Staff Paper

Determinants of Fertilizer Adoption by African Farmers: Policy Analysis Framework, Illustrative Evidence, and Implications

by
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No Abstract

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1. Introduction

The context. Fertilizer use is crucial for sustainable intensification and for raising farm productivity under increasing land constraints and declining soil fertility in Sub-Saharan Africa. Yet fertilizer use per hectare in SSA was already very low in the mid 1980s, and has declined even further over the recent decade (Naseem and Kelly 1999). There is also growing evidence of promising fertilizer-using technologies that are 'on the shelf' but that are not being adopted or are being disadopted because of policy-related disincentives or other constraints.

These trends in fertilizer use are all the more worrying because without significant increases in the use of chemical fertilizers it will not be possible for the production of food and fiber to keep up with demand from a rapidly growing population. Organic matter from manure and crop residues has an essential role to play in increasing land productivity, but it cannot provide the supply of nutrients (N, P, K) needed to maintain even current low levels of production (Kelly et al. 1998, Yanggen et al., 1999; Weight and Kelly, 1998 and 1999).

Objectives and structure of this report. Despite the alarming general trends and patterns, there is evidence of large differences among farmers in adoption and use of fertilizer, even in a given agroclimatic zone and on a given crop, let alone among zones in a given country or sub-region of Africa. It is our belief that by studying what is known about the factors that are eliciting these diverse responses to fertilizer technologies, one can develop a better understanding of the types of policies and investments most likely to stimulate fertilizer demand in the future.

In an effort to improve our understanding of these factors, we present a conceptual framework in section 2. The framework is based broadly on the economist's conceptualization of a fertilizer demand function, but divides the explanatory variables into two broad categories: incentives (a function of fertilizer response and prices) and capacity (household and community level factors that affect a farmers ability to purchase fertilizer). In section 3 we examine a broad range of variables that increase or decrease incentives to use fertilizer, drawing on a review of farm-survey case studies to illustrate the more common patterns. Section 4 presents a similar review of variables affecting farmers' capacity to purchase fertilizer, drawn primarily from farm-survey literature. Section 5 examines some of the more common combinations of incentive/capacity structures found in SSA. Section 6 discusses the problems of estimating fertilizer demand functions for SSA. Section 7 summarizes the lessons learned and policy implications.

Links to other MSU fertilizer papers. This document is one of four papers and two policy syntheses that the FS-II project at MSU has produced in an effort to review existing literature on fertilizer issues in SSA and improve the analytical frameworks used for fertilizer policy analysis. Other papers (with full citations in the list of references) include:

Incentives for fertilizer use in Sub-Saharan Africa: a review of empirical evidence on fertilizer response and profitability (Yanggen et al., 1998)

Macro trends and determinants of fertilizer use in Sub-Saharan Africa (Naseem and Kelly, 1999)

Fertilizer impacts on soils and crops of Sub-Saharan Africa (Weight and Kelly, 1999 (forthcoming).

Fertilizer in Sub-Saharan Africa: breaking the vicious circle of high prices and low demand (Kelly et al., 1998)

Restoring soil fertility in Sub-Saharan Africa: technical and economic issues (Weight and Kelly, 1998).

This report deals with the same general issues addressed in the Naseem and Kelly document but presents a much more extensive conceptual framework for the analysis of fertilizer demand, and draws on a review of published analyses using farm survey data in an effort to complement the analyses of macro data presented in Naseem and Kelly. Although the present report overlaps to some extent with the Yanggen et al. document where there was substantial discussion of price policy impacts on fertilizer profitability, this report has a strong focus on socioeconomic behavior of the farm household that was not presented in any of the other documents.

2. General Conceptual Framework

In this section we set out a conceptual framework for analysis of farm household fertilizer demand. The demand function shows quantity demanded (which can include zero use) of fertilizer as a function of a price and non-price factors. For a given household, "demand" is thus a general term that includes "adoption" as a subset (the distinction between zero and positive use); diffusion concerns the spread over households of adoption. The demand function can be specified at any level, from that of a specific household to the aggregate of farmers in a village or a region or a country.

The fertilizer demand function of a given farm household[1] arises from the economic and technical relationships perceived by the farmer. The main economic relationship is that between the use of fertilizer and its profitability, conditioned by the capacity to purchase the fertilizer. A change in fertilizer use affects cropping profits, mediated by the rate of fertilizer use (in turn a function of the underlying technology) and the fertilizer price. In turn, the choice of technology, and in particular the choice of level and type of fertilizer used, depends on what the farmer perceives to be the responsiveness of yield to fertilizer use for the crop in question, controlling for other conditions such as use of other inputs, and other factors such as rainfall, managerial ability, and other environmental attributes such as land quality.

Thus, the standard fertilizer demand function in economic theory is based on the variables that influence profitability, conditioned on the technology in use:

> Quantity demanded of fertilizer = function of (1) output prices, (2) input prices of variable inputs, (3) risk, (4) quasi-fixed capital on the farm, and (5) other shifters (such as rainfall) that condition output.[2]

The profit-maximizing dose of fertilizer occurs when the marginal cost of an additional kilogram of fertilizer is equal to the marginal value product (value of additional output obtained

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[1] We focus on the household-level decision, rather than "gendered" decisions within the household, for the following reasons. Although it is common to find that female-headed households and female farmers within households use less fertilizer than their male counterparts, several African studies have found that gender does not directly affect fertilizer use (after controlling for access to credit and cash income), but rather affects fertilizer use indirectly via gender's impacts on access to credit and cash income, and on what crops are is grown (with females' usually producing the subsistence crop and men producing a mix of subsistence and cash crops). See, for example, Gladwin (1992) for Malawi, von Braun et al. (1989) for The Gambia, and Due (1991) for a general review in Africa.

[2] This relationship, along with the output supply function, is derived from the profit function (which does not require the assumption of profit-maximizing behavior, see Sadoulet and de Janvry, 1995).

with the last kilogram of fertilizer). However, the farmer’s perceptions of risk affect his/her response to the determinants in the demand function. In practice, SSA farmers seldom apply a profit-maximizing dose of fertilizer, even if the average profitability of fertilizer use is positive. If the farmer believes that on average there is a 1:10 ratio of fertilizer to additional output (in physical terms), he/she may be unwilling to assume the risk of using it, if, during years of poor rains the farmer does not anticipate enough additional yield to "break even." In other words, risk-averse farmers may be likely to base perceptions of fertilizer response on the worst-case scenario rather on the average scenario.

Moreover, farmers’ perceptions of the fertilizer response function influence the amounts of fertilizer applied, given the determinants in the demand function. The greater the yield response (as perceived by the farmer), the greater the use of fertilizer, all else equal. A shift to a more yield-responsive crop or variety, or better environmental conditions, will imply an upward shift in the marginal product curve, so that the profit-maximizing point where fertilizer price and the marginal value product of that fertilizer are equated occurs at a higher level of fertilizer application. Farmers’ observation of yield response colors these perceptions. This militates against farmers’ actually using the full recommended doses of fertilizer because there is higher (and therefore more visible) yield response at lower levels of fertilizer application due to the greater marginal effects of additional increments to fertilizer use (given the usual shape of the fertilizer response function).

Table 1 collects the above points concerning the price, objective nonprice factors, and subjective or perceptional nonprice factors that influence farmer demand for fertilizer. It (roughly) categorizes these determinants as being "incentives" and "capacity" for fertilizer use.

Incentive variables comprise those that influence the level and variability of profitability (output and input prices, risk, and the household subjective attitudes that condition their response to these variables, such as perceptions of yield responsiveness). Note that these variables are in turn functions of variables that affect the context in which the household functions, that can be influenced by policies (market infrastructure, transactions costs, and so on). Capacity variables comprise the capital and other household and community level factors that affect the household's ability to obtain fertilizer (controlling for their incentives to do so).

We use this bifurcation (incentives and capacity) to structure the next two sections, in which we discuss in greater detail, with research illustrations from Africa, these determinants of household fertilizer demand.

3. Incentives for Farm Household Demand for Fertilizer

This section is organized with a logical flow that itself is meant to tell a story. It addresses demand incentives in a manner relatively unconventional. We begin here by laying out (in sections 3.1 and 3.2) two overarching incentives or conditioners of demand for fertilizer – that of the scarcity of land (hence the land price) and thus the need for intensification (with fertilizer, among other productive factors), and that of the farmers' perception of the responsiveness of yield to fertilizer, hence the practicability of intensification with fertilizer. Once those are accounted for, at issue is the economic profitability of fertilizer use. As there is evidence that farmers calculate that profitability primarily on the basis of the output price and the fertilizer price, and their ratio, we focus on these in sections 3.4-3.6. Secondarily, farmers take into account the prices of other non-land inputs such as organic matter, whose prices are discussed in section 3.7. Finally, as the prior sections focused on average levels of incentives, and not their variation over time, section 3.8 focuses on that variation in the form of risk as a (dis)incentive to demand. Note that we leave a discussion of the interest rate (the price of credit) to the section on capacity for demand. Note also that the discussion of each incentive is done "controlling for" the other variables (with the assumption of "all else equal").

3.1. The First Overarching Incentive: Land Scarcity or the Price of Land

The land price is an important determinant of demand for intensification practices and inputs, such as fertilizer use, based on the theory of induced innovation for agricultural intensification (Boserup 1965, Ruthenberg, 1980, Hayami and Ruttan, 1985). As the land price is often not an explicit market price in traditional agriculture, most of these theories have simply used a proxy for the effective price of land as the land/population ratio (in turn inversely reflected in the fallow period, the measure used by Boserup). As that ratio drops, use of methods and inputs to increase yields (per ha) increase. It is then uncommon to find fertilizer used in "extensive systems" where the land/population ratio is high, such as the Congolese agro-sylvo-pastoral system. De Alwis (1995), using data from a number of developing countries, shows that application of inorganic fertilizers to food crops becomes significant (by his definition, above 25 kg/ha) only after the area of cultivable land per person falls below approximately 0.2 ha. This relationship is frequently observed when one compares over zones in Africa.

Moreover, in general the relationship holds among farms in a given agroclimatic zone: the larger the farm, usually the lower the application rate per hectare, but the greater the total use of fertilizer (per farm). This is illustrated in Malawi (Gladwin 1992), where larger farms are more likely to adopt hybrid maize, but then have lower fertilizer application rates than smaller hybrid maize adopters. Similar results were found in Northern Tanzania by Nkonya et al. (1997) and in northern Nigeria by Norman et al. (1982).

The positive relation between land scarcity and fertilizer use does not always hold, due to due to intervening factors that overwhelming the essential relationship. For example, a zone with large farms next to a zone with small farms might demand more fertilizer per ha simply because there are more profitable cropping opportunities, more water, more credit, and so on, than in the smallholder zone. A typical situation in which larger farmers use more fertilizer per ha (than small farmers) is where large farmers have shifted to a cash crop that is more profitable than the subsistence crops grown by the small farmers. The large farmer has advantages over the small farmer in adoption of the cash crop (as the larger farmer usually has better access to roads, extension, education, and credit), and, in turn, the cash crop is usually produced for a market that has certain advantages that favor fertilizer use (greater profitability, input credit and access from crop purchasing company or agency, and so on).

For example, Jha and Hojjati (1993) found in Zambia that even within a given zone (hence controlling for agroclimatic factors), larger farms used more fertilizer per ha because of better access to credit, markets, and roads. The smallest farmers (using less than 1 ha) dedicated 87% of their fertilizer use to local maize (a subsistence crop), while larger farmers with more than 5 ha dedicated 67% to HYV maize (a cash crop). Moreover, Hassan and Karanja (1997) found in Kenya that larger farmers were the earliest adopters of the combination of high-yielding-variety (HYV) maize and fertilizer, although in similar agroclimatic circumstances, smaller farmers eventually achieved similar adoption rates. However, larger farmers still used more fertilizer per ha than did small farmers – 3.8 kg more – again, based on superior access to credit, roads, extension.

One also observes that the relation between the land/person ratio and the fertilization rate can differ as between cash and subsistence crops. In Mali, Coulibaly et al. (1993) found (in areas with relatively high land/person ratios) that the fertilizer application rate is greater in zones with shorter fallow periods. They qualified this result, however, by noting that the fertilization rate on cotton (a cash crop) is roughly the same regardless of zone, while the fertilization rate varies greatly on subsistence cereal crops (in inverse relation to the land/person ratio). They also found that in areas with more land per person, farmers tend to use fertilizer not to intensify (raising yields) but merely to maintain yields and address specific problems of infertility.

3.2. A Second Overarching Conditioner: Perception of Yield Responsiveness to Fertilizer

As noted above, the farmer's perception of the responsiveness of crop yield to fertilizer application conditions his/her response to changes in economic incentives. That perception is colored by his/her understanding of the underlying technical relationship between a particular formula or type of fertilizer, and particular types of seed, soil, and climate (temperature and rainfall). These perceptions are by nature subjective, and can be powerful in influencing fertilizer demand, given land scarcity and the economic incentives treated below (Adesina and Baidu-Forson, 1995). Moreover, the subjective perceptions of the need for fertilizer can differ greatly depending for example on whether the farmer sells (or only home-consumes) the crop in question (Gladwin, 1992).

That perception is influenced by several factors. The first influence is the farmer's access to information about fertilizer (for example, about crop requirements, or correct application practices, or market prices and availability). This depends on receipt of extension messages, observation of demonstration plots, and personal experience. A farmer's perception of fertilizer response may become more favorable if his/her skills in using fertilizer are improved by participation in an extension program. However, it may become less favorable if, having observed a successful demonstration plot, he/she attempts fertilizer use but obtains poor results because of a failure to respect key management practices (seed variety or plant density, for example).

The second factor that influences the farmer's perception of responsiveness is the crop technology used. In general, the most important distinction is whether the farmer uses high-yielding varieties of seed. There is abundant survey evidence (such as for maize) of the link between perception of fertilizer responsiveness (matched by reality), use of HYV seed, and relatively high fertilizer use – and the opposite on traditional varieties. Moreover, there is evidence that hybrid seed adoption is linked to commercialization of agriculture, which in turn increases the profitability of fertilizer use and access to seed and credit. Examples of these links can found in Jha and Hojjati (1993) in Zambia, who showed that fertilizer use was sparked by adoption of HYV maize and tobacco, and only later diffused to local maize grown by smaller farmers.

The third factor that influences perception of responsiveness (and its objective reality) is the agroclimatic character of the production zone – if only because water and organic matter are strong complements to fertilizer in production. The evidence of this correlation is abundant. For example, Hassan and Karanja (1997) found in Kenya that fertilizer adoption was much faster (and demand much greater) in the zones with better agroclimates, and on HYV maize as opposed to open-pollinated or traditional varieties. Similarly, in western Niger, Thompson (1987) found that fertilizer demand was much greater in the more favorable agroclimatic zone (Dosso) as compared to that of Niamey. The Dosso zone also had easier access to fertilizer (being on the border with Nigeria) and a history of cash cropping.

The fourth factor is the micro version of the third factor – the basic nutrient content of the farm's soil determines what kind and dose of fertilizer are needed and whether the crop in question will be responsive to the fertilizer. Soil and field characteristics such as slope and porosity affect runoff and leaching. For illustrations of the effects of farmer's perceptions of how field characteristics influence fertilizer responsiveness, see Shiferaw and Holden (1998) for Ethiopia, or Ndiaye and Sofranko (1988) in Senegal. In addition, Nkonya et al. (1997) found in northern Tanzania that farmers are "reactive not proactive" in their application of fertilizer given a plot's soil characteristics. Farmers apply fertilizer to less fertile plots where leaf yellowing indicates nitrogen deficiency. In qualitative surveys exploring this issue, Clay et al. (1995) also found this in Rwanda, as did Enyong et al. (1998) in various survey sites in the Sahel.

3.3. Aside Concerning Classification and Definition of "Prices"

Prices reflect relative scarcity and the opportunity cost of resources. For a given seed/fertilizer technology, farmers' perceptions of fertilizer profitability are influenced by the effective price paid for inputs and received for outputs. Effective prices are some combination of one or more of the following elements: (1) an observed market price (including interest payments if relevant);

(2) unobserved transactions costs associated with a market price (e.g., costs of getting to/from the market, of negotiating sales or purchases, of obtaining credit, or of discounting payments not made at the time that the output is exchanged); (3) opportunity costs for provision of non-market inputs (labor costs for collecting/applying manure, costs of purchasing substitute materials if organic matter such as manure and millet stalks are used for enhancing soil fertility rather than for cooking fuel, fencing, or animal feed); (4) opportunity costs for home consumption of the output (the cost of purchasing cereals at consumer prices rather than selling the output at producer prices).

Effective prices can be influenced by government policies (exchange rate policy, taxes, import duties, efficacy of contract enforcement), level of competition in the market, and the relative negotiating skills of farmers/farmers' organizations and input/output traders. Transport and other transaction costs condition the effective price of the input and output prices. These costs in turn are influenced by public investment in roads, exchange rate changes that affect imported inputs to the transport sector, and institutional changes affecting transaction regulations.

3.4. Output Prices

Normally, if the price of the crop in question increases, the quantity demanded of fertilizer for that crop rises. This is due to an area effect (there is an increase in the land under that crop) and to a dosage effect (fertilizer application is more profitable which may mean that the profit-maximizing dose of fertilizer per ha is higher). The output price elasticity of fertilizer demand will depend on the nutrient requirements of the crop, inter alia. For example, one expects a high elasticity for maize and irrigated rice because the new varieties of maize and rice (the latter under irrigation) respond well to fertilizer. By contrast, one expects a low elasticity for millet and cowpeas because there is a dearth of fertilizer-responsive millet and cowpea varieties (Matlon 1990).

Various policies affect fertilizer demand via their effects on crop prices. These policies include, for example: (1) public infrastructure investment; (2) cash crop schemes such as agroindustrial outsourcing of crop production (as in the cotton schemes of West Africa or the fruit production schemes of East Africa); (3) sectoral and macro policies such as subsidies, taxes and tariffs, floor and ceiling prices, and exchange rate changes; (4) marketing policies such as procurement. These policies and programs are discussed further below.

3.5. The Prices of Fertilizers

The expected effect of a price rise is a decrease in the quantity of fertilizer demanded. Note that this price change can either be ‘explicit’, for example when a subsidy is cut or a world price increase is reflected in local fertilizer prices, or ‘implicit’, where fertilizer is not available or is available too late for efficient use. Pinstrup-Anderson (1993) notes that the latter can have as strong an impact on fertilizer demand as can the former.

The price of other chemical fertilizers that are complements to or substitutes for the fertilizer in question can also have an effect on the demand for the fertilizer in question. There is agronomic evidence that nitrogen fertilizer (N) is more effective when applied in conjunction with phosphate fertilizer (P). Most crops do not respond well to N if there is a P deficiency – which is common in African soils. To the extent that the farmer knows that (itself a function of individual and collective assets in the form of extension and education access), a decrease in the effective price of P would increase the quantity demanded of N. The knowledge of the P-N interaction here is important – the time distribution of the P effect depends on the land and crop types, and tends to be uneven, and the effect is sometimes lagged. This is an important effect to study more, as P distribution programs are now becoming popular, as in the Senegal case, but little is known about how they affect farmer demand for nitrogen fertilizer. See for example Diagana (1999) for Senegal's P distribution program effects.

The own-price determinant dominates the current debate regarding fertilizer use in Africa, for two reasons. First, for one set of farmers, the recent removal of fertilizer subsidies and public marketing of fertilizer has increased the fertilizer price they face.[3] Second, for another set of farmers, fertilizer prices have continued artificially low because of the continuing large importance of fertilizer aid. Gerner and Carney (1998) point out that in 1990, almost one-third of fertilizer imports were financed by aid; for 21 African countries with small fertilizer markets, all fertilizer imports were financed by donors as aid.

3.6. The Relative Price of Output to Fertilizer, and Profitability

African farmers appear to be sensitive to the output price/fertilizer price ratio per se. There appears to be a consensus in research circles that the ratio needs to be well above 1 for farmers to use fertilizer. Heisey and Mwangi (1997) note that many observers contend that the marginal agronomic response must be at least twice the fertilizer:grain price ratio (in other words, the

[3] For example, Rusike et al. (1997) and Kelly et al. (1996) show for Zimbabwe and Senegal, respectively, that there was a marked correlation between fertilizer subsidy removal in the 1980s and a reduction in aggregate fertilizer use.

marginal rate of return on working capital invested in fertilizer must be at least 100 percent). For example, a farmer who believes that one kg of fertilizer can increase output by five kg may consider fertilizer use profitable when the output/fertilizer price ratio is as high as 2:1 – this would mean spending almost half the additional output to cover fertilizer costs, with the remaining half providing for fertilizer-related costs (extra labor for fertilizer application, weeding, harvesting, and the transaction costs of obtaining the fertilizer, plus an implicit risk premium) and potential profits. Despite this ‘observers’ consensus’, empirical evidence of farmers’ responses to fertilizer/output price ratios are rare. An example is Gaye and Sene (1994) in Senegal.

More generally, case studies have tended to show that farmers are responsive to the overall profitability of fertilizer use. For example, in Mali, Kebe et al. (1996) note that 80% of Malian fertilizer use is in the cotton zone, and mostly on profitable cotton and maize. They show that, as there was an increase in the profitability of maize due to the FCFA devaluation in 1994, there was a substantial increase in fertilizer use on maize. However, the results of the study were mixed. Although cotton profitability declined somewhat, cotton fertilizer demand was rather inelastic; fertilizer use on cotton did not decline in one study zone (Koutiala) where land constraints induce fertilizer demand (where fertilizer was indeed necessary for profitable production of cotton). But fertilizer use declined in another zone (Kadiola), where there is less land constraint.

A number of other studies show that fertilizer use is concentrated on profitable crops that are commercialized ("cash crops"). For example: (1) for Burkina Faso, Savadogo et al. (1995) show that the ratio of fertilizer use on cotton and maize to that on the less profitable and less yield-responsive sorghum and millet is a stunning 13 to 1; (2) for northern Ghana, al Hassan et al. (1996) find much higher fertilizer use on irrigated rice and hybrid maize than on subsistence grains and roots and tubers; (3) for Ethiopia, Demeke (1994) found that 70-80% of fertilizer is applied to teff, which has a more stable and higher price, and better yields vertisols, compared to other cereals.

Qualitative surveys (of perceptions and attitudes) also have tended to show that farmers conflate, using rough profitability calculations, the choices of crop and of fertilizer application. (E.g., see Enyong et al. (1998) for case study results in Burkina Faso, Mali, and Niger for maize and cotton.) Moreover, there is usually a confluence of crop profitability, yield response, and input and market access in the case of cash crops. This is explored further in section 5.

3.7. Prices of Complementary and Substitute Factors

Note that changes in the prices of complementary and substitute factors shift the demand curve of the factor in question.

The price of water. The (explicit) price of irrigation water is a potential determinant of fertilizer demand in the few irrigated areas of Africa (only 5% of African agriculture is irrigated). Adoption of irrigation increases fertilizer demand because irrigation: (1) water and fertilizer are production complements; (2) spurs adoption of high-value crops such as vegetables; (3) reduces the risk of farming. Hence, one generally observes high fertilizer use in irrigation schemes, such as the rice and horticulture areas of Mali (see Mariko et al. 1999). Of course, after the establishment of an irrigation scheme, an increase in the water charge would reduce fertilizer demand.

Likewise, when the "implicit price" of water drops when rainfall rises, and fertilizer demand increases. (This is the "price version" of the agroclimatic point made above, that fertilizer demand is higher in zones with better rainfall, all else equal).

The price of seed. The seed price affects the choice of crop variety, which in turn affects fertilizer demand depending on varietal yield response to fertilizer. The choice of seed is, of course, determined by both the seed price and by perceptions of the potential performance of the variety, given soil characteristics, rainfall, and so on. Hybrid maize seed tends to require fertilizer as a complement to be most effective. There is abundant evidence of the link between adoption of hybrid varieties and increased fertilizer demand among African farmers; see for example, Jha et al. (1991) for Zambia, or Rauniyar and Goode (1992) for Tanzania, or Smale et al. (1994). The effect is symmetrical – a fertilizer price increase reduces demand for hybrid maize seed. Where fertilizer subsidies have been removed, one observes some shift away from hybrids (see Rusike et al. (1997) for Zimbabwe and Zambia).

The price of organic matter. Another important set of prices are those of organic matter (OM), including manure, mulch, and so on.[4] From an agronomic perspective, NPK fertilizer and OM are complements.

Yet in theory (and in artificial situations such as field-station trials) OM could, in adequate quantities and in appropriate types, substitute for chemical fertilizer. This is a

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[4] It is not until recently that one observes a market price of manure in parts of rural Africa. Instead, more commonly one must consider the effective price of fertilizer, itself determined by (1) the cost of labor to collect and process the organic matter (such as collecting and transporting manure from area where the animals are penned at night, in the field), (2) access to pasture land (note that in Rwanda, disappearing pastureland has greatly increased the effective price of manure over the past two decades, see Clay et al. (1995)), and (3) household or village livestock holdings.

substitution that is commonly promoted in the environmentalist literature. However, in practice in a typical rural area in Africa, it is difficult or impossible to obtain sufficient OM to serve as a full substitute for inorganic fertilizer. Weight and Kelly (1998) calculate that it would take approximately 20 tons of OM to supplant 250 kg of urea on a hectare of sorghum. It would be very difficult for an African farmer to obtain these 20 tons.

There is, nevertheless, relatively little farm survey evidence concerning the sign or the magnitude of the coefficient on the effective OM price in determining fertilizer demand. An exception is Gladwin (1992), who finds in Malawi that manure availability has a positive effect on inorganic fertilizer demand (hence are complements) – those with greater livestock holdings used more fertilizer (in addition to the wealth effect). Her qualitative survey supported this interpretation. There is some evidence of substitution, however, where there is sufficient access to OM. Thompson (1987) found in Western Niger that farmers who do not use fertilizer do use OM (hiring herds of animals to 'park' on his farmland during the dry season, in exchange for cash or milk payments), while fertilizer users tend not to use this 'parking' practice.

The price of farm labor. In theory, and increase in the farm wage reduces farm fertilizer demand due to labor being required to acquire and apply fertilizer and handle the fertilizer-induced increase in weeds. In most systems the practical effect may not be great. However, in some systems, fertilizer mixing and application requires skilled labor, so the wage may have a significant effect. We have, however, not seen this directly empirically tested but some studies provide indirect evidence. Rusike et al. (1997) posited that an effect of labor costs for high-analysis fertilizer application by sprayer in large-scale horticulture in Zimbabwe. The causal direction could be the reverse. For Western Niger, Thompson (1987) showed that fertilizer users demand more labor for planting, weeding, and harvesting, increasing the implicit wage.

3.8. Variation in Prices and Non-price Conditions: Risk

Risk in crop production (weather, pests, disease) reduces fertilizer demand. This relationship was established in the investment literature (such as Newbery and Stiglitz 1981) as well as the farming systems literature. The key is that risk makes the payoff uncertain to the use of fertilizer. Risk aversion can account for reduction in fertilizer use of 20 percent or more below optimal application rates (Binswanger and Sillers, 1983). Irrigation investment can lower water access risk and increase fertilizer use.

Risk in product and input markets also reduces fertilizer demand. An example is that of uncertainty concerning delivery time of imported fertilizer. Moreover, wide bands between purchase and sale prices for crops (due to high market transaction costs and poor infrastructure) translates into autarchy (lack of commercialization), and reduction of incentive to use improved inputs such as fertilizer (de Janvry et al. 1991).

An increase in the price of formal crop insurance (the premium) in theory reduces fertilizer demand. But in practice in Africa, most crop insurance is purchased only by commercial largeholders where risk aversion is low and fertilizer central to the technologies used, such as in hybrid maize and horticulture and coffee/tea production in Kenya, Côte d’Ivoire, Zimbabwe, and South Africa.

However, the implicit price of informal insurance (the premium paid for "self-insurance") can be important to smallholder demand for fertilizer under most African conditions.

This link is explored for Burkina Faso in Sakurai and Reardon (1997). Greater income risk (unmitigated by self-insurance due to higher premiums, such as from entry barriers to income diversification activities off-farm) reduces fertilizer use. The exception is in smallholder cash crop schemes, which reduce the premiums for insurance for crop risk by forgiving debts for farmers hit by crop failure (Kelly, 1988, for Senegal).

Risk associated with uncertainty of land tenure, in theory, reduces fertilizer demand. The farmer's subjective "discount rate" here plays a role, in theory. If the farmer discounts heavily the future, that may lead to "soil mining" today and lack of use of long-run soil amendments. This is closely related to land tenure risk. However, the empirical evidence tends to show that the relationship between tenure uncertainty and the use of variable inputs is weak (for Senegal, see Golan (1990) and for Rwanda, Clay et al. (1998)). Land tenure uncertainty tends to have a stronger effect on formation of longer-term capital such as terraces.

4. Capacity for Fertilizer Demand

4.1. Access to Financial Capital

Wealth affects fertilizer demand in two ways. First, greater wealth lowers aversion to risk and thus increases the use of (risky) technologies like fertilizer. Second, as Heisey and Mwangi (1997) note, expenditures on fertilizer often represent an important part of total cash expenditures on farm inputs. Hence, access to cash is crucial. The main sources of this cash are as follows.

Access to Credit. Interest rates influence the effective price of fertilizer if the farmer has to borrow to buy fertilizer. There is strong evidence that credit policy influences fertilizer demand. For example, when credit subsidies were removed in Zimbabwe and Zambia, fertilizer use fell in smallholder areas (Rusike et al. 1997). Enyong et al. (1998) also show this in a qualitative survey of farmers in Burkina Faso, Mali, and Niger. In Malawi, Peters (1992) found that credit constraints caused by cuts in the smallholder credit system caused a substantial drop in fertilizer use (even though the relative price of fertilizer had not increased significantly). Falusi (1974) showed the importance of credit access to fertilizer demand by small farmers for Western Nigeria, as did Green and Ng'ong'ola (1993) for Malawi.

Cash crop sales. Jha and Hojjati (1993) found for Zambia that cash income, credit from cooperative membership, and education were very important to fertilizer acquisition. Hassan and Karanja (1997) found that farmers that grew tea and coffee, in addition to maize, used 5.5 kg more fertilizer on maize than those that produced maize without also growing a cash crop. A similar finding was made by Dione (1989) concerning cotton and maize production.

Nonfarm income. Nonfarm income is a very important source of cash for farm households in Africa. Reardon (1997) reviewed 28 case studies and found an average share of nonfarm income in total household income of 45 percent. The share in cash income, even in cash cropping areas, was often around two-thirds to three-quarters. There is evidence that nonfarm income is important specifically to capacity to purchase fertilizer. Three studies show this effect. Reardon and Kelly (1989) showed in Burkina Faso that the effect was important among households that did not have access to credit via cotton cropping. Green and Ng'ong'ola (1993) also showed this effect in Malawi (especially for those not producing a cash crop), as did Elkarib (1983) in Sudan.

However, in certain cases the effect is ambiguous. Nonfarm wage represents the opportunity cost of labor time and cash in agriculture, it increases (all else equal), nonfarm labor and capital formation look relatively attractive compared to labor and capital formation in the farm sector – which implies competition for funds for fertilizer. This is potentially important competition with farm investments in general, as for example Christensen (1989) shows in Burkina Faso.

4.2. Access to Human Capital and Information

There is abundant evidence that extension has an important impact on fertilizer use. For example, Thompson (1987) shows this in Western Niger. Heisey and Mwangi (1997) found that extension contacts were important to joint adoption of hybrid maize and fertilizer in East Africa. Inter-farmer communication, perhaps spurred by farmers' organizations and "social capital", further reduces the cost of information. Enyong et al. (1998), in their qualitative surveys in the Sahel, found that inter-farmer communication was a key determinant of fertilizer use. This communication might be formalized through demonstration projects, such as the SG 2000 project in northern Tanzania over three years (Nkonya et al.1997). Thompson (1987) showed in Western Niger that cooperative members were five times as likely to use fertilizer (as non-members); the respondents explained that this was due to information access.

Formal education also appears to influence fertilizer use (for Kenya by Pinckney (1994) and by Nkonya et al., 1997 in Northern Tanzania). However, there is mixed evidence in the literature as to the relative statistical importance of the effect, controlling for other factors.

Moreover, the effect may be indirect, working through adoption of hybrid maize and fertilizer together, and commercialization.

4.3. Access to "Quasi-fixed Capital" Such As Equipment

Quasi-fixed capital is, in theory, important to "divisible technology adoption" via its effect on the reduction of risk of the divisible technology (Feder 1982). There are several illustrations of this for fertilizer. One example is that of the acquisition of an adequate/appropriate sprayer/applicator for high-analysis fertilizer (see Rusike et al. (1997), for Zimbabwe). Another such example is on-farm water control infrastructure (irrigation, terraces, and bunds). The payoff in terms of returns and risk reduction to combined use of these measures and fertilizer has been established in field trials (see Matlon and Adesina, 1997). It is known to form part of farmers' knowledge in various parts of Africa (see Ndiaye and Sofranko (1988) for Senegal, and Clay et al. (1995) for Rwanda).

5. Categorizations of Cases: Incentive and Capacity "Packages"

For a given crop, there can be substantial variation in institutional and market arrangements. This variation can affect the collective capital, risk, transaction and credit costs, and other variables conditioning fertilizer demand. Here we contrast certain common combinations of crop, agroclimatic zone, and market/institutional arrangements that are associated with higher fertilizer use, with those associated with lower use. The characteristics of those combinations can be expressed in terms of combinations of incentives and capacity levels.

5.1 Cash Crop Production Areas

Cash crop schemes (with the producer-market interface mediated by contracts between agroindustrial firms (public or private)), or simply dynamic food product markets linked to urban or export markets (without the mediation of contracts) tend to be production and market situations of low price risk and high profits – relative to subsistence food cropping and selling in rural spot markets that tend to be thin. Relative to subsistence crops, cash cropping is usually located in fertile and well-watered areas with adequate road infrastructure. Moreover, especially in schemes, information costs for fertilizer use are low due to company-supplied extension, and input-credit interest rates are low due to company-supplied credit. Cash for fertilizer acquisition is relatively plentiful from crop sales or nonfarm activity that is a spin-off from the cash crop economy.

Hence, fertilizer demand is usually far higher in these cash cropping areas than in other areas in the same agroclimatic zone, and fertilizer use is much higher on the cash crops than on subsistence crops grown by cash cropping farmers (although there are spillover effects). Examples were discussed in previous sections. Heisey and Mwangi (1997), and Gerner and Carney (1998) showed that in the mid 1970s in Africa, most fertilizer was mainly used on traditional cash crops (e.g., cotton, sugar, tea, cocoa, coffee), and still is in some areas (such as on cotton in West Africa). However, for Africa as a whole there was a shift to fertilizer on maize, at least in the 1980s, especially in Southern Africa. There were exceptions however, such as teff in Ethiopia, wheat in Sudan, and non-cereal export crops in Kenya.

However, as Rusike et al. (1997) note, an important reason for the shift to fertilizer use on maize is that governments had created special conditions (via subsidies, public marketing schemes, cheap credit, and extension) that actually approximated on a large scale the traditional cash crop schemes. These policies required substantial – and fiscally unsustainable – outlays of funds by cash-strapped governments. When structural adjustment forced the elimination or reduction in these outlays, either fertilizer prices for maize rose which involved large reductions in fertilizer use at least by smallholders (e.g., in Zimbabwe and Zambia), or the continued propping up of fertilizer use on rainfed cereals via massive fertilizer aid (as noted above). In the areas where fertilizer on maize has been cut back, there has been a shift back to the majority being used by larger farmers mainly on export crops (traditional or nontraditional).

5.2. Areas of low use and/or areas of projects

Relatively low demand for fertilizer is found in situations, as is predictable from the discussion above, where water is scarce and rainfall unstable (as in the semi-arid zones), the effective price of OM is high (as in the high-density areas such as the Senegal Peanut Basin or Rwanda), there are low and variable crop prices, and expensive credit and transport (with implications for effective fertilizer prices). The difference between fertilizer use levels in this situation and in the above three situations is often quite striking, as noted in section 3.

Government or NGO projects, such as Sasakawa Global 2000, have tended to target these areas. The projects have many of the same characteristics of the cash crop schemes, except that they often focus on (what were formerly) subsistence crops, involve an implicit subsidy for transport and transaction cost reduction (company schemes also lower such costs, but because of economies of scale, not because of subsidies), often are designed to have some demonstration effect, and are not viewed as "permanent." Again, the use of fertilizer tends to be much higher in the project zones, mainly because the input, risk, transport, and information costs are much lower than outside the project zone.

However, recent history shows that where the State marketing interventions – and by extension one could posit this for the targeted project schemes – were withdrawn (following structural adjustment programs), there was a clear drop in fertilizer demand, especially in the risky smallholder zones, as explained above – unless there were sustained changes in the incentives and capacity of poor farmers.

6. Practical Data Problems of Estimating Farm Household Fertilizer Demand in Africa

Much of the discussion of trends in fertilizer demand in Africa has taken place with aggregate data, at the country level. With aggregate data one cannot begin to sort out the above issues regarding the relative importance in a specific zone of the various determinants, because one is not able to control for the local (meso) context and differences over households (micro level). See Naseem and Kelly (1999) for a discussion of the problems of modeling fertilizer demand in Africa at the meso and country levels.

For statistical research on fertilizer demand determinants in these specific contexts, one needs farm data. However, many sources of farm-level data in Africa present measurement problems for such research.

First, it is common for household fertilizer use to be poorly measured in national-level surveys in Africa. Ideally one would want to know the type of fertilizer applied (i.e., NPK content), the quantity, the crop to which it was applied, and the area treated. It is unusual to find all these details in farm surveys, particularly in national surveys. One frequently encounters studies that merely show the percentage of land on which some fertilizer was used (such as in the MINAGRI national survey in Rwanda, see Clay et al., 1995) – or that do not specify the type of fertilizer used, or do not indicate on which crops the fertilizer was applied.

Second, it is common for the determinants in the fertilizer demand equation to be poorly specified and measured in African survey-based studies. An important problem is omitted variable bias, as there may be no data on land improvements (e.g., bunds), application of organic matter (OM), or land quality variation. Even more rare is information on household characteristics such as access to nonfarm income, risk (such as differences in inter-temporal price variability between zones), and prices actually paid (gross or net of transport costs) for inputs or received for outputs. Third, most fertilizer use survey data comes from cross-section studies. One rarely finds a survey that revisited a zone and/or set of households over a long enough period to capture time-series changes in prices of outputs or inputs, and thus to capture inter-temporal risk. Hence, one must infer from cross-sectional (i.e., spatial) variation in prices or transport costs – a method which has its limitations, especially if one is trying to study the impacts of larger discrete changes such as removal of subsidies or a large currency devaluation. Moreover, few surveys cover more than a zone or two, hence may not even provide enough spatial variation.[5] Given poor measurements on prices and lack of sufficient zone or price variation, it is hard to estimate price formation equations to link specific policy changes (and non-policy changes) to the price variation in a demand function, and thus to establish a rigorous link between policy change and its impacts on fertilizer use.

[5] For example, in Savadogo et al., 1995 in Burkina Faso, fertilizer had to be treated as quasi-fixed capital in the profit function because of insufficient spatial and temporal variation.

Policy researchers should be aware of the above potential defects of data they may have access to or studies on which they would like to rely. Moreover, design of future survey studies should seek to avoid those pitfalls.

7. Implications

Several points stand out. First, the discussion emphasized that farmers need profitable, commercialized crops (whether food or nonfood products) to have the inducement to use fertilizer to raise productivity. That profitability issue means that output market development is as important as input market development in spurring productivity-enhancing fertilizer use.

Second, the discussion highlighted the importance of "capacity variables" – financial, human, and physical capital, private and collective – in the determination of fertilizer demand in African farming.

Third, it is common in the African fertilizer debate for economists and agronomists to talk in parallel discussions, with the first emphasizing opportunity costs and prices, and the latter appropriate technology options. These discussions do not do well hermetically sealed from each other: our discussion showed that the technology/crop combination is a crucial shifter of demand, but given the technology and crop, an array of prices and capital holdings determine demand.

Fourth, from our discussion one may infer that the unisectoral perspective of the current fertilizer policy debate is inadequate – one needs a multisectoral perspective. Nonfarm sector conditions, such as entry barriers to nonfarm activities and wage rates, potentially condition the fertilizer adoption decision. This is worrying because rural nonfarm income tends to be poorly distributed in Africa (see Reardon 1997). The combination of the latter, plus the removal of public credit schemes, makes the dearth of cash for fertilizer purchase an important demand constraint for fertilizer.

Fifth, the inclusion of risk in the discussion highlighted the importance of looking beyond levels of cost and profitability to variations in returns – hence risk. The policy debate has focused, however, on average returns (such as how a devaluation or subsidy cut affects fertilizer costs or cropping returns) – but not on the variability over years of those returns. But policies that raise the average profitability or lower the cost of fertilizer use do not necessary induce adoption, if risk remains high.

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	Table 1: Categories of Determinants of Chemical Fertilizer Adoption by Farm Households
	Incentives
1	shifter: perceptions of agronomic responsiveness of crop variety to fertilizer
2	crop output prices
3	fertilizer prices
4	prices of other inputs (complements to and substitutes for fertilizer)
5	Proximate conditioners of effective prices of outputs and inputs (such as transport costs)
6	risks
	Capacity
7	household quasi-fixed and fixed capital
8	collective capital