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Incentives for Fertilizer Use in Sub-Saharan Africa: A Review of Empirical Evidence on Fertilizer Response and Profitability

by

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by

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EXECUTIVE SUMMARY

BACKGROUND: To increase rural incomes and meet growing food demands Sub-Saharan Africa (SSA) must improve agricultural productivity. SSA is the only developing region where per capita food production has been declining; the region now has the largest cereal deficits in the world. If there is no change in productivity, deficits will more than triple by 2020.

Fertilizer is a powerful productivity-enhancing input, but SSA uses very little. Historical trends are abysmal (see Figure 1, page 6). In 1970, SSA used <5kg/ha while other developing regions used >15 kg/ha. In the 25 years from 1970 to 1995 fertilizer consumption grew only .23 kg/ha/year. Current use is only 9 kg/ha, down from highs of 11-12. This contrasts sharply with >50 kg/ha used in Latin America and >80 kg/ha in Asia.

Economists estimate that SSA agricultural production must grow by 4% per annum during the next decade to stimulate a satisfactory level of general economic development. This is faster than recent rates of 1-2%. Experience elsewhere has shown that fertilizer can provide a substantial productivity boost. A third of the increase in cereal production worldwide and 50% of the increase in India's grain production has been attributed to fertilizer-related factors.

OBJECTIVES AND METHODS: This research addresses two questions: Why is fertilizer not yet fulfilling its potential as a major stimulus to agricultural productivity in SSA? What can be done to improve the situation? Our answers are based on an extensive review of fertilizer-response, profitability, and policy literature as well as some analysis of crop budgets and aggregate national statistics on fertilizer consumption.

FINDINGS: Much of the debate about fertilizer use in SSA focuses on two issues: whether the profit *incentive* is adequate and, if so, whether farmers have the *capacity* to access and use it.

Incentives. Contrary to conventional wisdom, there are examples of fertilizer response and profitability in SSA that compare favorably to those in other parts of the world. Table 7 (see page 62) presents information about the relative importance of fertilizer consumption for seven SSA crops and synthesizes findings concerning three ratios measuring profit incentives. O/N (output/-nutrient) ratios show how many kgs of additional output a farmer can obtain from a kg of fertilizing nutrient; ratios ≥ 10 are considered efficient. An I/O (input/output price) ratio shows the number of kgs of production a farmer needs to purchase one kg of fertilizer; the lower the ratio, the higher the incentive. V/C (value/cost) ratios are rudimentary profit indicators that compare the gross income attributable to fertilizer with the costs of the input. Conventional wisdom holds that a V/C ratio must be ≥ 2 before a farmer will consider financial incentives adequate; many hold that in high-risk production environments the minimum V/C for adoption is 3 or 4.[1]

[1] V/C = (kg output attributable to fertilizer * output price) / cost of fertilizer. Most analyses include only the cost of fertilizer in the denominator; more thorough work includes other related costs (e.g., labor for application and additional weeding or harvesting).

Among the cereal crops covered, maize (SSA's most important fertilizer consumer) and irrigated rice exhibit the strongest incentives. O/N and V/C ratios equal or exceed standard benchmarks. 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. These factors discourage fertilizer use for the vast majority of maize farmers. High irrigation costs represent a negative for rice that can result in low overall profitability, canceling out fertilizer benefits.

Sorghum and millet exhibit poor incentives compared with maize and rice – not surprising given that sorghum and millet are grown in difficult agroclimates (poor soils, low rainfall). Using fertilizer in combination with crop residues, manure, or water and erosion control measures considerably increases the yield response, but aggregate output is usually <1 ton/ha.

Among the export crops covered, only tea – a crop whose production is limited to a few areas in SSA – exhibits good indicators. SSA's second largest fertilizer consumer--cotton--has relatively poor yield response and mediocre profitability (minimum V/C very low, with maximums at acceptable but not outstanding levels) despite extremely favorable I/O ratios (an apparent paradox discussed below).

In sum, (1) high-productivity maize and rice technologies are available, but more basic research and extension work is needed to adapt them to diverse smallholder production environments; (2) sorghum and millet technologies are not yet highly productive and more basic research is clearly needed, focusing on the use of fertilizer with complementary inputs; and (3) there is substantial room for improving technologies for export crops. For all crops and zones, major improvements in profitability could be realized by reducing SSA's I/O price ratios, which are among the highest in the world.

V/C ratios reported include fertilizer subsidies if they existed at the time of the analysis. Because fertilizer subsidies have been phased out and replaced with market development initiatives that have not yet reduced fertilizer costs, more recent ratios rarely approach the maximum V/C values in Table 7 (see page 62). Farm-level fertilizer prices in SSA are among the highest in the world. In 1991/92 SSA prices per ton ranged from $232 to $487 for urea and phosphates while the Asian equivalents ranged from $68 to $201. Unfavorable I/O price ratios confirm that the negative impact of high fertilizer prices is not offset by high producer prices.

Subsidies are one way of keeping fertilizer prices low. Proponents note that subsidies promoted rapid growth in fertilizer use and agricultural productivity in China, India, Mexico, Nigeria, Turkey, and Venezuela. Opponents point out that unless subsidies are accompanied by a clear program to rectify the underlying problems they are compensating for (e.g., inefficient markets, poor infrastructure) their demands on the budget grow rapidly, reducing the ability of government to make other agricultural investments.

For many reasons, *fertilizer market development* programs have not yet had the desired impact on fertilizer prices and demand. In some cases subsidy removal and devaluation reduced already low effective demand (Ghana and Senegal). In others, a lack of complementary actions to improve farmers' fertilizer techniques (e.g., extension programs), lower transactions costs (e.g., better regulatory environment), or reduce risk (e.g., fertilizer quality control) hampered market development. Inadequate access to foreign exchange and credit for dealers has also been a constraint (Ethiopia). Government's continued involvement in the distribution of fertilizer aid has also discouraged some private sector initiative. Another shortcoming noted was the failure to train private sector operators in product promotion skills (Kenya).

Some *output market development* programs have contributed to fertilizer profitability by reducing farmers' risks and transactions costs. Market information systems have reduced price differences between deficit and surplus zones (e.g., Mali). Liberalization of cereal exports and imports has stabilized prices at the national level (e.g., Kenya and Ethiopia). Expansion of market infrastructure has reduced farmers' marketing costs and increased profitability, thereby promoting smallholder use of fertilizer (e.g., Zimbabwe and Zambia in the 1980s).
Some measures improve *fertilizer and output market efficiency* simultaneously. The best documented evidence concerns reductions in marketing margins realized by reducing official and unofficial road taxes on goods transported within national boundaries (e.g., Mali and Senegal). Another example is infrastructure, particularly roads but also communications. There is a strong correlation between fertilizer use and kilometers of roads per hectare in SSA.

V/C ratios show only whether farmers are likely to make more money than spent when using fertilizer. The ultimate decision will depend on whether farmers believe they will make more money with the fertilizer than with alternative uses of the available cash. Although *analyses of 'relative' profitability* are rare, the few cases found showed that farmers failed to adopt fertilizer with V/C ratios ≥ 2 because purchasing and fattening an animal for resale or clearing new land to expand production was more profitable. Nonfarm activities also offer stiff competition. Hence, indicators such as those used in Table 7 (see page 62) must be complemented with more analysis of 'relative' profitability so that programs to develop fertilizer markets consider competing activities.

Capacity. Even in cases where the absolute and relative profitability are adequate, farmers may not have the capacity to act on these incentives. Capacity is affected by zone- and farm-level variables. Zone-level variables include:

- soil quality (particularly organic matter);
- water (rainfall >700 mm/year or irrigation);
- infrastructure (roads, electricity, phones);
- credit (for farmers, traders, processors);
- human capital (farmer literacy, researchers); and
- a critical mass of commercial farming activity

Losses of organic matter and acidification are major problems in the fragile soils of SSA. Fertilizer loses its effectiveness when soil organic matter falls below minimum levels, hence zones with serious soil degradation may have low capacity for fertilizer use. Rainfall is highly correlated with fertilizer use, as is road density, although the latter variable appears to have declined in importance since 1980. Traders and farmers both need access to financial resources beyond their own savings and income because fertilizer is an expensive input to market (high storage and transport costs) and to purchase (largest annual input expenditure made by most SSA smallholders). The link between human capital and fertilizer use is illustrated by the positive correlations between the number of agricultural researchers, general education (percent of school-age children in school), and fertilizer use. Commercial agriculture is a *sine qua non* for fertilizer. Three of the top fertilizer consuming countries (Zimbabwe, Kenya, and Zambia) benefitted from the establishment of large-scale commercial farms by European settlers. These farms have provided a minimum level of stable fertilizer demand that helps promote economies of scale and lower fertilizer prices. Realizing economies of scale when relying entirely on smallholders is more difficult, yet the success of SSA cotton systems shows that it can be done.

Even when zone-level factors are favorable, capacity may be limited by farm-level factors such as:

- cash constraints (own cash, credit);
- poor access to complementary inputs for which there are no markets (e.g., manure); and
- poor knowledge about adapting fertilizer to a particular production environment.

Before structural adjustment, governments administered agricultural credit programs that increased farmers' access to fertilizer. Now credit is rare and expensive. The few insights we have into what works in SSA come mainly from the cotton sector. In these vertically coordinated schemes, input, output, and credit markets are linked thereby reducing the costs and risks of administering the credit program. Credit is available to all cotton farmers, encouraging them to use fertilizer despite the low level of incentives reported in Table 7 (see page 62). Reimbursement of cotton credit is good because (1) there are few opportunities for farmers to sell output to anyone but the company that provided the credit, and (2) many cotton companies provide extension services and credit for food crops (e.g., Mali and Mozambique) which help farmers meet cash and food security goals. Outside the cotton sector, some post-structural adjustment initiatives to restore credit are underway, such as maize-fertilizer barter schemes run by South African companies in Zimbabwe and Zambia and distribution/credit schemes operated by local traders in Zambia. The vacuum is there and drawing in efforts, but credit demand is greater than supply.

Own-cash sources have taken on more importance with the decline of easy credit. Nonfarm income sources (e.g., wage employment, microenterprise earnings, and migration remittances) are playing an important role in financing input purchases. A problem, however, is that the bigger farmers in better agroclimates tend to have better access to credit *and* greater nonfarm earnings, which means that the capacity to buy fertilizer is becoming more skewed toward better-off households. This is a concern as it is the small, land-constrained farm that needs to intensify most by redressing current low levels of fertilizer consumption.

Access to complementary inputs (e.g., manure) is particularly important for crops and zones (e.g., millet and sorghum in the Sahel) where fertilizer response is poor without the complements. The issue will ultimately become important for all farmers because fertilizer yield response declines over time if soil organic matter is depleted. As chemical fertilizer does not add organic matter to the soil, farmers will need to increase the amount of crop residues and/or manure used. Some of this can come from increased production of crop residues obtained by using fertilizer.

The use of research and extension funding to adapt available fertilizer technologies to particular smallholder situations is emerging as a key tool for improving farmers' capacity to use fertilizer efficiently. A major problem has been 'pan-territorial' recommendations that fail to take into account differences in resource endowments (soil type, labor capacity, climatic risk, etc.). The situation is exacerbated by a failure to revise recommendations following dramatic changes in the I/O price ratios due to subsidy removal and devaluation (e.g., Ethiopia and Malawi). Farmers using fertilizer already experiment with doses and methods of application (few apply as recommended). There is a need for investment in research and extension programs that focus on adapting "good performers" to particular smallholder situations. The case of maize illustrates the point. Many SSA fertilizer/seed technologies for maize are "good performers," yet the vast majority of maize farmers are not yet using fertilizer. There is strong evidence from countries that have begun to focus on site-specific and adaptive research programs that this approach can have big payoffs in terms of increased fertilizer profitability and adoption (e.g., Malawi and Kenya).

CONCLUSIONS: The major findings from our literature review can be summed up in five key points.

- Declining soil fertility is a major constraint to agricultural productivity in SSA;
- More inorganic fertilizer is needed to reverse the decline as the supply of organic fertilizers is not adequate;
- Contrary to the conventional wisdom of the 1980s, there are many crop/zone combinations where SSA fertilizer use is now profitable and many more where it could be profitable with minor improvements in incentives and capacity;
- The vicious circle of high fertilizer prices and low demand constrains the development of efficient distribution systems. Some combination of market, agricultural research, and extension initiatives is needed to improve incentives and capacity, thereby breaking the cycle; and
- Privatization and liberalization of fertilizer markets are necessary but not sufficient conditions for breaking this cycle; neither policy adequately addresses the fundamental problems of high transactions costs and high risks that dampen incentives and the pervasive presence of rural poverty that reduces capacity.

POLICY IMPLICATIONS: It is necessary to break the high-price, low-demand cycle by stimulating a strong increase in fertilizer demand *at the same time* that programs are implemented to improve market efficiency. The focus needs to be on the narrow issue of getting fertilizer prices down and increasing demand in a cost-effective, sustainable manner. A combination of public and private actions is needed; the objective should not be getting government out of agriculture but identifying its proper role given the situation prevailing in each country. For most countries, the following five steps will be prerequisites for developing a viable program to simultaneously stimulate fertilizer demand and supply.

1. Prepare an inventory of what is known about fertilizer response and profitability by zone and crop (Kenya and Malawi provide good examples).
2. Using the inventory, identify the crops, zones, and types of households with the greatest potential for rapid increases in fertilizer demand, taking into account demand projections for domestic and export crops. Fertilizer consumption increases most rapidly on crops with strong demand and stable prices, but such crops can stimulate fertilizer use on other crops (e.g., cotton/maize complementarities).
3. Examine potential economies of size and scale capable of reducing fertilizer prices, including economies that could be realized by regional pooling of fertilizer procurement activities.
4. Using information from step 2, identify a *combination* of market, research, and extension activities to stimulate demand for selected target groups, aiming for the level of demand required to realize the economies identified in step 3.
5. Determine which of the initiatives identified have the strongest economic justification for a particular country and period of development.

The key to developing successful programs that improve input market efficiency while increasing fertilizer use is careful analysis of the costs and benefits of the many options discussed above, including the possibility that some type of subsidy might be an efficient way of priming the pump to get more efficient private sector involvement in the fertilizer sector. This will require careful identification and valuation of both private and social costs and benefits. A major shortcoming in the past has been the lack of attention to social costs and benefits. As concerns for the environment increase, more attention to fertilizer's environmental benefits (e.g., less production moving into marginal lands) and potential inconveniences once high levels of use are attained (e.g., soil acidification, water pollution) will be needed.

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1. INTRODUCTION

1.1. Agricultural Stagnation and Decline in Sub-Saharan Africa

Farmers in Sub-Saharan Africa (SSA) have traditionally relied on extended fallow periods of 10-15 years following a two-three year production cycle to maintain crop yields and soil fertility. While SSA population densities remained relatively low, it was feasible to simultaneously maintain fallows and increase aggregate agricultural production by bringing new land under cultivation. Population increases of nearly 3% a year since the mid-1940s, however, have made it difficult to maintain soil quality and increase production using these extensive techniques. Population is now doubling approximately every 25 years. It is estimated that by 2010, SSA fallows will have disappeared in 20 countries and will constitute less than 25% of arable lands in another 29 countries (Angé 1993).

Declining fallows lead to various forms of land degradation. The soil fertility of cultivated land is no longer able to regenerate naturally[1]; farmers are pushed onto marginal environmentally fragile lands; and vegetative cover, which protects soil against erosion, progressively disappears. It is estimated that 72% of African arable land and 31% of pasture lands have already been degraded as a result of soil erosion (Oldeman, Hakkeling and Sombroek 1991). Fragile soils with poor buffering capacity have been particularly susceptible to this type of degradation when cultivated continuously. This has caused a 7% loss of agricultural productivity on irrigated lands, 14% loss on rain fed crop land, and 45% loss on rangeland (Crosson and Anderson 1994). Declining soil fertility is considered by some to be the most fundamental impediment to agricultural growth and a major reason for decreasing trends in food production in SSA (Sanchez et al. 1995).

From 1976 to 1985, SSA moved from net exports of $3.2 billion of agricultural products to net imports of $4.5 billion (FAO 1993). SSA is the only major developing region of the world where per capita food and cereal output has been declining (USDA 1993). SSA now has the largest cereal deficits in the world; if there is no change in current productivity growth rates, deficits will more than triple by 2020 (Agcaoili and Rosegrant 1996a).

These negative trade and cereal balances are a reflection of recent agricultural productivity trends. Despite some debate over the best methods for estimating agricultural productivity growth (see, for example Block 1993 or Block 1995), most recent analyses conclude that growth

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[1] There is evidence from recent work in the U.S. that even during the period of long, traditional fallows African soils may not have been completely regenerated:

> "Relatively poor soil organic matter quality in the crop-fallow soils results because addition of organic residues is minimal or nil in the fallow years, but the warm and moist conditions in the fallow soil are ideal for organic matter decomposition." (Boehm and Anderson 1997)

As the conditions described above are typical of many production systems in SSA, it is possible for a fallow to result in reduction of soil organic matter, soil microbial populations, organic carbon, and nutrients rather than increases in each.

during the last decade was far from adequate. Timmer (1988), for example, found that both land and labor productivity declined from 1973 through 1984. A more recent analysis found that agricultural value added grew 1.8% annually from 1965 to 1980, but declined by 1.4% a year from 1980 to 1990 (World Bank 1993). Sub-Saharan Africa is the only major geographic area in the world that did not increase cereal yields in the 1982-90 period (Agcaoili and Rosegrant 1996b).

The human costs of stagnating agricultural production are particularly preoccupying. Without restoration of soil fertility, SSA faces the prospects of even more serious food imbalances, widespread malnutrition, and increasingly frequent periods of famine (World Bank 1995; Bumb 1995). SSA, for example, was the only region in which the proportion of its population with chronic dietary energy deficiency was almost constant from 1969-71 to 1988-90. One-third of the African population suffered from chronic malnourishment in 1988-90, the highest regional proportion in the world (FAO and WHO 1992). In fact, SSA is the only area where malnutrition among preschool children is expected to increase between 1990 and 2020 (Garcia 1996).

1.2. The Role of Fertilizers in Sub-Saharan Africa

1.2.1 The Need for Fertilizers

The World Bank has estimated that an agricultural production growth rate of 4% per annum is required to stimulate a satisfactory level of general economic development in Africa (World Bank 1989).[2] To achieve this rate, labor productivity must increase annually by 1.5% and land productivity by 3% (World Bank 1993).

A 4% agricultural growth rate is much greater than most rates reported in SSA during the last decade; these rates rarely exceed 2% and were frequently negative (Timmer 1988; World Bank 1993). A 4% growth rate is also higher than the very optimistic rates ranging from 1.7 (for the Sahel) to 3.4 (for East Africa) estimated by Block (1993).[3]

Some type of agricultural intensification (i.e., raising yields on fixed supplies of arable land using an appropriate combination of chemical and organic fertilizers, soil/water conservation technologies, improved seeds, pesticides, and animal traction) seems indispensable if the goal of

[2] A growth rate of 4% ranks among the highest rates ever achieved in the world, even including Asia at the height of the Green Revolution. South Asia (India, Bangladesh, Nepal, Pakistan, and Sri Lanka), for example, have increased agricultural productivity at rates ranging from 2.1 to 5.4% annually. Comparable numbers for Southeast Asia (Indonesia, Malaysia, Philippines, and Thailand) are 2.2 to 11% and for East Asia (China, Japan, South Korea, and Taiwan) are 2.4 to 4.5% (Ahmed 1995).

[3] Block (1993 and 1995) used a wheat-units approach to estimate productivity growth. This method reduces the generally negative impact that exchange rate changes (particularly devaluations) have on other productivity estimates, such as value added and purchasing power parity, used by Timmer, the World Bank, and other analysts.

a 4% growth rate is to be achieved. Consequently, there is an urgent need for research into understanding how best to meet the challenge of increasing African farmers' use of productivity enhancing inputs — particularly those that improve land productivity. Given the growing evidence from more intensive agricultural production systems that overuse of these productivity enhancing inputs can cause environmental damage, researchers in SSA will need to pay more attention to the environmental consequences of new technologies at an earlier stage in their agricultural transformation than their counterparts did in the industrialized countries, Asia, and Latin America. This does not mean that they should completely avoid using such inputs.

Moderate use of chemical fertilizers is one of the most important ingredients in the intensification process. In the developing countries of Asia and Latin America, chemical fertilizer has played a key role in helping farmers overcome land constraints and increase aggregate production (Bumb 1995). Fifty percent of the increase in India's grain production has been credited to fertilizer (Hopper 1993, quoted in Bumb 1995). A third of the increase in cereal production worldwide is due to the use of fertilizer and related factors (Bumb 1995 citing FAO). Often fertilizer has been as important a contributor to the Green Revolution as improved seeds, i.e., more than a simple complement (Tomich, Kilby and Johnson 1995). There is already ample evidence that inorganic fertilizers can substantially increase yields in SSA (Larson and Frisvold 1996). Cotton is a case in point. A review of nine West African cotton producing countries showed that fertilizer (combined with related intensification practices) tripled yields from about 310 to 970 kilograms per hectare during the 1960-1985 period (Pieri 1989).

1.2.2. Agroecological Constraints to Fertilizer Use in SSA[4]

Before discussing fertilizer issues, reviewing aspects of the African environment that strongly influence fertilizer needs and performance is helpful. First, most African soils have inherent difficulties for agriculture in terms of fertility or drainage. These are primarily "acid infertile soils" (Oxisols and Ultisols) which comprise 56% of African soils, followed by "very infertile sandy soils" (Psamments) at 16%, and "poorly drained soils" (Aquepts) at 12%. "Moderately fertile, well-drained soils" (Alfisols, Vertisols, Mollisols, Andepts, Tropepts and Fluvents) which account for 33% of Asian soils, represent only 12% of African soils (Brady 1990). That being said, it is just as important to underline the fact that farmers universally seek out soils that are high-base-status, non-acidic soils. Thus, the percentage of African cultivated soils that are moderately fertile is expected to be considerably higher than the overall figures suggest.

A second agroecological factor of importance is the level of available water from rainfall, measured as precipitation minus evaporation (cm/year). A survey of available data found African levels at 12.7 cm/year vs. North America at 25.8, South America at 64.8, and the world average at 24.9 (Brady 1990). Water is absolutely critical for fertilizer to be effective. Variability of rainfall is a critical factor in efficiency of fertilizers and in determining risk-

[4] The discussion in this section draws heavily on Weight (forthcoming) and uses the USDA soil classification system.

aversion strategies of farmers in SSA. The tendency of SSA rainfall to be both spatially and temporally concentrated has important implications for fertilizer use.

1.2.3. Trends in Fertilizer Use

Despite compelling evidence that chemical fertilizers have a critical role to play in increasing agricultural productivity, average per hectare use of fertilizer in SSA remains the lowest in the world and continues to decline as a share of total use by developing countries. The following facts drawn from recent analyses of fertilizer trade and consumption data provide a sobering view of aggregate fertilizer use levels and growth rates in SSA:

<u>Levels of fertilizer used in SSA:</u>[5]

- The average dose in 1994/95 for SSA was 10 kg/ha[6] while Latin America used 65, South Asia used 77, and East Asia used 216.

- Africa uses less than 1% of global fertilizer and less than 2% of developing country fertilizer.

- Soil nutrient extraction in SSA exceeds replenishment by three to four times.

<u>Rates of growth in SSA fertilizer use:</u>

- Fertilizer consumption grew annually an average of 8.3% from 1960 to 1990;

- But, annual growth in consumption has been declining in recent years
  Growth for 1975 to 1990 was 3.4%
  Growth for 1990 to 1993 was just 0.3%
  Growth from 1993 to 1995 was negative;

- Projected annual growth in SSA fertilizer use for 1990 through 2020 is 3.3%, far below the 8-10% growth rate needed to increase cereal production to a level that would ensure food security.

Given the very low SSA fertilizer consumption levels in 1960, an overall growth rate of 8.3% does not represent large increases in absolute amounts of fertilizer used. To put the more recent

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[5] Information concerning levels and rates of growth is drawn from Bumb and Baanante 1996; Bumb 1995; and Gerner and Harris 1993. South Africa is NOT included in statistics for SSA.

[6] Down from 11 kg/ha in 1992/93 (Bumb 1995). Estimates vary somewhat: Donovan (1996) uses a rate of 15 kg/ha of arable land while the rates used by Bumb (1995) and Bumb and Baanante (1996) report kilograms of nutrients per hectare of arable land <u>and</u> permanent crops.

(i.e., lower) growth rates in perspective, it is useful to know that Indian rates increased by 5.4% and Chinese rates by 9.8% from 1986-1991 (Donovan 1996). The differences are compounded when one takes into account the higher initial levels of fertilizer application in Asia, which would normally be associated with slower growth rates. Figure 1 illustrates the magnitude of the differences in fertilizer consumption trends between SSA and the rest of the developing world.

1.3. Choice of Objectives and Research Questions

There remains substantial debate about how much more inorganic fertilizer African farmers need to use and what the balance between inorganic, organic, and biological fertilizers should be. Environmentalists (particularly those in the industrialized nations) argue that inorganic fertilizers pollute and should, therefore, not be encouraged in SSA (Elwell, cited in Low 1993, or Pretty 1995, for example). Soil scientists are concerned about the acidification that too much nitrogen fertilizer can cause (and the ensuing yield loss attributable to it), particularly if inorganic fertilizers are used without organic supplements (Pieri 1989, for example). Agronomists are worried that without inorganic fertilizers, soil mining will continue, thereby reducing soil nutrients and soil organic matter (Smaling 1993). Economists and politicians are concerned about feeding growing populations, increasing incomes, and protecting forests, woodlands, and pasture from encroachment by farmers who are now expanding cultivation to these areas because current production fails to meet their needs for food and income (Reardon 1998). Having considered these diverse views, we find the weight of the literature suggests that African farmers must increase the use of inorganic fertilizers – in combination with complementary technologies and management practices – if SSA is to (1) raise agricultural productivity growth rates, (2) improve food security, and (3) preserve its natural resource base. Although in some situations fertilizer-free techniques may be the most appropriate[7], the evidence presented fails to convince us that generalized reliance on these techniques will redress the agricultural productivity shortfalls currently facing SSA countries. If these shortfalls are not redressed, environmental degradation is likely to increase. Consequently, the discussion in this paper is based on three important underlying premises:

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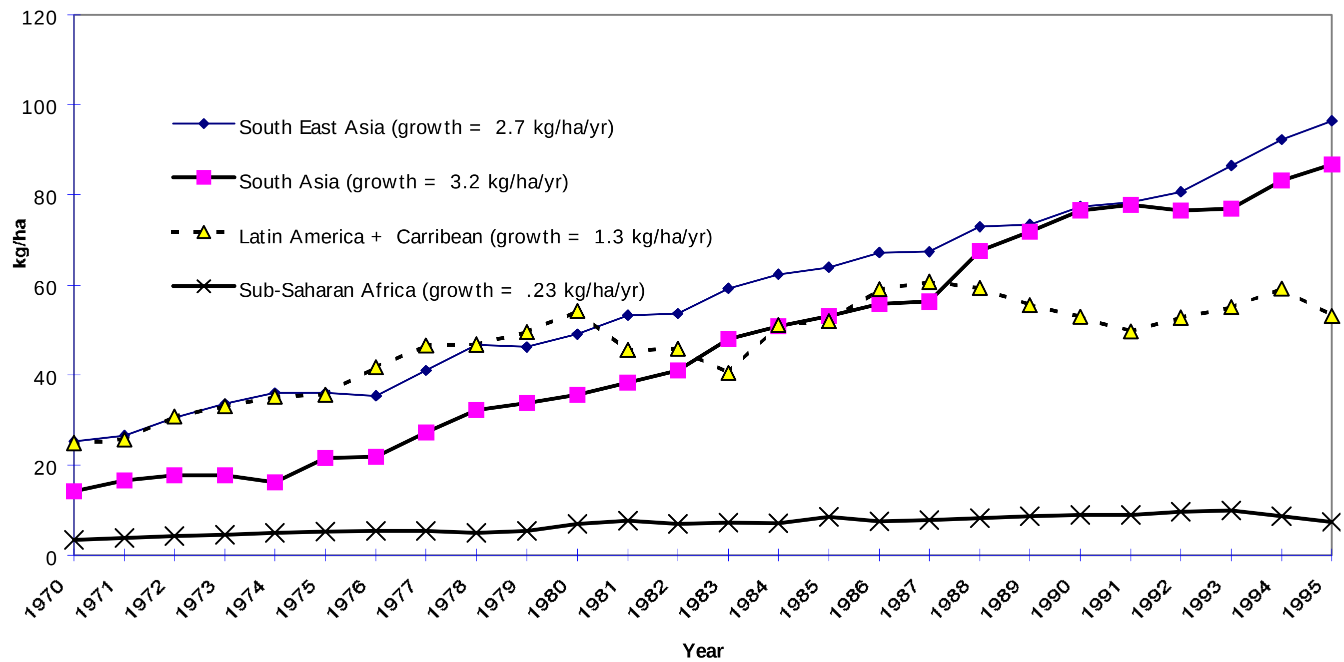
[7] Cases most frequently mentioned are acid soils with low buffering capacity as they are highly susceptible to aluminum toxicity; the situation is aggravated when these soils occur in areas with high temperatures and low rainfall (factors which contribute to low levels of soil organic matter).

Figure 1: Regional Trends in Fertilizer Consumption



- No fertilizer-free technologies are available that can generate the increases in African agricultural productivity (particularly land productivity) required to keep up with current population growth rates and food demand.

- Fertilizer technologies will be most productive if used in combination with complementary technologies such as improved seed or soil and water conservation practices.

- The environmental impact of moderately increasing African fertilizer use is likely to be positive rather than negative, <u>but warrants careful monitoring</u>.

Starting from these three underlying premises permits us to focus this report on the issue of how to moderately increase the use of chemical fertilizers in SSA rather than getting bogged down in the question of whether chemical fertilizers should be promoted at all — a debate that our review of the literature convinced us has little relevance for most of SSA at this point in time.

The specific objective of the report is to consolidate and synthesize the empirical evidence concerning fertilizer profitability throughout SSA. Although the profitability of fertilizer in

SSA has been questioned by many and continues to be a topic of discussion as SSA grapples with the problem of declining soil quality and stagnant agricultural production, few country-level and no region-wide efforts have attempted to consolidate and evaluate the empirical evidence on yield response, input prices, and output prices ― the key factors that determine whether fertilizer use is profitable. In reviewing the evidence on profitability we address the following questions:

- What is the fertilizer responsiveness of the principal crops grown in SSA?

  -How does this vary by region, country, and agroecological zone?

  -How does response in SSA compare with that in other parts of the world?

  -What are the key factors that influence yield response in SSA?

  -Can yield response be improved?

- Is fertilizer use profitable?

  -What are the value/cost ratios?

  -How do these ratios compare with those in other parts of the world?

  -What are the fertilizer/output price ratios?

  -How do they compare with ratios elsewhere?

  -What are the key factors that influence input and output prices?

  -How can price ratios and value/cost ratios be improved?

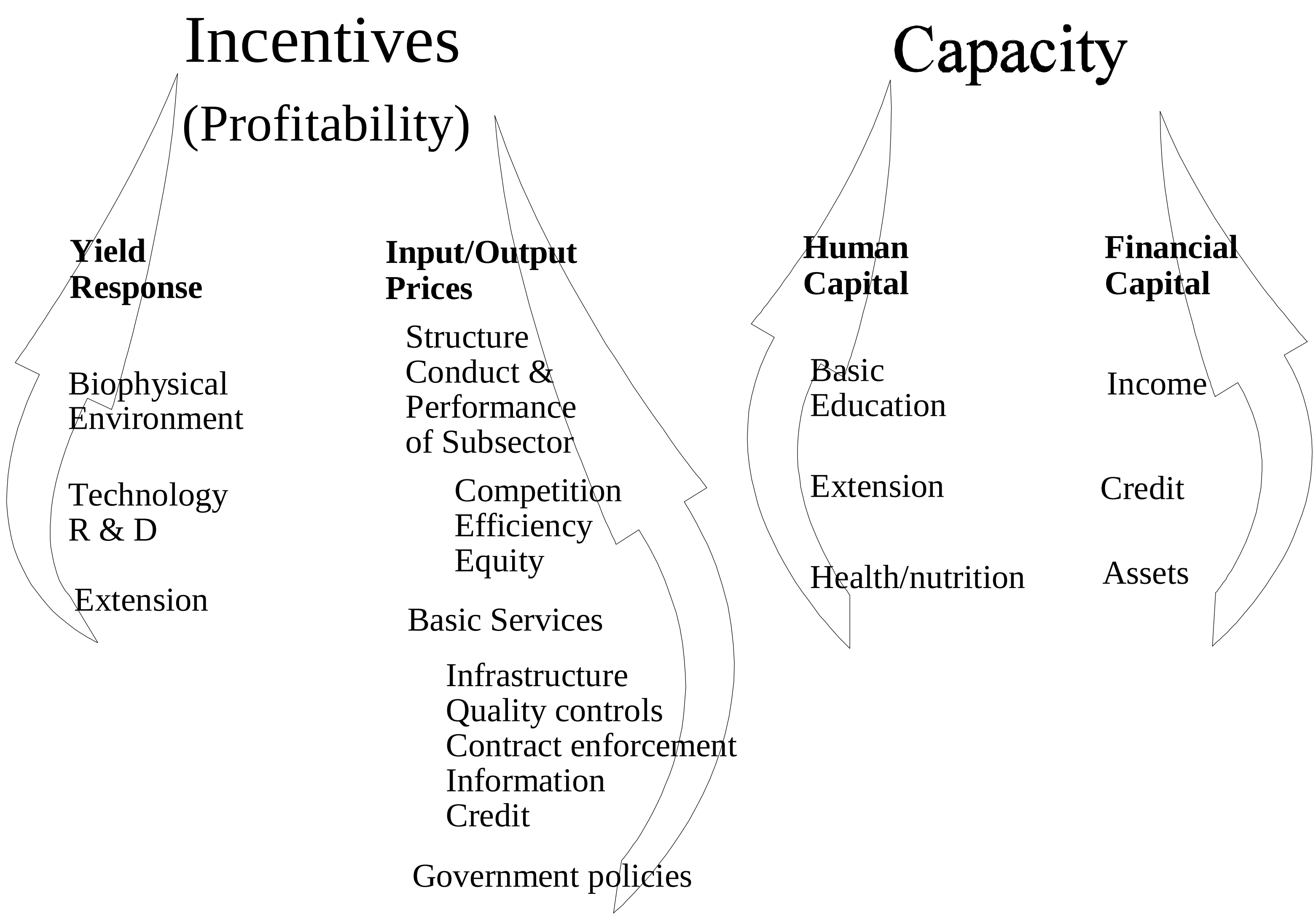
Despite our focus on profitability in this report, profitability is only one of the many factors that influence fertilizer consumption patterns. Fertilizer use needs to be understood as a major investment decision by farmers. Farmers need to make difficult decisions about how best to allocate scarce resources between consumption (e.g., education, health, housing) and production ends. For farmers in SSA who use recommended doses, fertilizer purchases can represent the largest single input expenditure for a production season. As purchasing fertilizer implies foregoing other consumption and/or investment (at least temporarily), farmers are likely to pose two basic questions before making a fertilizer purchase:

- Will fertilizer use be profitable? If so,

- Can I afford it?

Profitability can be thought of as the "incentive" to adopt fertilizer. The left side of Figure 2 summarizes some of the factors that affect yield response and prices, thereby shaping these

Figure 2. Factors Influencing Incentives and Capacity to Use Fertilizer



incentives. Perceptions of the absolute profitability of fertilizer will differ if individuals have different views about the fertilizer yield response or different price expectations. Perceptions of fertilizer profitability compared with perceptions of the profitability of alternative uses of available money will also differ to the extent that farmers face dissimilar sets of alternative investment opportunities.

Whether or not farmers can afford fertilizer depends on their capacity to purchase and correctly use it. The right side of Figure 2 illustrates that the capacity to adopt fertilizer has two components. Capacity depends on financial capital (cash and/or credit), which enables farmers to purchase fertilizer, and on human capital (education, management skills, health), which enables farmers to use the input correctly. The level of financial and human capital is often correlated with farm characteristics such as farm size, farm population, and location.

Although there is some interaction between profit incentives and capacity to purchase and use fertilizer (for example, human capital influences farmers' ability to attain maximum fertilizer response and, therefore, maximum profits), treating profit incentives and capacity as separate determinants of fertilizer use facilitates the task of reviewing the current state of knowledge on fertilizer use in SSA.

The focus on profit incentives in this report does not mean that we have neglected the issue of capacity. This document is part of a three-document series on fertilizer issues in SSA. The second document in the series discusses adoption issues, with particular attention to a review of the theoretical and empirical literature on the types of policies, programs, and investments capable of improving farmers' capacity to acquire and use fertilizer (Reardon et al. forthcoming). The third document deals with both profitability and capacity issues, but at a more macro level than the first two documents (Naseem and Kelly forthcoming). In this third document aggregate data on fertilizer consumption is used to examine the links between fertilizer consumption patterns and national characteristics thought to influence these patterns (population density, crop mix, irrigation infrastructure, road densities, price ratios, and agroclimatic factors, for example).

The rest of this report contains three sections: one on yield response, another on prices and profitability, and a concluding section which summarizes key points and discusses policy implications of the findings reported in earlier sections. In the yield response section we describe the strengths and weaknesses of the response data available, then draw some broad generalizations about the strength of the response for the seven most important crop types in SSA (maize, millet, sorghum, rice, peanuts, cotton, and beverages). This is followed by a discussion of the principal factors influencing fertilizer yield response and what can be done to improve response. In the price and profitability section we first discuss the quality of the data and profitability analyses available. Next we summarize the findings concerning private and social profitability of fertilizer. The profitability section ends with a discussion of the principal factors influencing input and output prices in SSA and the extent to which they are limiting fertilizer profitability. In the report's concluding section we make some broad recommendations concerning changes in government policies and investments that could improve fertilizer yield response and profitability.

2. EMPIRICAL EVIDENCE ON FERTILIZER YIELD RESPONSE IN SSA

2.1. Methods and Criteria for Evaluating Yield Response

A discussion of fertilizer response that draws heavily on reports of research trials and on-farm demonstrations (as this report does) must be viewed as a discussion of potential rather than effective response. The majority of farmers using fertilizer in SSA have not yet attained these levels of response. This is illustrated by the movement from higher to lower yields and fertilizer response as one moves from on-station trials to demonstration trials, and then to the few farm-survey observations that we found (see Appendix 1). Unfortunately, most of available literature deals with research station trials,[8] which attain artificially high results due to nutrient build up from previous experiments and more timely performance of key activities (seeding, weeding) than average farmers are able to attain. On-farm trials or demonstration plots do a better job of approximating typical yields, but farmers selected for these activities tend to be the better, more progressive farmers, leading to an upward bias in results. Despite these caveats, knowing whether research or demonstration trials provide evidence that there is good fertilizer response potential is an essential first step in understanding what needs to be done to increase fertilizer use in SSA ─ if fertilizer response from trials is poor, on-farm response clearly will not be adequate to stimulate increased fertilizer use.

Any determination of the adequacy of fertilizer response is subjective. For purposes of this review, we considered the response adequate if one of the two following conditions were met:

(1) a kilogram of fertilizing nutrients produced 10 or more kilograms of additional output (i.e., the output/nutrient ratio is ≥ 10); or

(2) the response for a particular crop cultivated in SSA was comparable to that for the same crop grown in other parts of the world that have already achieved high levels of fertilizer consumption.

Even with these criteria, the determination was difficult. The first criteria is a very rough rule of thumb that has been used for evaluating fertilizer efficiency with cereal crops, but the rule is not very useful when looking at crops such as cotton or coffee. Furthermore, problems using this criteria were encountered because many authors failed to specify whether response was average or marginal[9] and whether it was response to fertilizer only or to fertilizer and complementary practices. In making comparisons with response in other parts of the world, we faced even more serious information problems as documents consulted frequently failed to note the specific

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8 This situation suggests that more attention needs to be given to publishing the results of on-farm and demonstration trials, which tend to be hidden in difficult-to-access "gray" literature.

9 Average responses tend to be reported for demonstration trials where only one level of fertilizer is used. Marginal responses are often reported by researchers who estimate production functions from fertilizer trials used to test a range of application rates.

conditions under which the data were collected (amount of rainfall, irrigation or not, type of soil, research station vs. on farm trials, and farmer managed vs. researcher managed trials, for example).

Appendix 1 presents a detailed summary of fertilizer response results reported in the wide variety of documents reviewed. In addition to information on "pure" fertilizer response, we have documented evidence on several related themes of general interest to SSA soil fertility: the role of phosphate rock, organic matter supplements, biological nitrogen fixation, and soil moisture control. Most of these technologies are examined both with and without use of inorganic fertilizers. Information presented in Appendix 1 led us to the conclusions about fertilizer response potential in SSA that are summarized in Sections 2.2-2.10.[10] In Section 2.9 we review what is know about factors affecting fertilizer response, with particular attention to the issue of high variability in SSA fertilizer response.

2.2. Maize Response to Fertilizer

Maize is a crop that figures prominently in discussions of fertilizer use in SSA as it accounts for about 25% of fertilizer consumed in the region. Nevertheless, a high percent of maize continues to be produced with no application of inorganic 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 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, a level seldom reported in examples from other regions of the world.

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 >25 for Ghana and Nigeria. The lower ratios were, however, frequently less than 5, 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

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[10] As specific references for each source of yield response information are included in Appendix 1, we do not repeat this information in the summary discussion presented in Sections 2.2-2.10 below.

zone of southern Mali, for example, doubled between 1950 and 1980 (from 500 to 1000 kg/ha) (Pieri 1989). Trials with rock phosphates revealed that a basal dose every 10 years produced a strong response, though not always as strong as the basal dose plus annual supplements.

2.3. Sorghum Response to Fertilizer

Sorghum in SSA was much 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. The lower response is reflected in current fertilization patterns, as sorghum accounts for only 8% of fertilizer used in the region despite the fact that sorghum is one of the principal cereal crops.

East and Southern Africa exhibited the best response to NPK fertilizers. The output/nutrient ratio ranged from 4-21 in Kenya and from 10-13 in Tanzania. West African ratios did not exceed 15 and most examples were in the 4-6 range.

Nitrogen alone or in combination with phosphate generated the largest output/nutrient ratios when only inorganic fertilizer was used. 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 highly degraded soils), we found 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.

2.4. Millet Response to Fertilizer

Millet accounts for only 3% of fertilizer used in SSA, due in large part to the very low fertilizer response exhibited by this crop. 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 reported by Lele, Christiansen, and Kadiresan in 1989 were 3 and 7 but upper limits reached 11 and 21).

The frequency of ratios <10 contrasted sharply with the Indian trial responses reported by DeGeus (1970) which were in the 16-18 range for response of local varieties to nitrogen and in the 22-27 range for response of hybrids. On the other hand, an 11-year average (1969-80) for yields on farmers' fields in the Indian semi-arid tropics revealed a response of 3-4 kilograms of output per kilogram of nutrient ─ more comparable to those in SSA (Christianson 1988). The DeGeus examples are not clearly labeled, but they probably included production in the semi-arid tropics as well as more humid areas; this makes the Christianson examples more comparable to the SSA millet responses in Appendix 1, which come exclusively from Sahelian countries.

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),

Because millet response to fertilizer is generally poor but millet remains the principal crop in many of the less favorable agroecological environments of SSA, many of the more recent millet trials have been designed explicitly to evaluate the productivity potential of natural resource management techniques used in combination with fertilizer. We review research results for a few of the many techniques recently studied: *zai*, crop residues, agroforestry, and windbreaks.

Zai[11], which combine water conservation with chemical and/or organic fertilizers, were studied in Niger and Burkina Faso. The percent increase in yield was generally very high (250-550%) but the Namentenga area of Burkina Faso was an exception with farmers' estimating only 65-85% yield increases.

Addition of crop residues alone or in combination with chemical fertilizers was studied in Niger. The percent increase in yield due to crop residues alone was high (213%) but not as high as the increase due to fertilizer alone (359%); response to both crop residues and fertilizer combined was slightly greater than the sum of the individual responses (596%). These results are in line with expectations as higher fertilizer response is usually anticipated in earlier years and higher residue response in later years of long-term trials (due to the build up of organic matter over time). Niger has also examined the impact of increasing plant density alone and in combination with fertilizer. Higher plant density plus fertilizer increased yield by 170% while the percent response is less (56-65%) to fertilizer alone or increased plant density (20-37%) alone.

[11] *Zai* is a technique of placing millet or sorghum plants in a depression dug into a field. Some type of organic or inorganic fertilizer is added to the depression which captures water and improves the efficiency of nutrient uptake.

In Senegal, the effect of *acacia albida* trees alone or in combination with fertilizer and manure was investigated. Millet planted under an acacia albida exhibited a 100% yield increase over millet planted without the acacia albida; this was much less than the 175% increase associated with an application of fertilizer plus manure. Adding both fertilizer and manure to a crop planted under an acacia albida did little to increase yield beyond what the fertilizer and manure would do if no acacia albida were present.

Windbreaks seem to have a limited impact on yield, providing a small (6-15%) increase in millet yield in Niger. The smaller yield impact could be due in part to competition for nutrients between the plants used as windbreaks and the millet.

2.5. Rice Response to Fertilizer

Rice accounts for slightly more of the fertilizer used in SSA than millet (4% versus 3%). The low level of aggregate fertilizer consumed on rice is due more, however, to the smaller areas cultivated in rice than to the fertilizer response.

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

The yield for unfertilized rice in SSA was roughly the same as the Asian examples and the one set of trials from Latin America ─ generally in the upper 2000 to mid 3000 kg/ha range. This was more favorable than maize in Africa, the next highest yielding cereal crop, with control yields centered in the 500-2000 range; part of these apparent differences in land productivity is probably due to the fact that maize is a rainfed crop while most of the rice examples are from irrigated production systems.

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).

We did not find any analysis of yield impacts of alternative soil fertility techniques (manure or crop residues, for example) used alone or in combination with inorganic fertilizers. Because fertilizer responds so well when soil moisture is controlled, there is probably less pressure for researchers to study alternatives to inorganic fertilizers at this time.

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 (Pearson, Stryker and Humphreys 1981). 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 (see section 3).

2.6. Groundnut Response to Fertilizer

Groundnuts account for only 1% of recent fertilizer consumption in SSA. Groundnut response to fertilizer was poor compared with results reported for the Indian semi-arid tropics. Our hypothesis is that the lower fertilizer yield responses are due, in part, to the fact that without-fertilizer yields for SSA are better than those for Indian semi-arid areas, suggesting that SSA peanut production is found in areas with better soils and or rainfall (Table 1).

Table 1. Peanut Yields for Plots Grown Without Fertilizer

Country	Burkina Faso	Gambia	Niger	Zambia	Senegal	India
Yield/ha	1500-2000	1560	1230	1190-1310	800-1000	790-900

Source: Data summarized in Appendix 1.

Physical response of groundnuts to various combinations of NPK fertilizer (with phosphates predominating) generally failed to exceed 10 kilograms of additional output per kilogram of nutrient, ranging from 5 to 9 kg in most SSA countries and zones. 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). Peanut response to fertilizer was similar to that for millet and lower than that for other cereals.

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.

2.7. Cotton Response to Fertilizer

Cotton accounts for 17% of SSA fertilizer use; a very large share of SSA cotton area is fertilized. Despite the strong link between fertilizer and cotton, we had difficulty finding well-documented examples of cotton response to fertilizer. Those that we did find were diverse.

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). This is an unusual SSA case because application of fertilizer only (without organic matter supplements) produced high yields under conditions of continuous cultivation with only minor loss of soil organic matter.

Our general conclusion concerning cotton response to fertilizer is that the physical response (kilograms per hectare and/or percent increase in yield) is generally strong enough for farmers to see a marked difference in production. However, the recommended levels of NPK are high, leading to low output/nutrient ratios that can negatively affect profitability (see Section 3 for a discussion of profitability).

Despite the generally good response throughout SSA, a large number of 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 concerning the best approaches for increasing productivity in these areas are needed.

2.8. Beverage (Coffee and Tea) Response to Fertilizer

Although fertilizer is commonly used by coffee and tea producers in SSA, the total area cultivated in these crops is small and consequently the share of fertilizer going to each of these crops is also small (<1% for each crop). 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 collected thus far.

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.

2.9. Principal Factors Affecting Fertilizer Response

As documented by the information in Appendix 1 and the preceding summary of key findings concerning fertilizer yield response in SSA, response can be highly variable – even under the relatively controlled environments in which research and demonstration trials are conducted. Efforts to improve yield response in SSA must build on what is known about the wide range of factors that can affect the response. We have classified these factors into three broad categories: physical environment, plant material, and management practices.

2.9.1. Physical Environment

The physical environment includes factors such as soil quality (physical, chemical, and biological properties), rainfall (quantity and distribution over time), and temperature. As noted in Section 1.2.2, much of SSA is characterized by low, highly erratic and unpredictable levels of rainfall and high temperatures (>30 degrees centigrade) which lead to low soil organic matter and poor soil quality. All these factors can limit agricultural productivity in general and fertilizer response in particular.

Evidence showing that fertilizer responds better (and farmers are more likely to adopt it) in zones where rainfall exceeds 700 mm per year is abundant (Lele and Stone 1989; Matlon 1990; Jha and Hojjati 1993; and Thompson 1987). This reality justifies focusing fertilizer programs in higher rainfall areas while continuing to work on alternatives to chemical fertilizers and/or means of increasing fertilizer responsiveness in the many parts of SSA that have less than 700 mm of rainfall annually (see discussion of complementary practices at end of Section 2.9.3).

A key issue related to the physical environment is whether the common policy in SSA of using blanket fertilizer recommendations for farmers facing very different agroecological situations (particularly soil quality) is agronomically and economically appropriate. Carr (1993), writing primarily about East and Southern Africa, characterizes cotton as a "cash" crop of last resort for farmers in areas of unreliable rainfall. He identifies three factors that strongly influence cotton response to fertilizer:

- moisture,
- soil type, and
- insect control.

Carr’s overriding concern is that when cotton is promoted as a cash crop in difficult agroclimatic situations, care must be taken in developing fertilizer recommendations. He cites research in Tanzania, Uganda, and Zimbabwe having shown that fertilizer yield response can be extremely low when moisture and/or soil conditions are compromised (less than 1 kilogram of additional yield per hectare for recent trials using recommended doses at 21 sites in Tanzania). Soil acidity also needs to be considered when developing fertilizer recommendations as low ph (<5.4) is a sign of calcium deficiency and aluminum toxicity problems which inhibit fertilizer response.

Although some researchers have argued that developing a broader range of area-specific fertilizer recommendations is too expensive in SSA given the large number of small, geographically dispersed farms; evidence is growing that better targeted fertilizer recommendations could result in substantial private and social savings as well as major increases in productivity if such recommendations led farmers to adopt more profitable doses that better fit their needs (Lele, Christiansen, and Kadiresan 1989; Bensen 1997a and 1997b; Smaling et al. 1992; Kumwenda et al. 1997). Section 2.9.3 presents illustrations of some promising moves toward more site-specific recommendations.

2.9.2. Plant Material

The Green Revolution in Asia and Latin America built upon a series of technological breakthroughs that provided farmers with improved varieties that were very responsive to chemical fertilizers. Traditional crop varieties in SSA and elsewhere are generally not very responsive to fertilizer and/or exhibit undesirable side effects (lodging, for example) when fertilizer is applied. Consequently, fertilizer yield response is highly dependent on the development of improved, fertilizer-responsive plant varieties.

Although there has been considerable research in SSA to develop fertilizer-responsive hybrids and open-pollinated varieties for the principal cereal crops (maize, millet, and sorghum), debate continues on the success of these plant breeding programs. Researchers have made substantial progress on developing fertilizer-responsive varieties of maize for Eastern and Southern Africa (Byerlee and Eicher 1997). Recent evidence shows that hybrid maize grown without fertilizer (a practice that until recently was thought to be inappropriate) can perform better than traditional varieties (Smale and Heisey 1997). The picture for sorghum and millet is less clear. Some feel that progress to date for these crops has been poor (Matlon 1990) while others believe that enough progress has been made and the research focus should shift from plant breeding to improving soil and water management techniques (Sanders, Shapiro and Ramaswamy 1996). Plant breeding efforts for rice have focused on the need to develop varieties that are more appropriate for the climatic situation (lower temperatures, lower water levels) prevailing at the time that second or third crops of irrigated rice would be produced. Although some advances have been made here, most farmers are not yet doing second and third rice plantings.

Some additional issues that need to be considered when breeding plants for SSA are (1) how efficiently the plant can use available soil nutrients (rice and maize tend to do better), (2) how tolerant crops are of aluminum toxicity and acid conditions (upland rice and cassava do better here while sorghums and millets do poorly), and (3) how efficient they are in the production of crop residues (maize does well here).

2.9.3. Management Decisions

Crop response to fertilizer as well as fertilizer's impact on soil quality in the long-run is extremely sensitive to the manner in which fertilizer is introduced into traditional cropping systems as well as the evolution of management practices concerning the type of fertilizer used (formula, high vs. low analysis, etc.), doses applied, application methods used, and complementary practices employed.

Introducing Fertilizer: In many cases, fertilizer was first introduced to SSA farmers in conjunction with a new cash crop capable of providing income that could pay for the fertilizer (cotton and peanuts are common examples for West Africa). A review of the literature on longitudinal studies (>10 years) of cotton systems in West Africa documents that in countries where the new crops and technologies were added to existing systems in an "extensive" manner (substantially increasing total area cultivated per laborer) deterioration in soil quality due to erosion and expansion to marginal lands has often exceeded the benefits accruing from the introduction of fertilizer into the system (Pieri 1989). If, however, new crops were "rotated" into the cropping system and expansion of area cultivated was not common, benefits were substantial. Unfortunately, very little research has been done in this area other than that for the West African cotton zones. As the introduction of new cash crops and fertilizer increases throughout the continent, the lessons learned from the West African cotton experience need to be kept in mind.

Fertilizer Type: Usually decisions about the type of fertilizer used in SSA are made *for* farmers rather than *by* them.

Despite the fact that production environments in SSA are generally more variable over space and time than elsewhere, African farmers have a very limited range of fertilizer products from which to choose. One cause of this limited supply is heavy reliance on foreign aid, which means that countries frequently have little say about the products received. Kenya, for example, is distributing MAP (received as foreign aid from Japan) to farmers, even though DAP is generally recommended (Allgood and Kilungo 1996).

Another reason for the limited range of fertilizers available to farmers is that high agroecological diversity coupled with low effective demand for fertilizer makes it extremely costly to design research and distribution systems that target particular crops and production environments (Heisey and Mwangi 1997). It is a bit of a dilemma: low demand makes it difficult to recommend and supply a wide range of products, while reliance on "middle-of-the-road" formulae and recommendations means that yield response is often low, discouraging greater demand. Rarely do countries invest in national soil mapping exercises and the development of specific recommendations for different crop/soil combinations. Even when this has been done, it is often costly to provide farmers with a wide variety of formulae; complex mixes generally cost 15-20% more than it would cost for a farmer to purchase standard products such as urea or DAP and apply in recommended ratios. The conventional wisdom in much of SSA has long been that farmers' education and skill levels are not adequate for dealing with complex instructions for combining different types of fertilizer, hence the focus on a few generic products. As a result, many African countries have used one blanket fertilizer recommendation for decades, irrespective of crops grown, local conditions and changes in price relationships.

Evidence is emerging that more attention to site-specific fertilizer research and recommendations is a feasible option with good payoffs. In Malawi, for example, farmers using blanket fertilizer recommendations (92 kg N and 40 kg P_2O_5 per hectare) were achieving only 50% of potential yields. A series of multi-year trials at multiple sites throughout the country revealed that the blanket recommendation sometimes contained more and sometimes less phosphorus than necessary. In addition, the recommendation was frequently deficient in potassium and a variety of micronutrients. Research/industry collaboration (aided by the potential of fertilizer blending systems) resulted in the production of more targeted recommendations produced in small "runs" at a "surprisingly reasonable cost". Using the new fertilizers, farmers were able to increase yields by 40% (Kumwenda et al. 1997). Kenya provides another example where efforts to combine pre-existing soil mapping information with results from 70 four-year fertilizer trials resulted in the development of a wide range of area-specific fertilizer recommendations at relatively low research and extension costs (Smaling et al. 1992).

Despite the successes in Malawi and Kenya, experience shows that farmers do not always respond rapidly when new fertilizer recommendations and formulae are made available. Extensive fertilizer testing during the early 1990s in Ethiopia showed that the prevailing recommendation of 100 kg of DAP per hectare was no longer adequate due to growing nitrogen deficiencies. Urea has been made available and extension services have been recommending that farmers use 100 kg of DAP plus 100 kg of urea as top dressing. While 31% of farmers are using fertilizer, only 5% have been using both urea and DAP. Part of the problem is clearly financial (the cost of the new recommendation is more than double the old one due to both quantity and price increases), yet if the new recommendation is truly warranted by both agronomic and economic criteria, extension services and demonstration trials must find ways to convince farmers of the wisdom of changing (Mulat et al. 1997).

A similar situation exists in neighboring Kenya where farmers are using about 60 kg of DAP per hectare of maize—this provides less than 20% of the recommended nitrogen dose. Private stockists appear to be perpetuating the behavior by recommending that farmers use just one bag of DAP per acre (Allgood and Kilungo 1996). Recent research on the impacts of fertilizer market privatization and liberalization in Zambia and Zimbabwe (Rusike et al. 1997) has shown increased competition among fertilizer dealers and some efforts at product diversification. To date, however, the new products have more appeal to the larger, commercial farmers or producers of specialty products (vegetables or tobacco) than to the bulk of smallholders who are producing staple cereals. Furthermore, the introduction of more high analysis fertilizers is raising questions about whether long-term use of these products will lead to increased frequency of micro-nutrient deficiencies.

The above discussion brings to light a dilemma: technical scientists and economists are increasingly cognizant of the need to develop more site-specific fertilizer recommendations yet the emerging private sector distribution systems have not yet made a great deal of progress in helping farmers evaluate the new products being offered and make informed choices. There is a need to better understand the reasons for the fertilizer choices that farmers are making when they do not seem to be in line with research recommendations. Is it the underlying agronomic response that farmers are questioning? Is it a financial decision? Is it due to lack of technical knowledge on the part of fertilizer dealers, or their inability to share technical knowledge with farmers? In most cases it will be some combination of these factors, yet to design policies that encourage more efficient use of fertilizer a better understanding of the relative importance of the various factors in different locations or for different types of farmers could be extremely helpful. Low-cost, rapid appraisal surveys of both farmers and fertilizer dealers could be used to determine why adoption behavior differs from research recommendations and what types of adjustments in the system are necessary to improve adoption.

Another issue concerning fertilizer types is whether to use relatively expensive high-analysis phosphate fertilizers (imported products such as SSP, TSP, or DAP) or to use locally available rock phosphates. The skyrocketing cost of imported fertilizers following removal of subsidies renewed interest in field trials of millet and sorghum response to local sources of rock phosphate. To date, it is not clear that locally produced rock phosphates can provide an economically viable alternative to imported phosphates. Most rock phosphates examined thus far need to be partially acidulated before producing a significant yield response. Even after acidulation, response tends to be substantially lower than that of higher analysis fertilizers (see Appendix 1 tables for millet, maize, and sorghum for examples). Unfortunately, the economic potential of rock phosphates is difficult to evaluate because no commercial production of the product from which to estimate the farm-level costs exists (see section 3.3 for more discussion of the economics of rock phosphates).

Fertilizer Doses: A variety of rules are used to determine the "optimal" dose of fertilizer. The agronomic literature tends to stress maximum yields. The economic literature is shaped by those recommending profit-maximizing doses and those recommending more conservative doses (marginal rate of return of 100% or value/cost ratios equal to 2) that take into account risk and yield gaps between research trials and on-farm realities.

Mounting evidence supports the argument that an exclusive focus on a generic set of "optimal" doses — whether from an agronomic or an economic perspective — may not be the best approach in the long-run, as few farmers in SSA are in a position to correctly used optimal recommendations. In the more recent literature on fertilizer doses, we found numerous discussions about the need for research and extension services to help farmers adjust fertilizer applications to their individual cropping systems, resources, constraints, and ability to bear risk.

For example, poor weeding substantially reduces fertilizer response for most crops, hence farmers who do not have adequate labor to weed on time risk losing (or at least substantially reducing) the return to their fertilizer investment. For cotton, insect control is by far the most important prerequisite for fertilizer use; failure to control insects means that they, rather than the farmer, reap the value added from the fertilizer. Coffee provides yet another example; when grown in the shade it rarely responds to urea, but if grown in the sun it will exhibit rapid yield decline if an external source of nitrogen is not applied. Traditionally, weeding or insect control have been discussed as complementary practices to increase fertilizer efficiency (see discussion of complementary practices below). The point being made here is that when optimal weeding or insect control are NOT possible, adjustments should be made in fertilizer doses used.

Research and extension services alike need to pay more attention to the concept of "flexible" recommendations and the need to fit fertilizer into a complex farming system. How much fertilizer to use on each crop is a decision that must be based on many factors in addition to the underlying agronomic response function. What is right for one farmer may not be right for another, particularly when economic considerations such as debt carrying capacity and ability to bear risk enter the picture. Most SSA farmers will be making second-best fertilizer decisions for a long time to come; research and extension services as well as fertilizer suppliers should be armed with the knowledge and skills to help farmers make the best possible decisions.

In all fairness, it is important to note that this type of approach has only recently been broadly applied in countries such as the United States with much more developed agricultural sectors. Hence, it is understandable that not much thought has been given to such approaches in SSA where the high costs of on-farm soil testing and low rates of rural literacy render the approach difficult to implement. Nevertheless, moving in this direction by paying more attention to site-specific recommendations is a feasible first step in the process as illustrated by recent developments in Kenya and Malawi (Smaling et al. 1992; Bensen 1997a; Kumwenda et al. 1997).

Poor distribution systems have also been held responsible for supply shortages that led to low application rates. During the last decade there has been considerable reform in fertilizer distribution systems (liberalization, privatization, etc.), yet there is little evidence that these reforms have had much impact on the aggregate quantities or application rates of fertilizer used. Kenya provides an excellent example of stagnating fertilizer demand despite market reforms that are viewed as successful when measured in terms of private sector participation, breadth of geographic coverage, and competitiveness (Allgood and Kilungo 1996).

Application Methods: Research shows that fertilizers must be applied to crops at appropriate moments in their growth cycle to achieve maximum response. Researchers have examined alternative methods of applying fertilizer, particularly broadcasting versus side-dressing. Though some evidence suggests that one method may be better than the other under particular circumstances, most of the literature suggests that timing of applications is a much more important determinant of yield response than method of application (Bationo and Mokwunye 1991a and 1991b). In Zambia, for example, applying basal and top-dressing fertilizer when weeding maize at 20 cm in height saves a significant amount of labor time and increases yields by about 19% over standard practices (Kumwenda et al. 1997 citing Low and Waddington).

Recent work in SSA on *synchrony* (adapting input applications to schedules or pulses of the microbial ecosystem) highlights the importance of timing issues if SSA farmers are to efficiently use fertilizers and improve their profitability while reducing the possibility of polluting the environment with fertilizer runoff (Woomer and Swift 1994).

Farmers often fail to follow recommendations concerning timing of activities because the utility has not been adequately demonstrated by extension agents, labor bottlenecks make it impossible, or they have done their own research showing that by delaying application until after the rains are well-established they can reduce risk of low response due to drought. The last mentioned phenomenon could be considered an example of what some researchers are now referring to "response farming" — a system of production where critical activities (particularly amounts and timing of fertilizer applications) are adjusted to conform with expectations concerning water availability. An example of a sophisticated version of "response farming" would be the use of long-term data series on rainfall to develop water balance models that can be used to fine tune fertilizer recommendations (Stewart 1988).

Studies have also shown that factors beyond the farmers control frequently prevent timely fertilizer applications. Inadequacies in distribution systems resulting in late deliveries are a prime example (von Braun and Puetz, 1987, and Johm 1990, for Gambia; Crawford and Kelly 1984, for Senegal; Rusike et al. 1997). Dependence on foreign aid can also make it more difficult to ensure timely delivery as the timing of aid imports may have more to do with politics or fiscal appropriation schedules in the donor countries than with the agronomic calendars of the recipient countries. Poor roads and communication infrastructure limit the ability of suppliers to get fertilizer where it is needed when it is needed. Poor organization of the input marketing system also hampers timely delivery; this has been particularly true for government-run systems. Privatization and liberalization have improved some aspects of most input distribution systems, but these policy changes have also introduced new problems that are still being worked out (see, for example, Shepherd 1989, on SSA in general; Kelly et al. 1996, on Senegal; Allgood and Kilungo 1996, on Kenya; or Rusike et al. 1997, on Zimbabwe and Zambia).

Complementary Practices: The need for farmers to consider their ability to control weeds or insects when determining fertilizer doses has already been mentioned. Weed and insect control, as well as other factors such as seed quality, can also be considered as complementary practices that improve yield response to a given dose of fertilizer. A good example of the potential impact comes from Malawi where farmers who weed twice at the critical periods have achieved higher maize yields with half the amount of fertilizer than farmers who weed only once (Kumwenda et al. 1997, citing Kabambe and Kumwenda).

In addition to the above mentioned practices, which have been stressed by research and extension services for a long time, interest is growing in the improvement of soil moisture control (water harvesting, rock bunds, *zai*), use of organic matter (crop residues, manure, compost, planting under acacia albida trees, alley cropping), and better integration of nitrogen fixing crops (including inoculation). Many of these techniques complement fertilizer by reducing leaching and run-off and increasing nutrient availability at critical moments in the plant's development cycle.

Published results on direct links between fertilizer response and **soil moisture technologies** are not numerous, but some positive links have been documented. For example, when tied ridges were combined with moderate levels of inorganic fertilizer in the Sudanian region of Burkina Faso, sorghum yields increased by 90 to 440%. Using either of these practices alone increased yields by only 50%. An additional plus was a significant decrease in production risks and the possibility of financial losses from fertilizer adoption when the two technologies were combined (Sanders, Shapiro, and Ramaswamy 1996). Efforts have been made to synthesize indigenous knowledge concerning water harvesting in SSA as well as information on the agronomic and economic performance of these techniques. The consensus is that published information is very inadequate, focusing primarily on descriptions of different techniques with very little attention to measuring impacts on productivity or soil quality over time and even less attention to the economic costs and benefits of the technologies, adoption and sustainability issues (Reij, Mulder, and Begemann 1988; Critchley, Reij and Seznec 1992).

Organic fertilizers provide micronutrients not found in chemical fertilizers. The scarcity of a micronutrient may become a limiting factor thereby diminishing the effectiveness of chemical fertilizers (e.g., Malawi case reported by Kumwenda et al. 1996). Unlike chemical fertilizers, organic fertilizers improve soil structure (friability, porosity, etc.). This can help improve water infiltration and retention which can improve the effectiveness of chemical fertilizers.

Two of the most commonly studied sources of organic matter are crop residues and manure. There is a great deal of evidence on the ability of organic matter to increase yields when used alone or in combination with inorganic fertilizers. In the Sahel, plowing under crop residues *and* using chemical fertilizers increased yields 50 to 150% *more* than using either technique alone (Bationo, Christianson, and Klaij 1993). On millet fields where crop residues had been returned to the soil during a 4-year period, yields were comparable to those having been treated with inorganic fertilizers. When both fertilizer and crop residues were combined, millet grain yields were 15 times greater than the control (Bationo and Mokwunye 1991b). Four-year trials in three different agroecological units of Kenya found that maize yields increased substantially when manure was combined with fertilizer, however, the most profitable treatments were those using only chemical fertilizers, which were subsidized at the time of the analyses (Smaling et al. 1992)

Researchers have studied a variety of more complex **agroforestry techniques** that have been studied under controlled conditions in an effort to determine their potential contribution to both soil quality and crop productivity.[12] Hedgerow intercropping, windbreaks (live and dead), improved (planted) fallows, and parklands systems (planting cereals under fertility enhancing trees such as *acacia albida*) are among the most common techniques having direct impacts on cropping systems, while fodder banks have been examined for their indirect impact. Although results show that some of these technologies can improve soil quality and yields, the improvements are frequently not strong enough to compensate farmers for the associated labor demands and cash costs. One of the more promising examples of a positive

[12] All examples presented in this and the next paragraph come from work by ICRAF described in an unpublished paper (Place 1995); some references to these trials can also be found in ICRAF annual reports.

fertilizer/agroforestry interaction comes from 6-year trials of hedgerow intercropping (*leucaena leuocephala* used as double hedges and planted one year before the maize) in Zambia (Chalimbana). Although the plots with only hedgerows did not do much better than the control plots, the plots with hedgerows plus fertilizer produced aggregate yields over the 6-year period 3 times greater than the control and 25% greater than the plot receiving the standard fertilizer treatment. This is clearly a case in which fertilizer and agroforestry are complements rather than substitutes.

Other agroforestry trials have also produced some promising results, but they appear to represent substitutes for rather than complements to inorganic fertilizer. For example, 6-year maize trials in Zambia (Msekera) compared improved fallows (*sesbania sesban* planted as fallow for 1, 2, and 3 years) to continuous maize with and without fertilizer (112 kg/ha of the recommended fertilizer). Aggregate maize yield for the entire 6-year period was greatest for the continuous maize grown with fertilizer (28 tons); the next best production, however, was for the treatment with a 2-year fallow, which produced almost twice as much maize (14.3 tons) as the control (7.5 tons). All the fallows outperformed continuous maize without fertilizer, yet the fertilized fields were the overall best performers, even when costs were taken into account and net present values of production compared. Similar but less spectacular results were obtained from trials with relay cropping (*sesbania sesban* planted concurrently with maize) in Zambia (Makoka), with the relay techniques outperforming the control plots but trailing far behind the fertilized plots with respect to physical yields as well as economic returns.

Research on the use of **biological sources of nitrogen** has only recently been getting attention in SSA, despite the fact that farmers in SSA have a tradition of using nitrogen fixing leguminous crops in rotations (millet/peanuts, for example) or as intercrops (interspersed rows of cowpeas and millet or sorghum, for example). Some recent work in Niger has looked at the relative efficiency of intercropping versus crop rotation for adding nitrogen to the soil. Results show that both rotation and intercropping with nitrogen fixing crops increase soil nitrogen considerably. Total biological yield of an intercropped field, for example, can be as much as 50% greater than either crop grown individually (Fussel and Serafini 1985). In most cases of intercropping, the productivity of the cereal crop increases significantly while the yield of the leguminous crop are mediocre, suggesting that the cereals are benefitting most from the intercrop (Kumwenda et al. 1997).

To date, neither method (rotation vs. intercropping) has been shown to be conclusively better than the other, though the evidence is leaning toward crop rotation as the method most likely to obtain the greatest biological yields (Peter and Runge-Metzger, 1994). Williams (1994), for example, uses results from work in Niger to show that if farmers switched from intercropping to a cowpea/millet rotation with increased plant density for the millet, they could significantly increase their production and have a marketable surplus the first year that would permit purchase of chemical fertilizers in subsequent years.

Some work has been done on **inoculation of leguminous crops** to improve their nitrogen fixing capacity. Thus far, results show no statistically significant increase in nitrogen fixing capacity when crops traditionally grown in an area are inoculated, but for newly introduced crops, such as soybeans in Zambia, yield increases of almost 50% have been attributed to inoculation (Sloger et al., 1993). Most reports on inoculation in SSA agree that there has not yet been enough research on the topic to draw definitive conclusions concerning the technology's potential. At this point it is not clear if the poor response of traditional food crops to inoculation is because there is already an adequate population of rhizobia in the soil or because researchers have not yet perfected their inoculation techniques (Danso 1992).

Most of the research on complementary practices has been conducted on crops and zones where fertilizer response is low and variable, with poor economic potential. Given emerging evidence on loss of soil organic matter, declining ph, and problems of aluminum toxicity in the few areas of SSA where fertilizer has been used heavily over a long period of time (West African cotton zones, in particular), there emerges a recognition that this type of research must be expanded to crops and zones where fertilizer adoption and profitability have not been considered major problems in the past. Many soil scientists have been focusing in recent years on the need to return organic matter to the soil throughout SSA. Consensus is growing that once soil organic matter falls below a critical level, soil productivity will drop to zero and the costs of bring these soils back into production are likely to be prohibitive (Pieri 1989). Addressing this issue will require more research on the interactions between organic and inorganic fertilizers and how they affect both soil quality and yields, as well as research on how to increase the amount of organic matter available for soil enhancement. At present, most crop residues are used for animal feed or construction, and quantities of manure produced by livestock fall far below levels required to adequately treat the entire area currently under cultivation. Inorganic fertilizers could play a major role in addressing these problems as they can play a major role in increasing both the quantity and the quality of crop residues. Particularly encouraging is evidence concerning crop residue production of inorganically fertilized maize; not only does fertilizer increase the production of crop residues but the residues are high in organic matter, organic calcium, and nitrogen.

2.10. Overview of Findings on Fertilizer Yield Response

Our overall conclusion from the discussion in Sections 2.2-2.9 is that there are many instances of good fertilizer response in SSA. Tea appears to be most responsive, while cereals and cotton respond better than pulses. Among the grain crops, the greatest fertilizer response appears to be that of maize produced in Eastern and Southern Africa and rice farmers producing under irrigated conditions. The least favorable response is for millet produced in West Africa. The physical response for sorghum is highly variable across the continent, within agroclimatic regions, and within individual countries, but our review has identified a number of fertilizer packages that can significantly increase yields for this crop as well.

Recent efforts to improve fertilizer response on degraded soils by combining it with a variety of improved management practices have illustrated that large percentage increases in yield are possible, but total yield per hectare rarely exceeded one ton. In general, SSA farmers need higher yields than this if they are to earn adequate incomes and contribute substantially to their own and national food security goals. While such performance may be acceptable in the short-run for farmers in marginal areas, long-term yield objectives for the vast majority of farmers in SSA must be set higher than one ton per hectare.

Many of the management practices that have been evaluated as means of increasing fertilizer productivity in agroecologically disadvantaged areas will become increasingly relevant for areas that have been using fertilizer for extended periods of time. This is particularly true for areas with soils that are losing their organic matter content and areas where fertilizer was adopted in conjunction with extensive farming techniques that have led to erosion problems.

These conclusions about fertilizer response are admittedly based on fertilizer response data reported by agronomists and interpreted by agricultural economists. We are well aware of the dangers in such cross-discipline endeavors and encourage agronomists to increase the attention they give to synthesizing knowledge about fertilizer response in SSA and presenting it in "user-friendly" terms that can be understood and used by policy analysts and researchers in other disciplines. We need to examine more closely than we have the diverse sources of information on the conditions under which fertilizer gives a good response (which rainfall zones, which soil types, which varieties, and which types of complementary practices). We conclude, for example, that maize has the best overall yield response of the cereal crops examined. This is not very useful information for farmers in areas where maize cannot be grown. Hence, the myriad of fertilizer trial reports that are available in research centers throughout SSA need to be reviewed, the poor quality ones weeded out, and the good quality work synthesized and translated into meaningful insights that can be used to shape agricultural development strategies throughout the continent for both high and low potential areas and crops.

Caveats concerning the ability of economists to interpret agronomic documents aside, we do feel strongly that we have identified numerous cases of good fertilizer response in SSA and complementary technologies capable of significantly improving fertilizer response. Nevertheless, farmers are not likely to increase their use of chemical fertilizers if they do not find it profitable to do so. Hence, Section 3 reviews the literature on the profitability of chemical fertilizer in SSA.

3. EMPIRICAL EVIDENCE ON PRICES AND FERTILIZER PROFITABILITY

3.1. Methods of Evaluating Fertilizer Profitability

One can look at fertilizer profitability from two perspectives: private and social.[13] In examining the private profitability of fertilizer one uses the farmers' perspective asking questions such as:

> Is fertilizer absolutely profitable (i.e., does net income exceed costs)?
>
> Is fertilizer more profitable than alternative investments (i.e., is it profitable compared with other on-farm or off-farm opportunities for investing the same resources)?

If fertilizer is not privately profitable in both an absolute and a relative sense, farmers will invest their limited resources elsewhere.

In examining the social profitability of fertilizer one uses a community perspective asking questions such as:

> Do the benefits to society of farmers using more fertilizer exceed the costs?

Social analysis requires first that the community concerned be identified, and second that the full range of costs and benefits associated with fertilizer use be taken into account. The community of interest could be defined as a village or local administrative unit, a nation, or even the international community. Examples of costs that should be taken into account are the costs of government programs to encourage fertilizer use (subsidies or extension services, for example) and the costs of environmental damage from excessive use (water pollution from fertilizer runoff or soil acidification, for example). Benefits to consider might include improvements in national food security and balance of payments through increased agricultural productivity; preservation of soil quality for future generations through nutrient replacement; meeting national equity objectives by improving incomes of small farmers; and reduction of environmental degradation associated with expansion of cultivation to marginal lands or destruction of woodlands and forests.

Social analysis becomes important when individuals responding to the incentives of private profitability are making decisions that may have negative impacts on society in general. The growing concern about the links between current agricultural production patterns in SSA and environmental degradation suggests that questions of the social profitability of fertilizer will become more important in the future.

We begin this section with a review of the evidence on the private profitability of fertilizer, viewed in both absolute and relative terms, followed by a review of what is known about its

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[13] Analysis of private profitability is also referred to as "financial" analysis while analysis of social profitability is also referred to as "economic" analysis.

social profitability. The discussion then focuses on two of the most important determinants of fertilizer profitability: input and output (i/o) prices. We compare trends in i/o price ratios for different crops and countries, drawing conclusions about the extent to which i/o ratios are more (or less) favorable in SSA than in other developing agricultural systems. Finally we look at ways of improving i/o ratios for fertilizer in SSA.

3.2. Evidence on Financial (Private) Profitability

3.2.1. Analysis of Absolute Profitability

Reviewing the evidence on the absolute profitability of fertilizer in SSA was extremely difficult.[14] Many studies include profitability analysis of an entire package of inputs─fertilizer, seed, and pesticides, for example─rather than fertilizer only. While this information is useful, it does not help us to understand the role of fertilizer in generating the net income derived from the entire package. Most of the agronomic documents we consulted focused on measuring yield response or estimating physical production functions that could be used to identify yield maximizing fertilizer doses. Few studies included information on both physical response and prices, both of which are required for profitability analysis. When profitability analysis was included in the agronomic studies, it was usually as a value/cost (v/c) ratio or marginal rate of return (MRR) showing whether the financial return for the yield maximizing dose of fertilizer exceeded the cost of the fertilizer treatment. Very often these v/c ratios did not take into account indirect cost increases due to fertilizer use (increased weeding or harvesting costs, for example). We found very little sensitivity analysis on the v/c ratios to illustrate how profitability would change if yield or prices changed.

Another dimension of measuring fertilizer profitability is determining at what point the profitability incentive will be viewed as "adequate" by farmers. The cutoff points most commonly used in the literature were v/c ratios equal to or greater than 2 and MRR of 100%. Both indicators measure approximately the same concept: the increase in yield attributable to fertilizer must have a value at least double the cost of using the fertilizer for farmers to consider it a "profitable" input. Strictly speaking, fertilizer is profitable if the value of the yield increase exceeds the fertilizer cost. The rule-of-thumb requiring that the value of the yield increase be at least twice the fertilizer cost is a convention used in the fertilizer literature to allow for factors that affect farmers' input decisions but are not easily quantified─farmers' risk attitudes, on-farm yields that are lower than agronomic trial yields, or high yield variability due to climate, for example. A v/c of at least 2 reflects the need for some type of "insurance premium" to be built into fertilizer recommendations so that returns are high enough to cover undesirable eventualities. In some situations, analysts have suggested that a potential return of even three or

[14] Note that the 1989 World Bank MADIA fertilizer study covering six SSA countries (Lele, Christiansen, and Kadiresan) found many of the same obstacles to evaluating fertilizer profitability that we have encountered 10 years later.

four times the fertilizer cost is necessary to stimulate fertilizer adoption in SSA (Ruthenberg 1968 and 1980).

An alternative to developing rules-of-thumb about the adequacy of v/c ratios would be to use price and yield response data simultaneously to identify profit-maximizing doses of fertilizer; there were very few cases of this type of analysis in the literature reviewed (Mulat et al. 1997; Ho 1992). One problem with profit maximizing analyses, however, is that every farmer is really operating on a different production function due to differences in labor availability, soil quality, fixed assets, and access to financing. Consequently, the profit-maximizing dose may well differ across farms with different resources.

The substantial impact that differences in farmers' skills and/or resource base can have on fertilizer yield response and profitability was illustrated by a recent study of 231 farmers participating in the SG 2000 program in Mozambique (Howard, Jeje, Strasberg, and Tschirley, forthcoming). Farmers used improved maize seed and fertilizer on half-hectare demonstration plots. In two of four zones covered, only one-third of the farmers realized positive net profits when output was valued at harvest prices; in the third zone none of the farmers realized profits; and in the fourth zone two-thirds of the farmers were in the black.

Using supplementary survey information, the study found that yields of farmers with losses could be substantially improved if they increased plant density, planted earlier, or stored production several months in order to get better prices. This type of analysis provides guidance on how to increase profitability. It also suggests that for farmers with constraints that prevent earlier and/or more dense planting, fertilizer may not be the best technology for increasing yields.

Malawi provides another example of how attention to inter-farm differences can improve recommendations and profitability. During the development of a national Soil Management Action Plan, it was found that the v/c ratio was below 2 for all fertilizer recommendations being made throughout the country. The response was a concerted effort to update fertilizer trial data while taking into account the differences among seven agroecological zones, two types of soil texture, and whether farmers were producing primarily for household consumption or for the market (this latter point determined whether output was valued at the producer or the consumer price). Instead of one national recommendation for most production situations, there are now 28 different recommendations more finely-tuned to the particular circumstances of different farmers (Benson 1997a and 1997b). As a result of this work, there are many zones and soil types for which no profitable fertilizer recommendation was identified, leaving researchers (physical scientists, social scientists, and policy analysts) with a serious challenge: finding an alternative to chemical fertilizers that will maintain soil fertility in these zones or finding ways to improve fertilizer profitability (i.e., lowering cost, increasing yield response, or increasing output prices).

Despite the weakness in the profitability analyses reviewed and the spotty geographic coverage of the available data, we have attempted to summarize the key conclusions reported in the documents consulted.

The information found on v/c ratios or MRR is summarized in the tables of Appendix 1 (more precisely, in the sub-column labeled "v/c" under the broader column labeled "Financial Ratios"). In each case we indicated the year(s) for which the ratios were calculated. Ratios were based on prices faced by farmers (i.e., they reflect any subsidies or taxes in effect at the time).

One point amply illustrated by the documents reviewed was that v/c ratios in Nigeria during the 1980s (which went as high as 36) far exceeded those of other countries in SSA and elsewhere, regardless of the crop. High fertilizer consumption was encouraged by high fertilizer subsidies, made possible by government revenues from oil. The subsidy policy clearly had the desired impact on fertilizer consumption as Nigeria is one of the largest fertilizer consumers in SSA. Nevertheless, one wonders whether the same result might not have been achieved with more modest subsidies and lower v/c ratios.

It appears that v/c ratios for both millet and sorghum are frequently less than 2 in SSA and elsewhere. However, in some SSA cases (sorghum in Senegal and Nigeria during the late 1980s) ratios exceeded 3.

The v/c ratios for rice in SSA were nearly all in the 1.5 - 4.0 range which is comparable to the Asian examples. This range also means that most v/c ratios for SSA were over the rule-of-thumb threshold of 2. While these v/c ratios are promising, they are partial measures of profitability that do not account for the substantial private and public costs of irrigation infrastructure. (Pearson, Stryker, and Humphreys 1981; Baris et al. 1996).[15]

Maize, the product for which the yield potential is greatest, does not strongly outperform the other crops when it comes to profit. Frequently the v/c is less than 2 (Malawi in mid-90s, Zambia in mid-80s, and Senegal in the 1990s). V/c ratios for Latin America in the 1960s ranged from 1.2 to 5.3, but were generally greater than 2. The only maize v/c we found for India was 1.64 in the late 1970s, but comparing SSA maize profitability with Indian profitability may be of limited value as Indian fertilizer demand was launched by crops other than maize.

Because wheat is not a major crop in SSA, we have not systematically reported wheat response and profitability data. Nevertheless, it is interesting to look at Asian response and profitability for wheat as it was one of the major cereal crops on which Asian farmers began using fertilizer. Most output/nutrient ratios for wheat (both irrigated and non-irrigated) fell into a range from 6 to 18, with an occasional case of a ratio <2. The v/c information found for wheat comes from Pakistan; the ratio ranged from 2.9 for local varieties to 5.8 for improved varieties in the 1960s.

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[15] V/C ratios are a partial budgeting technique where only the difference between the with- and with-out fertilizer situation are taken into account. While a high v/c ratio suggests that farmers will be better off using fertilizer than not using it, the ratio does not address the issue of overall profitability of the irrigated rice enterprise. In some cases, the financial cost to farmers for access to water is considerable and overall profitability is poor. A more common case, however, is that the irrigation costs are subsidized. This frequently makes rice production (and fertilizer use) financially profitable for farmers but not economically profitable from a national accounting perspective (see Dimithe 1997, for example).

These numbers suggest that wheat farmers who participated in the Asian Green Revolution did enjoy better output/nutrient and v/c ratios than cereal producers in SSA now face.

Estimates of v/c ratios for export crops such as cotton and groundnuts are not numerous. Financial returns to fertilizer on SSA groundnuts were highly variable across countries and time periods, even under subsidized conditions. The range of v/c ratios was from 1.5 in Senegal to 15 in the highly subsidized Nigerian case. If we exclude the unusual Nigerian case, most SSA ratios are comparable to the Indian v/c of 2.4 during the late 1970s.

Very few of the studies reviewed reported v/c ratios for cotton. Given the importance of fertilizer use on cotton, we combined secondary data on prices with yield response information reported in Appendix I to estimate most of the v/c ratios reported in the "Financial Ratios" columns of the appendix tables. In comparing the o/n ratios with the v/c ratios for cotton one notices that v/c ratios generally do not exceed 2 unless the o/n ratio is at least 7. This suggests that for evaluating cotton response to fertilizer, an o/n ratio of 7 is probably more appropriate than the o/n ratio of 10 used for cereals. Almost 50% of the cotton examples in Appendix 1 have v/c ratios greater than 2; at least one case with good profit potential was found in each of the SSA regions examined. What is surprising is the number of cases where the v/c ratio is less than 2 in countries and zones where cotton is a major crop. Ratios for Mali ranged from .5 to 1.9 during the 1980-89 period. They were <2 in Senegal using 1989-90 prices and 1967-75 response rates; and <2 in four of the Mozambique examples. Despite these relatively low v/c ratios, cotton farmers are among the most important fertilizer consumers in West Africa. The following paragraphs provide some insights into why this is true.

Cotton in West Africa is frequently produced by farmers who sign production contracts with government parastatals or joint-venture companies formed by African governments and private European cotton companies having gained African experience during the colonial period. These cotton companies tend to be vertically coordinated enterprises that not only provide farmers with credit, inputs, and a guaranteed output market, but also perform numerous processing functions (ginning, in particular). In theory, the vertical coordination can substantially reduce farm-level costs and increase profits by reducing the transactions costs associated with input and output marketing activities. In several situations this model of vertical coordination throughout the subsector has contributed not only to the adoption of improved techniques for cotton production, but also to better food crop production through spillover effects (Dioné 1989, for example). However, in other situations there is evidence of inadequate "pass-through" of benefits from the cotton companies to the producers (Tefft and LeVallée 1996). In these latter cases farm-level profitability is poor after the cotton companies recuperate the credit advanced for fertilizer, pesticides, and herbicides, which are used in large quantities by most cotton producers. Despite low cotton incomes in particular countries, many farmers continue to produce at least one field of cotton in order to have access to modern inputs and credit for animal traction equipment both of which contribute to the overall productivity of farm and nonfarm activities.

Price relationships in the West African cotton producing countries that are members of the franc zone have been in flux since the January 1994 devaluation of the CFA franc. Evidence from a multi-country study on the impact of the devaluation (Tefft and LeVallée 1996) suggests that profitability of the standard package of cotton inputs (fertilizer, herbicides, and pesticides) increased in real terms by 12% in Mali, remained stagnant in Senegal, and decreased by 17% in Chad – this does not tell us anything about the absolute profitability of cotton fertilization. However, it does illustrate that a devaluation can have a net positive impact on the income of farmers producing input intensive export crops (i.e., the case of Mali). The range of outcomes across the region is a function of different rates of inflation after the devaluation and decisions taken by the cotton companies. In Mali, the cotton company managed to control rising input costs and to pass a larger share of the export price increase to farmers.

3.2.2. *Evidence on Relative Profitability*

Farmers often do not use fertilizer even in cases where strong evidence shows that fertilizer use is profitable in the absolute sense. We believe the explanation for this behavior lies in the fact that absolute profitability is a necessary but not a sufficient condition for fertilizer adoption. An investment in fertilizer needs not only to be absolutely profitable, but also more profitable than available alternative investments, including extensive production practices and nonfarm activities.

Research shows, for example, that Senegalese farmers used little fertilizer on peanuts during the 1980s because they could earn as much income by purchasing more seed with the "fertilizer money" and expanding cultivated area (Kelly 1988). More recent evidence for the same region of Senegal shows that farmers continue to cultivate without peanut fertilizer because they have found that increasing seeding densities permits them to generate higher yields and incomes than they would obtain with an equivalent expenditure on fertilizer (Diagana 1995; Diagana and Kelly 1996; Kelly et al. 1997). Many farmers in areas where interannual variation in fertilizer response is high also shy away from fertilizer use – despite strong evidence that it is profitable on average – because they perceive other less risky investments (e.g., raising small ruminants) as more profitable (Kelly 1988).

Another aspect of relative profitability relates to farmers' decisions about which crops to fertilize. Because most SSA farmers do not have the capacity to fertilizer all of their crops, the decision concerning which crop to fertilizer involves an analysis of the relative profitability across crops. Farmers' perceptions of which crops are most profitable to fertilize are often conditioned by their views about which crops have better marketing prospects and, therefore, better probability for generating adequate cash to reimburse fertilizer loans. As a result, farmers tend to use fertilizer on crops that have fixed prices known in advance, guaranteed purchases of unlimited quantities, and well-developed markets (numerous collection points, rapid payment procedures). Consequently, fertilizer may not always be used on the crop that exhibits the best v/c ratio. Reardon (1998) has compiled a number of illustrations showing that fertilizer tends to be used more frequently on cash or export crops than on food crops.

In Burkina Faso the payoff (in terms of marginal value product) to fertilizer and other capital inputs was much higher on cash crops (cotton and maize) than on semi-subsistence food crops such as millet and sorghum; hence, farmers were more likely to use purchased inputs on the cash crops (Savadogo 1995).

In Rwanda fertilizer use is strongly correlated with a crop's profitability; hence, more fertilizer is used on cash crops (white potatoes and coffee) as the payoff is much higher than on subsistence food crops (Clay et al.1995).

In Ethiopia a disproportionately large amount of fertilizer is applied on teff (a cereal crop with strong commercial demand) although fertilizer yield response is better on maize (which has weak commercial demand and therefor, lower profitability). The relatively high and stable output price for teff is the key incentive driving fertilizer use for many Ethiopian farmers (Mulat et al. 1997).

In Zimbabwe, farmers mainly use improved tillage practices and fertilizers if they produce at least one profitable cash crops (Mudimu 1996).

In northern Ghana, fertilizer use is low on average and very variable over farms, but tends to be applied only to marketed crops (hybrid maize, cotton, rice) and not on the subsistence food crops (millet, sorghum, and cowpeas) (al Hassan, Kyyd and Warner 1996).

In the highland tropics of Tanzania, farmers confine fertilizer and soil conservation practices to cash crops (Semgalawe 1997). The same pattern has been observed in Kenya (Tiffen, Mortimore and Gichuki 1994).

This summary helps us understand why fertilizer is not being used on cereal crops that exhibit v/c ratios above 2—farmers often perceive some other fertilizer investment as more profitable. The decision to invest in fertilizer must be understood in the multisectoral context in which it is made. Farmers have a wide range of income generating activities both on and off the farm in which they can engage. This may include petty commerce, animal husbandry, market gardening, and cottage industries. These activities may entail investments that compete for scarce resources.

Fertilizer investments are on-farm investments. Off-farm investments may have an added attractiveness to small farmers in that they may help mitigate food security risks. Income earned off the farm can be used to purchase food and is often not susceptible to drought, disease, and pests that compromise agricultural incomes. Investing in fertilizer may to some degree imply concentrating the "eggs in one basket" and run contrary to farmer strategies of risk mitigation through diversification. On average (27 case studies) 45% of farm household income comes from nonfarm sources (Reardon 1997). This represents a powerful "alternative investment" against which fertilizer investments must compete. The fact that farm wages in Rwanda are half of those of off-farm activities illustrates the potential differences in the relative payoffs (Clay et al. 1995).

In sum, measures of *absolute* profitability such as v/c ratios and MRRs need to be viewed with some caution if the objective is to understand adoption behavior and effective demand. The literature on fertilizer rarely raises the issue of relative profitability. Partially this is due to the inherent difficulty of doing a profitability study of investment alternatives. A positive rate of profitability for fertilizer investment is not an *a priori* indication it will be adopted by farmers if other investments are perceived by farmers as more profitable or less risky than fertilizer.
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3.3. Economic (Social) Profitability

Our review of the financial profitability of fertilizer has identified many situations in SSA where the private profitability at the farm level is low or negative. In such situations it is useful to look at the economic (i.e., social) profitability of fertilizer to evaluate the extent to which increases in fertilizer use may be socially profitable even though not privately profitable. Conventional economic theory suggests that where there is a divergence between private and public interests, government funding of subsidies or other types of incentives may be warranted. The literature reviewed mentions three types of social benefits of relevance to the fertilizer situation: environmental benefits, indirect macroeconomic benefits, and benefits that contribute to general social goals such as equity.

3.3.1. Environmental Benefits

Perhaps the most fundamental environmental benefit of fertilizer derives from its ability to increase land productivity. In the long run, increasing land productivity in the better agricultural regions through fertilizer use can enable a withdrawal of production from the more marginal agricultural regions (Sanders, Shapiro and Ramaswamy 1996; Reardon 1995). This can help alleviate various forms of land degradation including erosion, deforestation and desertification.

Preserving the fertility of the land base can also increase the amount of vegetative biomass. This helps preserve the quantity of biodiversity that, apart from an inherent existence value, may also have many current and future commercial uses (e.g., pharmaceutics). Furthermore, increased biomass translates into increased carbon sequestration, which can counteract the forces contributing to global warming.

3.3.2. Indirect Macroeconomic Benefits

Additional agricultural production resulting from increased fertilizer use can provide indirect stimuli for other sectors of the economy. Lower food prices associated with greater supply leads to a welfare gain in the form of increased consumer surplus. Lower food prices also increase real incomes which can be spent on industrial goods, thus generating economic growth (Mellor 1976). Employment generation and increased savings and investment due to agricultural development can likewise spur economic growth. A final indirect benefit may come as savings on foreign exchange resulting from greater domestic production and hence less import dependency.

3.3.3. Social Objectives

Fertilizer can promote poverty alleviation. Poor households spend a higher proportion of their incomes on food than richer households. Lower food prices from increased agricultural productivity should benefit the poor more than others. In general, if soil fertility is not restored, Africa faces the prospects of serious food imbalances and widespread malnutrition and the likelihood of eventual famine (World Bank 1995) The phenomenon of extremely rapid urbanization in Africa has, at least in part, been due to rural poverty resulting from stagnating agricultural productivity. Slowing urbanization via agricultural development may diminish some negative aspects of prevailing urbanization patterns such as inadequate urban sanitation infrastructures, urban unemployment, and high crime rates. Last is the issue of intergenerational equity. Actions by the current generation that degrade the natural capital of land will have a negative effect on future generations by undermining their agricultural production capacity. If the farmers discount rates are high, as is generally assumed in SSA, then the value of current production based on soil mining may be greater than the sacrificed (discounted) future flow of benefits. If private discount rates exceed social discount rates by a significant amount, a case for public intervention to secure continued production capacity in future periods may be made (Hanley and Spash 1993).

3.3.4. Empirical Examples of Economic/Social Analysis

Very few examples of cost/benefit analyses take into account the social dimensions of fertilizer use in SSA, although some cases exist where proponents of fertilizer subsidies justified their continued use on social grounds.

An early example of this type of analysis comes from Senegal and concerns the use of fertilizer subsidies on peanuts. Fertilizer subsidies began in 1951 after a 1950 attempt to sell fertilizer on credit at real prices was labeled a failure because farmers did not reimburse their debts. The subsidy was intended as a temporary measure to insure that farmers just learning fertilizer technology would realize a profit. In the late 1960s, the government began reducing subsidies. Bray, then Director of Agriculture, opposed these price changes, believing that they discouraged agricultural investments that brought the government more in tax revenues than the cost of the subsidy. Using then current prices, subsidy policies, and estimates of how increases in peanut production influenced gross domestic product and subsequently tax revenues, Bray (1969) shows that the government realizes a net profit on the fertilizer subsidy of 692 FCFA per hectare. Bray argued that although the farmer realized a profit on average with the 16 FCFA/kilogram fertilizer price, reducing the farm-gate price to 11 FCFA was necessary so that even in bad years a farmer would be ensured of a v/c ratio no lower than 1.5. Although the economic analysis is not sophisticated and the data (by the author’s admission) are "fragile", the argument presented here appears to have convinced policy makers that fertilizer subsidies were in the economic interests of the government. Prices were reduced and remained highly subsidized until the 1980s.

A similar attempt to justify fertilizer subsidies concerns Burkina Faso in the 1980s. Here, however, the argument is made because paying for a fertilizer subsidy is a better way of ensuring national food security than importing cereals. The author (Bikienga 1984) uses data for the early 1980s to show that farmers could significantly increase cereal yields by using fertilizer and the government would realize important budgetary and foreign exchange savings if they financed fertilizer rather than food imports.

More recently, the World Bank undertook three country studies (Zimbabwe, Burkina Faso, and Madagascar) to evaluate both financial and economic costs and benefits of programs to "recapitalize" national soil resources using locally available rock phosphates. The study consisted of (1) a background paper (World Bank 1994) that explained the objectives and identified an extensive list of costs and benefits to be considered by analysts, and (2) three country summaries reporting on the results of the analyses.

The conceptualization of fertilizers—particularly phosphates—as capital investments whose costs and benefits should be evaluated from a social rather than a private perspective was a major contribution of this work as it brought the attention of donors and SSA governments back to the important question of what role, if any, public institutions should play in maintaining and improving soil fertility on both public and private land. This was an important turnaround from the prevailing attitudes during the 1980s and most of the 1990s when developing farm-level fertilizer demand was treated as a strictly private sector affair from which government needed to distance itself.

Unfortunately, the empirical country studies ran into numerous difficulties because the necessary data to follow through on the suggestions in the background paper were frequently not available. For example, the weakest link in the Zimbabwe study was the quality of the agronomic response data for the different types of phosphates being evaluated. Another problem was how to measure future social benefits such as carbon sequestration due to farmers intensifying production enough to allow them to stop cutting down forests and woodlands. Because this is a relatively new topic in environmental studies, general agreement on methods used to estimate these parameters is lacking. Nevertheless, the fact that almost 50% of the benefits in the Zimbabwe study came from carbon sequestration diminishes confidence in the overall results.

Despite their shortcomings, the country studies have brought attention to a topic largely ignored by analysts looking at fertilizer profitability and government policies that affect it—the social costs and benefits of increasing (or not increasing) fertilizer use by farmers in SSA. The relative success with which these costs and benefits can be estimated depends to a large extent on the ability of physical scientists to quantify what happens to the environment when farmers do or do not use fertilizer. Given increasing evidence concerning the global dimensions of environmental problems, there is also a need to improve data and analytical techniques for taking into account national and international costs and benefits.

3.4. Input/Output Prices and Factors Affecting Them

If farmers are to use fertilizer, markets must function well, offering producers prices that cover their cost of production and provide adequate net income. The more efficiently the fertilizer import, production, and distribution functions are carried out, the easier it is to keep the fertilizer/output price ratios low.[16] Similarly, the more efficiently output is moved from one market to another and prices are communicated to market participants, the lower the marketing costs and the larger the share of the consumer price available to farmers. Many reviews of constraints to fertilizer adoption in SSA have noted that fertilizer prices in the region are frequently greater than those in other regions of the world. Table 2 provides a few examples of how urea, DAP, and MOP prices in 1991/92 compare for SSA and Asia.

Price data presented in Table 2 illustrate that, at least for the countries selected, fertilizer prices in SSA were substantially higher. For example, urea in SSA ranged from US$256 to US$359 per metric ton while the highest price among the five Asian nations shown was only US$162. Fertilizer prices are only half the picture, however, because high fertilizer prices may not be a constraint if output prices are also high. Consequently, the ratio of the fertilizer price to the output price of the crop on which the fertilizer is used is frequently employed as a rough indicator of fertilizer profitability. The lower the ratio – all else equal – the more profitable fertilizer is likely to be.[17]

[16] The fertilizer/output price ratio shows how many kilograms of output are needed to purchase one kilogram of fertilizer (or one kilogram of fertilizing nutrient). The higher the ratio – all else equal – the less profitable fertilizer is likely to be.

[17] The major weakness of the i/o price ratio is that "all else" is not equal. Because the ratio fails to take into account the yield response, it is a very crude indicator of potential profitability.

Table 2. Fertilizer Prices Paid by Farmers, 1991/92

Country	Prices		
	Urea	DAP	MOP
	----------(US $ per metric ton of product)----------		
SSA			
Senegal	na	365	na
Zambia	256	na	487
Zimbabwe	359	na	232
Asia			
Bangladesh	126	140	136
India	118	181	66
Indonesia	110	na	141
Nepal	120	176	68
Pakistan	162	201	na

Source: Adapted from Table 21 in Bumb and Baanante (1996) which used FAO and FADINAP as sources.

Using price information available in the FAO online data base from 1970 through the present, we made an exhaustive search for SSA farm-level prices of (1) urea and principal nitrogen-using crops (maize, sorghum, millet, rice, cotton, coffee, and tea), and (2) phosphate fertilizers and principal phosphate-using crops (peanuts). We also looked for comparable price information for Asian and Latin American countries producing these crops.[18] A thorough comparison of i/o price ratios across regions was hampered by an extremely large number of missing data points, for the SSA countries as well as those in other regions. Tables 3 through 5 summarize the results of our efforts for those countries exhibiting the most complete series on the price variables of interest.

Table 3 shows that urea/maize price ratios (ranging from a 1970-94 average of 1.7 for Togo to 7.4 for Malawi) are generally higher in SSA than in the other maize producing countries for which data were found (range of 1.5 to 3.2 for Philippines, Peru, and Mexico). The average across countries and years was 5 for SSA and only 2.4 for other countries, i.e., fertilizer was relatively more expensive for SSA maize producers during the period covered.
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The same pattern was observed for sorghum where the SSA range extended from 1.4 for Togo to 7.6 for Malawi versus ratios of 3 and 3.7 for Pakistan and India, respectively. The SSA average across years and countries was 5 vs. 3.4 for the Asia examples.

[18] FAO fertilizer price data is reported as price per kilogram of fertilizing nutrient rather than per kilogram of fertilizer. Although we believe SSA farmers make their fertilizer decisions based on the price of fertilizer (rather than nutrient prices), using the nutrient prices provides consistent cross-country and cross-crop comparisons.

Table 3. Examples of Nitrogen/Cereal Price Ratios for SSA, Asia, and Latin America

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Avg
Urea/Maize																											
SSA																											
Kenya	5.7	4.1	4.7	6.0	5.1	6.8	6.2	5.5	6.7	5.5	6.6	9.7	9.4	5.2	6.0	5.6	4.4	4.3	4.9	3.9		5.6	5.3	4.8			5.7
Malawi	5.4	6.4	6.4	6.4	17.4	11.4	9.1	9.1	9.1	9.1	6.9	6.9	4.1	4.1	3.7	3.6	9.3	9.6	7.5	5.4	5.9	7.2	7.0	7.0	5.9		7.4
Zambia	4.3	2.6	3.3	3.7	3.7	5.2	4.2	4.2	5.0	5.1	3.2	3.2	3.7	5.2	4.3	3.7	4.6	3.3	3.6	13.9	6.2	6.3					4.6
Zimbabwe											5.5	4.5	5.0	7.4	8.4	6.5	6.5	6.5	6.2	5.6	5.5	6.6	5.2	4.8			6.0
Togo		4.0		1.1	1.2	0.9	0.7	0.4	0.9	0.9	0.5	0.8	0.8	0.8	1.4	2.3	1.9	2.0	1.8	2.4	2.3	2.4	1.9	3.3	3.5		1.7
Ivory Coast	4.2	5.1	5.5	9.9	11.1	5.9	3.8	3.2		2.9	2.4	3.0	4.4		3.6	3.0	1.9	4.1	5.1	5.1	4.4	4.6					4.7
Other countries																											
Philippines		3.1	1.2	1.8	1.9	1.6	3.4	3.2	4.0	4.5	4.6	4.8	4.5	4.3	5.1	4.1	2.7	2.1	3.0	2.2	2.7	4.0	2.7	2.4	2.2		3.2
Peru		2.4	2.4	2.1	4.2	4.1	2.7	2.1	1.9	0.0	0.0	0.0	0.0	0.0	3.0	3.8	1.6	1.3	1.4	6.0	7.1	3.1	2.4	2.9	3.8	3.9	2.5
Mexico		2.9	2.5	2.6	2.5	2.2	1.7	1.9	1.9	2.1	2.2	1.5	1.5	1.6	1.3	0.0	0.0	0.0	0.0	1.1	1.1	1.1	1.7	1.3	1.3		1.5
Urea/sorghum																											
SSA																											
Burkina	4.9		4.9		15.7			4.1	3.3	3.3	2.4	2.0	2.2	2.1	1.8	2.5	4.9	3.6	4.5	4.9	3.7						4.1
South Africa					3.4	5.0	4.6	4.8	5.8	6.0	6.5				4.1	5.9	6.1	5.7		7.6	6.7	5.9	3.8	4.6	5.4	7.1	5.5
Malawi	5.5	6.6	3.7	6.4	17.4	13.8	10.4	10.4	9.1	9.1	9.1	9.1	9.1	4.6	4.7	3.2	5.3	8.0	9.3	7.2	8.5			4.2	3.5	3.4	7.6
Togo							0.7	0.4	0.7	0.7	0.5	0.9	0.8	0.8	1.2	1.9	1.9	2.1	1.4	2.0	2.1	2.1	1.5	2.2	3.2		1.4
Zimbabwe											5.0	4.7	5.2	7.4	8.4	6.5	6.5	6.5	6.2	5.6	5.5	7.1	8.1	8.4			6.5
Other countries																											
India			2.3	2.1	5.7	5.7	6.3	6.0	5.8	5.3	6.1	5.6		3.3	3.0	2.6	2.8	2.5	2.3	2.3	1.7	2.0	1.9	1.6			3.7
Pakistan	3.3		2.6	2.7	3.1	2.9	3.9	3.3	2.8																		3.0
Urea/wheat																											
India			2.6	2.5	3.1	3.1	3.2	2.8	2.7	2.5	3.1	3.3		2.4	2.5	2.5	2.6	2.4	2.2	2.0	2.0	2.2	1.6	1.5	1.4		2.5
Pakistan	2.6	2.5	3.0	4.1	4.8	3.2	2.8	2.7	2.2	2.6	3.2	2.9	3.4	3.5	3.5	3.2	2.8	2.8	2.7	3.0	2.9	2.8	2.9	3.0	2.5	3.1	3.0
Urea/paddy																											
SSA																											
Malawi	2.7	2.7	2.7	2.7	7.5	5.1	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.0	3.1	2.6	6.0	5.3	4.5	3.9	4.1	5.0	4.4	3.4	1.9		4.1
Mali							5.0	5.3	5.2	4.5	5.9	4.5	4.1	3.7	3.4	3.3	4.2	4.5									4.5
Niger	2.5	2.9	3.1	2.2	1.9	1.9	1.7	2.0	1.7	1.7	1.4	1.6	1.3	1.3	1.2	1.9	2.0	2.0	2.0	2.0	1.2	1.2					1.8
Urea/paddy cont'd.																											

Table 3. Examples of Nitrogen/Cereal Price Ratios for SSA, Asia, and Latin America

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Avg
Sierra Leone						1.5	1.7	1.6	1.0	1.5	1.2	1.0	0.8	0.7	0.6	0.8	2.2	0.8	0.3	0.2	0.2						1.0
Togo		5.4	4.7	1.3	1.3	0.8	0.7	0.5	0.6	0.6	0.5	0.9	0.8	0.8	1.1	1.1	1.6	1.9	1.4	1.8	2.1		1.5	2.1	2.2		1.6
Other countries																											
India			2.4	2.1		2.7	3.0	2.7	2.6	2.2	2.6	2.8		2.5	2.2	2.7	2.6	2.5	2.3	2.2	2.4	1.7	1.6	1.5			2.4
Indonesia	3.2	3.3	2.7	2.6	3.8	3.0	2.3	2.1	2.0	1.4	1.3	1.2	1.4	1.3	1.3	1.6	1.6	1.6	1.4	1.6	1.6	1.5	1.4	1.8	1.4	1.2	1.9
Philippines		2.9	1.0	1.4	1.9	1.5	3.3	3.3	3.9	4.0	4.2	4.4	4.1	3.8	4.9	3.5	2.4	2.2	2.7	2.3	2.4	3.0	2.7	2.1	1.9		2.9
Thailand	10.8	8.4	6.4	6.7	7.5	8.0	4.7	3.2	3.6		4.1	5.3	5.5	5.0	4.5	5.0	4.1	3.1	2.5	2.7	2.9	2.9	3.1	3.4		3.8	4.9
Peru		1.7	1.7	1.9	4.0	3.6	2.4	1.8	1.8	0.0	0.0	0.0	0.0	0.0	2.5	3.1	1.7	1.0	1.3	5.5	13.1	3.3	2.7	1.9	4.3	3.6	2.5

Source: Calculated from price data in the FAO online data base (FAOSTAT).
Notes: Fertilizer prices are per kg of nutrient. Fertilizer prices for Mexico from 1982 to present appeared to be in old pesos so we converted them to new pesos, the currency used for the producer prices.

Although wheat is not commonly grown in SSA, it was one of the principal Green Revolution cereal crops in Asia and therefore it is informative to compare representative Asian urea/wheat ratios with SSA ratios for other cereal crops. In India and Pakistan the urea/wheat ratios were 2.5 and 3, respectively, i.e., lower than the average SSA and Asian sorghum ratios reported in the previous paragraph. In other words, Asian farmers probably benefitted from more favorable i/o price ratios for their principal cereal crops than have farmers in SSA.

Rice was an exception to the patterns exhibited by urea/output price ratios for the other cereals. The SSA range of ratios was from 1 (for Sierra Leone) to 4.5 (for Mali) with an average of 2.6. The range for the five non-African countries selected was from 1.9 (Indonesia) to 4.9 (Thailand) with an average of 2.9—slightly higher than the SSA average.

The more favorable ratios for rice in SSA probably reflect the fact that in many countries rice is a preferred cereal for which domestic production is often inadequate. As a result, the producer price of rice is higher relative to urea than the price of more readily available coarse grains such as sorghum and maize.

Drawing firm conclusions about the representativity and magnitude of the differences in i/o price ratios for SSA versus other areas of the world is not possible because the examples shown in Table 3 were selected for the completeness of their data rather than their representativity. Nevertheless, the results do suggest that SSA price ratios for maize and sorghum were less favorable than those in other countries that produce large amounts of these cereals. The fact that ratios are more favorable for rice poses a bit of a dilemma given the continuing debate about the overall profitability of rice production under irrigated conditions and whether or not SSA countries should be investing more of their scarce resources in irrigation (see Section 2.5).

A similar comparison of fertilizer/output price ratios for peanuts and peanuts cotton is reported in Tables 4 and 5. For the peanut example Table 4 reports whatever phosphate price was available in the FAO data base, plus a price for an NPK complex (6-20-10) which is the most commonly used peanut fertilizer in Senegal. The non-African ratios seem to be lower (.8 and 1.1 for Pakistan and India, respectively) than the SSA ones (ranging from .9 in highly subsidized Nigeria to 2.2 for the NPK complex in Senegal), but the data are too spotty to draw any firm conclusions. Cotton ratios in Table 5 were calculated using the urea price and the price of cotton lint (the most commonly available prices in the FAO data base). There do not appear to be large differences in the ratio among the seven countries shown, but again the data are too spotty to draw any firm conclusions.

Although the details are not reported in Table form, i/o price ratios for individual SSA countries that had relatively complete data series for coffee (11 countries) and tea (3 countries) are generally favorable (<3 for tea producers and <1 for coffee producers). Comparing the overall average ratios for these countries with those for non-African producers, however, illustrated once again that the ratios in SSA were less favorable. For example, with coffee the SSA average ratio was .54 while that for Asia (Indonesia, Philippines, and Thailand) was .31.

Table 4. Nutrient/Groundnut Price Ratios

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Average
Senegal																										
DSP-TSP/GN	1.3	1.0	1.1	0.9			1.1													3.5	3.5	2.9				1.9
6-20-10/GN	2.1	1.4	1.4	1.5	1.1	1.3	1.7	1.7	1.7	1.7	1.4	1.2	1.0	2.0	3.6	3.6	2.0	2.4	3.2	3.5	3.5	3.5	3.5	2.5	3.0	2.2
Gambia																										
SSP/GN	0.5			2.1	1.5	1.5	1.6		1.4	1.4	1.3	1.2	1.5	2.0	2.4	2.6	2.2	3.1	4.2	3.2	2.7					2.0
Nigeria																										
SSP/GN				2.7	1.0	3.2		0.7	0.7	0.6	0.5	0.4	0.6	0.6	0.9	1.0	0.9	0.4	0.4	0.3	0.4	0.6	0.6	0.3	1.3	0.9
India																										
SSP/GN	0.0	0.0	1.7	1.4	1.5	1.9	1.6	0.9	1.1	0.9	1.0			1.3	1.2	1.2	1.1	0.9	1.0	0.8	0.7	0.8	1.1	1.4		1.1
Pakistan																										
SSP/GN	0.8	0.8	0.5	0.7	0.9	0.8																				0.8

Source: Calculated using FAO data base (FAOSTAT) except prices of 6-20-10 fertilizer based on Ministry of Agriculture data reported in Kelly et al., 1996.
Notes: Fertilizer costs are per kg of N, P_2O_5, and K_2O (i.e., not per kg of fertilizer). SSP, DSP, TSP = single/double/triple super phosphate, respectively; GN=producer price of groundnuts.

Table 5. Nutrient/Cotton Price Ratios

	1970-1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	Average
Kenya	not avail.				0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4						0.4
Zimbabwe	not avail.					0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.3	0.3	0.5	0.6		0.5
Chad	not avail.													0.7						0.7
Sudan	not avail.	0.6	0.5	0.4	0.5	0.6														0.5
Pakistan	not avail.	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
China	not avail.															0.3	0.3	0.2	0.2	0.3
Argentina	not avail.															0.0	0.5	0.4	0.4	0.4

Source: Calculated from data in FAO online data base (FAOSTAT).
Notes: Nutrient price is the price per ton of N obtained from a ton of urea. Cotton prices are per ton of cotton lint. Price data for cotton is quite spotty and difficult to compare as there are three possible categories used for reporting (lint, seed cotton, cotton seed); many SSA countries report prices for seed cotton and there are few equivalents for this in non-African countries.

Overall, the ratios for the export crops are lower (i.e., more favorable) than those for the locally consumed cereal crops. This lends support to the conventional wisdom that farmers are more likely to begin using fertilizer on export crops because the number of kilograms of export product required to purchase a kilogram of fertilizer is lower than the number of kilograms of cereal required.

Although not conclusive due to the numerous data problems encountered, the i/o price ratios presented in Tables 3-5 suggest that ratios for coffee, peanuts, sorghum, and maize are frequently less favorable to farmers in SSA than elsewhere while the ratios for rice are slightly better. As noted above, the i/o price ratio is a relatively crude indicator of the economic incentives to use fertilizer as it does not take into account yield response. Nevertheless, the general tendency of SSA price ratios to be higher and yield responses to be lower (see Section 2) than examples from other parts of the world lends credence to the argument that relatively low profitability is a major constraint to increased fertilizer use in SSA.

Unfortunately, the i/o price ratio does not tell us whether it is the producer price that is too low, the fertilizer price that is too high, or some combination of the two. Table 2 shown above, provides a number of examples where SSA fertilizer prices were substantially higher than those in Asia. Although the number of examples shown is limited, there is ample reason to believe that SSA fertilizer prices are generally higher than elsewhere. The causes of these higher prices are multiple as are the policy options for reducing them. We review the current thinking on causes and remedies for high SSA fertilizer prices in the following section (3.4.1.) and then move to a parallel discussion of the causes and potential remedies for low output prices (3.4.2.).

3.4.1. Input Prices

Input prices are shaped by government policies—taxes and subsidies, in particular, but also policies that influence the structure and performance of markets. Also very important are the costs of fertilizer importation, production or processing, storage, transport, and marketing. Fertilizer demanded and the degree of competition in the fertilizer market also influence fertilizer prices. This is perhaps more true for fertilizer than for other inputs as fertilizer exhibits important economies of size and scale, i.e., the larger the demand for a particular fertilizer product the lower the cost of producing and delivering it will be. As noted earlier, SSA fertilizer sectors face a difficult dilemma: high prices depress demand while low demand keeps prices high. Despite this dilemma, there are numerous initiatives which can incrementally lead to reduced fertilizer prices and higher demand.

During the 1980s and early 1990s many SSA countries undertook structural adjustment programs that included some combination of reduced government subsidies for fertilizer and agricultural credit programs, liberalization and privatization of fertilizer markets, and currency devaluations. The principal objective of these programs was to improve macroeconomic indicators (balance of payments, national debt, etc.) in the belief that an improved macroeconomic situation would stimulate growth in all sectors of the economy, including agriculture. Whether these adjustment measures have had a positive impact on the agricultural sector remains a topic of lively debate and what has happened to fertilizer prices and consumption is frequently at the center of the debate. We review the key arguments concerning the effect of fertilizer subsidies, input market development policies, credit policies, and the sequencing of policy initiatives on fertilizer prices and demand.

Fertilizer Subsidies: Our review of the literature reveals that there is not yet a consensus about the role those fertilizer subsidies should play in SSA. Fertilizer subsidies can increase consumption. Desai and Gandhi (1988), for example, found a statistically significant correlation between fertilizer doses and the presence of subsidies between 1979 and 1983 (.35 coefficient significant at 95% level). Nigeria has also used subsidies extensively and exhibited one of the strongest fertilizer growth rates in SSA until the mid 1990s.

Despite the need to get prices down and evidence that subsidies can effectively increase consumption, donors have put immense pressure on African governments to eliminate subsidies because they tend to be an expensive and inefficient means of promoting agricultural growth.[19] While acknowledging the theoretical soundness of many anti-subsidy arguments, numerous authors believe that the phasing out of fertilizer subsidies before other measures to support fertilizer use were in place was as a key factor contributing to a reduction in fertilizer use during the last decade (Kelly et al. 1996, for Senegal; Bumb et al. 1994, for Ghana; Bumb and Baanante 1996, for Zambia, among others).

Proponents of some type of fertilizer subsidy note that subsidies have promoted rapid growth of fertilizer use in many parts of the world. China, India, Indonesia, Mexico, Nigeria, Saudi Arabia, Turkey and Venezuela are the most noteworthy examples (Bumb and Baanante 1996).

The main arguments for fertilizer subsidies are:

> ...to compensate farmers for taxes levied through low output prices; to try to overcome farmer risk aversion; to speed up adoption of agricultural innovations in the early phases of uptake; and to encourage tackling head-on the declining soil fertility commonly observed as fallow systems and other means used to sustain soil productivity in the past break down under population pressure. (Donovan 1996, p. 58)

The theoretical literature, nevertheless, generally sides against input subsidies except for a very limited range of situations.[20] Timmer, Falcon, and Pearson (1983) believe using producer price

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[19] While the theoretic inefficiency of subsidies is well documented in the economic literature, whether or not a fertilizer is expensive tends to be an empirical question that needs to be examined in a particular contex.

[20] Shalit and Binswanger (1984) describe one of the few cases where fertilizer subsidies may be less costly than output price supports: when land supply is inelastic and the supply elasticity of fertilizer is greater than that of labor (cited in Donovan 1996).

supports to induce supply response is more efficient than using input subsidies. This has been the approach taken by many industrialized nations, and is well illustrated by the following examples of producer subsidy equivalents:

The principal argument against subsidies is that they become financially unsustainable. In India, for example, 1993/94 fertilizer subsidies represented 3% of the national budget (Bumb and Baanante 1996). In Ghana, which still has relatively low fertilizer use, the government spent 3.5% of its total agricultural budget on fertilizer subsidies in 1980; this increased to 10.6% by 1988 (Donovan 1996). Other common arguments against subsidies are:

> ...they do nothing to address the supply constraints which almost universally characterize fertilizer supply in SSA, and in particular they do not remove credit constraints or permanently lower transport costs; the argument is strengthened by acknowledging that fertilizer subsidies are almost universally captured by larger farmers, they are an extremely inefficient means for transferring income to the poor, they distort resource allocation, and hinder the development of competitive private sector marketing which might reduce fertilizer costs to farmers over time.... (Donovan 1996, p. 63)

Table 6. Producer Supports and Fertilizer Use in Selected Industrialized Nations

Country	Average Producer Subsidy Equivalent (%), 1979-89	Fertilizer Use, 1985 (Kg/ha)
United States	30	94
European Community	39	303
Canada	35	50

Source: Bumb and Baanante (1996) citing Anderson.

Assessing the impact of subsidies and subsidy removal on aggregate trends in fertilizer use in Africa is very difficult as policy changes tend to be lumped together and isolating the impact of a particular policy is often impossible. Donovan (1996), nevertheless, notes that 16 of 29 African countries reviewed in a World Bank study had reduced or eliminated fertilizer subsidies by 1994, yet "the uptake of fertilizer does not appear to have been substantially affected by the reduction." The argument is based on evidence that fertilizer use dropped in many cases while subsidy rates were being held constant (Ghana in the early 1980s, for example).[21] In other

[21] One could question whether the subsidy rate is the critical factor to examine when assessing the impact of subsidy removal on fertilizer uptake. Farmers respond to prices, not to subsidies. The subsidy's ability to keep the price at an affordable level is what counts. It is not surprising, therefore, that keeping or eliminating a fixed rate subsidy will have little impact on fertilizer purchases following a devaluation that raises fertilizer prices

words, many of SSA's sharp drops in fertilizer use can be more closely linked to other policy changes that affected input prices (devaluation, for example) or supply problems due to foreign exchange shortages (exacerbated by devaluations) or inefficient marketing systems.

One of our main conclusions concerning the debate about fertilizer subsidies is that there has been very little effort applied to systematically looking at the costs and benefits of alternatives to subsidies. Donovan (1996) presents a list of government policy changes and investments with potential to reduce farmgate fertilizer costs:

> The most effective way to reduce the price of fertilizer to farmers is to have policies which will encourage efficient, competitive marketing of it, and to make sure there are good roads and transport services. So important are these two factors that it is worthwhile for governments to invest money in them. They might find some funds by reducing subsidies on fertilizer. But few analyses look at alternative ways to spend the public funds devoted to fertilizer subsidies. Better roads and transport services could benefit all farmers, and make fertilizer available at affordable prices in areas where it was not available at all before. The other important things are for agricultural research to work out the best rates of fertilizer application, agricultural extension to carry the message about correct fertilizer use to the farmer, and improved soil testing [can] sharpen the recommendations for different agro-ecological zones. (Donovan 1996, p. 64)

These suggestions have as much theoretical appeal as the anti-subsidy arguments, but all of these alternatives require large government investments. In most cases, subsidies were eliminated to reduce government deficits, not to free up cash for other expenditures. Until someone puts precise numbers to these options in a country-specific situation, it remains unclear whether these alternatives are more cost-effective approaches to sustainably increasing fertilizer use than the old stand-by of subsidies.

Market Development Policies: Much of the market development literature for SSA focuses on the fertilizer supply side, though evidence is growing that well-functioning output markets also encourage fertilizer consumption (see section 3.4.2). Those who focus on supply generally claim that supply-side constraints are much more responsible for high fertilizer prices and low levels of fertilizer use than subsidy removal and devaluations. Donovan (1996), for example, argues that heavy government involvement in importation, processing, and marketing activities have frequently been the cause of high prices, inadequate supplies, and late deliveries. A major component of many structural adjustment programs has been input market liberalization. The most typical cases of liberalization involved opening import and domestic markets to the private sector, reducing foreign exchange restrictions and phasing out subsidies. The author fails to take a stand on the success or failure of these programs but notes a number of lessons learned from the various experiences:

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12 fold during a three-year period, as was the case in Ghana.

- Fertilizer reforms will not be successful unless implemented with more general reforms in agricultural production and marketing;

- The continuation of donor in-kind fertilizer aid keeps governments heavily involved in fertilizer and hinders private sector development; and

- Liberalization alone is an insufficient stimulus to build a privately run fertilizer sector; training, credit, and a supportive regulatory framework are also needed.

Despite his tendency to stress the supply side, Donovan clearly recognizes that a narrowly defined approach to fertilizer supply will not solve the problem. His observation is supported by a recent evaluation of the fertilizer market liberalization program in Kenya noting that the profitability of fertilizer declined during the liberalization period (v/c falling from 3.14 to less than 2 between 1989 and 1996) and fertilizer demand failed to increase, despite the successful development of competitive private-sector markets. A key lesson learned from the Kenyan experience was that:

> ...private sector initiative does not occur automatically, due to (1) cost and risk factors, and (2) lack of technical knowledge for carrying out market development programs, and (3) lack of appreciation of the benefits which may accrue from market development programs, and (4) a relatively myopic approach to business development. (Allgood and Kilungo 1996, p. 23)

Investment in infrastructure is one of the most frequently noted ways of improving marketing efficiency and developing new markets. Most discussion concerns transportation infrastructure, but one increasingly finds communication infrastructure mentioned. To the extent that infrastructure development can reduce the transportation costs in marketing margins, and these savings are equitably distributed throughout the subsector, farmers will benefit from both lower fertilizer prices and higher output prices.

Foreign exchange restrictions also adversely affect fertilizer prices. Many countries limit foreign exchange for fertilizer without adequately evaluating the potential gains from the additional production, used either as export crops or import substitutes (Desai and Gandhi 1988). A related issue is the timing of the foreign exchange made available. In Ethiopia, for example, importers could reduce the price by about US$10 per ton if they placed orders in January rather than in July (when the foreign exchange now becomes available). Though earlier ordering would increase domestic storage costs, estimates show there would remain a net cost reduction of about US$5 per ton (Mulat, Said, and Jayne; 1997).

Among other options for reducing fertilizer costs examined by Mulat, Said, and Jayne for the Ethiopian case are:

Option	Estimated savings
Economies of scale in purchasing	US$5/ton
Bulk (rather than bagged) purchases	US$4/ton
Using charter vessels for shipment	US$5/ton
Using larger vessels for shipment	US$4/ton

Credit: Credit is an essential ingredient for developing input markets, not only at the farm level but for actors throughout the agricultural sector—whether they participate in input or output marketing activities.

Farm-level fertilizer credit has a dismal record in SSA, characterized by unacceptably high default rates. The literature is full of examples of "successful" credit programs that were evaluated early in their history and later found to have been as unsustainable as their predecessors. We seem to know more about what does not work than what does work.

This literature review has led us to believe that a major reason for poor reimbursement of fertilizer credit is the relatively low agroeconomic potential[22] coupled with the extremely high interannual variability in production and output prices. Fertilizer recommendations made by extension services frequently do not consider these risks. Credit systems frequently fail to consider fertilizer risk when they design their programs and repayment schedules. Ethiopia, for example, has recently instituted a program designed to legally enforce rapid agricultural credit repayments, but the system appears to be contributing to marketing gluts, low producer prices, and liquidation of important farm assets:

> All farmers are forced to bring their produce to the market at the same time (to pay their fertilizer debts, taxes, etc.). As a result, supply exceeds demand and prices fall sharply whenever farmers are pressed for repayment. The system does not accommodate the interest of those who want to incur additional interest costs with the aim of gaining from higher prices later during the year.
>
> The penalties for all those who failed to repay immediately after harvest may include the sale of assets (e.g., oxen or other animals) by the authorities (together with policemen). (Mulat et al. 1997, p. 10)

Very little attempt has been made to provide farmers with extension services that help them evaluate their debt-carrying capacity. Another problem is that many programs are run by the government (or at least perceived as being run by it) and the government ranks quite low on the

[22] This term is borrowed from Desai and Stone (1987). They used it when referring to the potential for profitable fertilizer use when both agronomic (yield response) and economic (price) incentives are simultaneously taken into account.

hierarchy of creditors to be reimbursed in case of distress. Also, fertilizer programs run by non-government organizations receiving donor funding often do not give adequate emphasis to loan reimbursement.

A body of literature also suggests that access to credit needs to be expanded so many of the smaller farmers and otherwise disenfranchised groups (women, for example) have better access. Most of this literature focuses on issues of social and political equity without giving much attention to comparing the social costs and benefits of programs targeted at the disenfranchised to programs open to all producers demonstrating a capacity to use and reimburse the credit. We were unconvinced by the evidence reviewed to data that making credit more generally available to women and other disadvantaged groups would substantially increase fertilizer use and/or improve reimbursement rates in most areas of SSA.

A particularly important problem in the gender literature is the tendency to argue that agricultural credit for women should be substantially increased because "women produce most of the food in SSA". The argument that women produce most of SSA's food is a generalization that appears to have originated with work done in the early 1970s drawing on a variety of formal and informal sources of information, some dating back to the early 1900s, many of them anthropological in nature, reporting very site-specific results (Boserup 1970). Although the original author was careful to note the difficulties involved in drawing broad generalizations from the information available to her, many of Boserup's qualified generalizations about the dominant role of women in SSA agriculture have been quoted as fact in more recent works, without the aid of any new data to substantiate the claims. As Boserup noted, new technologies or dislocations due to migration often change the male/female allocation of labor and responsibilities and it is possible that there have been major changes in gender roles in the 25 years since she completed her study. To the best of our knowledge, however, no one has done a thorough, quantitative study to determine the share of SSA food produced by women or the share of cultivated area managed by women farmers. Nevertheless, identifying numerous countries where the predominant cropping system is currently managed by men and the major share of agricultural labor is provided by men is not difficult (Sahelian countries such as Senegal, Niger, and Mali have primarily male-dominated production systems).

We believe there is a danger of misallocating national resources if input credit programs are targeted at disenfranchised groups who play a relatively insignificant role in agricultural production; proposals for these types of programs need to be carefully analyzed and compared with alternative means of improving the particular group's access to income generating activities.
We recognize the importance of dealing with equity issues but believe that there is a need for substantial improvement in the quality of data and analyses used to justify and evaluate such programs. Too much of the available literature in this area is based on anecdotal information and poorly documented generalizations.[23]

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[23] We found, for example, the following type of comments in a short conference presentation, but were unable to locate a more complete report on the study that helped us better understand how the men's and women's

The few insights we have into what does work in SSA come from the various cotton production systems─many of them operating as joint public-private ventures. In general, reimbursement of credit to cotton farmers is better than other types of agricultural credit, in large part because farmers usually cannot sell their cotton to anyone but the company to whom they must reimburse their credit. Another factor is that several cotton companies also provide extension and input credit for food crops. This helps farmers to achieve both their cash income and food security goals, thereby improving their ability to reimburse the credit. Despite the relatively good credit performance in the cotton sector, there have been some problems. Following the 1994 CFA franc devaluation, cotton producers in Niger sold their output in Nigeria and producers in several other countries significantly reduced their production because the i/o price ratios passed on to farmers by the cotton companies were much less favorable than those of other crops.

As market liberalization programs are implemented and more private sector actors enter the fertilizer market, there is growing evidence that lack of credit for input wholesalers and retailers is also a constraint to increased fertilizer consumption. Limited credit for fertilizer dealers means inadequate stocks and/or poor geographic distribution of stocks; this increases the farm-level cost of acquiring fertilizer in a timely and efficient manner. The evaluation of the Kenyan market liberalization mentioned above noted that:

> ...credit for fertilizer procurement is critical to fertilizer business development, particularly at the stockist (retail) level. Few stockists have access to adequate credit for their working capital needs and a strategically designed credit component is essential to encourage bankers to expand their credit portfolios to include credit for fertilizer inventories. (Allgood and Kilungo 1996, p. 23)

Ethiopia, which is currently in the process of liberalizing its fertilizer market, is also running into problems as credit is not being equitably distributed among importers and wholesalers and also not being made available to local dealers. This has resulted in most retail sales being made by a select group of wholesalers who have concentrated retail outlets in large towns and along major highways.

> A more efficient, flexible and a wider distribution of fertilizer can only be ensured if local traders are allowed to participate fully. Among the major reasons for the lower rate of participation were the manner in which credit is allocated,

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programs differed and what the evidence was on women being better credit risks than men:

> The WID [women in development] project has hired and trained 18 female technical sales agents (TSA) to promote increased use of agricultural inputs, particularly by female farmers. Each female retailer had a TSA for the first two years to help with the bookkeeping and to advise customers. These private retailers are now extending credit to about 20% of their clients, 70% of whom are women. Apart from the expected higher repayment rates of women compared to men, which is a common phenomenon, this positive trend of the project is in stark contrast to a similar initiative with male retailers, which resulted in a 100% failure. This example demonstrates how improved access to inputs enhances the capabilities for women to increase their productivity and move into non-traditional work areas (Conijn and Morris-Hughes 1994).

> the removal of subsidy and the unattractive wholesale price fixed by the government, and limited access to credit. (Mulat et al. 1997, p. 10)

Sequencing Structural Adjustment Policies. Rather than trying to isolate the effects of individual reforms, Bumb and Baanante (1996) have focused on the issue of policy instability and the need to sequence the various policy measures to avoid sharp drops in fertilizer prices and use.

> Policy instability resulting from structural adjustment programs ...[has had] an adverse effect on fertilizer use in several countries, including Cameroon, Ghana, and Zambia. (p. 8)
>
> Although several policies affect fertilizer sector operations, policies dealing with devaluation, subsidy removal, and privatization seem to have a profound impact. Unless these policy changes are phased and sequenced properly, they may cause steep reductions in fertilizer use....During rapid devaluation, some safety nets should be put in place to prevent too sharp a decrease in fertilizer use. Furthermore, when the fertilizer market is shrinking due to devaluation and subsidy removal, sudden withdrawal of the government from production, import marketing, and distribution to promote privatization is not desirable. Successful privatization is a slow and time-consuming process, requiring investment in institutional and physical infrastructure and management skills. (p. 46)

The authors explicitly cited the case of Ghana as an example of poor sequencing, and needed to go to Asia (Bangladesh) to cite an example of good sequencing. For those dealing with market liberalization in SSA, it is useful to note the keys to success identified by those involved in the Bangladesh program (U.S.A.I.D. 1996):

- The 16-year time span of the program (i.e., slow, incremental reform);

- The vision, based on a step-by-step process that aimed to identify changes in fertilizer policies that would increase the availability and reduce the delivered cost of fertilizer (rather than basing a program on ideology about liberalized markets);

- The need to strengthen the input parastatal before replacing it;

- The need to show the government conclusively that the private sector would be able to distribute fertilizer more effectively and inexpensively than the parastatal BEFORE steps were introduced to phase out the parastatal; and

- Reliance on data, analysis, and demonstrated results, rather than on U.S.A.I.D.-imposed conditions.

3.4.2. Output Prices

Crop prices depend on several variables including: strength of demand for a crop, climatic effects on production, seasonal variability in demand and supply, the quality of market and transport infrastructure, the degree of market integration, and government policies that increase, decrease or stabilize effective output prices received by farmers.

Fertilizer was first introduced to farmers in SSA for use on export crops because the strong demand for these crops stimulated the development of rural markets to collect production from farmers. These markets were characterized by a broad network of collection points, relatively predictable prices, and guaranteed purchases of all production. In many cases the output markets were vertically integrated with input and credit markets, providing farmers with easy access to fertilizer.

Given the relative low level of urbanization in SSA at the time (fertilizer was introduced during 1950s and 1960s in most countries), there was little incentive to develop domestic cereal markets that would encourage farmers to increase cereal production through fertilizer use. This has been changing. The transition to more urbanized societies has resulted in a larger percentage of food crops being commercialized to feed urban populations. This transition is important; in the two decades since it began, cereal crops have come to dominate the aggregate use of fertilizers (Desai and Gandhi 1988; Gerner and Harris 1993). This is not necessarily an indication of a movement away from fertilizer use on cash crops. Rather, it reflects the fact that urbanization and the accompanying development of domestic food markets have progressively led to cereals becoming commercialized cash crops. Zambia and Zimbabwe are excellent examples of countries where the increase in fertilizer paralleled the emergence of maize as a cash crop for smallholder farmers (Jha and Hojjati 1993, Rusike et al. 1997). Unfortunately, fertilizer consumption dropped in both countries when governments were forced to cut back on support to maize output markets by reducing the number of collection points and discontinuing pan-territorial price policies (Howard and Mungoma 1997; Rusike et al. 1997).

Despite obvious progress in developing SSA cereal markets during the last 20 years, many continue to point out that cereal prices in SSA do not provide adequate incentive for fertilizer use. This is particularly true in countries where millet and sorghum are the principal cereal crops because few opportunities are available to stabilize prices through international trade. Sanders, Shapiro, and Ramaswamy (1996) believe it is the high variability in millet and sorghum prices that is problematic, noting that no industrialized country allows their cereal prices to "bottom out" the way SSA governments have done in recent years when there has been surplus production. Two studies in Zimbabwe support this point by showing that when markets are less risky, farmers are more willing to invest in fertilizer. Both fertilizer use and the marketed surplus increased when grain depots were used to stabilized output prices (Jayne et al. 1994, using zone-level data; Rohrbach 1989, using farm-level data).

Angé (1997) believes that low cereal prices are a more pervasive and constant problem caused, in part, by the desire of many governments to provide low-cost food to politically vocal urban residents. By converting SSA cereal prices to US dollars and comparing them with a reference price representing a level of remuneration that would encourage intensification, Angé found that only 9 of the 25 countries examined had prices exceeding the reference price for the 1984-93 period. For 14 countries prices were at least 25% below the reference price during the entire period and for another 3 countries prices fell to 25% below the reference price after 1989. He concludes that agricultural intensification of cereals in these 17 countries is seriously threatened by these low producer prices, noting that low output prices lead to nonoptimal (in an agronomic sense?) fertilizer doses.

Markets do not function efficiently in the absence of infrastructure. The most important infrastructure for output markets includes roads for transportation, storage facilities to stock grain until prices are higher, and various communication facilities to transmit information concerning market conditions. A 1993 study by the Prime Minister's office in Burkina Faso concluded that investments in road infrastructure had the potential to reduce farm-gate fertilizer costs by approximately the same amount as the fertilizer subsidy that was in effect at the time (Reardon, 1998). Poor infrastructure decreases the effective price a farmer receives for agricultural output by increasing transactions costs and marketing margins. Transactions costs due to poor infrastructure are notoriously high in SSA.

Poor infrastructure can also have a negative impact on output markets if it is a cause of thin markets, because thin markets can contribute to price volatility (Reardon et al. 1994). Essentially, surplus or deficit production on a local, regional, or national level cannot easily be compensated for via trade with other areas when transportation or communication infrastructure is inadequate. This, combined with the characteristically inelastic demand of staple food products, can lead to sharp price fluctuations and greater price risk. Smallholder farmers in SSA generally have limited cash resources and fertilizer typically represents a large share of total production costs for those who use it. Major swings in net income may therefore result from fertilizer adoption in the context of volatile output prices. This can be a major disincentive to fertilizer adoption.

A final broad category of initiatives capable of improving output markets (as well as input markets) are institutional reforms that would reduce hidden transactions costs associated with marketing in SSA. The best documented evidence concerns reductions in marketing margins that can be realized by eliminating road taxes (both official and unofficial) on goods transported within national boundaries (see, for example, Gabre-Madhin and Maiga 1990 on Mali). Other similar examples are improvements in regulation and enforcement of contracts and reduction in taxes and licensing fees. Although access to foreign exchange is generally considered more important for developing input markets, it can also be important for the development of domestic processing industries. Development of processing industries is particularly important in countries where easily prepared rice imports compete with domestic coarse grains that are very time-consuming to prepare without some type of industrial processing.

Another interesting suggestion made by Dembele (1996) is that more attention be given to market research that would permit longer term projections of demand for agricultural products.

His hypothesis is that products with increasing demand are likely to have higher prices and less risky markets, thereby encouraging fertilizer use while those with decreasing demand will not be good candidates for fertilizer (this point is related to our discussion in section 3.2.2 concerning allocation of fertilizer across crops and relative profitability). Were long-term projections possible, they could be used by agronomists to select the most "promising" crops for focusing their fertilizer research.

A recent analysis of the evolution of the fertilizer subsectors in Zambia and Zimbabwe brings to light several of the issues mentioned above. The study focused on the issue of increasing fertilizer demand by smallholder producers of domestically consumed cereal crops. In both countries strong government programs using fertilizer subsidies, maize marketing networks, and pan-territorial input and output prices significantly increased smallholder fertilizer use on maize during the 1980s. When the governments began withdrawing these supports, fertilizer demand fell substantially (more so in Zambia than Zimbabwe, which instituted a fertilizer aid distribution program). The withdrawal of government from direct participation in the fertilizer sector has stimulated some private sector interest in providing input services to smallholders. Among the key recommendations for government action that would further stimulate these private sector initiatives were: investment in roads and telecommunications infrastructure, regulation of fertilizer quality, investments in research and extension to improve productivity of technologies available to smallholders, better market information systems, better enforcement of contracts, encouragement of actions that would increase demand for maize (processing services, for example) (Rusike et al. 1997).

One shortcoming of most of the market development literature on both the input and the output side is inadequate attention given to evaluating the relative costs and benefits of the different options. Unfortunately, SSA governments have limited funds and are unlikely to work miracles in all these areas simultaneously. If SSA governments want to increase fertilizer consumption, they need to put numbers on these diverse policies and investment options, all of which have strong theoretical justifications, to determine which ones have the strongest economic justification for their particular country and period of development. This requires careful identification and valuation of both private and social costs and benefits.

4. MAJOR CONCLUSIONS AND SUMMARY OF KEY POINTS

4.1. Major Conclusions

The major conclusions from our literature review are:

- Declining soil fertility is a major constraint to agricultural productivity in SSA;

- More inorganic fertilizer is needed to reverse the decline as the supply of organic fertilizers is not adequate;

- Contrary to the conventional wisdom of the 1980s, there are many crop/zone combinations where SSA fertilizer use is now profitable and many more where it could be profitable with minor improvements;

- The vicious circle of high fertilizer prices causing low demand and constraining the development of efficient distribution systems can be broken by a combination of market, agricultural research, and extension initiatives that act concurrently to improve incentives and capacity; and

- Privatization and liberalization of fertilizer markets are a necessary but not a sufficient condition for breaking this cycle; neither policy adequately addresses the unresolved technical problems, nor the fundamental problems of high transactions costs and high risks that dampen incentives, nor the pervasive presence of rural poverty that reduces capacity.

4.2. Summary of Key Points and Policy Implications

To increase rural incomes and meet growing food demands, Sub-Saharan Africa (SSA) must improve agricultural productivity. SSA is the only developing region where per capita food production has been declining; the region now has the largest cereal deficits in the world. If there is no change in productivity, deficits will more than triple by 2020.

Fertilizer is a powerful productivity-enhancing input, but SSA uses very little. Historical trends are abysmal. In 1970, SSA used <5 kg/ha while other developing regions used >15 kg/ha. In the 25 years from 1970 to 1995 fertilizer consumption grew only .23 kg/ha/year. Current use is only 9 kg/ha, down from highs of 11-12. This contrasts sharply with >50 kg/ha used in Latin America and >80 kg/ha in Asia.

Economists estimate that SSA agricultural production must grow by 4% per annum during the next decade to stimulate a satisfactory level of general economic development. This is faster than recent rates of 1-2%. Experience elsewhere has shown that fertilizer can provide a substantial productivity boost. A third of the increase in cereal production world-wide and 50% of the increase in India's grain production has been attributed to fertilizer-related factors.

Given the situation described in the last several paragraphs, there is an urgent need to understand why fertilizer is not yet fulfilling its potential as a major stimulus to agricultural productivity in SSA and what can be done to improve the situation. Much of the debate about fertilizer use in SSA focuses on two issues: whether the profit *incentive* is adequate and, if so, whether farmers have the *capacity* to access and use it. This document has focused on the first issue: incentives to use fertilizer. Our analysis of fertilizer incentives is based on an extensive review of fertilizer-response, profitability, and policy literature as well as some analysis of crop budgets and aggregate national statistics on fertilizer consumption.

Contrary to conventional wisdom, our review of the literature found examples of fertilizer response and profitability in SSA that compare favorably to those in other parts of the world. Table 7 presents a summary of information presented in Sections 2 and 3 concerning fertilizer response and profitability. The summary uses three ratios commonly employed to evaluate fertilizer performance and profitability. O/n (output/nutrient) ratios show how many kgs of additional output a farmer can obtain from a kg of fertilizing nutrient; ratios $\geq$10 are considered efficient for cereals. An i/o (input/output price) ratio shows the number of kgs of production a farmer needs to purchase one kg of fertilizer; the lower the ratio, the higher the incentive; ratios <2 are generally attractive to farmers. Value/cost ratios are rudimentary profit indicators that compare the gross income attributable to fertilizer with the costs of the input. Conventional wisdom holds that a v/c ratio must be $\geq$2 before a farmer will consider financial incentives adequate; many hold that in high-risk production environments the minimum v/c for adoption is 3 or 4.

Among the cereal crops covered, maize (SSA's most important fertilizer consumer) and irrigated rice exhibit the strongest incentives. Output/nutrient and value/cost ratios equal or exceed standard benchmarks. 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. These factors discourage fertilizer use for the vast majority of maize farmers. High irrigation costs represent a negative for rice that can result in low overall profitability, canceling out fertilizer benefits.

Sorghum and millet exhibit poor incentives compared to maize and rice – not surprising given that sorghum and millet are grown in difficult agroclimates (poor soils, low rainfall, high temperatures). Using fertilizer in combination with crop residues, manure, or water and erosion control measures considerably increases the yield response, but aggregate output is usually <1 ton/ha.

Among the export crops covered, only tea – a crop whose production is limited to a few areas in SSA – exhibits good indicators. Cotton (SSA's second largest fertilizer consumer) has highly

Table 7. 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: Compiled by authors from extensive literature review.
Notes: Information on v/c ratios was sparse and costs used in calculating ratios poorly documented, hence no attempt was made to generalize about "typical" v/c ratios. 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.

variable yield response and mediocre profitability (minimum v/c very low and more than 50% of the v/c ratios reported in Appendix 1 being <2). The mediocre profitability occurs despite extremely favorable i/o ratios.

The evidence presented earlier in this document and summarized in Table 7 suggests that (1) high-productivity maize and rice technologies are available, but more basic research and extension work is needed to adapt them to diverse smallholder production environments; (2)

sorghum and millet technologies are not yet highly productive and more basic research is clearly needed, focusing on the use of fertilizer with complementary inputs; and (3) there is substantial room for improving technologies for export crops. For all crops/zones, substantial improvements in profitability could be realized by reducing SSA's i/o price ratios, which are among the highest in the world.

V/c ratios reported include fertilizer subsidies if they existed at the time of the analysis. Because fertilizer subsidies have been phased out and replaced with market development initiatives that have not yet reduced fertilizer costs, more recent ratios rarely approach the maximum v/c values in Table 7. Farm-level fertilizer prices in SSA are among the highest in the world. In 1991/92 SSA prices per ton ranged from $232 to $487 for urea and phosphates while the Asian equivalents ranged from $68 to $201. Unfavorable i/o price ratios confirm that the negative impact of high fertilizer prices is not offset by high producer prices.

Subsidies are one way of keeping fertilizer prices low. Proponents note that subsidies promoted rapid growth in fertilizer use and agricultural productivity in China, India, Mexico, Nigeria, Turkey, and Venezuela. Opponents point out that unless subsidies are accompanied by a clear program to rectify the underlying problems they are compensating for (e.g., inefficient markets, poor infrastructure) their demands on the budget grow rapidly, reducing the ability of government to make other agricultural investments.

For many reasons, **fertilizer market development** programs have not yet had the desired impact on fertilizer prices and demand. In some cases subsidy removal and devaluation reduced already low effective demand (Ghana and Senegal). In others, a lack of complementary actions to improve farmers' fertilizer techniques (e.g., extension programs), lower transactions costs (e.g., better regulatory environment), or reduce risk (e.g., fertilizer quality control) hampered market development. Inadequate access to foreign exchange and credit for dealers has also been a constraint (Ethiopia). Government's continued involvement in the distribution of fertilizer aid has also discouraged some private sector initiative. Another shortcoming noted was the failure to train private sector operators in product promotion skills (Kenya).

Some **output market development** programs have contributed to fertilizer profitability by reducing farmers' risks and transactions costs. Market information systems have reduced price differences between deficit and surplus zones (e.g., Mali). Liberalization of cereal exports and imports has stabilized prices at the national level (e.g., Kenya and Ethiopia). Expansion of market infrastructure has reduced farmers' marketing costs and increased profitability, thereby promoting smallholder use of fertilizer (e.g., Zimbabwe and Zambia in the 1980s).

Some measures improve **fertilizer and output market efficiency** simultaneously. The best documented evidence concerns reductions in marketing margins realized by reducing official and unofficial road taxes on goods transported within national boundaries (e.g., Mali and Senegal). Another example is infrastructure, particularly roads but also communications.

V/c ratios show only whether farmers' revenues are likely to exceed their costs when using fertilizer. The ultimate decision will depend on whether farmers believe they will make more money with the fertilizer than with alternative uses of the available cash. Although **analyses of "relative" profitability** are rare, the few cases found showed that farmers failed to adopt fertilizer with v/c ratios ≥ 2 because purchasing and fattening an animal for resale or clearing new land to expand production was more profitable. Nonfarm activities also offer stiff competition. Hence, indicators such as those used in Table 7 must be complemented with more analysis of "relative" profitability so that programs to develop fertilizer markets consider competing activities.

Loss of organic matter and acidification are major problems in the fragile soils of SSA. Fertilizer loses its effectiveness when soil organic matter falls below minimum levels, hence zones with serious soil degradation may have low capacity for fertilizer use. Rainfall and fertilizer use are highly correlated.

Commercial agriculture is a *sine qua non* for increasing fertilizer use. Three of the top fertilizer consuming countries (Zimbabwe, Kenya, and Zambia) benefitted from the establishment of large-scale commercial farms by European settlers. These farms have provided a minimum level of stable fertilizer demand that helps promote economies of scale and lower fertilizer prices. Realizing economies of scale when relying entirely on smallholders farming under rainfed conditions is more difficult, yet the success of SSA cotton systems shows that it can be done. Important boosts in aggregate fertilizer demand can also be obtained in areas where irrigation investments permit smallholders to produce rice (Mali) or sugarcane (Mauritius).

Access to complementary inputs (e.g., manure) is particularly important for crops and zones (e.g., millet and sorghum in the Sahel) where fertilizer response is poor without the complements. The issue is, however, becoming important for all farmers because fertilizer yield response declines over time if soil organic matter is depleted. As chemical fertilizer does not add organic matter to the soil, farmers will need to increase the amount of crop residues and/or manure used. Some of this can come from increased production of crop residues obtained by using fertilizer.

The use of research and extension funding to adapt available fertilizer technologies to particular smallholder situations is emerging as a key tool for improving SSA's capacity to use fertilizer efficiently. A major problem has been "pan-territorial" recommendations that fail to take into account differences in resource endowments (soil type, labor capacity, climatic risk, etc.). The situation is exacerbated by a failure to revise recommendations following dramatic changes in the i/o price ratios due to subsidy removal and devaluation (e.g., Ethiopia and Malawi). Farmers using fertilizer already experiment with doses and methods of application (few apply as recommended). There is a need for investment in research and extension programs that focus on adapting "good performers" to particular smallholder situations. The case of maize illustrates the point. Many SSA fertilizer/seed technologies for maize are good performers, yet the vast majority of maize farmers are not yet using fertilizer. Strong evidence from countries that have begun to focus on site-specific and adaptive research programs is showing that this approach can have big payoffs in terms of increased fertilizer profitability and adoption (e.g., Malawi and Kenya).

4.3. Design and Implementation of Programs and Policies to Stimulate Fertilizer Use

It is necessary to break the high-price, low-demand cycle by stimulating a strong increase in fertilizer demand *at the same time* that programs are implemented to improve market efficiency. The focus needs to be on the narrow issue of getting fertilizer prices down and increasing demand in a cost-effective, sustainable manner. A combination of public and private actions is needed; the objective should not be getting government out of agriculture but identifying its proper role given the situation prevailing in each country. For most countries, taking the following five steps will be prerequisites for developing a viable program to simultaneously stimulate fertilizer demand and supply.

1. Prepare an inventory of what is known about fertilizer response and profitability by zone and crop (Kenya, Malawi, and Mozambique provide good examples).

2. Using the inventory, identify the crops, zones, and types of households with the greatest potential for rapid increases in fertilizer demand, taking into account demand projections for domestic and export crops. Fertilizer consumption increases most rapidly on crops with strong demand and stable prices, but such crops can stimulate fertilizer use on other crops (e.g. cotton/maize complementarities).

3. Examine potential economies of size and scale capable of reducing fertilizer prices, including economies that could be realized by regional pooling of fertilizer procurement activities.

4. Using information from step 2, identify a *combination* of market, research, and extension activities to stimulate demand for selected target groups, aiming for the level of demand required to realize the economies identified in step 3.

5. Determine which of the initiatives identified have the strongest economic justification for a particular country and period of development.

The key to developing successful programs that improve input market efficiency while increasing fertilizer use is careful analysis of the costs and benefits of the many options discussed in the Sections 2 and 3 of this document, including the possibility that some type of subsidy might be an efficient way of priming the pump to get more efficient private sector involvement in the fertilizer sector. This will require careful identification and valuation of both private and social costs and benefits. A major shortcoming in the past has been the lack of attention to social costs and benefits. As concerns for the environment increase, more attention to fertilizer's environmental benefits (e.g., less production moving into marginal lands) and potential inconveniences once high levels of use are attained (e.g., soil acidification, water pollution) will be needed.

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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	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												
		'		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: '67-78 368	 1809	 1441		Avg 11	6.1*	('90) 2.5		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
Average yields: '67-78 368	 2726	 2358		Avg 9	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
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
Mz/Mz	Gdnt/ Mz				1.95*			Rsp to rotation	No fert: Mz/Mz vs Gdnt/Mz	Ghana	Guinea Savanna	'80s	RMFT?	ditto

[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												
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					
				4-22	('85-92)[c] 2 and 7[d]			N		Nigeria				Heisey & Mwangi '97
				5-14	.6*			NPK		Nigeria				Lele, Christiansen & Kadiresan '89

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

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

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												
					('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
				9-26	5.75*	1.7-4.8	Hybrid	N&P		Kenya				Lele, Christiansen & Kadiresan '89
				3.7 9.2 7.8					100 P_20_5 300 P_20_5 400 P_20_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

[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: W/O	With	Rsp	% 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
1346	3138	1792	133	13.5	('87-96)	1	Hybrid	Rsp to	92-40-0 (rec)	Malawi	country-wide	'95/6	RMFT	Benson '97 a
1346	2262	916	68	25	Avg: 7	2		recom-	35-0-0 + 2S					
1346	2825	1479	109	31.5		3		mended	35-10-0 +2S					
1346	3138	1792	133	19	min: 5	2		NPK vs	69-21-0 + 4S					
1346	3189	1843	136	16	max: 10	1		alternatives	92-21-0 + 4S					
				14-16	7.35		Local	N / N&P		Malawi				Lele, Christiansen &
				20-37			Hybrid							Kadiresan '89
				8-38	7.35		Local		N	Malawi				Heisey & Mwangi '97
				8-52			Hybrid							
1346	3138	1792	133	13.5	('87-96)	1	Hybrid	Rsp to	92-40-0 (rec)	Malawi	country-wide	'95/6	RMFT	Benson '97 a
1346	2262	916	68	25	Avg: 7	2		recom.	35-0-0 + 2S					
1346	2825	1479	109	31.5		3		NPK vs	35-10-0 +2S					
1346	3138	1792	133	19	min: 5	2		alternatives	69-21-0 + 4S					
1346	3189	1843	136	16	max: 10	1			92-21-0 + 4S					
				18-43	5.25*	('89)				Tanzania	S Highland			Heisey & Mwangi '97
				13-18		6-15					North			
				8-10		2.7-3.4					Dry			
				6	5.25*	2	Local	N&P		Tanzania				Lele, Christiansen &
				11-16		4-5	Hybrid							Kadiresan '89
1200	4000		233		('74-76)					Uganda			RMFT	Tukacungurwa '94
					196.2*									
					('86-92)									
					.41*									
				18.1	4.3*	('83/4)	Hybrid			Zambia	Plateau	'83/4,	FMT	Jha & Hojjati '93;
				11.1		2-4	Local				Region	'86/7		Heisey & Mwangi '97
879	1071	192	22	2	4.6*	.43	Local	Rsp total	81 NPK	Zambia	E Prov	'86	survey	Celis, Milimo &
879	2461	1582	179	9		1.49	Hybrid	nutrients	179 NPK					Wanmali '91
									manual labor only					
1172	1414	242	21	3	4.6*	2.8	Local	Rsp total	90 NPK	Zambia	E Prov	'86	survey	Celis, Milimo &
								nutrients	oxen traction					Wanmali '91

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												
				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
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

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												
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
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 W/O	With	Rsp	% 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
				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										
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								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 1275 1464 1325	-14 282 471 332	-2 28 47 33	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 Rec practice PR-basal application PR-annual application	Mali	Songoumba	'80s	RMFT	Bonsu '96 citing Bationo et al.
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

[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										
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
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
148	194	46	31				Pearl	Resid effect P in 3rd yr	13.1 P as SSP in 1st 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 3rd yr	13.1 P /PAPR-50%; 1st yr only	Niger	Gobery	'86-8	FMT	ditto
		Rsp to fert		Rsp density (%)		Rsp. Both	Pearl	Rsp to plant density and NP	pockets/ha: 5000 = current practice	Niger	Gobery	'86-8	RMT	ditto
		kg/ha	% chg	No fert	NP									
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			
				7-21		('87) 2-17					1000-1500			
487	934	447	104					Acacia Albida	planting under tree	Senegal	Sahel	'66-68	FMT	Dancette '85

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	1340	853	175		not avail			Rsp to fert + manure	??? & ???	Senegal	Sahel	'66-68	FMT	ditto
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						Type of data	Source
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		
W/O	With	Rsp												
2217	3617 4308 4540	1400 2093 2325	63 94 105	17.6 11.5 5.2					75N 75N 60P 75-60-45	Bangladesh	Aus	'76	RMFT FAO Trials	FAO '81
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 4200 4300	600 1000 1100	18 31 34	20 16.7 12.2			Avg of imprvd cultivars	Application of Nitrogen	30 N 60 N 90 N	India		'75-76		IRRI '79
2950	4100 4890 5330	1150 1940 2380	39 66 81	9.6 (N) 13.2(P) 7.3(K)		2.0 3.1 4		Sequential adding of different nutrrients	120-0-0 120-60-0 120-60-60	India		'67-77	FMT	ISMA '81 citing Kemmler

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 nutrrients	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										
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
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										
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
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

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												
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
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.

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