan, C., M. Damaseke, J. Govereh, and D. Simumba. 2002. *Framework and Initial Analyses of Fertilizer Profitability in Maize and Cotton in Zambia*. Zambia Food Security Research Project Working Paper 5. Zambia: Food Security Research Project.

Donovan, G. 1999. Building Markets and Making Them Work. Washington, D.C.: World Bank. Background paper.

Dorward, A., J. Kydd, and C. Poulton, eds. 1998. *Smallholder Cash Crop Production Under Market Liberalization*. Oxford and New York: CAB International.

Dorward, A., J. Kydd, J. Morrisson, and I. Urey. 2004. A Policy Agenda for Pro-Poor Agricultural Growth. *World Development* 32.1: 73-89.

Douthwaite, B., J.M. Ekboir, S.J. Twomlow, and J.D.H. Keatinge. 2004. The Concept of Integrated Natural Resource Management (INRM) and Its Implications for Developing Evaluation Methods. In *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts*, eds. B. Shiferaw, H.A. Freeman, and S.M. Swinton. Oxford and New York: CAB International.

Duflo, E., M. Kremer, and J. Robinson. 2004. Understanding Technology Adoption: Fertilizer in Western Kenya: Preliminary Results from Field Experiments. Cambridge: Poverty Action Lab, Massachusetts Institute of Technology. Unpublished report.

Eicher, C. 2002. Building African Models of Agricultural Extension: A Case Study of Mozambique. Paper presented at the Workshop Extension and Rural Development: A Convergence of Views on International Approaches? November 12-15, World Bank, USAID, and the Neuchatel Initiative, Washington, D.C.

Eicher, C. 2004. Flashback: Fifty Years of Donor Aid to African Agriculture. Revised version of a paper presented at the INWENT, IFPRI, NEPAD, CTA Conference Successes in African Agriculture, December 1-3, Pretoria, South Africa.

Eswaran, H., R. Almaraz, E. van den Berg, and P. Reich. 1997. An Assessment of the Soil Resources of Africa in Relation to Productivity. *Geoderma* 77: 1-18.

Fan, S., P. Hazell, and S. Thorat. 1999 *Linkages between Government Spending, Growth, and Poverty in Rural India*. IFPRI Report 110. Washington, D.C.: International Food Policy Research Institute.

Fan, S., L. Zhang, and X. Zhang. 2002. *Growth, Inequality, and Poverty in Rural China: The Role of Public Investments*. IFPRI Research Report 125. Washington, D.C.: International Food Policy Research Institute.

FAO. 2001. *No-tillage Farming for Sustainable Land Management: Lessons from the 2000 Brazil Study Tour*. Investment Center Occasional Paper No. 12. Rome: FAO.

FAO. 2002. *Fertilizer Use by Crop*. 5th Edition. Rome: FAO in collaboration with IFA, IFDC, IPI, PPI.

FAO. 2004a. Fertilizer Development in Support of the Comprehensive Africa Agriculture Development Programme (CAADP). Paper presented at FAO Twenty-third regional conference for Africa, 1-5 March, Johannesburg, South Africa.

FAO. 2004b. *Use of Phosphate Rocks for Sustainable Agriculture*. FAO Fertilizer and Plant Nutrition Bulletin 13. Rome: Food and Agriculture Organization of the United Nations.

Farrington, J. 1995a. The Changing Public Role in Agricultural Extension. *Food Policy* 20: 537-544.

Farrington, J. 1995b. Mobilising Science and Technology or Fostering Organisational Change?: A Response to Borlaug and Dowswell. *Development Policy Review* 13: 131-133.

Faruqee, R., and J.R Coleman. 1996. *Managing Price Risk in the Pakistan Wheat Market*. World Bank Discussion Paper No. 334. Washington, D.C.: World Bank.

Feder, G., R. Murgai, and J. B. Quizon. 2004. Sending Farmers Back to School: The Impact of Farmer Field Schools in Indonesia. *Review of Agricultural Economics* 26.1: 45-62

Franzel, S., and S. Scherr. 2002. *Trees on the Farm: Assessing the Adoption of Agroforestry Practices in Africa*. New York: CABI Publishers with ICRAF.

FSRP Zambia (Food Security Research Project Zambia). 2002. *Fertilizer Market Reform Strategies in Zambia*. Working paper. Lusaka, Zambia: Food Security Research Project.

Gabre-Madhin, E. 2003. From Crop Surplus to Food Shortage. What Happened? *The Daily Monitor*, 23 January, Addis Ababa.

Gabre-Madhin, E., C. Barrett, and P. Dorooh. 2003. *Technological Change and Price Effects in Agriculture: Conceptual and Comparative Perspective*. Discussion Paper 62. Washington, D.C.: International Food Policy Research Institute.

Galiba, M., and B. Gléhouénou. 1998. Les caisses rurales d'épargne et de prêt au Bénin: 1992-1998. Paper presented at the Workshop Partnerships and Rural Development in Sub-Saharan Africa, 11-15 September, Villars-Sur-Ollon, Switzerland.

Gautam, Madhur. 1999. *World Bank Agricultural Extension Projects in Kenya*. Report No.19523. Washington, D.C.: World Bank.

Gemo, Helder, and William M. Rivera. 2002. Mozambique: Dual Public-Private Services for Small Farmers. In *Contracting for Agricultural Extension. International Case Studies and Emerging Practices,* eds. William M. Rivera and Willem Zijp. New York: CABI Publishing.

Gerner, H., and G. Harris. 1993. The Use and Supply of Fertilizers in Sub-Saharan Africa. In *The Role of Plant Nutrients for Sustainable Food Crop Production in Sub-Saharan Africa*, eds. H. van Reuler and W.H. Prins. Leidschendam: Dutch Association of Fertilizer Producers (VKP).

Gigou, J., and S. K. Bredoum. 2002. Yield Trends, Soil Nitrogen and Organic Matter Content During 20 Years of Continuous Maize Cultivation. In *Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice,* eds. B. Vanlauwe, J. Diels, N. Sanginga, and R. Merck. New York: CABI Publishing in association with the International Institute of Tropical Agriculture, Wallingford, UK.

Gilbert, C.L. 1985. Futures Trading and the Welfare Evaluation of Commodity Price Stabilization. *Economic Journal* 95.379: 637-661.

Gilbert, D., D.W. Norman, and F.E. Winch. 1980. *Farming Systems Research: A Critical Appraisal*. MSU Department of Agricultural Economics Rural Development Paper. East Lansing: Michigan State University.

Giller, K. 2002. Targeting Management of Organic Resources and Mineral Fertilizers: Can We Match Scientists' Fantasies with Farmers' Realities? In *Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice,* eds. B. Vanlauwe, J. Diels, N. Sanginga, and R. Merck. New York: CABI Publishing in association with the International Institute of Tropical Agriculture, Wallingford, UK.

Gisselquist, D., and C. van der Meer. 2001. *Regulations for Seed and Fertilizer Markets: A Good Practice Guide for Policymakers*. Rural Development Working Paper. Washington, D.C.: World Bank.

Gladwin, Christina. 2002. Gender and Soil Fertility in Africa: An Introduction. *African Studies Quarterly* 6.1 and 2: [online] URL: http://web.africa.ufl.edu/asq/v6/v6i1a1.htm

Gordon, A. 2000. *Improving Small-Holder Access to Purchased Inputs in Sub-Saharan Africa*. Policy Series No. 7. Chatham, UK: Natural Resources Institute.

Gordon, A., and A. Goodland, 2000. Production and Credit for African Small-holders: Conditions for Private Provision. *Savings and Development* XXIV.1: 55-84.

Greenland, D., A. Wild, and D. Adams. 1992. Organic Matter Dynamics in Soils of the Tropics—From Myth to Complex Reality. In *Myths and Science of Soils of the Tropics: Proceedings of an International Symposium*, *October 17, 1989, Las Vegas, Nevada*, eds. R. Lal and P. Sanchez. SSSA Special Publication Number 29. Madison, WI: Rural American Society of Agronomy and Soil Science Society of America.

Haagblade, S., and G. Tembo. 2003. Conservation Farming in Zambia. Paper presented at the InWEnt, IFPRI, NEPAD, CTA Conference Successes in African Agriculture, December 1-3, Pretoria, South Africa.

Hardaker, B., R. Huirne, and J.R. Anderson. 1997. *Coping with Risk in Agriculture*. Wallingford: CAB International.

Hazell, P., C. Pomareda, and A. Valdés. 1986. *Crop Insurance for Agricultural Development: Issues and Experience*. Baltimore: Johns Hopkins University Press.

Heinemann, E. 2002. The Roles and Limitations of Producer Associations. Paper presented at the European Forum on Rural Development Cooperation, September 4-6, Montpellier.

Heisey, P.W., and W. Mwangi. 1997. Fertilizer Use and Maize Production in Sub-Saharan Africa. In *Africa's Emerging Maize Revolution,* eds. D. Byerlee and C.K. Eicher. Boulder, CO: Lynne Rienner Publishers.

Henao, J., and C. A. Baanante. 1999. An Evaluation of Strategies to Use Indigenous and Imported Sources of Phosphorus to Improve Soil Fertility and Land Productivity in Mali. Muscle Shoals, AL: International Fertilizer Development Center (IFDC). Mimeo.

Henao, J., J. Brink, B. Coulibaly, and A. Traoré. 1992. Agronomic Potential of Fertilizer Use in Mali. Bamako: Institut d'Economie Rurale. Unpublished report.

Hess, U., and J. Syroka. 2004. Weather Based Insurance Against Covariate Shocks in Southern Africa. Washington, D.C.: World Bank. Mimeo.

Hopper, W. 1993. Indian Agriculture and Fertilizer: An Outsider's Observations. Keynote address to the FAI Seminar on Emerging Scenario in Fertilizer and Agriculture: Global Dimensions. New Delhi: FAI.

Howard, J., V. Kelly, M. Maredia, J. Stepanek, and E. Crawford, 1999. *Progress and Problems in Promoting High External-input Technologies in Sub-Saharan Africa: the Sasakawa Global 2000 Experience in Ethiopia and Mozambique*. MSU Department of Agricultural Economics Staff Paper No. 99-24. East Lansing: Michigan State University.

IFDC. 1997. *PR Initiative Case Studies: Synthesis Report, An Assessment of Phosphate Rock as a Capital Investment: Evidence from Burkina Faso, Madagascar, and Zimbabwe*. Muscle Shoals, AL: International Fertilizer Development Center.

IFDC. 2002. *Collaborative Research Programme for Soil Fertility Restoration and Management in Resource-poor Areas of Sub-Sahara Africa*. Muscle Shoals, AL: International Fertilizer Development Center.

IFDC. 2005. *Factors Affecting Fertilizer Supply in Africa*. Muscle Shoals, AL: International Fertilizer Development Center.

INSAH. 2003. *Catalogue regionale des variétés de semences*. Bamako: INSAH.

Jaffee, S., R. Kopicki, P. Labaste, and I. Christie. 2003. *Modernizing Africa's Agro-food Systems: Analytical Framework and Implications for Operations*. Africa Region Working Paper Series No. 44. Washington, D.C.: World Bank.

Jayne, T.S., and S. Jones. 1997. Food Marketing and Price Policy in Eastern and Southern Africa: A Survey. *World Development* 25.9: 1505-1527.

Jayne, T.S., J. Govereh, A. Mwanaumo, J. Nyoro, and A. Chapoto. 2002. False Promise or False Premise: The Experience of Food and Input Market Reform in Eastern and Southern Africa. *World Development* 30.11: 1967-1986.

Jayne, T.S., J. Govereh, M. Wanzala, and M. Demeke. 2003. Fertilizer Market Development: A Comparative Analysis of Ethiopia, Kenya and Zambia. *Food Policy* 28: 293-316.

Jayne, T., R. Myers, D. Byerlee, and J. Anderson. 2004. Managing Food Price Instability and Risk in Low-Income Countries: The Problem and Emerging Policy Options. East Lansing: Michigan State University. Unpublished draft.

Jha, D., and B. Hojjati. 1993. *Fertilizer Use on Smallholder Farms in Eastern Province, Zambia*. Research Report No. 94. Washington, D.C.: International Food Policy Research Institute.

Jiggins, J., C. Reijntjes, and C. Lightfoot. 1996. Mobilising Science and Technology to Get Agriculture Moving in Africa: A Response to Borlaug and Dowswell. *Development Policy Review* 14: 89-103.

Kaboré, D., and Chris Reij. 2004. *The Emergence and Spreading of Improved Traditional Soil and Water Conservation Practices in Burkina Faso*. EPTD Discussion Paper 14. Washington, D.C.: International Food Policy Research Institute.

Kelly, V. 2000. Measuring the Impacts of Natural Resource Management Practices in the OHVN. Washington, D.C.: International Resources Group. Consulting report.

Kelly, V. 2003. *Measuring the Impacts of Natural Resource Management Activities in Mali's Upper Niger Valley*. Technical Paper No. 117. Washington, D.C.: SD Publications Series, Office of Sustainable Development, Bureau for Africa.

Kelly, V., and A. Murekezi. 2000. Fertilizer Response and Profitability in Rwanda. A synthesis of findings from MINAGRI studies conducted by the Food Security Research Project (FSRP) and the FAO Soil Fertility Initiative.

Kelly, V., and J. Nyirimana. 2002. *Learning from Doing: Using Analysis of Fertilizer Demonstration Plots to Improve Programs for Stimulating Fertilizer Demand in Rwanda*. Rwanda: Food Security Research Project (FSRP) and Division of Agricultural Statistics (DSA), Ministry of Agriculture, Livestock and Forestry, Ministry of Agriculture.

Kelly, V., A. Adesina, and A. Gordon. 2003. Expanding Access to Agricultural Inputs in Africa: A Review of Recent Market Development Experience. *Food Policy* 28: 379-404.

Kelly, V., E. Mpyisi, A. Murekezi, and D. Neven. 2001. Fertilizer Consumption in Rwanda: Past Trends, Future Potential, and Determinants. Paper prepared for the Policy Workshop on Fertilizer Use and Marketing, organized by MINAGRI and USAID, February 22-23, Kigali, Rwanda.

Kydd, J., A. Dorward, J. Morrison, and G. Cadisch, 2002. *Agricultural Development and Pro-poor Economic Growth in Sub-Saharan Africa: Potential and Policy*. ADU Working Paper 02/04. Wye: Imperial College.

Lal, R. 1990. *Soil Erosion in the Tropics: Principles and Management*. New York: McGraw-Hill, Inc.

Langyintuo, A., K. Foster, and J. Lowenberg-DeBoer. 2001. Potential Impact of Input Policy on Maize Supply in Ghana in Maize Revolution. In *West and Central Africa: Proceedings of a Regional Maize Workshop, IITA, 14-18 May, 2001*, eds. B. Badu-Apraku, M.A.B. Fakorede, M. Ouedraogo, R.J. Casky, and A. Menkir. Ibadan, Nigeria: West and Central Africa Collaborative Maize Research Network (WECAMAN).

Larson, D.F., J.R. Anderson, and P. Varangis, 2004. Policies Regarding Risk in Agricultural Markets. Washington, D.C.: World Bank: Mimeo.
.

Lele, U., R. Christiansen, and K. Kadiresan. 1989. *Fertilizer Policy in Africa: Lessons from Development Programs and Adjustment Lending, 1970-1987*. MADIA Discussion Paper 5. Washington, D.C.: World Bank.

Lopez, R. 2003. Under Investing in Public Goods: Evidence, Causes, and Consequences for Agricultural Development, Equity and the Environment. Paper presented at the Plenary Session, Agriculture and the Environment, Meetings of the International Agricultural Economics Association, August, Durban, South Africa.

Mariko, D., and A. Chohin-Kuper. 2001. Libéralisation et évaluation du franc CFA: la relance de la filière riz irrigué à l'Office du Niger au Mali? C*ahiers Agricultures* 10: 173-84.

McCown, R. 2001. Farming Systems Research and Practice. Proceedings of the 10th Australian Agronomy Conference, 28 January-1 February, Hobart, Australia. http://www.regional.org.au/au/asa/2001/plenery/4/mccown.htm#p2_45

McKinnon, R. 1967. Futures Markets, Buffer Stocks, and Income Stability for Primary Producers. *Journal of Political Economy* 75.6: 844-861.

Mortimore, M. 1998. *Roots in the African Dust: Sustaining the Drylands*. Cambridge, UK: Cambridge University Press.

Murage, E.W., N.K. Karanja, P.C. Smithson, and P.L. Woomer, 2000. Diagnostic Indicators of Soil Quality in Productive and Non-productive Smallholders Fields of Kenya's Central Highlands. *Agriculture, Ecosystems and Environment* 79: 1-8.

Murekezi, A. May 2000. Etude sur la rentabilité des engrais mineraux au Rwanda: Initiative sur la fertilité des sols-conservation des eaux et des sols (IFSCES) Resumé. Kigali, Rwanda: FAO and MINAGRI.

Myers, R.J. 1993. Strategies for Managing Coffee Price Risks in Costa Rica. In *Managing Commodity Price Risk in Developing Countries*, eds. S. Claessens and R.C. Duncan. Baltimore and London: Johns Hopkins University Press.

Myers, R.J., and S.R. Thompson. 1993. Managing Oil Import Price Risk in Costa Rica: Strategies and Benefits. In *Managing Commodity Price Risk in Developing Countries*, eds. S. Claessens and R.C. Duncan. Baltimore and London: Johns Hopkins University Press.

Neubert, D., and D. Sarda. 2000. Cooperative League of the USA Rural Group Business Programme Evaluation. Report prepared for USAID/Zambia. Arlington, VA: ARD/RAISE Consortium.

Nkonya, E., T. Schroeder, and D. Norman. 1997. Factors Affecting Adoption of Improved Maize Seed and Fertilizer in Northern Tanzania. *Journal of Agricultural Economics* 48.1: 1-12.

Norman, D.W. 1980. *The Farming Systems Approach: Relevancy for the Small Farmer*. MSU Department of Agricultural Economics Rural Development Paper No. 5. East Lansing: Michigan State University.

Norman, D.W., F.D. Worman, J.D. Siebert, and E. Modiakgotia. 1995. *The Farming Systems Approach to Development and Appropriate Technology Generation*. Rome: Food and Agriculture Organization of the United Nations.

Oehmke, James F., and Eric W. Crawford. 1996. The Impact of Agricultural Technology in Sub-Saharan Africa. *Journal of African Economies* 5.2: 271-92.

Okali, C., J.E. Sumberg, and K.C. Reddy. 1994. Unpacking a Technical Package: Flexible Messages for Dynamic Situations. *Experimental Agriculture* 30: 299-310.

Overdahl, J.A. 1987. The Use of Crude Oil Futures by the Governments of Oil-Producing States. *Journal of Futures Markets* 7.6: 603-17.

Oygard, R., R. Garcia, A. Guttormmsen, R. Kachule, and A. Mwanaumo. 2003. *The Maze of Maize: Improving Input and Output Market Access for Poor Smallholders in Southern African Region, the Experience of Zambia and Malawi*. Department of Economics and Resource Management Report No. 26. Norway: Agricultural University of Norway.

Palm, C., R.J.K. Myers, and S.M. Nandwa.1997. Combined Use of Organic and Inorganic Nutrient Sources for Soil Fertility Maintenance and Replenishment. In *Replenishing Soil Fertility in Africa*, eds. R.J. Buresh, P. Sanchez, and F. Calhoun. Madison, WI: Soil Science Society of American, Inc. and American Society of Agronomy, Inc.

Pickney, T.C. 1994. Does Education Increase Agricultural Productivity in Africa? In *Issues in Agricultural Competitiveness: Markets and Policies*, eds. R. Rose, C. Tanner, and M.A. Bellamy. Proceedings of the 22nd International Conference of Agricultural Economists, 22-29 August, Harare, Zimbabwe. IAAE Occasional Paper No. 7.

Pieri, C. 1989. *Fertilité des terres de savanes: Bilan de trente ans de recherché et de développement agricoles au sud du Sahara*. Montpellier: CIRAD.

Piha, M. 1993. Optimising Fertilizer Use and Practical Rainfall Capture in a Semi-arid Environment with Variable Rainfall. *Experimental Agriculture* 29: 405-415.

Place, F., C. Barrett, H.A. Freeman, J. Ramisch, and B. Vanlauwe. 2003. Prospects for Integrated Soil Fertility Management Using Organic and Inorganic Inputs: Evidence from Smallholder African Agricultural Systems. *Food Policy* 28: 365-378.

Place, F., S. Franzel, Q. Noordin, and B. Jama. 2002. Improved Fallows in Kenya: History, Farmer Practice, and Impacts. Paper presented at the IFPRI workshop on Successes in African Agriculture, June 10-12, Lusaka, Zambia.

Poulton, C., A. Dorward, and J. Kydd. 1998. The Revival of Smallholder Cash Crops in Africa: Public and Private Roles in the Provision of Finance. *Journal of International Development* 10.1: 85-103.

Poulton, C., J. Kydd, and A. Dorward. 2005. *E-Forum on Increasing Fertilizer Use in Africa: What Have We Learned*. Final Moderators' Report prepared for the World Bank by the Centre for Development and Poverty Reduction. Wye: Imperial College London.

Pound, B., S. Snapp, C. McDougall, and A. Braun. 2003. *Managing Natural Resources for Sustainable Livelihoods: Uniting Science and Participation*. London: Earthscan and International Development Research Centre.

Pretty, J. 1995. *Regenerating Agriculture*. London: Earthscan Publications, Ltd.

Quiñones, M., N. Borlaug, and C. Dowswell. 1997. A Fertilizer-Based Green Revolution for Africa. In *Replenishing Soil Fertility in Africa,* eds. R. Buresh, P. Sanchez, and F. Calhoun. Madison, WI: Soil Science Society of America and American Society of Agronomy, Inc.

Raynaut, C., ed. 1997. *Societies and Nature in the Sahel*. London: Routledge.

Reardon, T., E. Crawford, V. Kelly, and B. Diagana. 1995. *Promoting Farm Investment for Sustainable Intensification of African Agriculture*. MSU International Development Paper No. 18. East Lansing: Michigan State University.

Reardon, T., V. Kelly, D. Yanggen, and E. Crawford. 1999a. *Determinants of Fertilizer Adoption by African Farmers: Policy Analysis Framework, Illustrative Evidence, and Implications*. MSU Department of Agricultural Economics Staff Paper No. 99-18. East Lansing: Michigan State University.

Reardon, T., C. Barrett, V. Kelly, and K. Savadogo. 1999b. Policy Reforms and Sustainable Agricultural Intensification in Africa. *Development Policy Review* 17.4: 375-395.

Reijntjes, C., B. Haverkort, and A. Waters-Bayer. 1993. Inspecting the Toolbox: Look the Means for Achieving Sustainable Agriculture. Ceres, *The FAO Review* No. 144 25.6.

Robbins, P. 2000. *Review of Market Information Systems in Botswana, Ethiopia, Ghana and Zimbabwe*. Wageningen: Technical Centre for Agricultural and Rural Cooperation.

Rohrbach, D., and G.E. Okwach. 1998. Modeling Crop Performance or Cropping Decisions. In *Risk Management for Maize Farmers in Drought-prone Areas of Southern Africa*. Mexico: ICRISAT and CIMMYT.

Rolfo, J. 1980. Optimal Hedging Under Price and Quantity Uncertainty: The Case of a Cocoa Producer. *Journal of Political Economy* 88.11: 100-116.

Röling, N. 1988. *Extension Science: Information Systems in Agricultural Development*. Cambridge, UK: Cambridge University Press.

Rommelse, R. 2001. *Economic Analyses of On-farm Biomass Transfer and Improved Fallow Trials in Western Kenya*. Natural Resources Problems, Priorities and Policies Programme Working Paper 2001-2. Nairobi: International Center for Research in Agroforestry.

Roth, C.H. 1985. Infiltrabilität von Latosolo-Roxo-Böden in Nordparaná, Brasilien, in Feldversuchen zur Erosionskontrolle mit verschiedenen Bodenbearbeitungs-systemen und Rotationen. *Göttinger Bodenkundliche Berichte* 83: 1-104.

Sachs, J. 2001. New Approaches to International Donor Assistance. Presentation to International Development Research Center, Ottawa, Canada. In ECAPAPA Electronic Newsletter 4.37.

Sachs, J. 2003. The Case for Fertilizer Subsidies for Subsistence Farmers. Draft, December 7.

Sanders, J. 2002. Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL-Priority Countries. The International Sorghum and Millet Collaborative Research Support Program (INTSORMIL). Annual report 2002.

Sanders, J. 2003. Economic and Sustainability Evaluation of New Technologies in Sorghum and Millet Production in INTSORMIL-Priority Countries. The International Sorghum and Millet Collaborative Research Support Program (INTSORMIL). Annual report 2003.

Sanders, J., and M. Ahmed. 1998. *Developing a Fertilizer Strategy for Sub-Saharan Africa*. West Lafayette, IN: Purdue University.

Sanders, J., B. Shapiro, and S. Ramaswamy. 1996. *The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa*. Baltimore: Johns Hopkins University Press.

Sanginga, N. 2003. Role of Biological Nitrogen Fixation in Legume Based Cropping Systems: A Case Study of West Africa Farming Systems. *Plant Soil* 252: 25-39.

Sansoni, S. 2002. Silicon Mali. *Forbes Magazine*, February 4, 2002 available at: http://forbes.com/global/2002/0204/042.html

Sarris, A.H. 2000. World Cereal Price Instability and a Market-Based Instrument for LDC Food Import Risk Management. *Food Policy* 25.2: 189-209.

Schlesinger, W.H. 1999. Carbon Sequestration in Soils. *Science* 284: 2095.

Seward, P., and D. Okello, 1999. *SCODP's Mini-pack Method*. SCODP Special Report No. 1. Sustainable Community-Oriented Development Programme.

Shapiro, B., and J. Sanders. 1998. Fertilizer Use in Semiarid West Africa: Profitability and Supporting Policy. *Agricultural Systems* 56.4: 467-482.

Shepherd, A. 1997. *Market Information Services - Theory and Practice*. FAO Agricultural Services Bulletin 125. Rome: FAO.

Shields, J. 1976. Estimating Fertilizer Demand. *Food Policy* August.

Shiferaw, B., H.A. Freeman, and S.M. Swinton. 2004. *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environment Impacts*. Wallingford, UK: CAB International.

Snapp, S. 1998a. Phosphorous and Sustainability of Sub-Saharan African Smallholder Farms. In *Phosphorous in Plant Biology: Regulatory Roles in Molecular, Cellular, Organismic, and Ecosystem Processes,* eds. J.P. Lynch and J. Deikman, *American Society of Plant Physiologists*: 71-84.

Snapp, S. 1998b. Soil Nutrient Status of Smallholder farms in Malawi. *Communications in Soil Science and Plant Analysis* 29.17-18: 2571-2588.

Snapp, S.S., M.J. Blackie, and C. Donovan. 2003. Realigning Research and Extension to Focus on Farmers' Constraints and Opportunities. *Food Policy* 28: 349-364.

Snapp, S., and K. Heong. 2003. Scaling Up and Out. In *Managing Natural Resources for Sustainable Livelihoods: Uniting Science and Participation*, eds. B. Pound, S. Snapp, C. McDougall, and A. Braun. London: Earthscan and International Development Research Centre.

Sones, K.R., D. Duveskog, and B. Minjauw, eds. 2003. Farmer Field Schools: the Kenyan Experience. Report of the Farmer Field School Stakeholders' Forum, March 27, Nairobi, Kenya.

Stepanek, J. 1999. Lessons from Ethiopia's High-input Technology Promotion Program: How the Organization of the Fertilizer Subsector Affects Maize Productivity. Ph.D. dissertation, Michigan State University.

Stoorvogel, J.J., and E.M.A. Smaling, 1990. *Assessment of Soil Nutrient Depletion in Sub-Saharan Africa, 1983-2000*. Report 28. Wageningen, Netherlands: Winand Staring Center for Integrated Land, Soil and Water Research (SC-DLO).

Tahirou, A., and J. Sanders. 2002. Economics of Fertilizer Use in Semi-arid African Agriculture: Niger Experience. West Lafayette: Purdue University. Unpublished report.

Tappan, G., and M. McGahuey. 2004.Tracking Environmental Dynamics and Agricultural Intensification in Southern Mali. Paper presented at the SANREM workshop on Carbon, February, Bamako, Mali.

Tefft, James. 2000. Cotton in Mali: The 'White Revolution' and Development. In *Democracy and Development in Mali,* eds. R. James Bingen, John M. Staatz, and David Robinson. East Lansing: Michigan State University Press.

Thompson, T. 1987. *A Socioeconomic Study of Farm-level Constraints to Fertilizer Use in Western Niger*. Muscle Shoals: IFDC.

Timmer, C.P. 1974. The Demand for Fertilizer in Developing Countries. *Food Research Institute Studies* 13: 197-224.

Timmer, C.P. 1976. Fertiliser and Food Policy in LDCs. *Food Policy*, February: 143-154.

Tomich, T., P. Kilby, and B. Johnson. 1995. Transforming Agrarian Economies: Opportunities Seized, Opportunities Missed. Ithaca, NY: Cornell University Press.

Townsend, R.F. 1999. *Agricultural Incentives in Sub-Saharan Africa: Policy Challenges.* World Bank Technical Paper No. 444. Washington, D.C.: World Bank.

Traore, B., and J.B. Spinat. 2002. Des institutions de proximite pour resorber un endettement durable. In *Office du Niger, grenier a riz du Mali*, eds. P. Bonneval, M. Kuper, and J-P Tonneau. Paris: CIRAD/Karthala.

Twomlow, S. 2004. Review of *Managing Natural Resources for Sustainable Livelihoods: Uniting Science and Participation* by B. Pound, S. Snapp, C. McDougall, and A. Braun. *Development Policy Review* 22.5: 603-608.

Twomlow, S., J. Ruskie, and S. Snapp. 2001. Biophysical or Economic Performance—Which Reflects Farmer Choice of Legume 'Best Bets' in Malawi? Proceedings of the Seventh Eastern and Southern Africa Regional Maize Conference, 11-15 February.

UN Millennium Project. 2005. *Investing in Development: A Practical Plan to Achieve the Millennium Development Goals*. New York: UN Millennium Project.

van der Pol, F. 1992. *Soil Mining: An Unseen Contributor to Farm Income in Southern Mali*. Bulletin 325. Amsterdam: Royal Tropical Institute.

Vanlauwe, B., J. Diels, N. Sanginga, and R. Merck, eds. 2002. *Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice*. Wallingford, UK and New York: CABI Publishers in association with the International Institute of Tropical Agriculture.

Voortman, R., B. Sonneveld, and M. Keyzer. 2000. *African Land Ecology: Opportunities and Constraints for Development*. Center for International Development Working Paper No. 37. Boston: Harvard University.

Waddington, S. R., and J. Karigwindi. 2001. Productivity and Profitability of Maize + Groundnut Rotations Compared with Continuous Maize on Smallholder Farms in Zimbabwe. *Experimental Agriculture* 37: 83-98.

Wanzala, M. 2003. An Economic Analysis of the Performance of the Fertilizer Subsector in the Maize Belt of Western Kenya. Ph.D. dissertation, Michigan State University.

Wanzala, M., T.S. Jayne, John M. Staatz, Amin Mugera, Justus Kirimi, and Joseph Owuor. 2001. *Fertilizer Markets and Agricultural Production Incentives: Insights from Kenya*. Nairobi: Tegemeo Institute of Agricultural Policy and Development.

Weight, D., and V. Kelly. 1999. *Fertilizer Impacts on Soils and Crops of Sub-Saharan Africa*. MSU International Development Paper No. 21. East Lansing: Michigan State University.

Wetselaar, R., and M.J.T. Norman. 1960. *Soil and Crop Nitrogen at Katherine.* N.T. Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Land Research and Regional Survey Technical Paper No. 10. Canberra: CSIRO.

Winter-Nelson, A., and A. Temu. 2002. Institutional Adjustment and Transaction Costs: Product and Inputs Markets in the Tanzanian Coffee System. *World Development* 30.4: 561-574.

Wopereis, M.C.S., C. Donovan, B. Nebie, D. Guindo, and M.K. N'Diaye. 1999. Soil Fertility Management in Irrigated Rice Systems in the Sahel and Savanna Regions of West Africa, Part 1. Agronomic Analysis. *Field Crops Research* 61: 125-145.

World Bank. 2000. *Can Africa Claim the Twenty-First Century?* Washington, D.C.: World Bank.

World Bank. 2004. Promoting Use of Fertilizer to Increase Agricultural Productivity and Reduce Poverty and Hunger in Africa: Concept Note. Washington, D.C.: World Bank. Draft.

Yanggen, D., V. Kelly, T. Reardon, and A. Naseem. 1998. *Incentives for Fertilizer Use in Sub-Saharan Africa: A Review of Empirical Evidence on Fertilizer Yield Response and Profitability.* MSU International Development Working Paper No. 70. East Lansing: Michigan State University.

Yao, S. 1996. The Determinants of Cereal Crop Productivity of the Peasant Farm Sector in Ethiopia, 1981-87. *Journal of International Development* 8.1: 69-82.

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 ≥ 2, 3, 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 provides a simple example of how different decision rules can influence the net profits from a fertilizer application.

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 (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%.

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 (VMP/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 value - marginal cost)/marginal cost									

Appendix 3

(Appendix 1 from Yanggen et al. 1998. The entire document is available on the web at:

http://www.aec.msu.edu/agecon/fs2/papers/idwp70.pdf)

APPENDIX TABLES

LIST OF APPENDIX TABLES

ABBREVIATIONS USED IN APPENDIX TABLES

Avail	Available
Avg	Average
B	Boron
Chg	Change
Cmpst	Compost
Cp	Cowpea
Chpt	Chapter
Dif	Different
Dir	Direct
Eff	Effect
FAO	Food and Agricultural Organization
Fert	Fertilizer
Fin’l	Financial
Fm	Farms
FMT	Farmer Managed Trial (if farmer management was not explicitly stated, researcher management was assumed)
Gdnt	Groundnut
Ha	Hectare
Imprvd	Improved
I/O	Input-Output
K	Potassium
Kg	Kilogram
Masl	Meters above sea level
Max	Maximum
Min	Minimum
Mm	Millimeters
Mz	Maize
N	Nitrogen
NB	Net Benefit
Nutr	Nutrient
OFT	On-farm trial
OPV	Open pollinated variety
Organ mat	Organic matter
Otpt	Output
P	Phosphorus
PARP	Partially acidulated phosphate rock
Prov	Provence
Rec	Recommended amount
Recommend	Recommendation
Resid	Residual
RP	Rock phosphate
Rsp	Response
RMFT	Researcher managed on-farm trial (includes farm trials where farmer management

	not explicitly stated)
RT	Researcher managed on-station trial
S	Sulfur (sulfate)
Sorg	Sorghum
SSP	Super Simple Phosphate
Sub	Subsidy
TR	Tied Ridge
V/C	Value-Cost Ratio
W/	With
W/O	Without
Yld	Yield
Yr	Year
Zai	Indigenous conservation practice (not an abbreviation) consisting of holes dug farmers' fields during the dry season and filled with organic matter.

Table A1. Maize Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr										
W/O	With	Rsp			I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
		'		6-14 5-12 1-7					40 N 20 P 20 K	West Africa			FAO RMFT	Shalitzz & Binswanger '84
				10-20 2-8 2-5					20 N 20 P 20 K	West Africa			FAO FMT	Shalit & Binswanger '84
				7-32	3.82*[a]			Rsp to N		Cameroon				Heisey & Mwangi '97
					('80-92) 5.4					Cote d'Ivoire				Heisey & Mwangi '97
Average yields: '67-78				Avg	6.1*	('90)		NPK + manure	Yr 1&2:40-40-60 Yr 3:20-40-40 + 15 t manure; repeat for 10 yrs.	Cote d'Ivoire	Bouake	'67-78	RMT?[b]	Pieri '85
368	1809	1441		11		2.5								
Average yields: '67-78				Avg	6.1*			NPK + manure	Yr 1&2:80-80-120 Yr 3:40-80-80 + 15 t manure; repeat for 10 yrs	Cote d'Ivoire	Bouake	'67-78	RMT?	Pieri '85
368	2726	2358		9										
1187	2739	1552	131	10	.75*	('90) 7		NPK	75-40-38	Gambia		'81-84	RMFT at 24 sites	FAO mimeo '85
2110 4820 4750	4220 7520 7300	21102 70021 10	100 56 54	42 54 42	1.95*	('90) 20-26		Rsp N w/ various rotations	50 N: Mz-Mz 50 N: Gdnt-Mz 50 N: Cp-Mz	Ghana	Guinea Savanna	'80s	RMFT?	Bonsu '96 citing Schmidt & Frey

[a] An '*' in this column indicates that the fertilizer/output price ratio was calculated from data in the FAO online data base using urea price in the numerator. If a year is not mentioned, the i/o ratio (or average ratio) is for the same year(s) as the response data; when i/o price data were not available for desired year(s), we reported the closest year(s) available and noted which year(s) they were in parentheses.

[b] A '?' indicates that information in the original source was not clear or missing.

Table A1. Maize Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
Mz/Mz	Gdnt/ Mz				1.95*			Rsp to rotation	No fert: Mz/Mz vs Gdnt/Mz	Ghana	Guinea Savanna	'80s	RMFT?	ditto
2110	4820	2710												
				0-35	('82-7) 2 ('89) 8 ('91-4) 10			N		Ghana				Heisey & Mwangi '97
1047 1047 1047	2296 2192 1873	1249 1145 826	119 109 78		5.3*			Rsp to P	Farmers' practice Tilemsi PR: basal Tilemsi PR: annual	Mali				Bonsu '96 citing Bationo et al.
					4.4*	3.6 3.2		Rsp to Tilemsi P rock	Mz-Gdnt Rotation Basal 120 P vs. 289 P over 4 years	Mali		'82-85		Henao et al. '92
Total yield of maize over 10-yr period (5 maize production cycles)					5.3*			Rsp to basal vs. basal + annual P	Maize-Gdnt rotation: 120 P every 10 yr 120 P 1st yr + 25 P annually	Mali	Tinfongo		not specified	Kuyvenhoven, Becht & Rubin '95
3249 3249	4827 8284	1578 5035	48 150	13 21										
Min: 1258		Max: 3750		Avg: 12	5.3*	('87) 2	OPV	Rsp to NPK	80-79-50	Mali	N Sudan	'70-90	RMFT	Henao et al. '92
Min: 267		Max: 1314		Avg: 4	5.3*	.69	Local							
Min:1048		Max: 4603		Avg: 18	5.3*	3.1	OPV	Rsp to NPK	90-70-35	Mali	S Sudan	'70-90	RMFT/ FMT	Henao et al. '92
Min: 610		Max: 2000		Avg: 6	5.3*	1.04	Local		130-60-50					

Table A1. Maize Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr										
W/O	With	Rsp			I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
				4-22	('85-92)[c] 2 and 7[d]			N		Nigeria				Heisey & Mwangi '97
				5-14	.6*			NPK		Nigeria				Lele, Christiansen & Kadiresan '89
					('87) 2.9					Senegal				Lele, Christiansen & Kadiresan '89
					2.4*	248[e] 130[e]		N Rsp	55 N on 'champs de case'	Senegal	Casamance	'84 '85	RMFT	Ndiame '88
					2.4*	49[e] 217[c]			55 N on regular field	Senegal	Casamance >1000 mm	'84 '85	RMFT	Ndiame '88
589	1025	436	74	2	('90) 1.51	1.27 902[e]		NPK	Gdnt-Mz rotation	Senegal	Peanut Basin 429 mm	'90	FMT	Ndiaye & Sidibe '92
441	745 817 875	301 373 431			1.65*			Rsp to different types of P	P brut P 61% acidulated P souluable	Togo				Pieri '85, citing Sivenge & Timac
				9-17	4.5*			N		Ethiopia				Heisey & Mwangi '97
2475	3884	1409	57	11.3	4.5*	('92) 4.2 ('97) 1.4			60 N 64 P	Ethiopia				Mulat et al. '97
				7-36	5.75*	('94) 1.3 to 6.7			N	Kenya				Heisey & Mwangi '97

[c] Median rather than average values for 1985-1992 shown in box.

[d] With subsidy i/o=2 and without subsidy i/o = 7.

[e] Marginal rate of return rather than v/c ratio.

Table A1. Maize Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
				9-26	5.75*	1.7-4.8	Hybrid	N&P		Kenya				Lele, Christiansen & Kadiresan '89
				3.7 9.2 7.8					100 $P_2 0_5$ 300 $P_2 0_5$ 400 $P_2 0_5$	Mada- gascar				Peters '95
				14-16 20-37	7.35		Local Hybrid	N / N&P		Malawi				Lele, Christiansen & Kadiresan '89
				8-38 8-52	7.35		Local Hybrid		N	Malawi				Heisey & Mwangi '97
1346 1346 1346 1346 1346	3138 2262 2825 3138 3189	1792 916 1479 1792 1843	133 68 109 133 136	13.5 25 31.5 19 16	('87-96) Avg: 7 min: 5 max: 10	1 2 3 2 1	Hybrid	Rsp to recom- mended NPK vs alternatives	92-40-0 (rec) 35-0-0 + 2S 35-10-0 +2S 69-21-0 + 4S 92-21-0 + 4S	Malawi	country-wide	'95/6	RMFT	Benson '97 a
				14-16 20-37	7.35		Local Hybrid	N / N&P		Malawi				Lele, Christiansen & Kadiresan '89
				8-38 8-52	7.35		Local Hybrid		N	Malawi				Heisey & Mwangi '97
1346 1346 1346 1346 1346	3138 2262 2825 3138 3189	1792 916 1479 1792 1843	133 68 109 133 136	13.5 25 31.5 19 16	('87-96) Avg: 7 min: 5 max: 10	1 2 3 2 1	Hybrid	Rsp to recom. NPK vs alternatives	92-40-0 (rec) 35-0-0 + 2S 35-10-0 +2S 69-21-0 + 4S 92-21-0 + 4S	Malawi	country-wide	'95/6	RMFT	Benson '97 a
				18-43 13-18 8-10	5.25*	('89) 6-15 2.7-3.4				Tanzania	S Highland North Dry			Heisey & Mwangi '97
				6 11-16	5.25*	2 4-5	Local Hybrid	N&P		Tanzania				Lele, Christiansen & Kadiresan '89

Table A1. Maize Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr										
W/O	With	Rsp			I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
1200	4000		233		('74-76) 196.2* ('86-92) .41*					Uganda			RMFT	Tukacungurwa '94
				18.1 11.1	4.3*	('83/4) 2-4	Hybrid Local			Zambia	Plateau Region	'83/4, '86/7	FMT	Jha & Hojjati '93; Heisey & Mwangi '97
879 879	1071 2461	192 1582	22 179	2 9	4.6*	.43 1.49	Local Hybrid	Rsp total nutrients	81 NPK 179 NPK manual labor only	Zambia	E Prov	'86	survey	Celis, Milimo & Wanmali '91
1172	1414	242	21	3	4.6*	2.8	Local	Rsp total nutrients	90 NPK oxen traction	Zambia	E Prov	'86	survey	Celis, Milimo & Wanmali '91
				6-26	6.0*	('93) 1-5			N	Zimbabwe				Heisey & Mwangi '97
					6 1.4 1.6					Latin America	Brazil Colombia Mexico	Avg '80-92		Mwangi '96
 627 1679	 740 2130	 113 451	 18 27	 .47 2			Local	Rsp of Mz vs Sorg to NPK	90-90-60 to both Maize Sorghum	Brazil	semi-arid 147-322 mm	'76	RMT	Sanders '79
1616	2505	889	55	10	3.0			Application NPK	45-45-0	Colombia		Early '60's	FAO RT	DeGeus '70 citing FAO
3565	4492	927	26	6.5		1.7		Application NPK	80-60-0	Costa Rica	High & Low Regions	Early '60's	FAO RT	DeGeus '70 citing FAO
2743	4005	1262	46	7		2.0		Application NPK	80-60-40	Costa Rica	Low Regions	Early '60's	FAO RT	DeGeus '70 citing FAO
900	2200	1300	144	14.7					28-45-15	Ecuador		?	FAO RMFT	FAO '81

Table A1. Maize Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
2211	3405	1194	54	13.5		4.2	High-land Maize	Application NPK	45-45-0	Ecuador		Early '60's	FAO RT	DeGeus '70 citing FAO
2656	4566	1912	72	10.5		3.4		Application NPK	90-90-0	El Salvador	Central	Early '60's	FAO RT	DeGeus '70 citing FAO
3956	5222	1266	32	4.5		2.2		Application NPK	90-90-90	El Salvador	East	Early '60's	FAO RT	DeGeus '70 citing FAO
2606	4326	1720	66	9.5		3.1		Application NPK	90-90-0	El Salvador	West	Early '60's	FAO RT	DeGeus '70 citing FAO
2625	3360	735	28	6.5		1.2		Application NPK	75-40-0	Guatemala	Low Region	Early '60's	FAO RT	DeGeus '70 citing FAO
2171	3604	1433	66	10.5		2.0		Application NPK	75-60-0	Guatemala	Medium Region	Early '60's	FAO RT	DeGeus '70 citing FAO
2624	4725	2101	80	11.5		2.1		Application NPK	100-80-0	Guate-mala	High Region	Early '60's	FAO RT	DeGeus '70 citing FAO
3315	3946	630	19	14		2.8	Local Imprvd	Application NPK	45-0-0	Honduras		Early '60's	FAO RT	DeGeus '70 citing FAO
2477	3220	743	30	5.5		1.6	Local Unimp-roved	Application NPK	45-45-45	Honduras		Early '60's	FAO RT	DeGeus '70 citing FAO
5013	9880	4867	105	18		5.3	Local Imprvd	Application NPK	90-90-90	Honduras		Early '60's	FAO RT	DeGeus '70 citing FAO
					2.1 2.2 2.6 2.9 7.9					Asia	India Indonesia Pakistan Philippines Thailand	Avg '80-92		Mwangi '96

Table A1. Maize Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
1780	3240	1460	82	29					N-50	Burma	Thayetchung	?	?	DeGues '70 citing Hirose
950	2190	1240	131	8.5		1.64		Rsp to NPK	N-60, P_20_5-60, K_20-30.	India		'77/8 to 78/9	Farmer field trials	FAO '83a/b
815	2111	1296	159	8.0					N+P205+K20 67+45+50	Indonesia		?	FF demo's FAO trials	FAO '81

Source: Compiled by authors from documents listed in the 'source' column.

Table A2. Sorghum Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
				5-10 4-8 0-6					20 N 20 P 20 K	West Africa		'70s	FAO RT	Shalit & Binswanger '84
				6-14 6-15 4-7					20 N 20 P 20 K	West Africa		'70s	FAO RMFT	Shalit & Binswanger '84
		75	33 41 55 11			1.17 1st yr		PARP & NPK	RP- 200 kg PARP 50-87 NPK; 50-100 Rock bunds PARP/NPK doses varied by location & rainfall	Burkina	3 zones: <600 mm 6-800 mm >800 mm degraded soil	'90-94	FMT: avg yld chg estimated using regres- sion model	Kaboré, Bertlelsen & Lowenberg-DeBoer '94
848 with NK only	929 1128 1217	81 280 369	9 33 44					Rsp to types of P in presence NK	P rock 29 % acidulated P SSP	Burkina		'70s	RT by phosphate companies	Pieri '85 citing Siveng & Timac
157	431	274	174	4	NB= 147F per hr	('83) 1.9 ('85) 1.1		Rsp to NPK	37-23-15 and manual tilling	Burkina	450-650 mm degraded soil	'84	FMT	Nagy, Ohm & Sawadogo '90
157	416	259	165		NB= 238F per hr			Rsp to tied ridges	no fert, manual tilling	Burkina	450-650 mm degraded soil	'84	FMT-small sample	Nagy, Ohm & Sawadogo '90
157	652	495	315	7- TR effect included	NB= 177F per hr			Rsp to NPK + tied ridges	37-23-15, manual tilling and tied ridges	Burkina	450-650 mm degraded soil	'84	FMT-small sample	Nagy, Ohm & Sawadogo '90
444 173	962 773	518 600	117 347	7 8 - TR effect included				Rsp to NPK + tied ridges (TR)	37-23-15 and donkey traction	Burkina	450-650 mm degraded soil	'83 '84	FMT- 11 fm FMT- 19 fm	Nagy, Ohm & Sawadogo '90

Table A2. Sorghum Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
Maximum potentials with and without fertilizer								Rsp to NPK (max potentials)		Mali	Sudanian	'70-90	RT + FMT	Henao et al. '92
660	1445	785	118	5		1.1	Local		80-60-20					
931	2653	1722	184	9		1.9	CE 151		100-70-20					
Maximum potentials with and without fertilizer							CMS 388	Rsp to NPK (max potentials)	120-95-30	Mali	Sudano-Guin.	'70-90	RT + FMT	Henao et al. '92
726	2162	1436	197	6										
993	979	-14	-2	Note: Rec./PR-b/PR-a all significantly better than cont. and farmer but not different from each other.				Rsp to dif. techniques	Farmers' practice	Mali	Songoumba	'80s	RMFT	Bonsu '96 citing Bationo et al.
	1275	282	28						Rec practice					
	1464	471	47						PR-basal application					
	1325	332	33						PR-annual application					
1795	2390	595	33	13				Effect of N on land fallowed $3 years	45 N	Niger	Sudan/ Sahel 825 mm	'88	RT on N and rotations	Bationo et al. '94b
				3-8 4-9		('85) 6-18 ('87) 3-8		NPK	Imprvd practices Local practices	Nigeria	500-1000 mm 1000-1500 mm		FAO RMFT	Lele, Christiansen & Kadiresan '89
				3.9				Rsp to fert	not available	Cameroon				Lele, Christiansen & Kadiresan '89
1140	1710	570	50	14		3.7 for 4-yr rotation		Rsp to NPK	21-10.5-105 4-yr rotation of fallow/gdnt/ sorghum/gdnt	Senegal	Sudano-Sahel	'60s	RMFT	Kelly '88 adapted from Tourte et al.
				4-6		1.5 in '87		Rsp to N+P		Senegal				Lele, Christiansen & Kadiresan '89
630	1000	370	59	6				Rsp to N	60 N	Ghana	Guinea Sav.			Bonsu '96

Table A2. Sorghum Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
1514	2150	636	42	6	2.4 4	('92) 2.6 ('97) 1.6			67 P + 34 N	Ethiopia	variable	'88-91	RT	Mulat et al. '97
				4-21				Rsp to N+P		Kenya	West of Rift Valley			Lele, Christiansen & Kadiresan '89
				10-13				Rsp to N+P		Tanzania			FAO RT	Lele, Christiansen & Kadiresan '89
1500	2500	1000	67					Rsp to fertilizer	4 bags	Zambia		'96	Estimate of national avg.	Stringfellow '96
1679	2130	451	27	2			Imprvd.	Rsp to NPK	90-90-60	Brazil	<350 mm		RT	Sanders '79 citing Faris and de Lira
450	1630	1180	264	24				Rsp to NP	10-40-0	India	Hyderabad	'76-78		De '88 citing Hegde
1080	2130	1050	97	7		1.39		Rsp to NPK	60-60-30.	India		'77/8- '78/9	RMFT	FAO '83a/b
836	1400 1553 2645 3912	564 717 1809 3067	67 86 116 280	13 8 40 34			Local Local CSH-2 CSH-2	Rsp to N	N-45 N-90 N-45 N-90	India				DeGeus '70 citing Swaminathan
1100	1660 1980 2170	560 880 1070	51 80 97	6 6 5				Sequential adding of different nutrients	90-0- 0 90-60-0 90-60-60 (no irrigation)	India	Monsoon season	'69-80	RMFT	Christianson '88 citing Randhawa & Tandon

Source: Compiled by authors from documents listed in the 'source' column.

Table A3. Millet Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
				5-10 4-8 0-6				Rsp to N Rsp to P Rsp to K	20 20 20	West Africa	various	'60s and '70s	FAO trials	Shalit & Binswanger '84
				6-14 6-15 4-7				Rsp to N Rsp to P Rsp to K	20 20 20	West Africa	various	'60s and '70s	FAO RMFT	Shalit & Binswanger '84
0 161 253	86 722 876	86 561 623	 348 246		('90) 3.7*[a]		IKMV-8201	Zai, 1st yr Zai, 2nd yr Zai, 3rd yr	60-23-14 NPK 6-S & 2-B for all plots w or w/o zai Rock bunds also	Burkina	Yilou; very degraded soil; 600 mm	'91-93	RT on re-claiming degraded soil	Kambou et al. '94
			65-85		('90) 3.7*			Zai	avg 8 tons manure/ha	Burkina	Namentenga area	'93	Farmers' opinion survey	Robins & Sorgho '94
			38 41 57 17		('90) 3.7*			PARP & NPK	RP- 200 PARP 50-87 NPK; 50-100 Rock bunds. PARP/NPK varies by location & rainfall	Burkina	3 zones: <600 mm 6-800 mm >800 mm degraded soil	'90-94	FMT: avg yld chg estimated using regres-sion model	Kaboré, Bertlelsen & Lowenberg-DeBoer '94
905	1525	620	69	5	.8*	('88-90) 2.9		Rsp to NPK	53-31-37	Gambia	450-800mm	'81-84	RT/24 sites across country	FAO '85
718	745 894 1039 961	27 176 321 243	3 25 45 34	Note: PR-basal significantly better than farmer and w/o fert treatment, but not significantly different than other fertilizer practices				Rsp to dif techniques	Farmers' practice Rec practice PR-basal application PR-annual application	Mali	Tafla	'80s	RT	Bonsu '96 citing Bationo et al.

[a] An '*' in this column indicates that the fertilizer/output price ratio was calculated from data in the FAO online data base using urea price in the numerator. If a year is not mentioned, the i/o ratio (or average ratio) is for the same year(s) as the response data; when i/o price data were not available for desired years, we reported the closest year(s) available and noted which years they were in parentheses.

Table A3. Millet Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr										
W/O	With	Rsp			I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
Maximum potentials with and without fertilizer						('76-88)		Rsp of variety to NPK		Mali	Southern Sahel	'70-90	RMFT	Henao et al. '92
787	1845	1058	134	4		0.82	M2D2		90-125-70					
Maximum potentials with and without fertilizer						('76-88)		Rsp of dif variety to dif doses NPK		Mali	Sudano-Guinean	'70-90	RMFT	Henao et al. '92
392 687	691 1,910	299 1223	76 178	2.8 4	5.5*	0.6 0.8	Local M2D2		30-60-15 100-150-60					
174	960	786	552		not avail			Zai	?? tons manure[b]	Niger	Sahel	'89-93	RT	Amadou '94
182	571	389	213	Note: figures to left repre-sent the average response over 4 years	1.4*		Pearl	Response to crop residues	4 tons millet stover yr 1 then all stover produced on field	Niger		'83-86		Bationo et al. '94a citing Bationo et al.
182	836	654	359		1.4*		Pearl	Rsp to fert	???	Niger		'83-86		ditto
182	1267	1085	596		1.4*		Pearl	Rsp to fert + crop residues	???	Niger		'83-86		ditto
			6.5 15					Rsp to windbreaks		Niger Niger	Maggia Valley	'91-3 '80s	FMT ??	Lamers '95 Dennison '86
915	1233	318	35	7	not avail	('70-85) 3.7	Pearl CIVT	Rsp to N	45 N; follows a fallow of $3 years	Niger	Sadore 690 mm	'88	RT of N + rotations	Bationo et al. '94b
266	684	418	157	10	not avail	5.4	Pearl	Rsp to N + SSP	13.1 P + 30 N	Niger	Gobery	'86-8	FMT	Bationo & Mokwunye '91a
266	741	475	178	11	not avail	5.9	Pearl	Rsp to N + PAPR-50%	13.1 P + 30N	Niger	Gobery	'86-8	FMT	ditto

[b] A '?' in the table indicates that the information in the reference document was unavailable or not clear.

Table A3. Millet Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
148	194	46	31				Pearl	Resid effect P in 3^{rd} yr	13.1 P as SSP in 1^{st} yr only	Niger	Gobery	'86-8	FMT	ditto
538	1036 804				not avail		Pearl	Rsp different P	SSP Tahoua RP	Niger	Djakindi	'89	RT	ditto
SSP statistically better yield response than TPRB for Gobery SSP better response than TPRB but difference not statistically significant for Gaya								Rsp to different P	SSP vs. Tahoua rock phosphate	Niger	Gobery Gaya	'88	RT	ditto
148	309	161	108				Pearl	Resid. eff P in 3^{rd} yr	13.1 P /PAPR-50%; 1^{st} yr only	Niger	Gobery	'86-8	FMT	ditto
		Rsp to fert: kg/ha	Rsp to fert: % chg	Rsp density (%): No fert	Rsp density (%): NP	Rsp. Both	Pearl	Rsp to plant density and NP	pockets/ha: 5000 = current practice	Niger	Gobery	'86-8	RMT	ditto
480	750	270	56	--	27				5000 + NP					
575	950	375	65	20	37				7000 + NP					
not avail	1300	--	--			170			10000 + NP					
		Rsp	% chg yield	kg otpt/ kg nutr	I/O price	V/C		Rsp to fert	not avail	Nigeria		'60s-'70s	RMFT	Lele, Christiansen & Kadiresan '89
				3-11	('87) 1.3	('85) 6-39					500-1000mm 1000-1500			
				7-21		('87) 2-17								
487	934	447	104					Acacia Albida	planting under tree	Senegal	Sahel	'66-68	FMT	Dancette '85
487	1340	853	175		not avail			Rsp to fert + manure	??? & ???	Senegal	Sahel	'66-68	FMT	ditto

Table A3. Millet Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
487	1388	901	185		not avail			Rsp to fert + manure + ac- acia albida	??? & ???	Senegal	Sahel	'66-68	FMT	ditto
				7	('87) 2.9	('87) 2.7		Rsp to fert	not avail	Senegal	350- $1000 mm	'70s	RMFT	Lele, Christiansen & Kadiresan '89
430	700	270	62	6		2 during 4-yr. rotation	90-day	Rsp to traditional recommend	21-10.5-10.5 in a 4-yr rotation: fallow/gdnt millet/gdnt	Senegal	N Peanut Basin <500 mm	late '60s	RT	Kelly '88, adapted from Tourte et al.
1060	1640	580	55	29			Pearl	Response to fert	20-0-0	India				FAO '83a/b citing Hegde
460	810	350	76	2		<1		Rsp to NPK	60-60-30	India		'77/8-'78/9	RMFT	De '88
1855 2569	2569 3561	714 1082	38 42	18 27			Local Hybrid	Rsp to N	N-40+other fert?? N-40+other fert ??	India	Northwest			DeGeus '70 citing Hendrix et al.
1855 2569	3069 4348	1214 1779	65 96	15 22			Local Hybrid	Rsp to N	N-80+other fert?? N-80+other fert ??	India	Northwest	?		DeGeus '70 citing Hendrix et al.
1855 2569	3806 5645	1951 3076	105 120	16 26			Local Hybrid	Rsp to N	N-120+other fert?? N-120+other fert ??	India	Northwest	?		DeGeus '70 citing Hendrix et al.
500	770 1050 1150	270 550 650	54 110 130	3 4 3			Pearl	Sequential adding of different nutrients	90-0-0 90-60-0 90-60-60 (no irrigation)	India	Post monsoon season	'69-'80	RMFT	Christianson '88 citing Randhawa & Tandon

Source: Compiled by authors from documents listed in the 'source' column.

Table A4. Rice Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
				10-20 8-15 5-10					Nitrogen Phosphate Potassium	West Africa				Shalit & Binswanger '84
3499	4974	1474	42	11	2.23	-	Imprvd	Rsp to farmers' fert. practices	76 N 40 P 24 K	Burkina	Irrigated	'95	FMT (Survey of 40 fields)	Donovan et al. 1998
2938	4064	1126	38	7	2.7*[a]	1.9 1.6	Imprvd	Rsp to farmers' fert. practices	91 N 40 P 24 K	Burkina	Irrigated	'96	FMT (Survey of 39 fields)	Donovan et al. 1998
				12-39			HYV	Rsp to N	N	Cameroon	Northern plain			Lele, Christiansen & Kadiresan '89
3517	5750	2233	63	12	2.05*	2.9 2.2	Imprvd	Rsp to farmers' fert. practice	143 N 45 P single crop	Mali	danga soils, Office du Niger, Irrigated	'95	FMT (Survey of 18 fields)	Donovan et al. 1998
2625	5025	2400	91	16	2.05*	3.96 2.74	Imprvd	Rsp to farmers' fert. practices	110 N 42 P double crop	Mali	ditto	'95	FMT (Survey of 16 fields)	Donovan et al. 1998
1271	3157	1887	148		4.2*					Mali	upland	'80-90	RT & RMFT	Henao et al '92
2217	3658	1441	65		4.4*					Mali	lowland	'80-90	RT & RMFT	Henao et al '92

[a] An '*' in this column indicates that the fertilizer/output price ratio was calculated from data in the FAO online data base using urea price in the numerator. If a year is not mentioned, the i/o ratio (or average ratio) is for the same year(s) as the response data; when i/o price data were not available for desired year(s), we reported the closest year(s) available and noted which year(s) they were in parentheses.

Table A4. Rice Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
3642	4857	1215	33	9	1.87*	2.6 1.6	Imprvd	Rsp to farmers' fert. practices	89 N 43 P avg single + double crop	Senegal	Irrigated Thiagar, rainy season	'95	FMT (Survey, 16 fields)	Donovan et al. 1998
2867	5570	2703	94	16	2.13*	3.97 2.1	Imprvd	Rsp to farmers' fert. practices	117 N 49 P avg single + double crop	Senegal	Irrigated Guede, rainy season	'96	FMT (Survey, 20 fields)	Donovan et al. 1998
3642	4857	1215	33	9	1.87*	2.6 1.6	Imprvd	Rsp to farmers' fert. practices	89 N 43 P avg single + double crop	Senegal	Irrigated Thiagar, rainy season	'95	FMT (Survey, 16 fields)	Donovan et al. 1998
2867	5570	2703	94	16	2.13*	3.97 2.1	Imprvd	Rsp to farmers' fert. practices	117 N 49 P avg single + double crop	Senegal	Irrigated Guede, rainy season	'96	FMT (Survey, 20 fields)	Donovan et al. 1998
				4-11 4-7	1.7*			Rsp to total nutrients		Senegal	Upland Swamp			Lele, Christiansen & Kadiresan '89
3312	6109	2797	84	14	1.7*				100 NK 100 P Irrigation?[b]	Senegal	Basse Casam.		RT	Diangar and Sene '91
				5.6	1.7*			Rsp to total nutrients		Senegal	Casamance			Lele, Christiansen & Kadiresan '89
				16.7					300 P	Madagascar				Peters '95
		11-13			2.4*				N&P	Tanzania				Lele, Christiansen & Kadiresan '89

[b] A '?' in the table indicates that the information in the reference document was unavailable or not clear.

Table A4. Rice Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
2217	3617	1400	63	17.6					75N	Bangladesh	Aus	'76	RMFT	FAO '81
	4308	2093	94	11.5					75N 60P				FAO Trials	
	4540	2325	105	5.2					75-60-45					
2625	3818	1193	45	10				Rsp to N	120 N	India	Rabi, Avg 6 Zones humid to semi-arid	'74/5-'77/8	RMFT	FAO '83a/b
2768	3933	1165	42	9.7				Rsp to N	120 N	India	Karif, Avg 4 Zones humid to semi-arid	'74/5-'77/8	RMFT	FAO '83a/b
2608	4930	2322	89	9.7				Rsp to NPK	120-60-60.	India	Karif, Avg 5 Regions	'77/8-78/9	RMFT	FAO '83a/b
2030	4130	2100	103	8.8				Rsp to NPK	120-60-60.	India	Rabi, Southern Region	'77/8-78/9	RMFT	FAO '83a/b
1070	2220	1150	107	7.7		1.52		Rsp to NPK	60-60-30.	India		'77/8-78/9	RMFT	De '88
3020	5710	2690	89	33.6				Rsp to N	80 N	India		'74-75		FAO '83a/b
3020	6740	3720	123					Rsp to N	80 N + green manure	India		'74-75		FAO '83a/b
3200	3800	600	18	20			Avg of imprvd cultivars	Application of Nitrogen	30 N	India		'75-76		IRRI '79
	4200	1000	31	16.7					60 N					
	4300	1100	34	12.2					90 N					
2950	4100	1150	39	9.6 (N)		2.0		Sequential adding of different nutrrients	120-0-0	India		'67-77	FMT	ISMA '81 citing Kemmler
	4890	1940	66	13.2(P)		3.1			120-60-0					
	5330	2380	81	7.3(K)		4			120-60-60					

Table A4. Rice Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
2420	3600 4220 4590	1180 1800 2170	49 74 90					Sequential adding of different nutrients	120-0-0 120-60-0 120-60-40 (no irrigation)	India	Monsoon season	'69-80	FMT	Christianson '88 citing Randhawa & Tandon
				14.8 8.1 12.4 3.2					90 N 180 N 30 P 30 K	Indonesia	Flooded Rice	'73-79	RMFT FAO Trial	FAO '81
3110	5280 5950 5490 6650 6780	2170 2840 2380 3540 3670	69 91 76 114 118	Avg NPK= 13.6				Application NPK	140-0-0 140-60-0 140-0-60 140-60-60[c] 140-60-60[d]	Philippines		'68-72	RT	FAO '81 citing Kemmler and Malicourt
3602	4245	643	18	19.5				Response to N	33 N (from ammonium sulphate)	Surinam		Late '50's Early '60's	RT	DeGeus '70 citing Ten Havg
3602	4233	631	15	19.1				Response to N	33 N (from urea)	Surinam		Late '50's Early '60's	RT	DeGeus '70 citing Ten Havg
4846	5998	1150	24	23				Response to N	50 N	Surinam		Late '50's Early '60's	RT	DeGeus '70 citing Ten Havg

Source: Compiled by authors from documents listed in the 'source' column.
Notes:

[c] 100 kg N as basal dressing and 40 kg as top dressing at panicle initiation.

[d] 30 kg K_2O as basal dressing and 30 kg as top dressing at panicle initiation.

Table A5. Groundnut Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
				2-40 4-8 3-4				Rsp to N Rsp to P Rsp to K	10-25 N 20 P 20 K	W. Africa			FAO trial	Shalit/ & Binswanger '84
				2-12 9-17 2-4				Rsp to N Rsp to P Rsp to K	10-20 N 20-40 P 20 K	W. Africa			FAO demo	ditto
1500-2000							120-150 day	Current practice	no fert, extensive production	Burkina	high rainfall, low land constraint	'90s	Farm survey	Cattan & Schilling '90 citing Kaboré
1561	2129	568	36	7		('85) 5.8		Rsp toNPK	18-27-31	Gambia	1000-1200 mm	'81-84	FAO RT	FAO '85
780	884 851 775 852	71	9	Note: no treatment statistically better than the others				Rsp to dif techniques	Farmers' prac Rec prac PR-basal PR-annual	Mali	Tafla	'80s	RT	Bonsu '96 citing Bationo & Mokwunye
1228	1979	751	61					Rsp to N	45	Niger	Sahel/ Sudan	'88	RT	Bationo et al. '94b
				7-13 9-21	('86) .8	('85) 13-38 ('87) 14-41		Rsp to total nutrients	not avail	Nigeria	500-1000 mm 1000-1500 mm		FAO FT	Lele, Christiansen & Kadiresan '89
758	1268	510	67					Rsp to manurein pres NPK	10 T manure 12-27-40.5 plowing (10 cm)	Senegal	Thimakha 200-450 mm; degraded soil	'72-81	RT	Cissé '86
521 1273	877 1542	356 269	68 21				Grain Hay	Rsp to compost	2 tons dry cmpst millet/gn rotation	Senegal	Sahel; sandy soil w/ low organic matter	'94	FMT - 1 yr; 3 repetitions only	Badiane et al. '95

Table A5. Groundnut Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
				5 40				Rsp to N		Senegal	500-700mm 800-1000mm	Early '70s		Shalit & Binswanger '84
				7	('87) 2.3* [a]			Rsp to total nutrients	not avail	Senegal	Peanut Basin 500-1200 mm	'70s	FAO trials	Lele, Christiansen & Kadiresan '89
950	1090	140	15	4		2 for full 4-yr rotation	120 day	Rsp to traditional recommen-dations	9-15-15 4 yr rotation fallow/grdnut/ millet/grdnut/	Senegal	N. Peanut Basin <500 mm	late '60s	RT	Kelly '88 adapted from Tourte et al.
n.av.	n.av.	139 229 200				('68 avg) 1.5	120 day	Rsp to traditional recommend	9-15-15	Senegal	poor rain good rain average	'58-67	Summary of various RTs	Bray '69
875	1075	200	23	9	('92) 3*	('92) 2.9	55-437 90 days	Rsp to reduced levels fert	0-23-0	Senegal	Sine Saloum, Sob 300-500mm	'86-92	FT	Clouvel '93
1380	1720	340	25	10	('92) 2.9*	('92) 3.4	77-33 110 days	Rsp to reduced levels fert	0-15-20	Senegal	Sine Saloum, DarouKoud. 450-750mm	'86-92	FT	Clouvel '93
800-1000							120 day	Current practice	no fert.	Senegal	Sine Saloum 700-1000 mm	'90s	Farm survey	Cattan & Schilling '90

[a] An '*' in this column indicates that the fertilizer/output price ratio was calculated from data in the FAO online data base using urea price in the numerator. If a year is not mentioned, the i/o ratio (or average ratio) is for the same year(s) as the response data; when i/o price data were not available for desired year(s), we reported the closest year(s) available and noted which year(s) they were in parentheses.

Table A5. Groundnut Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
Sum of 1st yr (direct) and 2nd yr (residual) effects							69-101	Dir and residual effect of P from Matam	55 P in presence 9N + 15 K + S	Senegal	Peanut Basin	'82/3	RMT	Diangar & Sene '91 citing Cissé
2785 + 2719 = 5504	2812 + 2883 = 5695	27 + 164 = 191	3	3										
1313 1197								Current practice	no fert, oxen no fert, hoe	Zambia	E. Prov.	'86-88	Farm survey	Jha '91
790	1100 1370 1450	310 580 660	39 73 84	16 7 6				Sequential adding of different nutrients	20-0-0 20-60-0 20-60-40 (no irrigation)	India	monsoon season	'69-'80	Farmer field	Christianson '88 citing Randhawa & Tandon
900	1580	680	76	6		2.40		Rsp to NPK	20-60-40.	India		'77/8 to '78/9	FT	FAO '83a/b

Source: Compiled by authors from documents listed in the 'source' column.

Table A6. Cotton Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg cotton per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
2066	2783	717	35	12	not avail	('89) 3.7		Rsp to N	60 N + SB	Chad	Bebedja	63-78	RT	Pieri '89 citing Richard & Djoulet
Avg net FCFA/ha during 3 yrs[a]					('89) 3.2*[b]			Rsp to NPK	100 kg NPKSB (nutrient content not reported)	Chad	Sudanian	93/94-95/96	Farm survey (31 farms)	Yacoub, Mahamat & Yadjine '96
11900	14800	2900	24											
Kg cotton/ha					3.5*	('76-87) 1.2	BJA	Rsp to NPK	50-40-30	Mali	Sudano-Guinean 1225 mm	80-90	Production function estimated w. RT data	Henao et al. '92
822	1310	488	59	4										
476	1445	969	200	5	3.5*	('76-87) 1.5	B163	Rsp to NPK	110-55-30	Mali	ditto	ditto	ditto	ditto
801	1120	319	40	2	3.5*	('76-87) 0.6	BJA	Rsp to NPK	35-65-30	Mali	Sudanian 723-1142 mm	ditto	ditto	ditto
759	1669	910	100	5	3.5*	('76-87) 1.5	ISAB	Rsp to NPK	35-65-80	Mali	Sudanian 723-1142 mm	ditto	ditto	ditto
1094	1886	792	72	7	not avail	('76-87) 2.2		Rsp to NPK + manure	43-68-0	Mali	N'Tarla	69-71	RT	Pieri '89 citing Gakou et al.
1107	1830	723	65	3	3.4*	('76-87) 0.92		Rsp to NPK + manure	91-68-120, rotation	Mali	N'Tarla	79-82	RT	ditto

[a] Although the 3-year averag returns were better using fertilizer, the returns for 1995/96, the first year fter the FCFA devaluation, were 45,000 FCFA for the unfertilized fields and only 30,000 FCFA for the fertilized ones.

[b] An '*' in this column indicates that the fertilizer/output price ratio was calculated from data in the FAO online data base using urea price in the numerator. If a year is not mentioned, the i/o ratio (or average ratio) is for the same year(s) as the response data; when i/o price data were not available for desired year(s), we reported the closest year(s) available and noted which year(s) they were in parentheses.

Table A6. Cotton Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg cotton per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
870	1000	230	15		('91) 2.1*	6		Rec vs. farmer practices	Rec:200 kg NPK + 50 kg urea Farmer: 155 NPK + 15 urea (NPK nutrient content not available)	Senegal	>1000 mm	94/5 - 95/6	Farm survey and trial data	Calculated from info in Fall and Sow '96
622	960	338	54	5	('70-73) 0.8*	('89-91) 2.4	BJA	Rsp to NPK	200 kg NPK = 66 kg nutrients	Senegal	Missirah 500-900 mm	67-75	RT	Pieri '89, citing Tourte et al. and Sarr & Rabot
569	1179	610	107	n.a.	1.6	4.2	Remu40	NPK + herbicide	89 kg 12-24-12 3.5 lt herbicide	Mozamb.	Nampula 770 mm	'94	Farm survey (107 farms)	Strasberg '97
750	1400	650	87	5		1.7		NP	60 N 60 P	Mozamb.	North (lixisols) 0-200 masl 800-1200 mm	various	RT	Geurts '97
1100	1700	600	55	5		1.7		NP	50 N 60 K	Mozamb.	North (nitosols) 200-600 masl 800-1200 mm	various	RT	Geurts '97
1250	1700	450	36	4		1.1		NP	50 N 60 K	Mozamb.	North (luvisols) 0-200 masl 800-1200 mm	various	RT	Geurts '97
1400	2400	1000	71	8		2.6		NP	60 N 60 K	Mozamb.	North (lixisols) 200-600 masl 800-1200 mm	various	RT	Geurts '97

Table A6. Cotton Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved						Type of data	Source
kg cotton per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years		
W/O	With	Rsp												
1450	3250	1800	124	16		5.0		NP	50 N 60 K	Mozamb.	North (luvisols) 600-1000 masl 800-1200 mm	various	RT	Geurts '97
1500	2250	750	50	7		1.7		NP	50 N 60 K	Mozamb.	North (luvisols) 200-600 masl 800-1200 mm	various	RT	Geurts '97
458	525	67	15	1		0		Rsp to NP	30 N 35 P	Tanzania			RT	Carr '93
881	1116	235	27	5	('75-76) 109			Rsp to N	50 N	Uganda		75-78	RT	Kintukwouka '91
				7.0	2.2*	('83) 3.1 ('86) 2.5		Rsp to NPK	40-20-10	Zambia	Plateau Region	83/4 & 86/7	FMT	Jha and Hojjati '93
		no signif rsp. with poor rains; 300 kg rsp. with good rains						Rsp to recom-mended dose of NP		Zimbabwe	Poor rains Good rains	83/4 85/6	FMT	Carr '93, citing Cotton Research Institute of Zimbabwe annual reports

Source: Compiled by the authors from the documents listed in the 'source' column.

Table A7. Beverage (Coffee and Tea) Response and Profitability for Selected Soil Management Practices

Crop response					Fin'l Ratios		Conditions under which response achieved							
kg grain per ha			% chg in yield	kg otpt per kg nutr	I/O price ratio	V/C ratio	Variety	Practice evaluated	Kg nutr/ha and complementary practices	Location	Climate/ rainfall	Years	Type of data	Source
W/O	With	Rsp												
				30-35 15-20	('80s) 0.5-1.4		Green Tea	Rsp to N		Kenya	East & West of Rift Valley			Lele, Christiansen & Kadiresan '89
				10.4	.27		Coffee Arabica	Rsp to N		Kenya	East of Rift Valley			Lele, Christiansen & Kadiresan '89
				5-6 2-3	('70-'91) 0.57		Arabica Robusta	Rsp to N		Camer-oon				Lele, Christiansen & Kadiresan '89
	920 1840 3450	 920 1610	 100 88	 9 13	('90-'95) <2	good	Tea	Rsp to increases in NPK	50-10-10 125-25-25 220-40-40	Kenya	Smallholders	late '80s	Farm survey	Carr '93, citing Gov of Kenya
1000-1500	3000	1500-2000	100	8	('90-'95) <2	good	Tea	Rsp to N in presence of P, K, and S	188-37.5-37.5 (plus 37.5 S)	Kenya	Estates	late '80s	Expert opinion	Carr '93
				5-10	('70-'93) 0.27		Robusta Coffee	Rsp to N		Kenya	Unshaded w. mulch for K and good weeding	late '80s	Expert opinion	Carr '93
	1000 1500 2000	 500 500	 50 33	 8			Arabica Coffee	Rsp to increasing dose of N	80 140 200	Kenya	ditto	ditto	ditto	Carr '93
					0.12 0.09 0.19 0.11		Arabica Arabica Robusta Robusta	Application of 65%N and 35%S fert.		Cameroon		'67-75 '76-84 '67-75 '76-84		Shaefer-Kehnert '88

Source: Compiled by the authors from the documents listed in the 'source' column.

Appendix 4
Crop Level Synthesis of Fertilizer Incentives Drawn 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.[28] (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).

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[28] 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.

(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.