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Impacts Of Inventory Credit, Input Supply Shops, and Fertilizer Microdosing in the Drylands of Niger

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ABSTRACT

This study investigated the impacts of access to inventory credit, input supply shops, fertilizer microdosing demonstrations, and other factors on farmers' use of inorganic fertilizer and other inputs in Niger and on crop yields. We found that access to inventory credit and input supply shops has increased the use of inorganic fertilizer and seeds and that microdosing demonstrations have increased the use of inorganic fertilizer. Ownership of traction animals and access to off-farm employment have also contributed to the use of inorganic fertilizer, while larger farms use less fertilizer and labor per hectare.

The impacts of these interventions and technologies depend on the crop mix. Inorganic fertilizer has a positive impact on millet and millet–cowpea yields when applied using microdosing, with an estimated marginal value-cost ratio greater than 3 for those crops indicating significant profitability. By contrast, microdosing has a negative impact on yields of the millet–sorghum–cowpea intercrop, suggesting that microdosing should not be promoted when sorghum is part of the crop mix. However, better access to input supply shops has contributed to higher yields of the millet–sorghum–cowpea intercrop.

The predicted effect of inventory credit on farmers' income as a result of increased inorganic fertilizer use is an increase of 5,000 to 10,000 FCFA per hectare (about US$10 to US$20 per hectare in 2005) in millet or millet–cowpea production. Similarly, being 10 km closer to an input supply shop is predicted to increase farmers' income by 3,200 to 4,500 FCFA per hectare. These benefits do not take into account the impacts of the interventions on seeds or other inputs, which are also generally positive. The positive impacts are linked to the use of fertilizer microdosing, which has increased the productivity of fertilizer use in millet and millet–cowpea production, indicating synergies among the various interventions. They are also linked to these specific crops, because we found less favorable impacts of these interventions for the millet–sorghum–cowpea intercrop and for peanuts.

Other interventions that could help to boost the use of inputs and productivity include promotion of improved access to farm equipment and traction animals and promotion of higher-value crops such as hibiscus. Further research on these topics appears warranted. Research on the implications of interventions on land degradation would also be useful.

Keywords: fertilizer microdosing, inventory credit, *warrantage* (the French term for inventory credit), input supply shops, drylands, Niger, Sahel

ABBREVIATIONS AND ACRONYMS

DAP	Diammonium phosphate fertilizer; minimum 18 percent nitrogen (N), 46 percent phosphate (P_2O_5) by weight
FAO	Food and Agriculture Organization of the United Nations
FCFA	Common currency in francophone West Africa (roughly 500 FCFA = US$1 for most of 2005)
GMM	Generalized method of moments
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
K	Potassium
N	Nitrogen
NGO	Nongovernmental organization
NPK	Compound inorganic fertilizer containing nitrogen (N), phosphorus (P), and potassium (K); minimum of 15 percent each of N, P_2O_5 and K_20 by weight
OLS	Ordinary least squares
OPVN	Office des Produits Vivriers du Niger
P	Phosphorus
SSP	Single super phosphate fertilizer; minimum 16 percent water soluble P_2O_5 by weight
TSP	Triple super phosphate fertilizer; minimum 42 percent water soluble P_2O_5 by weight

1. INTRODUCTION

1.1. Background and Rationale

Niger is a vast land-locked country in West Africa with a total area of 1,267,000 km^2 and a population of about 11 million in 2001. It is one of the poorest nations on Earth, ranking 177 of 177 nations on the Human Development Index. More than three-fifths of households live below the international poverty line of US$1 per day, life expectancy is only 49 years, the literacy rate is only 14 percent, and most households lack access to potable water or proper sanitation (UNCTAD 2002). Eighty-six percent of the poor live in rural areas. Nationwide, 40 percent of children are underweight and undersized for their age (Republic of Niger 2002).

More than 90 percent of the labor force is employed in agriculture, which is predominantly subsistence oriented, dependent on the dry and drought-prone climate and mostly sandy soils, and focused on production of a few basic dryland food crops (mainly pearl millet, sorghum, and cowpeas) and livestock. Two-thirds of the country is in the Sahara Desert, and only one-eighth of the land is considered arable. Pastoralism is the main activity in the Sahelian zone south of the Sahara, while agropastoralism and food crop cultivation dominate in the higher-rainfall Sahelo Sudanian and Sudanian zones in the south. The population growth rate is the highest in the Sahel (3.3 percent per year). Agricultural production growth is lagging behind population growth, and food insecurity remains widespread. Most small-scale farmers still fail to produce enough food to meet household requirements.

Traditionally, clearing additional land for cultivation was the primary means of increasing agricultural production used by Nigerien farmers (Abdoulaye and Lowenberg-DeBoer 2000). Now, new cropland is becoming scarce (Charlick 1991; Ramaswamy and Sanders 1992). Since 1986, pearl millet yields have been declining at a yearly rate of 1 percent, even though pearl millet remains the main staple, accounting for 72 percent of total grain cereal area and 80 percent of cereal grain production (FAOSTAT database 2005). Low and declining productivity of millet and millet-based crop systems is largely a result of the harsh and variable climate and poor physical and chemical characteristics of the predominantly sandy soils, exacerbated by limited use of inputs and land degradation. Because of rapid rural population growth, the per capita cultivated area has been declining. Consequently, the length of the fallow period has declined, forcing farmers to cultivate more marginal lands. Increases in production have resulted from expansion of cultivated area rather than increased productivity.

Soils in Niger are generally sandy, low in organic matter and moisture-holding capacity, and deficient in both phosphorus (P) and nitrogen (N), although P tends to be more limiting to crop productivity (Abdoulaye and Sanders 2005). Crop response to N is minimal until P requirements have been satisfied (Traore 1974). However, use of fertilizer is very limited. On average, farmers in Niger apply less than 1 kg/ha of plant nutrients via inorganic fertilizer, compared with 200 kg/ha in western Europe, and insufficient quantities of organic material, resulting in depletion of soil nutrients. Soil nutrient mining in Niger was estimated to average 15 kg/ha of N, 2 kg/ha of P, and 11 kg/ha of K per year, equivalent to an annual loss of about 440 kg of millet grain and 1,860 kg of straw per hectare (Buerkert and Hiernaux 1998; Smaling et al. 1997). As a consequence, yields are low, typically less than 500 kg/ha.

Increased input use per hectare is needed to increase agricultural production in these millet-based farming systems. This depends on the development and availability of new technologies and on institutional reforms to improve input supplies to farmers and stimulate market opportunities. In the last 30 years, fertilizer recommendations made by scientists and extension agents have rarely been applied by farmers, often because of poor access, unavailability, and/or the high cost of mineral fertilizers (Abdoulaye and Lowenberg-DeBoer 2000). Cost-effective fertilization strategies that are affordable to cash-poor farmers have been lacking.

Experiments with pearl millet were conducted in southwestern Niger from 1994 to 1996 using low levels of fertilizers applied at sowing time. Results showed that application of 4 kg/ha of P at the side of the planting mound provided the highest additional income to smallholder farmers (Buerkert and Hiernaux 1998). This technology requires 20 kg/ha of diammonium phosphate, or DAP (18-46-0) fertilizers or 60 kg/ha of NPK (15-15-15) for a planting density of 10,000 planting mounds per hectare—that is, only about one-fifth to one-third the amount previously recommended by scientists and extension agents.[1]

Production risks, poor market and credit access, unstable output prices, lack of awareness of profitable technologies and use rates, and the low availability and high cost of inorganic fertilizer are major barriers to the uptake of fertilizer technology in Niger. To help address these constraints, Projet Intrants, a project of the Food and Agriculture Organization of the United Nations (FAO), initiated a large development program in four Nigerien regions in 1999: Tillabery, Maradi, Zinder, and Tahoua. The main objectives of the program are to increase farmers' access to fertilizers of high quality, improve farmers' awareness and knowledge of the efficient use of fertilizers, improve farmers' liquidity position, and empower farmers' associations and increase their bargaining power in negotiating fertilizer contracts with traders.

Currently, little is known about the levels of diffusion of targeted applications of fertilizers or the impact of input supply shops and inventory credit schemes, such as those promoted by the FAO Projet Intrants, on farmers' access to and use of modern inputs and on agricultural productivity. This report addresses those issues.

1.2. Objectives of the Study

The key issue that motivated this study is whether and how the initial success in millet fertilization in Niger can help to stimulate a pathway of sustainable development. The specific objectives of the study include the following:

1. Identify the key factors that determine input use (labor, seeds, organic, and inorganic fertilizers) and crop yields in different production systems of Nigerien rainfed agriculture.
2. Assess the impacts of inventory credit, development of input supply shops, and promotion of fertilizer microdosing on input use and crop yields in Niger.

The report is organized as follows: Section 2 presents a description of the study region and the major changes in the policy environment influencing fertilizer use. Section 3 describes the technologies and programs being investigated (fertilizer microdosing, input supply shops, and inventory credit) in more detail. Section 4 presents the methodology of data collection and descriptive results of the survey. Section 5 presents the conceptual framework, empirical methods, and hypotheses tested using econometric methods. Section 6 presents the econometric results, and Section 7 discusses conclusions and implications for policies, programs, and further research.

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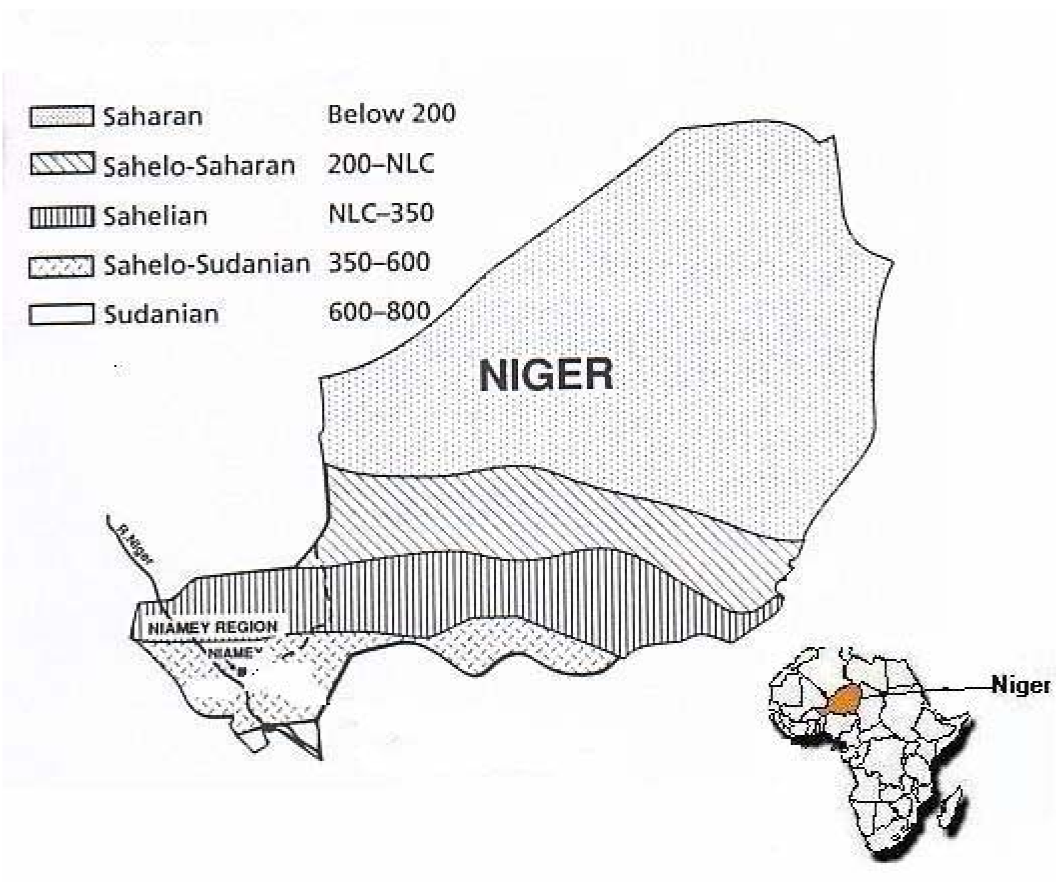
[1] The composition of macronutrients (N, P, and K) in inorganic fertilizers are expressed as the percentage by weight of the fertilizer made up of elemental N, P_2O_5, and K_20. For example, DAP contains a minimum of 18 percent N and 46 percent P_2O_5, by weight, while NPK contains a minimum of 15 percent N, 15 percent P_2O_5, and 15 percent K_20 (http://chemicalland21.com/industrialchem/inorganic/NPK.htm). Because NPK (15-15-15) contains only one-third as much phosphorus per kilogram as DAP, three times as much NPK fertilizer is needed to apply the same amount of phosphorus to a crop.

2. DESCRIPTION OF THE STUDY REGION AND POLICY ENVIRONMENT

2.1. Biophysical and Socioeconomic Environment

Agricultural land is located mainly within a 150-km-wide band in the south of the country (Figure 1). Dryland crops are grown in this band in the rainy season (June to October). The crop-growing region extends from the Sahelian zone in the north (where annual rainfall averages less than 350 mm) to the more favorable (for crop agriculture) Sudanian zone at the extreme south of the country (where annual rainfall averages between 600 and 800 mm). Agriculture in Niger is mainly rainfed, although about 60,000 ha were under irrigation (mainly paddy rice) in 2000 (FAOSTAT database 2001). The major rainfed crops are millet, sorghum, and cowpea; other rainfed crops include peanuts (groundnuts), maize, hibiscus, and Bambara nuts.

Figure 1. Agro-ecological zones in Niger



Source: Adapted from Sanders et al. (1996)

Note: NLC = northern limit of cultivation. The isohyets are given in millimeters at 90% probability.

This study was undertaken in the regions of Dosso, Maradi, Tillabery, and Zinder in Niger, which are mainly in the southern Sahelian, Sahelo-Sudanian, and Sudanian agro-ecological zones, where crop production is most feasible (Figure 2). Agriculture differs across these regions as a result of differences in rainfall, soils, population density, and access to markets, services, and assets.

Figure 2. The study sites

Source: ICRISAT GIS Laboratoy, Niamey

Most soils in the agricultural zone of Niger are sandy with light texture. However, some heavy clay soils can be found along the Niger River, in other river valleys in the Dosso and Tillabery regions, and in the south of the Maradi region along the *goulbi* (Temporary River). Most of the agricultural area in Niger is quite flat, with relatively small plateaus bordering the river and some valleys.

Of the four study regions, Maradi and Dosso are the most densely populated (Table 1), mainly because they are in the higher-rainfall zones of southern Niger and are relatively close to urban centers in Nigeria. Tillabery and Dosso are close to Niamey, the capital city. Of the four regions, Zinder is the most remote from markets.

Table 1. Characteristics of the study regions

Item	Dosso	Maradi	Tillabery	Zinder
Area (1,000 km^2)	33.8	41.8	97.3	155.8
Population in 2001 (in millions)	1.5	2.2	1.9	2.1
Population density (persons/km^2)	44	53	19	13
Annual population growth rate, 1988–2001 (%)	3.05	3.73	2.75	3.03
Average annual rainfall (mm)	400–900	400–800	300–700	200–700

Source: Republic of Niger (2005) for population data.

The region of Dosso, located in southwest Niger, accounts for 14 percent of the total population of Niger (Republic of Niger 2005). The climate is mainly the Sahelo-Sudanian type, with annual rainfall averaging between 400 and 900 mm. Soils are mainly sandy in two-thirds of the region, with clay soils in less than 10 percent of the region. There are hydromorphic soils located in the river valleys, very rich in organic matter (Danguiwa 2000). Zarma, Maouri, and Peulh are the main ethnic groups. The main rainfed crops grown are millet, sorghum, cowpea, peanut, and Bambara nuts. Irrigated crops such as rice, vegetables, and fruit trees are grown in the river valley and floodplains. Major crop associations include millet–cowpea, followed by millet–sorghum–cowpea, millet–sorghum, and millet–cowpea–sesame.

The region of Maradi, located in the center of southern Niger, accounts for 20 percent of Niger's population. The climate is the Sahelian type in the north and Sahelo-Sudanian in the south, with annual rainfall ranging from 400 to 800 mm. Hausa, Peulh, and Touareg are the main ethnic groups. Probably because of better access to markets and relatively favorable production conditions, population growth is more rapid in Maradi than in the other regions. Maradi is among the highest crop production regions in Niger. Many farmers are exposed to and are using modern technologies because of numerous interventions from rural development projects and nongovernmental organizations (NGOs) during the last 30 years. More than 50 percent of households in Maradi are equipped with animal traction, a higher share than in other regions. Millet/cowpea/fallow is the major production system. Millet and sorghum remain the major cereal crops. Peanut, sesame, and cowpea are the major cash crops. The importance of vegetable crops is growing rapidly.

The region of Tillabery is located in southwestern Niger and accounts for 17 percent of the total population. The climate is mainly Sahelian, with annual rainfall ranging from 300 to 700 mm. Crop production dominates in the southern part of the region, while agropastoralism and transhumant pastoralism are common in the drier northern parts of the region. The soils are mainly sandy, except in river valleys and floodplains. Numerous projects promoting land rehabilitation and sustainable land management have operated in this region during the past three decades, contributing to the adoption of various land management practices (Pender and Ndjeunga 2008).

The region of Zinder is located in south-central Niger and accounts for 19 percent of the country's total population. Rainfall is somewhat lower in Zinder than in the other study regions, averaging 200 to 700 mm annually. The soils are mainly sandy or saline. Fewer government or NGO projects promoting land management technologies have been initiated in Zinder than in the other study regions (Pender and Ndjeunga 2008). Nevertheless, substantial increases in tree cover have occurred in Zinder in the past 20 years as a result of farmer-managed natural regeneration of trees, as well as some project interventions (Adam et al. 2006; Pender and Ndjeunga 2008).

Intercropping, involving three crops or more (two cereals and a legume such as millet, sorghum, cowpea, or peanut), is more common in Maradi and Dosso because these regions have higher rainfall and heavier soils than the other two regions, enabling farmers to grow a more diverse crop mix. Southern Maradi and Dosso (to a lesser extent) are the regions where rainfed crop production is the most intensive, with greatest use of animal traction and external inputs. These regions also benefited in the past from the availability of subsidized fertilizer from Nigeria. Farmers in these two regions are thus expected to use more inorganic fertilizer than are farmers in the Tillabery and Zinder regions.

2.2. Policy Environment

Agricultural policies have evolved through four main phases in Niger. After independence in the early 1960s, industrialization of the economy was the main objective of the government, and the country engaged in import substitution with the creation of several local industries. Agriculture was largely neglected except for export crops such as peanuts and cotton. Fertilizer distribution systems targeted export crops because of the need to generate the foreign exchange earnings necessary for the development of other sectors of the economy. Agricultural research on food crops was mainly conducted by a French research agency, and extension services were concentrated on promoting peanut production. During the period, marketing boards were created and agroindustries developed, including groundnut oil refineries and state-managed rural cooperatives. This policy was supported by rural development projects.

Following the unprecedented drought of 1970–1973, the primary government objective shifted to ensuring food security and self-sufficiency. Rural production projects were the main government focus. Many irrigation projects were established and managed by the Office National des Amenagements Hydro-Agricoles. A government-controlled agency, the Centrale d'Approvisionnement du Niger, sold subsidized inputs (fertilizers, insecticides, agricultural equipment). To address seed constraints, the United States Agency for International Development developed a large project to supply the seed of food security crops, such as millet, sorghum, and cowpea, to farmers and to reinforce the research capacity of the Institut National de Recherche Agricole du Niger, which was created in 1975. The policy was more interventionist in product markets. The Office des Produits Vivriers du Niger (OPVN) was given a monopoly over cereal trade until the market liberalization period (Abdoulaye 2002). This period also marked the beginning of the era of large integrated rural development projects, such as Projet Maradi, which had a significant impact on agricultural technology adoption in the Maradi region.

The market liberalization period began in the early 1980s. Market reforms were started at this time but not fully implemented.[2] In particular, the government retained its direct involvement in the cereal markets. In the 1990s, more pressure from the International Monetary Fund and the World Bank led to the implementation of the food security program, under which the role of the OPVN was reduced from that of having a monopoly on trading cereals to one of managing a buffer stock to regulate prices. Later, the OPVN's role was further limited to managing a small food security stock of 40,000 tons of millet (3 percent of total production) and a price information system (Abdoulaye 2002; Hamadou 1999).

The 1994 FCFA currency devaluation was perhaps the most significant policy change used to correct trade account deficits in West Africa as a whole. Two effects were expected: the increased prices of imported goods and services would increase the demand for domestically produced commodities and reduce imports, and the increased supply of internationally tradable goods and services would increase export revenues. Unfortunately, the major inputs essential to increase crop productivity are imported, and their prices also increased as a result of devaluation and reduction of fertilizer subsidies in Nigeria. The combined effect of currency devaluation and subsidy reduction led to a very large increase in input prices.

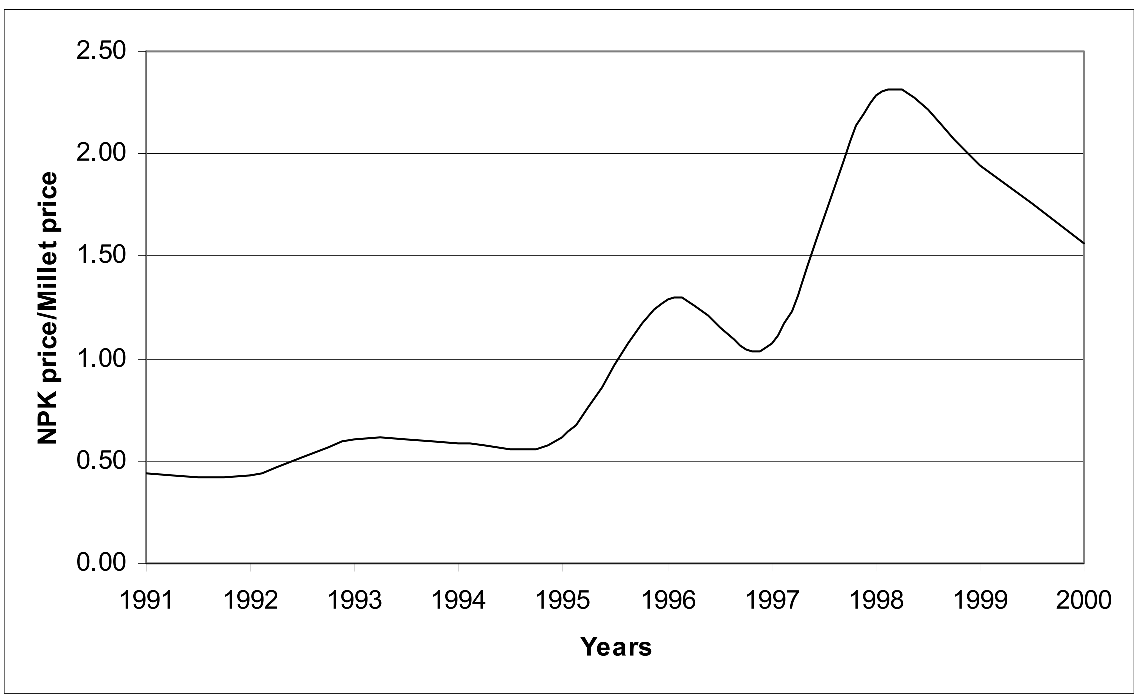
[2] The reform package included privatization or liquidation of most state-owned companies.

In 1996, the price of inorganic fertilizers increased four to five times from their initial level before currency devaluation and removal of subsidies (Evéquoz and Guéro 1998).

On the product market side, output prices did not increase as much as input prices because of government interventions; imports from neighboring francophone countries and successive devaluations in Nigeria (an important trade partner for Niger). As a consequence, the price of fertilizer relative to the price of millet more than tripled during the 1990s (Figure 3). This trend has hindered intensification of Nigerien agriculture, especially fertilizer use. In addition, the government policy of maintaining output prices low even in a period of high input prices has further discouraged farmers from intensifying and increasing crop productivity. As a result, many farmers have shifted from being net food suppliers to being net buyers.

Most recently, policy has focused on poverty reduction programs. Development in the rural areas is now viewed as encompassing broader improvements in livelihoods, including improved supplies of basic services such clean water, electricity, and health services. Agriculture and microfinance programs (many targeting women) are now the main focus of the rural development programs in Niger. The Niger government has also started (on a limited scale) a fertilizer subsidy program. In 2005, a 50-kg bag was being sold for 10,000 FCFA instead of the market price of 13,000 to 14,000 FCFA. For now, the primary beneficiaries of this price reduction are farmers located near urban areas, but the program is expected to have an effect on other regions in the future. Although the government has received some commendation for this program, opponents argue that the fertilizer subsidy is not sustainable because the government does not have the resources to continue it and that this hinders efforts to develop an input market.

Figure 3. Ratio of fertilizer price to millet price



Source: Abdoulaye and Sanders, 2005.

3. RESEARCH AND DEVELOPMENT PROGRAMS TO IMPROVE INPUT USE IN NIGER

In this section, we discuss the development of a fertilizer microdosing technology, input supply shops, and inventory credit in Niger in more detail.

3.1. Microdosing Technology

To develop cost-effective fertilization strategies that are affordable to cash-poor farmers, on-station work to develop a microdosing technology was undertaken between 1994 and 1996 by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the University of Hohenheim (Germany), and the International Fertilizer Development Center. These experiments involved the use of low levels of fertilizers applied to the planting mound at sowing time. Results showed that placed application of 3, 5, and 7 kg/ha of P led to significant productivity gains of 72 percent, 81 percent, and 88 percent, respectively. Partial budgeting analysis showed that the profitability of P application, defined as marginal income gains per unit of fertilizer, was highest for the placement of between 3 and 5 kg/ha of P. Further refinements show that 4 kg/ha of P applied to the mound at the time of planting provided the highest additional income (Bationo et al. 1997; Buerkert and Hiernaux 1998).

On-station results were validated through on-farm trials undertaken by the FAO Projet Intrants and other development partners at early stages of dissemination with backstopping from ICRISAT. Since 1996, more than 5,000 on-farm trials and demonstrations have been carried out with farmers throughout Niger. These trials were designed to evaluate the biophysical performance of the technology and to gather important diagnostic information about farmers' assessment of the technology. Productivity gains were estimated to average more than 50 percent over the local practice, with value-cost ratios ranging from 2 to 4.

Further refinements of the technology consisted of using a different type of fertilizer with higher P concentration and using DAP instead of NPK. No significant yield differences were found between the NPK and DAP applications (for the same level of P application). However, significant cost reductions resulted from using DAP instead of NPK, estimated at 7,800 FCFA per hectare (US$16 per hectare), leading to higher benefit-cost ratios using DAP.

As originally developed by agricultural researchers, microdosing meant applying small quantities of fertilizer with the seed in the planting hole. However, because of labor constraints, farmers have modified this application method. To save labor, farmers usually mix their seed with the fertilizer and then plant them together. Other variants include applying the fertilizer directly to the plant after it emerges, allowing farmers to maximize fertilizer uptake by the plant. This side dressing of inorganic fertilizer is farmers' attempt to reduce the quantity applied while increasing the efficiency, because the fertilizer is applied directly to the plant and usually covered by soil. In this paper, the term *microdosing* is be used to mean any application of a small quantity of inorganic fertilizer, whether applied directly in the hole during planting, mixed with seed before planting, or applied after the plant emerges.

The most common method of applying inorganic fertilizer to millet in western Niger consists of mixing the seed and inorganic fertilizer (most often NPK) before planting. For this type of application, the quantities applied are generally small. Abdoulaye and Sanders (2005) estimated application rates of 2 to 8 kg/ha in the Fakara plateau of western Niger (in the Tillabery region). In Maradi and parts of Zinder, application directly to the plant after it emerges is most common.

Because of the positive research results for fertilizer microdosing, the FAO Projet Intrants decided to use the microdosing technology as an important component of its strategy to improve the use of mineral fertilizer in Niger. Despite the economic advantages of this technology, its uptake continues to be constrained by access, affordability, and availability of fertilizers.

3.2. Input Supply Shops

In 1999, the FAO Projet Intrants designed and initiated the establishment of a network of input supply shops and inventory credit schemes to (1) increase farmers' access to fertilizers at affordable prices, (2) improve the financial liquidity of farmers through inventory credit (*warrantage*) schemes, and (3) improve farmers' income from sales of their produce at the end of the dry season and by their engagement in a range of income-generating activities during off-seasons. Through an effective partnership and collaboration with farmers' associations, the project established input supply shops throughout the country (see Figure 2). Input supply shops are cooperatives operated and managed by local communities to sell inputs to local farmers. They also serve as advisory centers for the use of inputs. In many cases, they are linked to microcredit organizations. These shops repackage inputs in small quantities, allowing farmers to purchase small quantities, such as 500-gram or 1-kg packages of fertilizer or improved seed.

By 2005, 217 input shops had been established throughout Niger, with 78,348 affiliated members (FAO Projet Intrants 2005). Twenty-six input shops were established in the region of Dosso, 62 in Maradi, 19 in Tillabery, and 41 in Zinder. These shops supply inputs such as seeds, fertilizers, phytosanitary products (insecticides and fungicides), and veterinary products to affiliated and nonaffiliated members of farmers' associations. These input shops belong to unions of farmers' associations (47 percent of shops), individual farmers' associations (43 percent), or others (10 percent). Some 13,011 farmers are affiliated with input shops in Dosso, 1,479 farmers in Maradi, 9,472 farmers in Tillabery, and 4,226 farmers in Zinder (FAO Projet Intrants 2005). Outside financing from the project helps farmers' associations to establish the shops and establish the initial inventory. About one-fourth of the cost of constructing input shops and nearly one-half of the initial capital stock were financed by farmers' associations. The profits from sales of inputs are returned to a revolving fund used to finance expansion of the shops, their capital stocks, and activities. The initial size of revolving funds averaged about 400,000 FCFA, and by 2005 these averaged about 1 million FCFA (FAO Projet Intrants 2005).

Fertilizers account for most of the sales in these shops. The number of sales and the quantity of fertilizers purchased by farmers from these shops has steadily increased. In 2004, a survey of 16 monitored input shops showed that 55 percent of sales transactions were for fertilizers, and about 52 tons of fertilizers were sold in those shops. The average quantity of fertilizers purchased per sale ranged from a low of 0.5 kg to a high of 35 kg. This variation is largely explained by the involvement of some farmers in producing cash crops, for which larger quantities of fertilizer are sometimes purchased. Many villages are connected to input shops. More than 469 surrounding villages were reportedly buying inputs from the 16 shops surveyed.

3.3. Inventory Credit Scheme

Since 1999, the FAO Projet Intrants has attempted to improve household liquidity by introducing and promoting inventory credit (warrantage) schemes. These schemes provide credit to farmers at harvest time using part of their production pledged as collateral. In 2004, the value of credit supplied was estimated at about US$1.4 million.

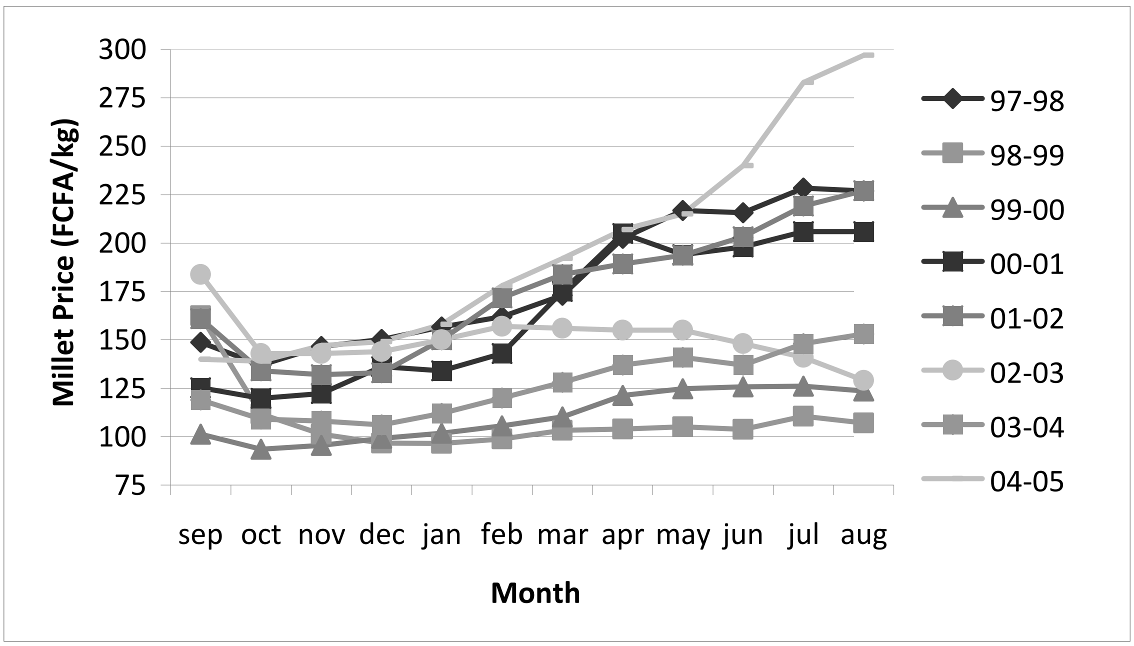
At harvest, farmers place part of the produce (usually millet or sorghum) in a local storage warehouse ("crop bank"), usually operated by a farmers' association, in exchange for a warehouse receipt that can be used as collateral with a financial institution. Against this, farmers receive an amount of credit less than the current value of the collateral at harvest, helping to reduce default risk. The fact that prices normally rise after harvest also helps to reduce default risk by increasing the borrower's equity. Formally, farmers are obligated to repay the loan even if the value of their collateral falls rather than rises while in storage. However, the risk of default by borrowers is greater in this case, of course.

Crop banks are often linked to small savings and loans institutions as sources of funding for the inventory credit scheme. In addition, the Projet FAO Intrants conducted a training program on alternative income generating activities enabling farmers to use the credit to invest in those activities.

Crop prices are usually low at harvest, and farmers are liquidity constrained. Six months later at the beginning of the cropping season, prices are often very high. Supplying credit to farmers enables them to benefit from rents that would otherwise be taken by traders. The credit supplied can be invested in alternative income-generating activities, thus providing additional income to farmers. Among the expected uses of the profits generated by the scheme is purchasing mineral fertilizers.

Although prices usually rise after harvest, the price rise is not always large enough to justify inventory credit. Figure 4 shows seasonal market price variations for millet in Niger during the marketing periods of 1997–1998 to 2004–2005. In four of the eight years, millet prices either declined or increased only modestly. These figures suggest that inventory credit can be risky, both for borrowers and lenders.

Figure 4. Seasonal market price patterns for millet, monthly average prices in Niger



Source: Data from Système d'Information sur les Marchés Agricoles (SIMA)

4. DATA COLLECTION METHODS AND DESCRIPTIVE RESULTS

4.1. Methods of Data Collection

The study was carried out in the four regions of Niger—Dosso, Maradi, Tillabery, and Zinder—where the FAO Projet Intrants has established input supply shops and where the microdosing technology has been promoted through on-farm trials and demonstrations. In Tillabery, the survey was conducted in the central and southern parts of the region. In Dosso, it was conducted in Fawel (northern part of the region) and in the south, where the potential for agricultural production is higher. In Maradi, the survey was conducted in the southern part of the region, which is one of the highest-rainfall and best-market-access areas of the country. In Zinder, the survey was conducted in both the northern and southern parts of the agricultural zone, including the Tanout district, which is almost at the northern limit of the agricultural production zone in Niger.

The sample selection procedure used both purposive and random sampling. In line with the objectives of the study, 10 of the 14 well-monitored input shops and the villages they operate in were purposely selected (Table 2). The major selection criteria for the input shops were at least two years of operation in the village and representation of various agro-ecological zones. For each selected input shop, a set of three other villages at varying distances were purposely chosen: one village was selected around 5 km away, a second about 10 km away, and a third about 20 km away.[3] In each of the selected villages, a random sample of 10 households was selected based on a listing of households in the village.[4] Overall, 40 villages were selected and a total of 397 households were interviewed (see Figure 2).[5]

A structured survey was carried out from December 14, 2004, to January 15, 2005. Data were collected at village, household, and plot levels. At the village level, information was gathered on institutions and infrastructure. At the household and plot levels, data were gathered on household characteristics (characteristics of household heads and members, land, agricultural equipment, rental of equipment, and livestock ownership); pathways of fertilizer diffusion (knowledge of fertilizers and source of first information, and participation in on-farm trials and demonstrations on fertilizer use); use of input shops and inventory credit schemes; input–output data at the plot level in 2003 and 2004; plot characteristics (plot size, distance to the plot, plot status, plot ownership, plot age, soil type, and toposequence); crops planted; proportion of area by crop; use of crop rotation; use of inorganic and organic fertilizers (quantities of fertilizers used, supply sources, methods of application, period of application, and costs of fertilizers); types of seed; seed treatment; use of soil and water conservation methods and labor use; periods of sowing and harvest; and farmers' perceptions of plot fertility levels and evaluation of plot production. A range of other questions focused on households' affiliations with farmers' associations and the benefits derived from those associations; households' perceptions of welfare changes since the establishment of input shops; and households' transactions, credit transactions, and some welfare proxies.

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[3] Because the villages selected were purposely chosen, the population statistically represented by our sample of households is the population only of these 40 villages. However, because this population includes villages of varying agro-ecology and distance to input markets (and because our purposeful selection was not based on any other characteristics), our results should be fairly representative of other villages of the study regions having similar agro-ecological and market access characteristics. Nevertheless, we cannot claim a specified measure of statistical confidence in the representation of this larger population, as would be possible if random selection of villages had been used.

[4] For this study, we defined a household as a production unit sharing income from productive resources such as land. This is different from defining a household as a consumption unit sharing consumption goods, especially for polygamous households, which may have several consumption units within one production unit.

[5] Three of the 400 sampled households were not available for the survey.

Table 2. Characteristics of input shop villages selected for the survey

Region	Village	Population	Number of households	Average annual rainfall zone
Tillabery	Bokki	2,008	278	500–600 mm
Tillabery	Diantiandou	1,887	250	400–500 mm
Tillabery	Karabédji	1,947	246	400–500 mm
Dosso	Sambéra	654	89	500–600 mm
Dosso	Alfa Tessa	1,508	208	500–600 mm
Dosso	Falwel	1,341	162	400–500 mm
Maradi	Gabi	924	131	500–600 mm
Zinder	Bandé	1,601	218	350–450 mm
Zinder	Yagaji	1,208	214	250–350 mm
Zinder	Sabon Kafi	3,042	689	250–350 mm

Source: FAO Projet Intrant database.

Data were collected as stocks and flow variables. No physical measurements were taken; all values are the respondents' estimates. Although estimated land stocks are consistent with regional averages, the accuracy of such data is questionable because many farmers cannot accurately estimate the area owned or cultivated. This adds error to estimates of productivity and input use per hectare, as do inaccuracies in respondents' estimates of quantities of inputs and outputs. The impacts of such errors on the econometric estimation results are discussed in Section 5.

4.2. Descriptive Results

This section reports on the characteristics of the households and plots in the sample by region and on farmers' awareness of fertilizers and methods of application; access to, awareness of, and use of input supply shops and inventory credit; use of fertilizer and other inputs on various crops; and crop yields.[6]

4.2.1. Household Characteristics, and Awareness and Use of Inputs and Inventory Credit by Region

Sample households in Dosso have the most physical assets, especially more durable goods, followed by those in Tillabery, Maradi, and Zinder (Table 3). Households in Zinder also have the smallest value of traction animals and other livestock on average, while those in Maradi and Dosso have the largest. Households in Maradi have the largest value of crop sales, while households in Dosso have the largest value of livestock sales and other income (e.g., income from off-farm employment and nonfarm activities), followed by Tillabery. We found no statistically significant differences across regions in area of land owned or cultivated. However, farmers in Dosso fallow more on average than those in other regions.

[6] All statistics reported in this and subsequent sections are adjusted using sample probability weights (reflecting the number of households in each study village represented by each sample household).

Table 3. Household characteristics, and awareness and use of inputs and inventory credit by region

Variable	Dosso (n = 128)		Maradi (n = 50)		Tillabery (n = 110)		Zinder (n = 109)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
Physical assets (‘000 FCFA)									
Value of durable assets	481.457	907.871	140.44	161.287	391.378	562.94	63.123	78.561	acf
Value of equipment	165.02	852.41	62.17	54.995	80.450	95.285	32.526	46.731	
Value of livestock	108.289	97.35	90.197	83.23	88.31	88.64	54.40	93.32	cf
Value of traction animals	132.039	175.87	174.44	193.905	85.865	149.642	41.745	81.921	cde
Land (ha)									
Cultivable land owned	13.280	17.768	7.070	4.601	11.342	27.070	14.248	15.106	
Land cultivated	10.267	12.997	6.550	4.571	9.576	24.183	10.463	11.007	
Land rented	0.11	0.68	0.13	0.73	0.91	1.68	0.47	3.21	b
Land borrowed	0.290	0.905	0.000	0.000	3.349	12.196	0.064	0.436	bdf
Land mortgaged	0.037	0.229	0.450	1.254	0.045	0.476	0.028	0.213	ad
Land received	0.873	3.990	0.080	0.444	1.295	9.551	0.137	0.600	
Land fallowed	4.928	8.366	0.600	1.591	0.810	2.194	0.991	1.455	abc
Human capital									
Age of household head	53.56	11.77	48.08	10.86	57.17	12.207	49.248	13.693	acdf
Education of household head									
None	0.852	0.356	0.711	0.458	0.843	0.365	0.852	0.357	
Primary	0.069	0.256	0.044	0.208	0.068	0.254	0.056	0.230	
Secondary	0.043	0.205	0.022	0.149	0.019	0.139	0.027	0.165	
Literacy training	0.017	0.131	0.222	0.420	0.068	0.254	0.065	0.247	ade
Agriculture as primary activity	0.922	0.269	0.875	0.334	0.955	0.209	0.963	0.189	

Table 3. Continued

Variable	Dosso (n = 128)		Maradi (n = 50)		Tillabery (n = 110)		Zinder (n = 109)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
Ethnicity									
Zarma	0.922	0.269	0.082	0.276	0.655	0.478	0.028	0.167	abcf
Haoussa	0.007	0.088	0.898	0.306	0.064	0.245	0.830	0.377	acdf
Fulani	0.070	0.257	0.000	0.000	0.255	0.438	0.000	0.000	abf
Other	0.000	0.000	0.020	0.142	0.027	0.163	0.142	0.350	
Household cash revenue (‘000 FCFA)									
Value of crop sales	26.26	38.31	93.44	104.92	17.01	36.80	20.57	32.26	ade
Value of livestock sales	84.39	135.82	5.10	14.71	52.79	113.65	26.21	63.75	abc
Rental income from animal services	5.46	19.40	0.00	0.00	5.28	50.09	0.00	0.00	
Other income	197.68	404.64	37.83	54.99	138.68	416.96	71.60	349.02	acef
Social capital									
Number of household members in farmers’ association	1.06	1.27	1.64	1.65	0.96	0.98	0.34	0.49	acdef
Village chief	0.070	0.257	0.060	0.290	0.064	0.245	0.055	0.229	
Use of an input shop									
Aware of existence of an input shop	0.703	0.458	0.900	0.303	0.864	0.345	0.688	0.465	abef
Bought from input shop	0.527	0.502	0.318	0.471	0.537	0.501	0.395	0.492	
Bought inorganic fertilizer	0.388	0.492	0.071	0.267	0.358	0.484	0.133	0.346	
Bought pesticides	0.020	0.143	0.000	0.000	0.000	0.000	0.300	0.466	cef
Bought insecticides	0.000	0.000	0.000	0.000	0.000	0.000	0.067	0.254	
Bought seeds	0.041	0.199	0.071	0.267	0.039	0.196	0.067	0.254	
Bought other	0.000	0.000	0.214	0.426	0.000	0.000	0.033	0.183	ade
Distance to input shop (km)	8.496	6.693	8.980	5.054	7.136	6.037	8.968	6.567	

Table 3. Continued

Variable	Dosso (n = 128)		Maradi (n = 50)		Tillabery (n = 110)		Zinder (n = 109)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
Inventory credit									
Value of credit received ('000 FCFA)	29.757	46.99	23.3	106.116	23.942	60.697	6.385	15.121	c
Number of household members who obtained credit	0.63	0.85	0.58	0.76	0.55	0.77	0.32	0.51	c
Aware of existence of inventory credit	0.422	0.496	0.64	0.485	0.655	0.478	0.422	0.496	abf
Received inventory credit	0.211	0.409	0.38	0.49	0.255	0.438	0.193	0.396	
Fertilizer demonstrations and trials									
Participated in trials	0.453	0.499	0.760	0.431	0.645	0.481	0.486	0.502	abc
Participated in micro application trails	0.362	0.485	0.474	0.506	0.549	0.501	0.415	0.497	
Participated in broad application trails	0.276	0.451	0.079	0.273	0.619	0.489	0.358	0.484	abdef
Participated in spread application trails	0.103	0.307	0.000	0.000	0.098	0.300	0.019	0.137	
Aware of fertilizers									
NPK	0.921	0.270	0.851	0.359	0.881	0.326	0.602	0.492	cef
SSP	0.086	0.282	0.894	0.312	0.229	0.422	0.378	0.487	abcdef
TSP	0.071	0.258	0.319	0.471	0.046	0.210	0.071	0.259	ade
Urea	0.717	0.452	0.915	0.282	0.908	0.289	0.776	0.419	ab
DAP	0.259	0.440	0.744	0.441	0.358	0.481	0.327	0.471	ad
Aware and tested fertilizer									
NPK (n = 312)	0.898	0.304	0.787	0.414	0.752	0.434	0.347	0.478	bcef
SSP (n = 115)	0.063	0.243	0.809	0.397	0.183	0.389	0.245	0.432	acde
TSP (n = 36)	0.063	0.244	0.298	0.462	0.046	0.210	0.051	0.221	ade
Urea (n = 309)	0.591	0.494	0.787	0.413	0.734	0.444	0.429	0.497	ef
DAP (n = 139)	0.236	0.426	0.659	0.479	0.303	0.462	0.163	0.372	a,d,e

Table 3. Continued

Variable	Dosso (n = 128)		Maradi (n = 50)		Tillabery (n = 110)		Zinder (n = 109)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
Ever used fertilizer									
NPK	0.732	0.444	0.745	0.441	0.615	0.489	0.204	0.405	c,e,f
SSP	0.016	0.125	0.745	0.441	0.092	0.289	0.133	0.341	a,c,d,e
TSP	0.016	0.124	0.297	0.462	0.037	0.189	0.020	0.142	a,d,e
Urea	0.346	0.478	0.723	0.452	0.514	0.502	0.214	0.412	a,b,e,f
DAP	0.157	0.365	0.638	0.486	0.229	0.422	0.143	0.352	a,d,e

[a] Significant difference between Dosso and Maradi regions at 5% level.
[b] Significant difference between Dosso and Tillabery regions at 5% level.
[c] Significant difference between Dosso and Zinder regions at 5% level.
[d] Significant difference between Maradi and Tillabery regions at 5% level.
[e] Significant difference between Maradi and Zinder regions at 5% level.
[f] Significant difference between Tillabery and Zinder regions at 5% level.

Household heads are oldest on average in Tillabery. Literacy of household heads is highest in Maradi, where 22 percent of sample households are literate compared with less than 10 percent in the other three regions. Most households are of the Zarma ethnic group in the western regions of Dosso and Tillabery, while most are Haoussa in the central and eastern regions of Maradi and Zinder. Membership in farmers' associations is most common in Maradi and least in Zinder.

Farmers are most likely to be aware of an input supply shop in Maradi and least in Zinder. We found no statistically significant differences across the sample households in different regions in whether farmers bought fertilizer from an input shop (reflecting the nature of our sample villages, which were selected to be close to input shops), but households in Zinder are most likely to buy pesticides. Farmers in Maradi are most likely to have participated in fertilizer demonstrations. Farmers in Zinder are less aware of NPK fertilizer than are households in other regions, while farmers in Maradi are more aware of urea and DAP than are farmers in other regions. Farmers in Zinder are less likely to have tested or ever used most types of fertilizer than are farmers in other regions, while those in Maradi are most likely to have tested and used most types of fertilizer, except NPK (which is commonly used in Dosso and Tillabery).

Farmers' awareness of inventory credit is highest in Tillabery and Maradi, while the amount of such credit received is largest in Dosso and smallest in Zinder.

These results are generally consistent with our earlier characterization of differences across regions. Sample households are poorest on average in Zinder, and many indicators of input use and crop production are highest in Maradi and Dosso. These regional differences likely stem mainly from differences in climate (which is least suitable for agriculture in the Zinder villages) and access to markets (which is most favorable in Maradi and Dosso).

4.2.2. Plot Characteristics, Input Use, and Crop Yields by Region

Collective (family) ownership of plots is most common in Maradi and least in Tillabery, where individual ownership is more common (Table 4). The most common means of plot acquisition is inheritance, especially in Zinder and Dosso. In Maradi, land purchases are also common. Sharecropping is most common in Dosso, while cash rental is most common in Tillabery.

Plots are furthest from the homestead on average in Zinder. The proportion of plots with sandy soils is highest in Maradi and Zinder. Clay and clay/sand soils are most common in Dosso. Farmers report the highest proportion of infertile plots in Zinder, although a higher proportion of plots (15 percent) are reported to have "very good fertility" in Zinder than in other regions. This may be only in comparison to generally poor soils in this region (and not in comparison to soils in other regions) but indicates that farmers in Zinder perceive substantial variation in soil fertility across their plots.

Table 4. Plot characteristics, input use, and crop yields by region

Variable	Dosso (n = 949)		Maradi (n = 286)		Tillabery (n = 626)		Zinder (n = 485)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
Plot ownership									
Plots collectively owned	0.666	0.472	0.881	0.325	0.292	0.455	0.756	0.429	abcdef
Plot acquisition									
Inherited	0.81	0.39	0.65	0.477	0.573	0.495	0.835	0.371	abef
Rented	0.01	0.10	0.00	0.00	0.17	0.37	0.00	0.06	bdf
Mortgaged	0.001	0.03	0.02	0.14	0.01	0.07	0.02	0.13	ad
Bought	0.002	0.045	0.227	0.419	0.022	0.148	0.098	0.299	acdef
Sharecropping	0.24	0.153	0.000	0.000	0.061	0.239	0.004	0.064	bdf
Soil fertility status									
Not fertile	0.289	0.454	0.178	0.383	0.288	0.453	0.375	0.485	acdef
Average fertility	0.473	0.499	0.720	0.449	0.413	0.493	0.270	0.440	acdef
Good fertility	0.233	0.42	0.07	0.26	0.29	0.45	0.21	0.41	adef
Very good fertility	0.005	0.07	0.03	0.18	0.013	0.113	0.146	0.353	cef
Plot crops rotated	0.009	0.10	0.06	0.24	0.03	0.18	0.43	0.50	acef
Plot distance from homestead (km)	1.806	2.015	2.154	2.104	1.748	1.775	2.385	2.542	cdf
Soil type									
Sandy	0.549	0.497	0.874	0.332	0.747	0.434	0.831	0.375	abcgf
Clay	0.148	0.355	0.108	0.311	0.056	0.229	0.025	0.155	bce
Sand and clay	0.231	0.422	0.017	0.131	0.188	0.391	0.047	0.212	acdf
Other	0.0727	0.259	0.000	0.000	0.008	0.088	0.096	0.296	abef
Proportion of plots using inorganic fertilizers									
NPK	0.216	0.411	0.206	0.405	0.232	0.422	0.037	0.189	cef
SSP	0	0	0.024	0.155	0.006	0.079	0.010	0.101	ad

Table 4. Continued

Variable	Dosso (n = 949)		Maradi (n = 286)		Tillabery (n = 626)		Zinder (n = 485)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
Plot ownership									
TSP	0.006	0.079	0.080	0.272	0.002	0.039	0.002	0.045	ade
DAP	0.037	0.191	0.077	0.267	0.009	0.098	0.004	0.064	abcde
Urea	0.026	0.16	0.094	0.292	0.014	0.119	0.021	0.142	ade
Quantity of inorganic fertilizer applied, if used (kg/ha)									
NPK	19.718	74.409	5.60	5.65	3.32	5.05	2.32	2.78	b
SSP			10.357	2.672	1.90	1.39	0.37	0.21	de
TSP	3.278	2.462	27.54	21.08	2.00		0.50		
DAP	8.516	11.27	28.06	18.56	6.22	5.60	11.25	1.77	a
Urea	11.792	8.166	4.93	3.23	3.90	4.51	5.81	4.78	abc
Value of inorganic fertilizer (FCFA per ha)	2661.704	4463.517	4258.888	5608.935	1473.724	3530.114	1162.282	1162.281	abcd
Proportion of plots with microdosage	0.364	0.482	0.311	0.464	0.341	0.475	0.064	0.245	cef
Organic manure									
Proportion of plots with organic manure	0.281	0.449	0.357	0.479	0.338	0.474	0.326	0.469	
Quantity of organic manure used (kg/ha)	1761	2032	1312	1121	3905	3086	1177	1380	bcdf
Yields (kg/ha)									
Millet	656.735	752.693	520.010	576.361	616.104	793.778	571.222	918.027	
Sorghum	672.949	759.077	549.018	924.554	1182.521	1742.033	480.430	639.876	df
Cowpea	424.195	568.148	918.495	1397.216	668.124	1335.449	655.651	1313.950	a

[a] Significant difference between Dosso and Maradi regions at 5% level.
[b] Significant difference between Dosso and Tillabery regions at 5% level.
[c] Significant difference between Dosso and Zinder regions at 5% level.
[d] Significant difference between Maradi and Tillabery regions at 5% level.
[e] Significant difference between Maradi and Zinder regions at 5% level.
[f] Significant difference between Tillabery and Zinder regions at 5% level.

Inorganic fertilizer use is least common in Zinder. NPK is used on less than 4 percent of plots in Zinder but more than 20 percent of plots in the other three regions. Other fertilizers are less common, being used on less than 10 percent of plots in any region. Use of other fertilizers is most common on plots in Maradi (where urea, DAP, and PST is used on about 8–9 percent of plots). Although fertilizer use is most common in Maradi, the average amount of NPK and urea used per hectare (if applied) is largest in Dosso. The amount of other fertilizers [DAP, PST, and single super phosphate (SSP)] used per hectare is largest in Maradi. The average value of fertilizer used per hectare is also largest in Maradi (nearly 4,300 FCFA per hectare) and smallest in Zinder. The use of fertilizer microdosing is most common on plots in Dosso and Tillabery and least common in Zinder.

Use of crop rotation is most common in Zinder. Application of manure occurs on a similar proportion of plots in all regions (from 28 percent in Dosso to 36 percent in Maradi, differences that are not statistically significant). The average quantity of manure applied (if applied) is largest in Tillabery: nearly 4 tons on average compared with between 1 and 2 tons in the other regions.

Despite substantial differences in climate, soil quality, and use of inputs across the four study regions, we did not find statistically significant differences in average estimated millet yields across the regions, with these ranging between 520 and 660 hg/ha. Average sorghum yields are highest in Tillabery (nearly 1.2 tons/ha) and lowest in Zinder (480 kg/ha), while cowpea yields are highest in Maradi (920 kg/ha) and lowest in Dosso (420 kg/ha).

4.2.3. Users versus Nonusers of Inorganic Fertilizer

Half of the farmers in the four study regions use inorganic fertilizer in 2004 and half do not (Table 5). Fertilizer users own significantly more physical assets, including more durable goods, farm equipment, traction animals, and other livestock. On average, the value of the physical assets owned by fertilizer users is 83 percent higher than the value of the assets owned by nonusers. Fertilizer users also earn a 66 percent higher cash income from all sources (crop sales, livestock sales, rental income, and other income, such as from nonfarm activities and off-farm employment). These results suggest that lack of wealth and cash constraints limit nonusers' ability to use fertilizer (although crop sales could be higher among fertilizer users because they use fertilizer). We tested this and other hypotheses about determinants of fertilizer use in our econometric analysis, as reported in Section 6.

Table 5. Characteristics of fertilizer users and nonusers

	Did not use fertilizer (n = 199)		**Used fertilizer (n = 198)**		**Statistical significance**
Variable	Mean	Std. dev.	Mean	Std. dev.	P value
Physical assets ('000 FCFA)					
Value of durable assets	206.73	387.04	419.52	794.13	0.001***
Value of equipment	50.87	69.93	85.36	85.02	0.000***
Value of livestock	74.46	93.28	96.95	94.00389	0.0172**
Value of traction animals	68.78	129.37	130.97	175.0806	0.0001**
Total value of assets	400.85		732.80		
Land (ha)					
Cultivable land owned	12.02	12.91	9.89	10.99	0.079*
Land cultivated	9.45	9.89	8.00	5.73	0.077*
Land rented	0.49	2.45	0.37	1.35	0.551
Land borrowed	1.07	6.57	1.01	6.61	0.923
Land mortgaged	0.11	0.62	0.07	0.47	0.432
Land received	0.35	2.22	0.52	2.52	0.475
Land fallowed	1.41	2.78	2.91	7.30	0.007***
	10.86		10.91		

Table 5. Continued

Variable	Did not use fertilizer (n = 199)		Used fertilizer (n = 198)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	P value
Human capital					
Age of household head	51.79	13.26	53.59	12.22	0.161
Education					
None	0.855	0.353	0.808	0.395	0.228
Primary	0.052	0.222	0.073	0.262	0.391
Secondary	0.026	0.159	0.034	0.181	0.652
Literacy training	0.062	0.242	0.079	0.271	0.526
Agriculture as primary activity	0.960	0.197	0.914	0.282	0.061*
Ethnicity					
Zarma	0.299	0.459	0.704	0.458	0.000***
Haoussa	0.528	0.500	0.184	0.388	0.000***
Fulani	0.122	0.328	0.066	0.249	0.059*
Other	0.051	0.220	0.046	0.210	0.8235
Household cash income (‘000 FCFA)					
Value of crop sales	24.22	40.36	37.01	66.77	0.02**
Value of livestock sales	36.14	95.50	63.28	115.67	0.01***
Rental income from animal services	0.80	6.12	5.66	39.94	0.090*
Other income	77.22	218.97	123.60	208.50	0.032**
Total cash income	138.38		229.55		
Social capital					
Number of household members in farmers’ association	0.638	1.073	1.182	1.182	0.000***
Village chief	0.065	0.248	0.061	0.239	0.847
Inventory credit					
Value of credit received (‘000 FCFA)	12.800	56.100	29.073	57.147	0.004***
Number of household members who obtained credit	0.357	0.567	0.677	0.859	0.000***
Aware of existence of inventory credit	0.432	0.497	0.596	0.492	0.001***
Received inventory credit	0.131	0.338	0.348	0.478	0.000***
Use of an input shop					
Aware of existence of an input shop	0.688	0.464	0.848	0.359	0.000***
Bought from input shop	0.265	0.443	0.628	0.485	0.000***
Bought inorganic fertilizer	0.270	0.450	0.303	0.462	0.7103
Bought pesticides	0.194	0.401	0.028	0.165	0.001***
Bought insecticides	0.056	0.232	0.000	0.000	0.013***
Bought seeds	0.083	0.280	0.037	0.190	0.2664
Bought other	0.028	0.167	0.043	0.205	0.3693
Distance to input shop (km)	9.54	6.07	7.02	6.31	0.000***

*, **, *** mean difference statistically significant at 10%, 5%, and 1% levels, respectively

In contrast to differences in nonland physical assets and cash income, fertilizer users own and operate less land than nonusers and keep more than twice as much land fallow (2.9 ha compared with 1.4 ha on average). Fertilizer users' holding more land fallow suggests that they are not forced by land constraints to use fertilizer; rather, it appears that using fertilizer enables or causes farmers to fallow more land. Because applying fertilizer requires additional labor and capital at planting time, this may prevent fertilizer users from being able to plant as much area as nonusers, and the additional production resulting from fertilizer use may make it less necessary to plant extensively (to the extent that crop production is primarily for subsistence). Whatever the reason for this finding, it suggests that fertilizer may indirectly (as well as directly) help to increase soil fertility by increasing the use of fallowing. It also suggests that the smaller size of some farms is not an important constraint to fertilizer use.

Users and nonusers of inorganic fertilizers do not differ significantly based on their age and education, but they do differ in terms of the importance of agriculture to their livelihood strategies and in their ethnicity. A smaller proportion of fertilizer users (91 percent) compared with nonusers (96 percent) report agriculture as their main livelihood activity, suggesting that off-farm income may help farmers to finance the use of fertilizer. Zarma and Haoussa are the predominant ethnic groups, with most of the fertilizer users (70 percent) belonging to the Zarma tribe and most nonusers (53 percent) belonging to the Haoussa tribe. The results also show that fertilizer users are more often members of farmers' associations (1.2 members per household on average among fertilizer users compared with 0.6 members per household for nonusers). This evidence suggests the important role of social capital in promoting fertilizer adoption.

Not surprisingly, fertilizer users live closer to input shops than do nonusers (7.0 km average distance of users from an input shop compared with 9.5 km for nonusers), are more aware of the local input shop, and are more likely to have bought fertilizer from it (fertilizer users apparently buy fertilizer from other sources as well). Interestingly, a smaller proportion of fertilizer users buy pesticides than do nonusers. Farmers who need to use pesticides may not be able to purchase fertilizers as well because of cash constraints or because they are producing different crops for which fertilizers are of less benefit.

Prior participation in fertilizer demonstrations is also, not surprisingly, associated with farmers' current use of fertilizer. Sixty-four percent of fertilizer users had participated in fertilizer demonstrations compared to 47 percent of nonusers. Awareness of most kinds of fertilizer (except SSP) is greater among fertilizer users, and fertilizer users are much more likely to have tested and used each type of fertilizer in the past (if aware of it). The most common type of fertilizer used is NPK (15-15-15), which has been used (at some time, even if not in 2004) by 85 percent of current fertilizer users and 27 percent of current nonusers. Use of urea and DAP is also fairly common among current fertilizer users (used at some time by 55 percent and 37 percent of current users, respectively) but much less common among current nonusers (25 percent and 9 percent, respectively).

Fertilizer use is also strongly associated with awareness and use of inventory credit. Farmers using fertilizer are much more likely to be aware of and to use inventory credit (35 percent of fertilizer users received inventory credit versus 13 percent of nonusers) and have received more than twice as much inventory credit on average. These results are consistent with the hypothesis that credit constraints limit fertilizer adoption and suggest that the availability of inventory credit helps farmers to overcome such constraints. Inventory credit also may encourage more fertilizer use by enabling farmers to earn a better return on their investment in fertilizer. However, causality could also run in the reverse direction: users of fertilizer may be more oriented to the market and more likely to produce surplus amounts of crops, based on which inventory credit can be obtained. In either case, a synergy between inventory credit and fertilizer use is apparent.

4.2.4. Users of Fertilizer Microdosing

Most of the differences between users and nonusers of fertilizer microdosing are qualitatively similar to the differences between users and nonusers of fertilizer in general. Users of microdosing own more physical assets than do nonusers, especially farm equipment and traction animals, and earn more income from crop and livestock sales (Table 6). We found no significant difference in land owned or operated between users and nonusers of microdosing, but users of microdosing have more fallow land. They tend to be somewhat older, are less likely to report agriculture as their primary income source, and are more likely to be a member of a farmers' association. Microdosing users are mostly Zarma, while almost half of nonusers are Haoussa. Users tend to live closer to input shops and are more likely to be aware of and have bought inputs from such shops but are less likely to use pesticides. They are more likely to have participated in fertilizer demonstrations, are more aware of most types of fertilizer, and are more likely to have tested and used different fertilizers in the past. They are more likely to be aware of and have used inventory credit and more likely to have received a larger amount of such credit.

Table 6. Characteristics of microdosing users and nonusers

	Did not use microdosing (n = 215)		Used microdosing (n = 182)		Statistical significance
Variable	**Mean**	**Std. dev.**	**Mean**	**Std. dev.**	**P value**
Physical assets ('000 FCFA)					
Value of durable assets	378.735	389.75	406.426	823.256	**0.864**
Value of equipment	52.29	69.10	139.46	716.84	**0.077***
Value of livestock	81.635	95.71	90.454	92.42	**0.35**
Value of traction animals	73.057	135.73	131.38	173.663	**0.000*****
Land (ha)					
Cultivable land owned	12.267	15.591	12.178	22.986	**0.963**
Land cultivated	9.10	9.59	10.32	21.03	**0.45**
Land rented	0.46	2.37	0.40	1.40	**0.73**
Land borrowed	1.07	6.34	1.01	6.87	**0.92**
Land mortgaged	0.10	0.60	0.07	0.49	**0.57**
Land received	0.46	2.38	0.96	7.75	**0.37**
Land fallowed	1.41	2.67	3.05	7.60	**0.003*****
Human capital					
Age of household head	51.61	13.09	53.96	12.29	**0.067***
Education of household head					
None	0.848	0.359	0.813	0.391	**0.374**
Primary	0.059	0.236	0.066	0.249	**0.768**
Secondary	0.025	0.155	0.036	0.187	**0.514**
Literacy training	0.064	0.245	0.078	0.269	**0.586**
Agriculture as primary activity	0.963	0.190	0.906	0.293	**0.022****
Ethnicity					
Zarma	0.330	0.471	0.702	0.459	**0.000*****
Haoussa	0.491	0.501	0.198	0.400	**0.000*****
Fulani	0.127	0.334	0.055	0.229	**0.015****
Other	0.052	0.222	0.044	0.206	**0.724**

Table 6. Continued

Variable	Did not use microdosing (n = 215)		Used microdosing (n = 182)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	P value
Household cash income (‘000 FCFA)					
Value of crop sales	24.55	40.56	37.74	68.43	**0.018****
Value of livestock sales	34.62	91.57	67.46	120.18	**0.002*****
Rental income from animal services	1.62	10.62	5.12	40.62	**0.23**
Other income					
Social capital					
Number of household members in farmers’ association	0.66	1.03	1.20	1.23	**0.000*****
Village chief	0.055	0.230	0.071	0.258	**0.524**
Use of an input shop					
Aware of existence of an input shop	0.693	0.462	0.857	0.350	**0.000*****
Bought from input shop	0.302	0.461	0.622	0.486	**0.000*****
Bought inorganic fertilizer	0.304	0.465	0.290	0.456	**0.861**
Bought pesticides	0.156	0.367	0.030	0.172	**0.006*****
Bought insecticides	0.044	0.208	0.000	0.000	**0.035****
Bought seeds	0.067	0.252	0.040	0.197	**0.500**
Bought other	0.022	0.149	0.030	0.172	**0.786**
Distance to input shop (km)	9.245	6.131	7.151	6.345	**0.001*****
Inventory credit					
Value of credit received (‘000 FCFA)		13691	54773	29450.55	**0.006*****
Number of household members who obtained credit	0.362	0.519	0.697	0.911	**0.000*****
Aware of existence of inventory credit	0.46	0.499	0.577	0.495	**0.021****
Received inventory credit	0.181	0.386	0.307	0.463	**0.003****
Demonstrations and trials					
Participated in trials	0.469	0.500	0.654	0.477	**0.000*****
Participated in micro application trials	0.425	0.497	0.478	0.502	**0.432**
Participated in broadcast trials	0.396	0.492	0.353	0.479	**0.512**
Participated in line spreading trials	0.039	0.195	0.084	0.279	**0.180**
Aware of fertilizers					
NPK	0.715	0.453	0.933	0.249	**0.000*****
SSP	0.330	0.471	0.271	0.446	**0.209**
TSP	0.060	0.238	0.133	0.340	**0.016****
Urea	0.790	0.408	0.834	0.373	**0.272**

Table 6. Continued

Variable	Did not use microdosing (n = 215)		Used microdosing (n = 182)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	P value
DAP	0.305	0.462	0.431	0.496	**0.011*** **
Aware and tested the fertilizer					
NPK (n = 312)	0.706	0.457	0.982	0.132	**0.000*** **
SSP (n = 115)	0.696	0.463	0.897	0.306	**0.009*** **
TSP (n = 36)	0.750	0.452	0.958	0.204	**0.064* **
Urea (n = 309)	0.613	0.488	0.907	0.290	**0.000*** **
DAP (n = 139)	0.623	0.489	0.923	0.268	**0.000*** **
Ever used fertilizer					
NPK	0.305	0.462	0.851	0.357	**0.000*** **
SSP	0.110	0.314	0.209	0.408	**0.007*** **
TSP	0.015	0.122	0.105	0.307	**0.000*** **
Urea	0.250	0.434	0.580	0.494	**0.000*** **
DAP	0.140	0.347	0.337	0.474	**0.000*** **

*, **, *** = mean difference statistically significant at 10%, 5%, and 1% levels, respectively.

4.2.5. Awareness of Input Shops

Households that are aware of input shops own more durable assets and traction animals on average than those that are not aware (Table 7). Aware households have higher-value crop sales but lower-value livestock sales. They are less likely to have no education and more likely to be literate. They are more likely to be from the Zarma ethnic group and less likely to be from the Haoussa ethnic group. They are more likely to be a member of a farmers' association but less likely to be a village chief. Households that are aware of input shops are more likely to have participated in a fertilizer demonstration, are more aware of several fertilizers, and are more likely to have tested and used most fertilizers than are households that are not aware of input shops. Aware households are also more likely to be aware of and to have used inventory credit, and they have received more of such credit on average.

Table 7. Characteristics of households aware or not aware of input supply shops

Variable	Not aware of input shop (n = 92)		Aware of input shop (n = 305)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	P value
Physical assets ('000 FCFA)					
Value of durable assets	155.192	264.34	341.98	690.29	0.011***
Value of equipment	41.54	50.07	107.55	556.787	0.257
Value of livestock	90.451	89.62	84.239	95.63	0.58
Value of traction animals	94.923	113.23	110.31	166.466	0.015**

Table 7. Continued

Variable	Not aware of input shop (n = 92)		Aware of input shop (n = 305)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	P value
Land (ha)					
Cultivable land owned	10.778	17.428	12.663	19.848	0.413
Land cultivated	8.69	8.95	9.96	17.44	0.50
Land rented	0.55	3.49	0.40	1.21	0.53
Land borrowed	1.44	8.82	0.92	5.75	0.51
Land mortgaged	0.08	0.36	0.09	0.60	0.80
Land received	0.21	1.09	0.83	6.28	0.34
Land fallowed	1.80	3.07	2.27	6.12	0.48
Human capital					
Age of household head	50.91	14.05	53.21	12.34	0.13
Education of household head					
None	0.898	0.303	0.811	0.392	0.054**
Primary	0.056	0.232	0.064	0.245	0.789
Secondary	0.011	0.106	0.035	0.185	0.239
Literacy training	0.022	0.149	0.085	0.279	0.043**
Agriculture as primary activity	0.967	0.178	0.927	0.259	0.168
Ethnicity	0.347	0.479	0.548	0.498	0.000***
Zarma	0.391	0.491	0.346	0.476	0.424
Haoussa	0.196	0.399	0.063	0.244	0.000***
Fulani	0.065	0.248	0.043	0.204	0.389
Other					
Household cash income (‘000 FCFA)					
Value of crop sales	19.49	24.49	33.95	61.44	0.028**
Value of livestock sales	67.33	144.84	44.35	91.92	0.070*
Rental income from animal services	0.05	0.34	4.18	32.59	0.22
Other income	79.62	200.82	140.76	407.58	0.17
Social capital					
Number of household members in farmers' association	0.41	0.92	1.06	1.19	0.000***
Village chief	0.108	0.313	0.049	0.216	0.039**
Inventory credit					
Value of credit received (‘000 FCFA)	10991.85	27718.62	23909	63117.49	0.057*
Number of household members who obtained credit	0.261	0.489	0.593	0.789	0.000***

Table 7. Continued

Variable	Not aware of input shop (n = 92)		Aware of input shop (n = 305)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	P value
Aware of existence of inventory credit	0.119	0.326	0.633	0.483	0.000***
Received inventory credit	0.054	0.228	0.295	0.026	0.000***
Demonstrations and trials					
Participated in fertilizer trials	0.250	0.435	0.646	0.479	0.000***
Participated in micro application trials	0.304	0.470	0.472	0.500	0.128
Participated in broadcast application trials	0.565	0.507	0.350	0.478	0.044**
Participated in line spreading trials	0.043	0.209	0.066	0.249	0.677
Aware of fertilizers					
NPK	0.694	0.464	0.854	0.353	0.000***
SSP	0.271	0.447	0.311	0.464	0.478
TSP	0.059	0.236	0.105	0.307	0.203
Urea	0.753	0.433	0.828	0.378	0.121
DAP	0.259	0.441	0.395	0.489	0.021**
Other	0.047	0.213	0.006	0.082	0.008***
Aware and tested the fertilizer					
NPK (n = 312)	0.695	0.464	0.893	0.309	0.000***
SSP (n = 115)	0.565	0.507	0.836	0.371	0.004***
TSP (n = 36)	0.800	0.447	0.903	0.300	0.509
Urea (n = 309)	0.609	0.492	0.795	0.404	0.002***
Dap (n = 139)	0.727	0.456	0.834	0.399	0.424
Ever used fertilizer					
NPK	0.329	0.472	0.632	0.483	0.000***
SSP	0.047	0.213	0.189	0.392	0.002***
TSP	0.000	0.000	0.074	0.262	0.009***
Urea	0.188	0.393	0.469	0.499	0.000***
DAP	0.129	0.338	0.264	0.441	0.009***

*, **, *** = mean difference statistically significant at 10%, 5%, and 1% levels, respectively.

4.2.6. Users of Inventory Credit

Households that use inventory credit own more durable assets, farm equipment, and traction animals than nonusers (Table 8). Users have more income from crop sales and rental of animal services and other income. They are less likely to report agriculture as their primary occupation. They are less likely to be of the Fulani ethnic group than are nonusers. They are more likely to be members of a farmers' association. They are more likely to be aware of and to have purchased inputs from an input shop, and they live closer to input shops. They are more likely to have participated in fertilizer demonstrations, are more aware of most fertilizers, and are more likely to have tested and used fertilizers.

Table 8. Characteristics of inventory credit users and nonusers

Variable	Did not use inventory credit (n = 302)		Used inventory credit (n = 95)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	P value
Physical assets (‘000 FCFA)					
Value of durable assets	236.551	376.31	496.23	109.04	0.000***
Value of equipment	64.547	76.36	180.33	989.61	0.044**
Value of livestock	82.022	5.31	97.303	10.25	0.17
Value of traction animals	90.948	150.64	127.92	17.731	0.045**
Land (ha)					
Cultivable land owned	12.289	16.490	12.026	26.458	0.908
Land cultivated	9.54	11.38	10.03	2.61	0.79
Land rented	0.47	2.18	0.32	1.12	0.52
Land borrowed	0.79	5.37	1.84	9.45	0.17
Land mortgaged	0.11	0.63	0.01	0.01	0.13
Land received	0.40	2.18	1.61	10.61	0.063*
Land fallowed	2.37	6.22	1.50	2.37	0.18
Human capital					
Age of household head	52.91	13.15	51.97	11.53	0.53
Education of household head					
None	0.847	0.359	0.778	0.418	0.137
Primary	0.052	0.222	0.098	0.300	0.123
Secondary	0.024	0.154	0.049	0.218	0.239
Literacy training	0.069	0.254	0.074	0.263	0.879
Agriculture as primary activity	0.950	0.217	0.893	0.039	0.049**
Ethnicity					
Zarma	0.488	0.500	0.543	0.500	0.360
Haoussa	0.357	0.480	0.351	0.479	0.904
Fulani	0.110	0.314	0.043	0.203	0.049**
Other	0.043	0.204	0.064	0.245	0.424
Household cash income (‘000 FCFA)					
Value of crop sales	26.05	48.01	45.04	72.71	0.004***
Value of livestock sales	49.69	111.35	49.63	91.25	1.00
Rental income from animal services	1.48	10.00	8.77	5.70	0.030**
Other income	99.93	284.28	211.33	557.47	0.011***

Table 8. Continued

Variable	Did not use inventory credit (n = 302)		Used inventory credit (n = 95)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	P value
Social capital					
Number of household members in farmers' association	0.735	1.148	1.463	1.019	0.000***
Village chief	0.073	0.260	0.032	0.176	0.149
Use of an input shop					
Aware of existence of an input shop	0.711	0.454	0.947	0.224	0.000***
Bought from input shop	0.349	0.477	0.756	0.432	0.000***
Bought inorganic fertilizer	0.351	0.480	0.232	0.425	0.118
Bought pesticides	0.092	0.291	0.044	0.207	0.261
Bought insecticides	0.000	0.000	0.029	0.170	0.134
Bought seeds	0.068	0.249	0.029	0.170	0.314
Bought other	0.013	0.115	0.044	0.206	0.262
Distance to input shop (km)	8.695	6.090	6.925	6.842	0.020**
Demonstrations and trials					
Participated in fertilizer trials	0.490	0.500	0.757	0.431	0.000***
Participated in micro application trials	0.500	0.501	0.361	0.483	0.053**
Participated in broadcast trials	0.486	0.502	0.139	0.348	0.000***
Participated in line spreading trials	0.054	0.227	0.083	0.278	0.406
Aware of fertilizers					
NPK	0.791	0.407	0.903	0.297	0.015**
SSP	0.274	0.447	0.387	0.489	0.039**
TSP	0.056	0.229	0.215	0.043	0.000***
Urea	0.813	0.391	0.806	0.397	0.897
DAP	0.274	0.447	0.645	0.481	0.000***
Other	0.017	0.131	0.011	0.104	0.657
Aware and tested the fertilizer					
NPK (n = 312)	0.824	0.381	0.940	0.238	0.009***
SSP (n = 115)	0.708	0.457	0.944	0.232	0.004***
TSP (n = 36)	0.813	0.403	0.950	0.224	0.203
Urea (n = 309)	0.718	0.451	0.880	0.327	0.004
DAP (n = 139)	0.696	0.463	0.917	0.279	0.004***

Table 8. Continued

Variable	Did not use inventory credit (n = 302)		Used inventory credit (n = 95)		Statistical significance
	Mean	Std. dev.	Mean	Std. dev.	P value
Ever used fertilizer					
NPK	0.507	0.500	0.742	0.439	0.000***
SSP	0.107	0.310	0.311	0.466	0.000***
TSP	0.021	0.143	0.172	0.379	0.000***
Urea	0.354	0.479	0.569	0.498	0.000***
DAP	0.142	0.350	0.516	0.502	0.000***

*, **, *** = mean difference statistically significant at 10%, 5%, and 1% levels, respectively.

4.2.7. Use of Fertilizer and Other Inputs by Crop Combination

The crop combinations (from most to least common) grown on the plots in the sample are millet–cowpea, millet–sorghum–cowpea, millet–cowpea–hibiscus, millet in pure stands, peanuts in pure stands, millet–sorghum–peanut–cowpea, sorghum in pure stands, and cowpea in pure stands (Table 9). Use of NPK is most common on the millet–cowpea–hibiscus intercrop, being used on 34 percent of such plots. NPK is used on about one-fifth of millet pure stands and millet–cowpea plots, and on smaller proportions of other crop mixes. Other types of fertilizer are used on less than 10 percent of plots under any type of crop or intercrop: DAP and triple super phosphate (TSP) are most common on millet–sorghum–peanut–cowpea plots (DAP on nearly 10 percent and TSP on nearly 9 percent of such plots), and urea is most common on millet–cowpea–hibiscus and cowpea pure stands (used on 6 percent of each type). SSP is not used on more than 1 percent of plots having any crop type.

Table 9. Use of fertilizer and other inputs by crop

Variable	Millet (n = 304)		Peanut (n = 262)		Sorghum (n = 64)		Cowpea (n = 16)		Millet–cowpea (n = 723)		Millet–sorghum–cowpea (n = 476)		Millet–cowpea–hibiscus (n = 378)		Millet–sorghum–peanut–cowpea (n = 102)		Total
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. error	Mean	Std. error	
Proportion of plots with inorganic fertilizers																	
NPK	0.2013	0.402	0.038	0.191	0.125	0.333	0.167	0.408	0.219	0.414	0.092	0.289	0.342	0.474	0.068	0.253	0.182***
SSP	0.01	0.099	0	0	0	0	0	0	0.012	0.111	0.004	0.065	0	0	0.019	0.139	0.007
TSP	0.026	0.15	0	0	0.031	0.175	0	0	0.011	0.103	0.004	0.065	0.008	0.089	0.087	0.284	0.013***
DAP	0.019	0.139	0	0	0	0	0	0	0.034	0.18	0.008	0.091	0.054	0.227	0.097	0.298	0.028***
Urea	0.043	0.203	0.004	0.062	0.016	0.125	0.063	0.25	0.026	0.16	0.015	0.12	0.063	0.244	0.049	0.217	0.030***
Quantity of inorganic fertilizers applied, if fertilizer applied (kg/ha)																	
NPK	5.1 (n = 61)	9.3	10.4 (n = 10)	14.6	7.8 (n = 8)	3.8	1.0 (n = 1)		4.3 (n = 164)	5.6	4.1 (n = 44)	5.0	25.9 (n = 132)	91.2	14.6 (n = 7)	11.3	11.5** (n = 427)
SSP	12.5 (n = 3)								4.8 (n = 9)	4.2	0.3 (n = 2)	0.3			0.3 (n = 2)	0.1	5.1** (n = 16)
TSP	13.9 (n = 7)	16.6			37.5 (n = 2)	17.7			6.4 (n = 8)	5.8	0.7 (n = 2)	0.4	1.9 (n = 3)	0.5	47.2 (n = 9)	8.3	21.2*** (n = 31)
DAP	9.7 (n = 6)	15.0							12.6 (n = 25)	7.8	12.1 (n = 4)	5.9	6.8 (n = 21)	12.8	41.8 (n = 10)	17.3	14.9*** (n = 66)
Urea	3.3 (n = 13)	2.8	0.8 (n = 1)		3.3 (n = 1)		1.5 (n = 1)		5.4 (n = 20)	3.3	6.3 (n = 7)	5.0	12.1 (n = 24)	8.2	6.0 (n = 5)	5.0	7.3*** (n = 71)
Method of application																	
Broadcast	0.050 (n = 80)	0.219	0.100 (n = 10)	0.316	0.100 (n = 10)	0.316	0.000 (n = 1)	0.000	0.029 (n = 201)	0.171	0.055 (n = 54)	0.231	0.048 (n = 164)	0.216	0.409 (n = 22)	0.503	0.059 (n = 542)
Mixed with seed	0.675 (n = 80)	0.471	0.900 (n = 10)	0.316	0.300 (n = 10)	0.483	0.000 (n = 1)	0.000	0.761 (n = 201)	0.427	0.444 (n = 54)	0.502	0.707 (n = 164)	0.456	0.682 (n = 22)	0.476	0.690 (n = 542)
Micro dose	0.200 (n = 80)	0.402	0.000 (n = 10)	0.000	0.500 (n = 10)	0.527	0.000 (n = 1)	0.000	0.263 (n = 201)	0.442	0.389 (n = 54)	0.492	0.268 (n = 164)	0.444	0.318 (n = 22)	0.477	0.271 (n = 542)
Line spreading	0.013 (n = 80)	0.112	0.000 (n = 10)	0.000	0.000 (n = 10)	0.000	0.000 (n = 1)	0.000	0.025 (n = 201)	0.156	0.074 (n = 54)	0.264	0.049 (n = 164)	0.216	0.045 (n = 22)	0.213	0.035 (n = 524)

Table 9. Continued

Variable	Millet (n = 304)		Peanut (n = 262)		Sorghum (n = 64)		Cowpea (n = 16)		Millet–cowpea (n = 723)		Millet–sorghum–cowpea (n = 476)		Millet–cowpea–hibiscus (n = 378)		Millet–sorghum–peanut–cowpea (n = 102)		Total
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. error	Mean	Std. error	
Value of fertilizer applied (FCFA/ha)																	
Value	2935	6409	5423	8545	4082	5621	175		1892	3132	1449	1704	2105	2674	10892	9078	2429***
	(n = 103)		(n = 10)		(n = 12)		(n = 1)		(n = 266)		(n = 69)		(n = 181)		(n = 20)		(n = 662)
Organic manure																	
Applied	0.218	0.413	0.019	0.137	0.078	0.27	0.167	0.408	0.422	0.494	0.353	0.478	0.301	0.459	0.62	0.489	0.315***
Amount applied	1613	1576	1670	1681	930	442	387		2574		2130		1790		806	683	2068***
(kg/ha)	(n = 63)		(n = 5)		(n = 5)		(n = 1)		(n = 269)	2585	(n = 161)	2499	(n = 108)	2274	(n = 62)		(n = 674)
Labor (days/ha)																	
Family labor	35.5	64.9	115.1	174.2	24.8	57.6	80.4	102.4	66.2	97.5	29.4	41.6	29.7	47.2	25.1	25.8	51.3***
Hired labor	5.2	25.1	7.4	27.4	3.0	5.2	6.6	10.3	2.9	11.7	4.0	7.6	1.4	4.4	5.8	10.7	3.8***
Total labor	40.7	75.0	122.4	176.0	27.9	57.4	87.0	98.3	69.1	97.9	33.4	42.9	31.1	47.7	30.9	27.1	55.2***
Yield (kg/ha)																	
Millet	388	589	0	0	0	0	0	0	645	768	639	843	697	853	505	789	608***
Sorghum	0	0	0	0	330	228	0	0	0	0	702	1072	0	0	416	616	602***
Cowpea	0	0	0	0	0	0	417	410	528	1060	859	1515	394	402	611	1040	594***
Hibiscus	0	0	0	0	0	0	0	0	0	0	0	0	973	1262	0	0	973

*, **, *** = mean differences statistically significant at 10%, 5%, and 1% levels, respectively.

The average amount of fertilizer applied (on plots where fertilizer is used) is very small across all crop types. NPK use ranges from a low average of 4.1 kg/ha on millet–sorghum–cowpea plots to a high average of 25.9 kg/ha on millet–cowpea–hibiscus. Apparently, production of a higher-value crop such as hibiscus promotes greater use of inorganic fertilizer. Use of other types of fertilizer are also quite small, with the largest being use of TSP and DAP on millet–sorghum–peanut–cowpea (47 kg/ha of TSP and 42 kg/ha of DAP), although these are used on few plots. The average value of fertilizer applied per hectare is also greatest on millet–sorghum–peanut plots where fertilizer is used.

The most common method of applying fertilizer is mixing it with seed at the time of planting (used on 69 percent of plots applying fertilizer). This method is particularly common for peanuts and millet–cowpea plots (when fertilizer is applied at all) and is least common for sorghum and millet–sorghum–cowpea plots. Microdosing (fertilizer applied at the side of the planting mound either at the time of planting or after emergence) is the second-most common method of application (used on 27 percent of plots applying fertilizer). Microdosing is most common for millet–sorghum–cowpea (39 percent of plots) and millet–sorghum–peanut–cowpea (32 percent). On the remainder of the plots, fertilizer is broadcast (in a line or otherwise).

Application of manure is most common on millet–sorghum–peanut–cowpea (62 percent), millet–cowpea (42 percent), and millet–sorghum–cowpea intercropped plots (35 percent) and is least common on pure stands of peanuts (2 percent) and sorghum (8 percent). The average amount of manure applied (for plots where manure was used) was largest on millet–cowpea and millet–sorghum–cowpea intercropped plots (more than 2 tons/ha in both cases) and smallest for pure stands of cowpea and sorghum (less than 1 ton/ha).

Family labor accounts for more than 90 percent of the labor used in crop production. The total amount of labor used is greatest for peanuts (averaging more than 120 days/ha), cowpea (87 days/ha), and millet–cowpea intercrop (69 days/ha) and is lowest for sorghum, millet–sorghum–peanut–cowpea, millet–cowpea–hibiscus, and millet–sorghum–cowpea (between 28 and 33 days/ha).

4.2.8. Yields by Crop Combination

Interestingly, millet yields are higher on millet intercropped plots than on plots where millet is grown in a pure stand, averaging less than 400 kg/ha in pure stands but more than 600 kg/ha on millet–cowpea, millet–sorghum–cowpea and millet–cowpea–hibiscus plots, and about 500 kg/ha on millet–sorghum–peanut plots (see Table 9). Similarly, average sorghum yields are lower in pure stands (330 kg/ha) compared with sorghum yields on millet–sorghum–cowpea (700 kg/ha) and millet–sorghum–peanut–cowpea plots (420 kg/ha). Cowpea yields are also lower in pure stands (420 kg/ha) than on millet–sorghum–cowpea (860 kg/ha), millet–sorghum–peanut–cowpea (610 kg/ha) and millet–cowpea (530 kg/ha) intercropped plots. These results suggest that positive synergies between different crops in intercropped plots may help to boost yields (e.g., positive impacts of nitrogen fixation in cowpeas and peanuts on cereals); however, greater use of manure and inorganic fertilizer on intercropped plots may also be at least partly responsible for higher yields on intercropped plots.

Although these descriptive results are suggestive of several interesting conclusions, we had to try to control for other factors affecting input use and yields (such as plot-quality, differences in climate, etc.) if we were to draw robust conclusions about the impacts of fertilizer microdosing, input shops, and inventory credit on use of inputs and yields. We did that using econometric (multiple regression) methods, as described in the next section.

5. METHODOLOGY

This section presents the empirical model we used in this study, the key hypotheses we tested, and the econometric methods we used to test the hypotheses.

5.1. Empirical Model

We assumed that production per hectare by household *h* of crop *c* on plot *p* ($y^c{}_{hp}$) is determined by the following production function:

$$y^c{}_{hp} = F^c(l_{hp}, x_{hp}, A_{hp}, z_{hp}, PC_h, HC_h, I_h, R, \theta) \tag{1}$$

where

- l_{hp} is the labor input per hectare applied to the plot;
- x_{hp} is a vector of nonlabor inputs applied to the plot per hectare (e.g., seeds, inorganic fertilizer, organic fertilizer);
- A_{hp} is the area of the plot;[7]
- z_{hp} is a vector of quality characteristics of the plot that affect its productivity (e.g., soil texture, fertility);
- PC_h is a vector of types of quasi-fixed, productive, physical capital owned by the household that influence agricultural productivity (e.g., farm equipment, traction animals);
- HC_h is a vector of types of human capital that influence productivity (e.g., education, farming experience);
- I_h is a vector representing access to information and technical assistance that influences productivity (e.g., prior participation in training on use of inputs);
- *R* is a vector of regional dummy variables reflecting agro-ecological potential (e.g., average rainfall, temperature) and other regional factors; and
- θ represents unobserved random factors affecting productivity of the plot (e.g., weather or pests affecting the specific plot in a specific year).

We assumed that the production function takes the following heteroskedastic form:

$$F(X,\theta) = f(X) + h(\theta)g(X) \tag{2}$$

[7] We included plot area in the yield function to allow for nonconstant returns to scale production at the plot level. With constant returns to scale, the yield function should not depend on the plot size. However, if returns to scale are decreasing, the yield function will be a decreasing function of plot size, and if returns to scale are increasing, the yield function will be an increasing function of plot size. Plot size may also be correlated with unobserved aspects of plot quality, causing yields to be a function of plot size after controlling for observable quality characteristics. For example, smaller plots may have resulted from larger plots that had been in long use and then were subdivided through inheritance over the years. Those small plots may be of better quality for crop production and thus might tend to have higher yields, controlling for input levels per hectare.

where:

- X represents all arguments of $F(\,)$ except θ, and we assumed that $g(X) > 0$, $h'(\theta) > 0$, and $E(h(\theta)) = 0$;
- $f(X)$ represents the expected mean level of production, and we assume that $\partial f/\partial X_i > 0$ and $\partial^2 f/\partial X_i^2 < 0$ (positive but diminishing marginal product of input X_i); and
- $g(X)$ determines the variance component, and we made no assumption about $\partial g/\partial X_i$ or $\partial^2 g/\partial X_i^2$. The input X_i is said to be risk increasing if $\partial g/\partial X_i > 0$, risk neutral if $\partial g/\partial X_i = 0$, and risk reducing if $\partial g/\partial X_i < 0$. This form of production function allows inputs to have differential impacts on the mean and variance of production (Just and Pope 1979).

We assumed that the household selects the level of inputs to maximize the expected utility of income, where income includes income earned from crop production on all operated plots as well as income earned from other economic activities:

$$\max_{l_{hp}, x_{hp}, L_o} Eu[\sum_p A_{hp}(p^c y^c{}_{hp} - w_x x_{hp}) - w_l(\sum_p A_{hp} l_{hp} + L_0 - L_h) + OI(L_0, PC_h, HC_h, SC_h, OC_h)] \quad (3)$$

where:

- $u(\,)$ is the utility function, which is assumed to be concave ($u'' \leq 0$);
- p^c is a vector of farm-level prices of crops c;
- w_x is a vector of farm-level prices of inputs x;
- w_l is the wage rate for hired labor (hired in or out);
- L_o is labor used for noncrop activities (e.g., in livestock production, off-farm agricultural labor, nonfarm activities);
- L_h is the household's total endowment of labor;
- $\Sigma A_{hp} l_{hp} + L_o - L_h$ is the net amount of labor hired in (negative if net hiring out);
- OI is other income from labor and capital used for other noncrop activities (on or off farm);
- SC_h is a vector of types of social capital that influence opportunities and returns from other activities (e.g., leadership in the community, membership in community organizations); and
- OC_h is a vector of other types of physical or human capital not directly affecting crop production that influence opportunities and returns from other activities (e.g., durable assets such as a bicycle or a motorcycle, experience in nonfarm activities).

The household's optimal decision about input use may be affected by various constraints. We considered two common constraints: a cash/credit constraint and a labor constraint. The cash/credit constraint is given by

$$w_l(\sum_p A_{hp} l_{hp} + L_o - L_h) + \sum_p w_x A_{hp} x_{hp} \leq OI(L_0, PC_h, HC_h, SC_h, OC_h) + B(A_h, L_h, PC_h, HC_h, SC_h, OC_h) \quad (4)$$

where:

- $B(\ )$ represents the maximum amount that the household can invest in inputs by liquidating its assets or borrowing; and
- A_h is the household's total endowment of land (= ΣA_{hp}).

The labor constraint is given by:

$$\sum_p A_{hp} l_{hp} + L_o \leq L_h + L_{\max}(L_h, HC_h, SC_h) \tag{5}$$

where $L_{\max}$ is the maximum amount of labor that can be hired in by the household. This may result from limited labor supervision capability of the household (limitations on L_h and HC_h) or limited access to trustworthy workers who do not require supervision (limitations on SC_h). Cash constraints could also limit the ability to hire labor, but this is already incorporated into relation (4).

The household's optimal use of labor and other inputs is determined by maximization of (3) subject to constraints (4) and (5). The first-order conditions that must be satisfied at the optimum are:

$$E(u'(C))(p^c \frac{\partial f}{\partial x_{hp}} - w_x) + p^c E(u'(C)h(\theta)) \frac{\partial g}{\partial x_{hp}} - \lambda_B w_x = 0 \tag{6}$$

$$E(u'(C))(p^c \frac{\partial f}{\partial l_{hp}} - w_l) + p^c E(u'(C)h(\theta)) \frac{\partial g}{\partial l_{hp}} - \lambda_B w_l - \lambda_L = 0 \tag{7}$$

$$Eu'(C)(\frac{\partial OI}{\partial L_o} - w_l) - \lambda_L = 0 \tag{8}$$

where C is the stochastic value of income, λ_B is the shadow value of the cash/credit constraint, and λ_L is the shadow value of the labor constraint.

Note that if the cash/credit constraint and labor constraint are not binding ($\lambda_B = 0$, $\lambda_L = 0$) and either $u'(C)$ = constant (risk neutral preferences) or $\partial g/\partial x_{hp} = 0$ (risk neutral technology), then equations (6) and (7) reduce to the standard conditions for profit maximization in crop production:[8]

$$\frac{\partial f}{\partial x_{hp}} = \frac{w_x}{p^c} \tag{9}$$

$$\frac{\partial f}{\partial l_{hp}} = \frac{w_l}{p^c} \tag{10}$$

Equations (9) and (10) imply the following form of the solution for x_{hp} and l_{hp}:

$$x_{hp} = x(\frac{w_x}{p^c}, \frac{w_l}{p^c}, A_{hp}, z_{hp}, PC_h, HC_h, I_h, R) \tag{11}$$

[8] If the labor constraint is not binding (regardless of other constraints or risk parameters), equation (8) reduces to the condition $\partial OI / \partial L_0 = w_l$. If the labor constraint is binding, $\lambda_L > 0$, hence $\partial OI / \partial L_0 > w_l$.

$$l_{hp} = l(\frac{w_x}{p^c}, \frac{w_l}{p^c}, A_{hp}, z_{hp}, PC_h, HC_h, I_h, R) \quad (12)$$

Only the exogenous variables present in equations (9), (10), and (1)—the latter possibly influencing $\partial f/\partial x_{hp}$ and $\partial f/\partial l_{hp}$—can influence the optimal choice of x_{hp} and l_{hp} in this case.

More generally, if either of the constraints is binding or if the household's preferences and technology are not risk neutral, the optimal choice of x_{hp} and l_{hp} may depend on all the exogenous variables in the optimization problem:

$$x_{hp} = x(w_x, w_l, p^c, A_{hp}, z_{hp}, PC_h, HC_h, I_h, R, SC_h, OC_h, A_h, L_h) \quad (13)$$

$$l_{hp} = l(w_x, w_l, p^c, A_{hp}, z_{hp}, PC_h, HC_h, I_h, R, SC_h, OC_h, A_h, L_h) \quad (14)$$

We did not include wages or input and output price data at the household level. We assumed that these prices are determined by regional-level prices (incorporated into R) as well as by the household and plot's access to the local markets (MA_{hp}). Land tenure of the plot (T_{hp}) may also influence effective input and output prices (e.g., the effective price paid to the farmer will be reduced by the share paid to the landlord in a sharecropping arrangement) or may affect the household's access to credit. Based on these assumptions, we rewrote equations (13) and (14) as:

$$x_{hp} = x(MA_{hp}, A_{hp}, z_{hp}, T_{hp}, PC_h, HC_h, I_h, R, SC_h, OC_h, A_h, L_h) \quad (15)$$

$$l_{hp} = l(MA_{hp}, A_{hp}, z_{hp}, T_{hp}, PC_h, HC_h, I_h, R, SC_h, OC_h, A_h, L_h) \quad (16)$$

Substituting equations (15) and (16) into equation (1), we obtained the reduced-form equation for crop yield:

$$y_{hp}{}^c = y^c(MA_{hp}, A_{hp}, z_{hp}, T_{hp}, PC_h, HC_h, I_h, R, SC_h, OC_h, A_h, L_h) \quad (17)$$

Equations (1), (15), (16), and (17) form the basis of the econometric estimation. A test of the statistical significance of explanatory variables not included in equations (11) and (12) but included in equations (13) and (14)—that is, SC_h, OC_h, A_h, L_h—can be used to test whether the assumptions underlying equations (11) and (12)—no binding constraints and risk neutrality—hold.

5.2. Hypotheses and Methods of Testing

Several key hypotheses related to the impacts of inventory credit, input supply shops, and fertilizer microdosing can be tested within the framework presented in the previous section:

> ***Hypothesis 1:*** *By relaxing credit constraints and improving marketing of output, availability of inventory credit will increase adoption of inorganic fertilizer and other purchased inputs, leading to higher yields.*

This hypothesis follows from equation (6). The shadow value of the cash/credit constraint acts as an additional cost of purchased inputs,[9] and relaxing this constraint through inventory credit should

[9] Assuming risk-neutral technology for simplicity, equation (6) reduces to pc∂f/∂xhp = (1 + λB / Eu′(C))wx. The left side of this equation represents the marginal benefit of increasing use of an input, and the right side represents the marginal cost.

increase use of purchased inputs, if the credit constraint was binding. By improving farmers' ability to market their output for a better price, inventory credit can help increase the price received by the farmer, which also promotes increased input use. As long as inputs are not strongly risk reducing, the marginal product of inputs must be positive at the optimum, according to equation (6).[10] Thus, since input use is increased by relaxing the cash/credit constraint, yields must also increase.

The impacts of inventory credit on purchased input use can be tested using the specification in equation (15). The impacts of inventory credit on yields are tested in two ways: first, by testing the impacts of inventory credit on input use [using equation (15) as noted above] and then testing the impact of input use on yield using the production function in equation (1); and second, by testing the full impact of inventory credit on yield using the reduced-form specification [equation (17)]. Since the impacts of inventory credit on yield may occur by affecting use of more than one input, the total impact of inventory credit may be complex. The reduced form assesses the total impact directly, but without accounting for which inputs are responsible for changing yields.[11] Using both approaches to test this hypothesis enabled us to check the robustness of our conclusions.

> ***Hypothesis 2:*** *By reducing farmers' cost of purchased inputs, availability of input supply shops will increase use of purchased inputs and increase yields.*

This hypothesis also follows from equation (6). Improved availability of input supply shops should reduce the marginal cost of inputs and increase the optimum level of use, leading to increased yields because of the positive marginal product of inputs. As for hypothesis 1, the impacts of access to input supply shops on input use and yields can be tested using a structural approach based on equations (15) and (1) and a reduced-form approach based on equation (17).

> ***Hypothesis 3:*** *Technical assistance promoting fertilizer microdosing will lead to either less or more use of inorganic fertilizer, depending on the level of fertilizer used and its profitability before such assistance. For households not previously using fertilizer, demonstrations of the effectiveness of microdosing will promote increased fertilizer use, and for households that had used fertilizer in larger doses, microdosing will reduce use. In either case, the marginal productivity of fertilizer use will increase.*

This hypothesis follows from equations (1) and (6). Before the availability of information about microdosing (I_h), the optimum level of fertilizer use according to equation (6) may be zero.[12] According to equation (1), new technological information can increase the marginal productivity of using inputs, so that the optimal level of use may become positive. By contrast, if the household is already using fertilizer in larger doses, information on microdosing may convince farmers that a smaller dose is more beneficial. The theory could not show this if we assumed that the farmer is already fully informed about the production function and already chose to use a smaller dose. This impact can only result if the farmer is

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Reducing λB by increasing credit availability reduces this marginal cost and thus promotes increased use of inputs.

[10] If an input is strongly risk reducing, the second term in equation (6) is positive and large. By Jensen's inequality, $E(u'(C)h(\theta)) < 0$, and if the input is risk reducing, $\partial g / \partial xhp < 0$.

[11] If the relationships between explanatory variables, input use, and yields in equations (15), (16), and (1) were all linear relationships, it would be possible to derive explicit linear expressions for the total marginal impact of inventory credit on yield based on the marginal impacts of inventory credit on each input and the marginal impacts of each input on yield [similar to the approach used by Fan et al. (1999)]. In our case, input use is a nonlinear function of explanatory variables, because fertilizer use is zero for many observations and only positive above a certain threshold. This means that the total impacts of changes in explanatory variables on yield cannot be derived as a simple linear function of coefficients in regressions based on estimating equations (15), (16), and (1), though such total impacts could be simulated using the regression results [as in Pender et al. (2004)]. In this study, we used reduced-form estimation [equation (17)] to estimate the total impacts of explanatory variables on yield.

[12] Technically, equation (6) must hold as an equality only if optimum $x_{hp} > 0$. More generally, the Kuhn-Tucker complementary slackness condition holds: either $x_{hp} = 0$ or equation (6) holds.

not fully informed about the production response to smaller doses of fertilizer or did not make an optimal choice earlier. This impact can be treated as a new technological opportunity. If the farmer adopts a lower level of fertilizer use, it will increase the marginal productivity of fertilizer use because of the assumed diminishing marginal product of inputs.

We tested whether and how technical assistance promoting fertilizer microdosing affects the use of fertilizer using equation (15), and how this affects productivity using a structural approach based on equation (1) and a reduced-form approach based on equation (17). We also tested whether use of microdosing increases marginal productivity for a given level of fertilizer use by including interaction terms between the method of fertilizer application and the quantity used, as explained in the Section 5.3.

> ***Hypothesis 4:*** *Income-generating assets (including human and physical capital) and activities may (but will not necessarily) promote increased use of purchased inputs by relaxing cash and credit constraints. The impact of such assets and activities on crop yields is ambiguous, however, because they compete with crop production for labor.*

The first part of this hypothesis is similar to hypothesis 1 and follows for the same reason. By increasing noncrop income and relaxing credit constraints, greater income-generating assets and activities may reduce the shadow value of the household's cash/credit constraint (holding use of inputs constant), which promotes greater use of inputs, as in hypothesis 1. Further, increases in assets that increase productivity of inputs in crop production also increase the demand for inputs, which will also tend to increase use of inputs and yields in crop production. These predictions may not occur, however, if income-generating assets or activities increase the demand for labor or cash in activities other than crop production, possibly resulting in a higher, rather than a lower, shadow value of the cash/credit constraint. In that case, income-generating assets and activities may be associated with lower use of purchased inputs and yields in crop production. Even if this does not occur, greater opportunities for labor use outside crop production will increase the shadow value of the labor constraint and thus tend to reduce the allocation of household labor to crop production, possibly leading to reduced yields even if use of purchased inputs increases.

This hypothesis can be tested using equation (15) to test whether and how income-generating activities affect the use of purchased inputs, and using equation (16) to test how they affect labor use in crop production. The impacts on yield can be tested using a structural approach based on equation (1) and a reduced-form approach based on equation (17).

> ***Hypothesis 5:*** *Larger farms will tend to use more inputs in total than smaller farms. However, the amount of inputs used per hectare will be lower on larger farms as a result of cash/credit or labor constraints. As a result, crop yields will also be lower on larger farms.*

The first part of the hypothesis is based on two points. First, if the same amount of inputs is applied to a larger area, the marginal product of inputs will be greater (from the assumption of diminishing marginal product of inputs). This will lead to a greater demand for use of inputs in crop production. Second, if access to credit is increased by having a larger farm, this will relax the cash/credit constraint and promote increased use of inputs. However, the prediction that more inputs in total will be used by larger farms does not imply that the amount of inputs per hectare will be as large on larger farms. Without any binding cash or labor constraints and risk neutral technology, equations (11) and (12) imply that input use per hectare is independent of total farm size. If credit is constrained, however, the impact of farm size on input use per hectare depends on how much additional land relaxes the credit constraint. If the amount of borrowing allowed fails to increase proportionately with the size of farm, larger farms will have less cash available per hectare; thus, the shadow value of their cash/credit constraint is likely to be higher than for smaller farms, resulting in lower use of inputs per hectare and lower yields. If labor availability is constrained, larger farms will have less labor available per hectare, tending to increase the shadow value of the labor constraint and reduce labor use and yield per hectare.

We tested the impacts of farm size on input use per hectare using equation (15) and tested the impacts on labor use per hectare using equation (16). The impacts on yield were tested using a structural approach based on these equations combined with equation (1) and using a reduced-form approach based on equation (17).

5.3. Econometric Approach

The appropriate estimation approach depends on the nature of the dependent variable, explanatory variables, and the error term in each model. We discuss separately the approach used for equations (1), (15), (16), and (17).

5.3.1. Structural Production Functions: Equation (1)

In the specification of equation (1), we used a modified translog functional form, in which the dependent variable and all the continuous explanatory variables are transformed by their natural logarithms.[13] Such transformations generally improve the performance of linear regression models by transforming the variables toward normal distributions and reducing the sensitivity of the transformed variables to outliers (Mukherjee et al. 1998). We did not include all the interaction terms or the squared terms normally included in a translog production function because that leads to severe problems of multicollinearity. We were mostly interested in whether and how organic and inorganic fertilizer interact in the production function—that is, whether they have positive or negative cross-productivity effects. Thus, we included interactions only between inorganic and organic fertilizer inputs. We also wanted to know whether the microdosing technology has shifted the production function; we therefore allowed for different intercepts and slope coefficients for microdosing versus macrodosing. The resulting production function specification is[14]

$$y_{hp} = \alpha + (\alpha_{micro} D_{micro} + \beta_{micro} D_{micro} \ln(inorg_{hp})) + (\alpha_{macro} D_{macro} + \beta_{macro} D_{macro} \ln(inorg_{hp})) + \beta_x \ln(x_{hp}')$$
$$+\gamma_x \ln(inorg_{hp}) \ln(org_{hp}) + \beta_l \ln(l_{hp}) + \beta_K \ln(K_{hp}) + \beta_D D_{hp} + u_{hp} \qquad (1')$$

where:

- α_{micro} and α_{macro} represent production intercept shifts caused by applying fertilizer via microdosing or macrodosing;
- D_{micro} and D_{macro} are dummy variables indicating whether fertilizer microdosing or macrodosing is used;
- β_{micro} and β_{macro} represent the response of production to the level of fertilizer used if applied using microdosing or macrodosing;
- $inorg_{hp}$ is the value of inorganic fertilizer applied per hectare;
- org_{hp} is the amount of organic fertilizer applied per hectare;
- x_{hp}' is a vector of input amounts applied (other than inorganic fertilizer);

[13] For variables that take a value of zero for some observations (e.g., fertilizer use), a simple logarithmic transformation cannot be used because the logarithm of zero is undefined. Instead, we used the transformation ln(x + 1), which is defined for x ≥ 0, which is equal to zero when x = 0 and monotonically increases with x.

[14] We have suppressed the c superscripts to simplify the notation.

- K_{hp} is a vector of all other continuous variables represented in equation (1), such as plot area, value of physical capital owned; and
- D_{hp} is a vector of all other dummy variables, such as plot level dummies representing different soil types and fertility classes, regional dummy variables.

In estimating equation (1′), we faced the issue that the input variables ($inorg_{hp}$, x_{hp}', and l_{hp}) may be statistically endogenous, meaning that they may be correlated with the error term in the regression because the farmer may have some information about the error term (which we have not observed) when deciding how much of each input to apply. For example, the error term in equation (1) may include unobserved (by the researchers) plot-quality characteristics or weather conditions that the farmer took into account in deciding how much fertilizer, labor, or other inputs to apply to his or her plots. In that case, the coefficients of input use in the regression may "pick up" the effect of the unobserved factors. For example, higher fertilizer use may be associated with higher yields in part because farmers apply more fertilizer to better-quality plots or when weather conditions are favorable. Thus, in this example, the coefficient of fertilizer in the production function regression would tend to overstate the true partial impact of fertilizer (controlling for other factors) on production. In other cases, the true impact could be underestimated.

We addressed this potential problem in a few ways. First, we included indicators of plot quality, such as soil texture and perceived fertility, in the regression model to reduce the problem of unaccounted-for plot-quality characteristics. Of course, the indicators that we observed likely do not perfectly account for all plot-quality characteristics that influence input use and production, so an endogeneity bias may still exist. We used the generalized method of moments (GMM) estimator[15] to estimate equation (1), tested for noncorrelation between the error term and the explanatory variables using the C test for orthogonality, and tested the validity of the overidentifying restrictions in the GMM model using Hansen's J test (Baum et al. 2002; Davidson and MacKinnon 2004). We also tested the relevance of the excluded instrumental variables as predictors of the potentially endogenous explanatory variables. The results of these tests are reported with the results of the estimations in Section 6. In all cases, the tests support the validity of the overidentifying restrictions in the regression models and the lack of correlation between the input variables and the error term in the regression.[16] Because we found that the GMM model treating inputs as exogenous is valid, we report the results of that regression.[17]

The overidentifying restrictions imposed on the GMM model for equation (1) are based on theory and preliminary statistical testing of a larger model. Theoretically, many variables should affect crop production on a particular plot only by affecting the farmer's use of inputs. Access to credit, distance to an input supply shop, ownership of assets not directly used in crop production, and land tenure are examples of variables that should not affect crop production directly (these are reflected in MA_{hp}, OC_h, and T_{hp} in the earlier discussion). However, if productive inputs, plot quality, or other factors directly affecting production are not perfectly measured, variables such as access to credit may have significant impacts on production, even after controlling for input use, because they may act as proxies for other factors that directly affect production. For example, plots of different land tenure may have different unobserved quality characteristics, while distance to an input supply shop or access to credit may reflect access to information about how to use inputs productively.

[15] The GMM estimator is similar to instrumental variables estimation, except that it is efficient in the presence of arbitrary heteroskedasticity. When all explanatory variables are treated as exogenous, the GMM model is equivalent to "heteroskedastic OLS [ordinary least squares]" (Baum et al. 2002).

[16] More precisely, the statistical tests fail to reject the null hypotheses that the overidentifying restrictions are valid and that the tested input variables are orthogonal to the error term.

[17] We also ran versions of the GMM model for each crop mix treating inputs as endogenous. In those models, almost all coefficients are statistically insignificant because of the inefficiency of the models. Results of those models are available from the authors on request. Given the results of the orthogonality tests, however, the GMM models treating inputs as exogenous are consistent and preferred, since they are more efficient.

Because of these considerations, we ran an initial unrestricted ordinary least squares (OLS) regression for equation (1′), including all the exogenous variables specified as explanatory variables in equations (15) through (17), as well as the potentially endogenous input variables. Then we used Wald tests in the unrestricted model to identify variables among those believed not to have a direct effect on production that were jointly statistically insignificant and which could therefore be dropped from the model. The results of these Wald tests are also reported with the regression results in Section 6. Because our models passed these Wald tests, as well as the C and J tests mentioned earlier, and because these exclusion restrictions are for variables that we expect for theoretical reasons did not belong in the model, we are confident that the restrictions used to improve model identification are valid.

In addition to the GMM model, we estimated equation (1′) using median regression, which is robust to problems of outliers and heteroskedasticity. In discussing results, we give greater emphasis to results that are robust across both GMM and median regression models.

Variables such as plot area and quantities of inputs and outputs are likely measured with error in the survey. If such measurement errors affect only dependent variables, are randomly distributed, and are not correlated with explanatory variables of interest in the regression analysis, they do not cause any bias in the econometric regression results, although they increase the standard errors and the confidence intervals of the estimated coefficients (Greene 1993). On the other hand, when measurement errors affect the explanatory variables, such as the use of inputs per hectare in estimating equation (1′), these can bias the estimated coefficients and affect the standard errors. Such measurement errors in explanatory variables tend to bias the estimated coefficients toward zero (this can be proven if only one explanatory variable is measured with error; Greene 1993), although with errors in multiple explanatory variables, it is not possible to formally prove the direction of bias. Thus, in our production function estimations, the coefficients of inputs such as fertilizer may be conservatively estimated (i.e., estimates smaller than their true values) as a result of measurement errors.

5.3.2. Input Demand Equation: Equation (15)

In equation (15), the dependent variables include use per hectare of inorganic fertilizer, organic fertilizer, traditional seeds, and improved seeds. All these variables are censored at zero; that is, the value of inputs used is zero for a substantial number of plots. Use of OLS estimation to estimate parameters in censored regression models leads to biased and inconsistent parameter estimates (Maddala 1983). A commonly used alternative model for censored regressions is the Tobit model, which is a maximum likelihood estimator that accounts for the censoring rule (Maddala 1983). A drawback of the Tobit model (or any maximum likelihood estimator) is its sensitivity to distributional assumptions. If the error term is not normally distributed and homoskedastic, as assumed by the standard Tobit model, this estimator also yields biased parameter estimates. In the estimated models for input use, we tested for normality and homoskedasticity using the test of Pagan and Vella (1989) and in all cases rejected this assumption.

An alternative estimator for censored regressions that is robust to such distributional assumptions is the censored quantile regression model, which is a generalization of the censored least absolute deviations estimator of Powell (1984). Two drawbacks of this model are that the algorithm often fails to converge and that the estimator does not account for the sampling probability of the observations in the sample, so the regression results are not representative of the underlying population sampled. The first drawback can be addressed by adjusting the quantile level of the regression; in general, higher quantile levels are needed to estimate the algorithm if a larger fraction of the observations are censored. This points to another drawback of the censored quantile regression algorithm; namely, that the results of the estimation may vary depending on the quantile level used.

We addressed these issues by estimating the input use regressions using both Tobit models (with coefficients corrected to account for probability weights in the sample and robust standard errors used, which are robust to heteroskedasticity) and censored quantile regressions.[18] We report results for different

[18] Although the standard errors as computed are robust to heteroskedasticity, the coefficients of the Tobit model are still

quantile levels at which convergence was achieved, as well as from the Tobit models, and emphasize in our discussion conclusions that are robust to the model specification.

Because the dependent variables take zero values, we could not use a logarithmic transformation of the dependent variable. We therefore estimated these models using untransformed values of the dependent variables and explanatory variables.

5.3.3. Labor Demand Function and Reduced-Form Yield Function: Equations (16) and (17)

The reduced-form yield function specified in equation (17) and the labor demand function in equation (16) were consistently estimated using OLS, because in this case endogenous explanatory variables were not a concern. As in equation (1′), logarithmic transformations of the dependent variable and all continuous explanatory variables were used. We also estimated these functions using median regression to investigate robustness of the results to alternative approaches.

5.3.4. Dependent Variables

The dependent variables used in the econometric analysis are as follows:

- Crop yield: For sole crop stands (millet and peanuts), we used the quantity produced in kilograms per hectare. For intercrops (millet–cowpea and millet–sorghum–cowpea), we used the value of crops produced in FCFA per hectare, based on village level prices of crops. We did not estimate production functions for other crop mixes because of missing price information (e.g., for hibiscus) or a small number of observations.
- Inorganic fertilizer: We estimated determinants of the total value of fertilizer used in FCFA per hectare and of the quantity of NPK used in kilograms per hectare. There were insufficient observations of other types of fertilizer to be used for regression analysis.
- Organic fertilizer: We used the quantity of organic fertilizer applied in kilograms per hectare.
- Seeds: We used the quantity of traditional seeds and the quantity of improved seeds planted per hectare.[19]
- Labor: We used pre-harvest labor used in days per hectare.

5.3.5. Explanatory Variables

In addition to the material and labor inputs listed in the previous section (which were explanatory variables in the structural production function regressions), the explanatory variables used in the reduced-form yield models and the labor and input demand models included the following:

- Plot-level variables:
    - Area of the plot in hectares
    - Soil texture categories (sand, clay, sand and clay, loam, sand and other)
    - Perceived soil fertility categories (poor, average, good)
    - Ownership of the plot (individual or collective by the household)
    - How the plot was acquired (inherited, rented, purchased, sharecropped, other)
    - Distance of the plot from the residence in kilometers
- Household-level variables

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biased in the presence of heteroskedasticity and/or non-normality of the error term.

[19] For intercrops, the amount of seed used per hectare may vary according to the types of crops planted. This effect is captured by including the types of intercrop mixes as explanatory variables in the regression, as noted in Section 5.3.5. We thank an anonymous reviewer for raising this point.

    - Value of assets owned in FCFA (equipment, durable goods, traction animals, other animals
    - Total area of land cultivated in hectares
    - Labor-to-land ratio
    - Dependency ratio
    - Number of household members belonging to a farmers' association
    - Distance to the nearest input shop
    - Whether the household received inventory credit in the past
    - Whether the household participated in fertilizer demonstrations in the past (microdosing, line spreading, broadcast spreading)
- Characteristics of the household head
    - Educational attainment (none, primary, secondary, literacy training, other)
    - Age (and age squared to account for possible nonmonotonic relationships of input use and production with age)
    - Whether head is a village leader
    - Occupational categories (agriculture only, nonagricultural work, agriculture and nonagricultural work, agriculture and other)
- Regional characteristics: dummy variable for each region (Dossa, Maradi, Tillabery, Zinder)

In the labor use and input use regressions, we also included the crop mix on the plot (millet, peanut, cowpea, millet–cowpea, millet–sorghum–cowpea, millet–cowpea–hibiscus, millet–sorghum–cowpea–peanut, other). In the input use censored regressions, linear forms of all continuous explanatory variables were used. To account for a possible nonlinear response of input demand to the age of the household head, we included age squared as well as age.[20] Multicollinearity was not a serious problem (variance inflation factors < 5) for any variables except age and age squared (variance inflation factors > 50).

[20] A squared transformation of ln(age) was not used in the other regressions because of very high multicollinearity in this case [variance inflation factors > 400 for ln(age) and $(\ln(age))^2$].

6. ECONOMETRIC RESULTS

The results of the input use regressions are reported in Tables 10 through 13 (by input type), for labor use in Table 14, for the structural production functions in Tables 15 through 18 (by crop type), and for the reduced-form yield functions in Table 19.

6.1. Inorganic Fertilizer Use

We obtained convergence of the censored quantile regressions for inorganic fertilizer use for two quantile levels—85 percent and 90 percent—and report these results as well as the Tobit model results in Table 10. We found several variables with statistically significant (at the 10 percent level) and robust associations—either positive (+) or negative (–)— with inorganic fertilizer use across all three regression specifications; including plot area (–), sandy and other soils (– compared with sandy soils), ownership of traction animals (+), Maradi and Zinder regions (– compared with Dosso region), distance to the nearest input shop (–), access to inventory credit (+), participation in fertilizer microdosing demonstrations (+), occupations in agriculture and nonagriculture (+, compared with agriculture only), and peanut production (– compared with millet). In addition, we found associations that were robust in two of the three specifications (and insignificant in the third) for the following variables: sand and clay soils (–), soil fertility (+ for good relative to poor), purchased plots (+ relative to inherited plots), ownership of equipment (+) and other animals (+), literacy of the household head (+), membership in a farmers' association (–), participation in a demonstration of line spreading of fertilizer (+), agriculture and other occupation (–), and cowpea (+) and millet–cowpea–hibiscus (+) production.

The findings with respect to distance to an input supply shop and access to inventory credit confirm hypotheses 1 and 2. The findings concerning the impacts of participation in microdosing and line spreading demonstrations suggest that most households participating in these demonstrations were not previously using fertilizer and that participation thus leads to increased fertilizer use (as suggested in part of hypothesis 3). The positive impacts of equipment, traction animals, other animals, literacy, and nonagricultural employment are consistent with hypothesis 4.

Most other findings are as one would expect, although we did not specify hypotheses about these factors. For example, greater use of fertilizer for millet–cowpea–hibiscus is consistent with the higher value of this crop mix than sole millet production, which would tend to increase the profitability of input use. Greater use of fertilizer on plots already perceived as of good fertility is probably because the returns to using inputs on inherently good soils is greater than on poor soils, although this result also could reflect reverse causality (soils where fertilizer is used become more fertile).

Table 10. Determinants of value of inorganic fertilizer used (FCFA/ha)

Explanatory variable	Tobit model		Censored quantile regression (85%)		Censored quantile regression (90%)	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Plot characteristics						
Plot area (ha)	-287.48***	95.16	-380.56***	63.05	-426.23***	77.97
Soil type (cf. sandy)						
Clay	-282	689	-145	304	-203	593
Sand and clay	-1097	669	-512**	254	-1047**	457
Loam	2031	1980	-220	773	2983***	995
Other	-3067**	1361	-1417***	446	-3507***	806

Table 10. Continued

Explanatory variable	Tobit model		Censored quantile regression (85%)		Censored quantile regression (90%)	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Soil fertility (cf. poor)						
Average	34	631	65	233	21	435
Good	590	848	492*	274	1077**	495
Collectively owned plot	52	505	301	205	380	333
How plot acquired (cf. inherited)						
Rented	974	740	-166	358	-472	703
Purchased	1169*	696	761**	327	703	680
Sharecropped	-4182***	1483	139	664	-980	1028
Other	-2176***	779	139	274	-520	493
Distance from residence (km)	88.0	94.3	-2.70e-06	33.7	124.9**	57.5
Household characteristics						
Value of assets (FCFA)						
Farm equipment	205.34	197.21	152.52**	61.81	164.23*	86.65
Durable assets	-1.432E-03**	7.070E-04	-.0000741	.0001853	-.0001003	.0003578
Traction animals	2.997E-03**	1.492E-03	.001567***	.0004129	.003649***	.0007235
Other animals	-1.739E-03	2.629E-03	.003108***	.0009598	.004439***	.0016951
Land area cultivated (ha)	4.433	24.108	-2.967	5.208	17.140	11.628
Characteristics of household head						
Education (cf. none)						
Primary	-445	843	-262	406	182	704
Secondary	1946**	974	750	467	407	795
Literacy training	903	991	1135***	342	1645***	615
Other	-1052	1836	601	916	-740	2160
Age (years)	-228.8	152.9	-55.4	45.4	-19.9	81.5
Age^2 ($years^2$)	2.318	1.467	.5248	.3955	.2156	.7369
Village leader	-872	1071	343	403	80	695
Member of a farmers' association	-252	318	-241***	77	-293**	144
Region (cf. Dosso)						
Maradi	-2361**	1098	-1153***	337	-1777***	564
Tillabery	-738	723	-1467***	255	-1031**	434
Zinder	-4899***	1150	-3069***	683	-2752**	1076
Distance to input shop (km)	-140.2**	56.4	-99.4***	18.3	-112.2***	33.8
Received inventory credit	3209***	703	1795***	179	1619***	346
Participated in fertilizer demonstrations						
Microdosing	1243*	741	510**	235	768*	460
Broad spreading	-183	640	566***	214	-347	430

Table 10. Continued

Explanatory variable	Tobit model		Censored quantile regression (85%)		Censored quantile regression (90%)	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Line spreading	2612**	1027	1308***	392	613	786
Occupation (cf. agriculture only)						
Nonagriculture	226	2332	1406**	599	354	1259
Agriculture and nonagriculture	3838***	1174	2196***	556	7771***	930
Agriculture and other	-842	1025	-1377***	454	-1447*	822
Labor-to-land ratio (persons/ha)	-22	209	141.18*	78.63	199.38	150.55
Dependency ratio	1921	1875	716.6	513.4	1124.7	924.6
Crops produced on plot (cf. millet)						
Peanut	-5945***	1759	-2912***	679	-3673***	1331
Cowpea	805	3384	1144*	612	3044**	1311
Millet–cowpea	351	764	256	267	313	478
Millet–sorghum–cowpea	270	870	-166	358	-373	685
Millet–cowpea–hibiscus	916	847	768***	299	1131*	545
Millet–sorghum–cowpea–peanut	480	1708	1242*	720	151	1514
Other	158	1103	-101	310	0	557
Intercept	1415	4457	1489	1442	362	2510
Number of uncensored observations/total number of observations	494/2052		1015/2052		1137/2052	
Pseudo R^2	0.0423		0.1101		0.1442	

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

The fact that fertilizer use declines with plot size suggests that there may be diminishing returns to scale in production. However, this finding also may have resulted from unobserved plot-quality variation correlated with plot size or from errors in measuring plot sizes. Smaller plots may tend to be of higher quality than larger plots because better-quality land may be more likely to have been farmed earlier and subdivided through inheritance practices. Thus, to the extent that farmers tend to apply more fertilizer to better land, this could result in more fertilizer applied to smaller plots. Alternatively, if plot size is measured with error, that would induce a negative correlation between measured plot size and measured fertilizer use per measured area of the plot. For example, if the measured plot size is larger than the actual plot size, measured yield would tend to be lower than actual yield per hectare, and conversely if measured plot size is smaller than actual plot size.

A few of the findings are surprising. We did not expect that membership in a farmers' association would be associated with less fertilizer use. Perhaps such farmers' associations are promoting alternatives to purchased input use or focus on other activities besides crop production. We also did not expect peanut production to be associated with less fertilizer use than millet, because peanuts are a higher-value cash crop. This may reflect the fact that peanuts are a legume and thus may need less nitrogen than millet. However, the same argument could apply to cowpeas, which were found to use more fertilizer than millet (in two of the regressions).

We investigated these relationships further for a specific type of fertilizer—compound NPK (15-15-15)—in Table 11.[21] Many of the relationships we found for inorganic fertilizer use as a whole we also found for NPK fertilizer: NPK use is greater closer to an input supply shop for households that have received inventory credit or have participated in fertilizer microdosing demonstrations, for households that own more farm equipment, and for household heads who have nonagriculture and agriculture occupations. NPK use is greater on purchased plots than on inherited plots and on millet–cowpea–hibiscus than on millet; and NPK use is lower on larger plots, on other soils, on peanuts, and in Maradi and Zinder regions than in the Dossa region. Other robust relationships in Table 11 include associations of NPK use with clay soils (–), collective ownership of the plot (+), distance of the plot from the residence (+), land cultivated by the household (–), primary education of the household head (–), and household head being a village leader (+).

Table 11. Determinants of use of NPK fertilizer (kg/ha)

Explanatory variable	Tobit model		Censored quantile regression (90%)	
	Coefficient	Std. error	Coefficient	Std. error
Plot characteristics				
Plot area (ha)	-0.485*	0.285	-0.694***	0.144
Soil type (cf. sandy)				
Clay	-7.875*	4.721	-6.833***	1.254
Sand and clay	-2.302	1.827	-1.340*	0.735
Loam	2.686	5.399	4.360***	1.593
Other	-22.790***	8.484	-6.981***	2.542
Soil fertility (cf. poor)				
Average	2.131	1.770	0.663	0.721
Good	0.250	1.990	0.544	0.880
Collectively owned plot	2.402*	1.310	1.778***	0.632
How plot acquired (cf. inherited)				
Rented	3.914*	2.099	0.690	1.288
Purchased	3.592*	2.089	4.408***	1.073
Sharecropped	-18.110***	5.532	-0.120	1.502
Other	-3.208	2.012	-0.854	0.876
Distance from residence (km)	0.883**	0.345	0.456***	0.129
Household characteristics				
Value of assets (FCFA)				
Farm equipment	0.980*	0.510	1.498***	0.260
Durable assets	-3.050E-06**	1.430E-06	-1.320E-07	5.300E-07
Traction animals	1.020E-05***	3.950E-06	-3.260E-06**	1.530E-06
Other animals	-2.860E-05***	1.030E-05	9.240E-07	2.750E-06
Land area cultivated (ha)	-0.941***	0.188	-0.649***	0.083
Characteristics of household head				
Education (cf. none)				
Primary	-12.663***	3.949	-5.199***	1.390
Secondary	-4.005	4.127	1.216	1.501
Literacy training	-5.230*	3.106	-0.543	1.014
Other	-64.450***	10.126		
Age (years)	-0.054	0.278	0.208	0.147
Age^2 ($years^2$)	6.032E-04	2.454E-03	-1.884E-03	1.353E-03
Village leader	4.305*	2.522	2.758**	1.090
Member of a farmers' association	0.248	0.499	0.171	0.200

[21] In this case, we were able to obtain convergence of the censored quantile regression algorithm only at the 90 percent quantile level.

Table 11. Continued

Explanatory variable	Tobit model		Censored quantile regression (90%)	
	Coefficient	Std. error	Coefficient	Std. error
Region (cf. Dosso)				
Maradi	-8.260***	2.760	-6.259***	0.957
Tillabery	-2.958	1.852	-4.866***	0.837
Zinder	-12.145***	3.016	-10.039***	1.934
Distance to input shop (km)	-0.437***	0.139	-0.347***	0.059
Received inventory credit	6.747***	1.766	1.762***	0.639
Participated in fertilizer demonstrations				
Microdosing	4.687***	1.528	2.306***	0.716
Broad spreading	-0.681	1.414	-1.297*	0.729
Line spreading	11.629***	3.766	0.086	1.218
Occupation (cf. agriculture only)				
Nonagriculture	-61.378***	10.790		
Agriculture and nonagriculture	24.546***	9.395	20.470***	1.767
Agriculture and other	7.044**	2.881	3.717**	1.481
Labor-to-land ratio (persons/ha)	-1.885***	0.657	NE	
Dependency ratio	5.970**	2.832	NE	
Crops produced on plot (cf. millet)				
Peanut	-9.169**	3.679	-9.055***	1.504
Cowpea	14.337	11.277	2.680	2.418
Millet–cowpea	2.198	1.786	0.000	0.938
Millet–sorghum–cowpea	5.098**	2.137	1.120	1.202
Millet–cowpea–hibiscus	8.333***	2.464	4.841***	0.974
Millet–sorghum–cowpea–peanut	4.754	5.405	10.613***	1.891
Other	4.264	3.301	0.693	1.033
Intercept	-14.010	9.343	-9.117*	4.756
Number of uncensored observations/total number of observations	319/2052		1067/2247	
Pseudo R^2	0.1189		0.1341	

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

NE: Variables dropped to achieve convergence of the censored quantile regression algorithm.

Again, these relationships support hypotheses 1, 2, and 3, and several are consistent with hypothesis 4. The negative association of primary education (compared with no education) with NPK use was not expected. The negative association of land cultivated by the household with NPK use per acre is consistent with hypothesis 5 and suggests that cash constraints limit larger farmers' ability to use fertilizer as intensively on a given plot more than they limit smaller farmers. The finding that NPK fertilizer use is greater on plots that are collectively owned within the household than on plots that are individually owned may be the result of greater importance attached by the household head to collectively owned plots (which the household head controls) and greater availability of household resources to finance inputs on such plots. The positive association of distance to the plot with NPK use may reflect substitution of NPK for organic fertilizer, which is bulky and difficult to transport to more-distant plots. Supporting this explanation is the finding, discussed in Section 6.2, that organic fertilizer use is lower on more-distant plots. The finding that village leaders use more NPK than do other households may reflect better access to information or credit resulting from social capital.

6.2. Organic Fertilizer Use

As noted in the previous section, organic fertilizer use is lower on plots further from the household residence because of the bulky nature of this input (Table 12). This finding is robust across all three specifications (Tobit and censored quantile regression at 85 percent and 90 percent quantiles) of the regression model. Other robust findings include associations of organic fertilizer use with the means of plot acquisition (less use on plots acquired by borrowing and other means than on inherited plots), household ownership of equipment (+) and durable assets (+), membership in a farmers' association (+), Tillabery region (– compared with Dossa region), and crop mix (more use of organic fertilizer on all millet intercrops compared with sole millet). Findings that were robust in two of the three specifications include associations of organic fertilizer use with plot size (–); other soil type (+); soil fertility (higher on average than on poor fertility); ownership of traction animals (+); land area cultivated (–); the labor-to-land ratio of the household (+); the dependency ratio (–); secondary education of the household head (–); other education of the household head (+); household head being a village leader (+); participation in demonstrations of fertilizer microdosing (+), broad spreading, (+) and line spreading (–); occupations other than agriculture only (+); and peanut production (–).

The negative association of farm size with organic fertilizer use is consistent with hypothesis 5 and suggests that labor or livestock constraints are limiting use of this input. Supporting the interpretation of labor constraints are the findings that organic fertilizer use is greater for households with larger labor-to-land ratios, less for households with higher dependency ratios and household heads with secondary education, and less on more distant plots. The finding that organic fertilizer use is greater for households owning more traction animals supports the suggestion that livestock constraints are also important.

The finding that households with occupations other than agriculture only were positively associated with organic fertilizer use was not expected. We would expect households with other occupations to have higher opportunity costs of labor and thus be less likely to use labor-intensive agricultural practices such as organic fertilizer use, as suggested in hypothesis 4. Perhaps such households are pushed into nonagricultural activities as a result of limited agricultural endowments or ability. If that is the case, those households may have lower labor opportunity costs. However, we found no significant differences in labor use per hectare across occupational categories (as discussed in Section 6.4). More direct information on labor opportunity costs of different households would be needed to fully understand these findings.

The positive impact of most assets on organic fertilizer use indicates that capital as well as labor constraints have an important influence on use of this input. Equipment and durable assets such as carts are needed to transport organic materials, and traction animals are a source of manure as well as a possible means of transporting materials.

The positive impact of being a member of a farmers' association on organic fertilizer use, and the negative impact of such membership on inorganic fertilizer use, as discussed earlier, suggests that such associations may be promoting organic practices as an alternative to inorganic inputs.

Table 12. Determinants of use of organic fertilizer (kg/ha)

Explanatory variable	Tobit model		Censored quantile regression (85%)		Censored quantile regression (90%)	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Plot characteristics						
Plot area (ha)	40.8	106.0	-756.4***	52.6	-742.2***	55.7
Soil type (cf. sandy)						
Clay	-3312.2	2217.5	-975.1***	360.0	-750.0**	379.5
Sand and clay	-603.0	1725.0	-298.3	253.2	-890.9***	248.3
Loam	5948.2	4161.8	122.4	512.9	-1278.8**	504.1
Other	4076.6*	2351.1	872.9**	360.6	-156.5	356.9

Table 12. Continued

Explanatory variable	Tobit model		Censored quantile regression (85%)		Censored quantile regression (90%)	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Soil fertility (cf. poor)						
Average	1800.5	1101.6	985.6***	195.6	716.0***	189.4
Good	745.6	1438.6	0.0	248.6	368.0	250.5
Collectively owned plot	-646.2	1004.0	-370.6**	179.1	-172.3	173.8
How plot acquired (cf. inherited)						
Rented	-1318.0	2699.5	-431.1	307.2	-69.7	318.1
Purchased	-5103.7	3382.7	-194.6	341.6	-147.1	332.7
Sharecropped	-7036.0	4584.4			-4569.2***	663.8
Other	-5568.2**	2202.5	-3154.3***	330.9	-3358.1***	316.2
Distance from residence (km)	-2256.4***	761.4	-1546.1***	79.4	-1407.7***	70.1
Household characteristics						
Value of assets (FCFA)						
Farm equipment	776.3*	407.4	259.3***	44.2	519.6***	57.5
Durable assets	4.2E-03**	2.1E-03	3.5E-03***	1.7E-04	3.261E-03***	1.794E-04
Traction animals	4.6E-03*	2.7E-03	1.2E-03**	4.6E-04	8.050E-05	4.582E-04
Other animals	7.3E-05	4.8E-03	-6.4E-04	1.1E-03	6.873E-04	8.009E-04
Land area cultivated (ha)	-136.35	85.97	-29.07***	4.74	-29.5***	3.4
Characteristics of household head						
Education (cf. none)						
Primary	-1851.8	1762.2	-222.0	366.2	-236.4	375.0
Secondary	-1694.0	1808.1	-1311.2**	643.6	-3096.1***	762.2
Literacy training	-1373.4	2363.1	509.7	331.5	457.1	348.0
Other	6361.0	3905.6	5069.2***	753.0	67314.2***	465.2
Age (years)	235.5	281.8	142.6***	50.0	-93.6**	47.1
Age^2 (years^2)	-2.320	2.568	-1.369***	0.470	0.747*	0.415
Village leader	-1988.9	2988.1	1946.5***	336.5	771.6**	357.0
Member of a farmers' association	935.0*	549.0	484.7***	70.5	353.9***	71.6
Region (cf. Dosso)						
Maradi	4734.3	3248.1	-1008.4***	356.2	320.8	313.9
Tillabery	3521.9*	1953.6	3737.7***	290.8	3952.1***	284.3
Zinder	4540.0	2875.9	507.2	321.9	268.7	341.2
Distance to input shop (km)	-21.7	85.7	10.1	13.8	13.8	13.8
Received inventory credit	-1303.6	1142.6	312.5	224.9	-316.0	233.2
Participated in fertilizer demonstrations						
Microdosing	640.0	1183.9	1573.6***	195.9	1020.2***	198.7
Broad spreading	1750.0	1265.2	2942.8***	189.1	2221.7***	208.9
Line spreading	1029.5	2778.3	-2178.0***	385.1	-2708.0***	449.1
Occupation (cf. agriculture only)						
Nonagriculture	3669.7	2630.8	3273.2***	609.7	1133.8**	463.5
Agriculture and nonagriculture	1118.9	1638.3	4821.1***	436.2	3338.3***	609.2
Agriculture and other	4422.6**	1883.9	992.7***	380.2	142.3	348.6
Labor-to-land ratio (persons/ha)	841.5	639.9	315.3***	68.5	277.6***	72.1
Dependency ratio	-4176.9	2957.2	-1604.7***	453.7	-4049.4***	416.8

Table 12. Continued

Explanatory variable	Tobit model		Censored quantile regression (85%)		Censored quantile regression (90%)	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Crops produced on plot (cf. millet)						
Peanut	-10634.4**	4406.1			-7920.6***	406.2
Cowpea	-2298.2	6064.9	-1273.4**	635.2	-692.8	572.1
Millet–cowpea	5627.9***	2062.2	2659.6***	268.2	3584.5***	257.1
Millet–sorghum–cowpea	4278.6**	1724.0	2348.5***	327.7	2467.7***	350.3
Millet–cowpea–hibiscus	3679.0**	1853.3	2949.8***	327.9	3202.9***	310.8
Millet–sorghum–cowpea–peanut	7453.5**	3016.0	3254.8***	459.6	3471.4***	493.1
Other	-133.7	1430.8	330.8	340.9	714.5**	343.0
Intercept	-24232.4**	11278.4	-5422.2***	1292.7	116.4	1354.3
Number of uncensored observations/total number of observations	620/2052		1067/2052		1261/2052	
Pseudo R^2	0.0333		0.2515		0.3130	

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

Both education and participation in fertilizer demonstrations have mixed associations with manure use. Although secondary education appears to inhibit use of organic fertilizer, probably because of the labor constraints and higher labor opportunity costs of more-educated households, other education appears to promote it. The content of education may have an important bearing on agricultural practices, by influencing awareness of or attitudes about land management practices. Perhaps other forms of education besides formal schooling are influencing such awareness and attitudes. A similar explanation may account for the differential associations of organic fertilizer use with participation in fertilizer demonstrations.

The positive association of organic fertilizer use with millet intercrops compared with sole millet production suggests that organic practices are better suited to intercropping. As with inorganic fertilizer, organic fertilizer is less used on peanuts than on millet. It appears little soil nutrients are added in peanut production in the study regions.

6.3. Seed Use

Use of traditional seeds per hectare has a statistically significant and robust association with several factors (Table 13), including soil fertility (higher on average than poor fertility), means of plot acquisition (lower on rented or purchased plots than on inherited plots), distance to the plot (–), ownership of traction animals (+) and other animals (+), distance to an input supply shop (–), access to inventory credit (+), membership in a farmers' association (–), participation in fertilizer microdosing (–) or broad-spreading demonstrations (–), occupation of the household head (greater for households with agriculture and nonagriculture employment than for those with agriculture employment only), and crop mix (greater on millet–cowpea than on millet only).

These results support hypotheses 1, 2, and 4 (i.e., the positive impacts of inventory credit, input supply shops, nontraction animals, and nonagriculture employment). Most of the other results are consistent with explanations already discussed. For example, more seeds are used on more-fertile plots, probably because the marginal returns to inputs are greater on more-fertile plots. Fewer seeds are used on more-distant plots, probably because the costs of farming more-distant plots are greater and thus the marginal returns to seeds are lower. More seeds may be used on millet–cowpea intercropped plots than on millet plots, probably because the plant density is greater in the intercrop system. Alternatively, the same number of seeds may weigh more in the millet–cowpea intercrop because cowpea seeds weigh more than millet seeds.

The finding that seed use is lower for households that have participated in fertilizer demonstrations is interesting. In the case of microdosing demonstrations, this could be because of the preparation and careful placement of fertilizer with the seeds involved in microdosing, which may reduce the optimal seeding rate and planting density. The negative association of seed use with demonstrations on broadcast spreading of fertilizer is more surprising but still may have resulted from improved information about optimal seeding rate and planting density provided as part of these demonstrations.

Another surprising finding is the negative association of membership in a farmers' association with use of traditional seeds. We also found a negative association of such membership with use of improved seeds. Perhaps such associations are promoting reduced seeding rates and/or planting density as well.

Several variables were found to have statistically significant associations with improved-seed use, including soil type (less use on clay and on other soils), collective plot ownership (–), means of plot acquisition (lower on rented or sharecropped plots than on inherited plots), ownership of durable assets (+), land cultivated (–), education (lower for households heads with secondary or other education), age of household head (+ at younger ages, – at ages above 42), member of a farmers' association (–), occupation (less for agriculture only than for other occupations), crop mix (less for millet–cowpea–hibiscus than for millet only) and region (less in Tillabery and more in Zinder than in Dossa). Unfortunately, we were unable to obtain convergence in any censored quantile regression model because of the small number of positive observations of improved-seed use (93 plots). Thus, these findings may be less robust than those cited for other inputs.

The negative association of farm size with improved-seed use is consistent with hypothesis 5, and the positive associations of durable assets and nonagricultural occupations with improved-seed use are consistent with hypothesis 4. Other findings are as one would expect; for example, lower use of improved seeds on sharecropped plots may result from disincentives to produce as intensely on sharecropped plots (Shaban 1987). Some findings are surprising, however. For example, improved-seed use is lower on collective plots whereas use of NPK is higher, as discussed earlier, and more-educated farmers use less improved seeds. We are not sure of the explanations for these unexpected findings. They may simply be statistical anomalies resulting from the small number of positive observations in this case and our inability to check for robustness using censored quantile regressions.

Table 13. Determinants of seed use (kg/ha)

Explanatory variable	Traditional seeds (Tobit)		Traditional seeds (censored quantile regression, 80%))		Improved seeds (Tobit)[a]	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Plot characteristics						
Plot area (ha)	2.950**	1.310	-4.373***	0.102	-1.966	2.163
Soil type (cf. sandy)						
Clay	-78.754	72.717	0.089	0.700	-36.695**	18.582
Sand and clay	-41.132	43.103	-1.919***	0.454	12.036	11.856
Loam	22.576	22.544	8.348***	1.305	-30.674	27.687
Other	-183.518	146.830	16.120***	0.895	-227.463***	36.850
Soil fertility (cf. poor)						
Average	52.007**	23.542	3.613***	0.422	18.805	14.029
Good	42.055	27.362	5.357***	0.483	23.813	14.937
Collectively owned plot	-12.466	18.148	1.280***	0.405	-30.078***	9.118

Table 13. Continued

Explanatory variable	Traditional seeds (Tobit)		Traditional seeds (censored quantile regression, 80%))		Improved seeds (Tobit)[a]	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
How plot acquired (cf. inherited)						
Rented	-152.405**	60.295	-22.764***	1.142	-211.270***	34.049
Purchased	-140.076**	55.517	-12.902***	1.086	-4.417	13.331
Sharecropped	-19.166	47.399	6.851***	0.865	-146.076***	48.471
Other	33.579	45.769	-14.030***	0.570	-52.058*	27.642
Distance from residence (km)	-7.243*	3.876	-0.377***	0.118	-1.210	2.416
Household characteristics						
Value of assets (FCFA)						
Farm equipment	1.250	4.518	2.506***	0.115	8.286*	4.784
Durable assets	-1.060E-05	2.360E-05	-4.520E-07	4.550E-07	4.780E-05***	1.470E-05
Traction animals	1.065E-04*	6.310E-05	3.080E-05***	1.180E-06	-3.370E-05	4.510E-05
Other animals	2.154E-04**	1.038E-04	2.450E-05***	1.790E-06	3.360E-05	4.310E-05
Land area cultivated (ha)	-0.547	0.560	-1.3600***	0.0377	-2.192**	1.076
Characteristics of household head						
Education (cf. none)						
Primary	-4.328	31.659	-16.192***	0.848	12.659	14.353
Secondary	59.674	50.496	18.754***	1.013	-236.862***	34.905
Literacy training	62.979	40.241	9.542***	0.738	12.724	19.185
Other	10.104	91.328			-203.710***	45.750
Age (years)	2.124	4.291	3.783***	0.126	6.998**	2.859
Age^2 ($years^2$)	-0.0229	0.0392	-2.997E-02***	1.091E-03	-0.0832***	0.0304
Village leader	-3.767	30.566	-11.428***	0.803	-17.024	15.542
Member of a farmers' association	-51.252**	23.178	-4.280***	0.265	-14.231**	7.037
Region (cf. Dosso)						
Maradi	-162.255*	88.571			45.017*	24.038
Tillabery	81.458**	31.964	13.070***	0.622	-245.869***	43.874
Zinder	-49.117	46.249	1.051	0.693	59.112**	27.693
Distance to input shop (km.)	-5.507***	2.133	-0.807***	0.033	-1.956	1.218
Received inventory credit	71.481**	30.962	16.272***	0.469	-16.392	12.859
Participated in fertilizer demonstrations						
Microdosing	-92.069***	34.283	-15.475***	0.683	-17.878	15.063
Broad spreading	-156.847***	56.855	-23.469***	0.596	-28.034*	14.309
Line spreading	40.716	38.142	0.789	0.710	-27.126	22.238
Occupation (cf. agriculture only)						

Table 13. Continued

Explanatory variable	Traditional seeds (Tobit)		Traditional seeds (censored quantile regression, 80%))		Improved seeds (Tobit)[a]	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Nonagriculture	-110.048	83.404	-24.796***	1.213	-138.597***	42.176
Agriculture and nonagriculture	317.083***	119.985	93.896***	1.022	-224.546***	42.166
Agriculture and other	28.833	68.934	21.196***	1.337	-191.557***	36.037
Labor-to-land ratio (persons/ha)	9.472	7.592	0.022	0.131	-7.045*	3.934
Dependency ratio	-48.481	47.091	20.912***	1.094	-13.045	23.991
Crops produced on plot (cf. millet)						
Peanut	-146.652***	54.136	8.049***	1.029	7.501	16.195
Cowpea	216.209*	124.485	-3.502**	1.395	-84.697*	43.232
Millet–cowpea	-55.094**	27.236	-4.083***	0.565	-18.283	17.086
Millet–sorghum–cowpea	51.960	46.768	11.157***	0.675	-1.868	16.184
Millet–cowpea–hibiscus	9.190	31.956	4.761***	0.601	-210.604***	29.055
Millet–sorghum–cowpea–peanut	26.136	52.151	19.065***	1.303	29.956	20.810
Other	98.982	85.280	2.419***	0.708	14.533	16.922
Intercept	-108.297	127.886	-107.783***	3.743	-250.648***	90.223
Number of uncensored observations/total number of observations	618/2052		779/2052		93/2052	
Pseudo R^2	0.0798		0.0837		0.2522	

[a] We could not obtain convergence of censored quantile regressions for improved seeds for any quantile level, due to the small number of uncensored observations.

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

6.4. Labor Use

Labor use per hectare is significantly and robustly associated with several factors (Table 14), including plot size (–), soil fertility (higher on average- and good-fertility plots than on poor-fertility plots), means of plot acquisition (higher on rented plots than on inherited plots), ownership of equipment (+), land area cultivated (–), age of the household head (+), participation in fertilizer microdosing (+) or broad-spreading demonstrations (+), crop mix (higher for peanuts and all millet intercrops than for millet only), and region (lower in Maradi but higher in Tillabery than in Dosso).

The negative association of labor use with farm size is consistent with hypothesis 5, suggesting that labor constraints limit labor use on larger farms. The positive association of household age with labor use may also be a reflection of labor constraints, since households have more usable labor as they age. However, we find insignificant associations of labor use with the labor-to-land ratio, dependency ratio, and occupation, suggesting that labor-scarce households are able to overcome labor shortages through labor market transactions or other means.

The positive association of equipment ownership with labor use suggests that farm equipment and labor are complementary inputs. Soil fertility is also complementary to labor use, increasing the marginal return to labor and thus leading to more intensive labor use.

The positive association of fertilizer demonstrations with labor use suggests that these demonstrations are promoting labor-intensive practices. This is not surprising with regard to microdosing, which requires careful preparation and placement of seeds. It was less expected with regard to fertilizer broadcasting, which seems to be less labor intensive. However, these demonstrations may be promoting other labor-intensive practices.

Virtually all crop mixes are more labor intensive than millet only. This may limit adoption of other cropping systems among labor-constrained households, even if other systems are more productive and profitable.

Table 14. Determinants of ln(labor use per hectare

Explanatory variable	OLS		Median regression	
	Coefficient	Std. error	Coefficient	Std. error
Plot characteristics				
ln (plot area)	-0.9331***	0.0691	-0.7713***	0.0544
Soil type (cf. sandy)				
Clay	-0.1289	0.1201	-0.1208	0.0961
Sand and clay	0.1301*	0.0758	0.0335	0.0768
Loam	0.0291	0.2399	-0.0966	0.1853
Other	-0.1469	0.1965	-0.4070	0.3115
Soil fertility (cf. poor)				
Average	0.1231*	0.0728	0.1522**	0.0700
Good	0.1741*	0.0998	0.1692**	0.0817
Collectively owned plot	-0.2342***	0.0858	-0.0555	0.0680
How plot acquired (cf. inherited)				
Rented	0.8071***	0.1479	0.8240***	0.1285
Purchased	-0.1636	0.1140	-0.0009	0.1198
Sharecropped	0.1192	0.2228	-0.2959	0.2309
Other	-0.0355	0.0916	-0.0282	0.0757
ln(distance from residence)	0.1181*	0.0637	0.0598	0.0505
Household characteristics				
ln(value of assets)				
Farm equipment	0.3362*	0.2025	0.2515***	0.0757
Durable assets	0.00959	0.01417	0.00591	0.01066
Traction animals	-0.00039	0.00710	0.00581	0.00493
Other animals	-0.02365	0.01798	-0.02652**	0.01285
ln(land area cultivated)	-0.2569***	0.0893	-0.3107***	0.0578
Characteristics of household head				
Education (cf. none)				
Primary	-0.2070	0.1834	0.1564	0.1427
Secondary	-0.2591	0.2258	-0.0415	0.1817
Literacy training	-0.1995	0.1843	0.0570	0.1227
Other	0.3549	0.3067	-0.1143	0.5117
ln(age)	0.4498***	0.1633	0.6140***	0.1025
Village leader	-0.0988	0.1982	-0.1605	0.1208
Member of a farmers' association	0.0291	0.0784	0.0302	0.0601
Region (cf. Dosso)				
Maradi	-0.6114***	0.1525	-0.5575***	0.1184
Tillabery	0.3653***	0.1302	0.5713***	0.1062
Zinder	0.1888	0.1392	0.1754	0.1223
ln(distance to input shop)	-0.0002	0.0421	-0.0516	0.0353
Received inventory credit	-0.0408	0.1050	-0.1317**	0.0658
Participated in fertilizer demonstrations				
Microdosing	0.1746**	0.0881	0.2246***	0.0710
Broad spreading	0.2810***	0.0978	0.2726***	0.0731

Table 14. Continued

Explanatory variable	OLS		Median regression	
	Coefficient	Std. error	Coefficient	Std. error
Line spreading	0.0826	0.2184	0.0927	0.2164
Occupation (cf. agriculture only)				
Nonagriculture	-0.0720	0.2470	-0.0179	0.2722
Agriculture and nonagriculture	-0.2607	0.2174	-0.3564*	0.2097
Agriculture and other	0.1734	0.2463	-0.0150	0.1752
ln(labor-to-land ratio)	0.0771	0.0715	0.0433	0.0534
ln(dependency ratio)	-0.4134	0.2728	-0.4771**	0.2081
Crops produced on plot (cf. millet)				
Peanut	0.5715***	0.1324	0.7747***	0.1537
Cowpea	0.6434**	0.2682	0.6077	0.4786
Millet–cowpea	0.4196***	0.0954	0.4068***	0.0973
Millet–sorghum–cowpea	0.2625***	0.0980	0.2185**	0.0904
Millet–cowpea–hibiscus	0.3940***	0.1069	0.4145***	0.1075
Millet–sorghum–cowpea–peanut	0.6053***	0.1765	0.6590***	0.1279
Other	0.0447	0.1078	0.2110**	0.0911
Intercept	1.9797**	0.8567	1.4107***	0.5248
Number of observations	2043		2043	
R^2/Pseudo R^2	0.6800		0.3853	

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

6.5. Millet Yields

Results of the structural production function model for millet-only plots are presented in Table 15. Variables having a statistically significant and robust impact (across GMM and median regressions) on millet yield include labor input (+), amount of inorganic fertilizer applied using microdosing (+), plot size (–), ownership of traction animals (+), membership in a farmers' association (–), and region (lower in Maradi than in Dosso). Most of these results are consistent with our expectations.

Based on the estimated elasticity of yield with respect to fertilizer applied through microdosing (0.067),[22] the average ratio of the prices of fertilizer to millet (estimated to average about 2.4 in our survey sites during 2004), the average level of fertilizer use on pure millet stands with microdosing (about 3.25 kg/ha), and the average yield of millet in pure stands (388 kg/ha), the estimated marginal value cost ratio (VCR) of fertilizer used in the process of microdosing on millet is 3.35, indicating that fertilizer microdosing was profitable for farmers.[23] This result accords well with results of thousands of on-farm trials of fertilizer microdosing in Niger, which have found VCRs in the range of 2 to 4 (Tabo et al. 2005). Of course, improvement in the fertilizer-to-millet price ratio would increase the profitability of microdosing.

The negative association of membership in a farmers' association with millet yields is surprising. The coefficient in the GMM regression implies that, controlling for other factors, doubling average

[22] Because the explanatory variable (quantity of fertilizer use) and dependent variable (millet yield) are both estimated in logarithmic form, the coefficient can be interpreted as an elasticity. The coefficient used in this example is the coefficient of the interaction of fertilizer use with microdosing, which measures the marginal impact of fertilizer use on yield if the fertilizer is applied using the microdosing method of application.

[23] The VCR is defined as the marginal increase in value of production divided by the marginal cost of an additional small amount of an input. It can be shown that VCR = $\varepsilon_{yx}(y/x)(p_y/p_x)$, where ε_{yx} is the elasticity of output y with respect to a particular input x, y is the quantity of output per hectare, x is the quantity of the input used per hectare, and p_y and p_x are the prices of the output and input per kilogram, respectively. The VCR must be greater than 1 for use of the input to be profitable, and it is generally believed that VCR > 2 is needed for substantial adoption of fertilizer use to be widely adopted in a risky environment (CIMMYT 1988).

membership in farmers' associations would reduce millet productivity by about 19 percent.[24] This negative impact may be a result of such associations promoting use of organic inputs as alternatives to inorganic fertilizer, as hypothesized earlier. As shown in Table 15, organic inputs have an insignificant impact on production in the short term, although they may help to increase the sustainability and resiliency of production and thus increase productivity in the longer term. Unfortunately, we were unable to identify the long-term impacts of organic matter inputs using our cross-sectional survey data.

Table 15. Determinants of ln(quantity of millet production per hectare), structural models

Variable	**GMM**		**Median regression**	
Inputs	Coefficient	Std. error	Coefficient	Std. error
ln(labor/ha)	0.3100***	0.0652	0.2532**	0.1049
ln(quantity of organic fertilizer/ha)	-0.0155	0.0183	-0.0032	0.0292
ln(quantity of traditional seeds/ha)	0.1116***	0.0407	0.0777	0.0645
ln(quantity of improved seeds/ha)	0.0491	0.0497	0.0419	0.1058
Used pesticide	-0.0343	0.0949	0.0294	0.1783
Fertilizer macrodosing used	-0.1195	0.2645	0.5301	8.6455
Fertilizer microdosing used	-0.1465	0.1535	-0.2584	0.2582
Inorganic x organic fertilizer interaction	-0.0066*	0.0034	-0.0061	0.0062
ln(value of inorganic fertilizer/ha.) x macrodose	0.0899*	0.0466	-0.0345	1.1541
ln(value of inorganic fertilizer/ha.) x microdose	0.0674***	0.0254	0.0736**	0.0364
Plot characteristics				
ln(plot area)	-0.5264***	0.1241	-0.4569**	0.2088
Soil type (cf. sandy)				
Clay	0.2024	0.1601	-0.3227	0.2758
Sand and clay	-0.0565	0.1542	-0.0643	0.2542
Soil fertility (cf. poor)				
Average	0.0133	0.1363	0.1728	0.1985
Good	0.2367	0.1537	0.3030	0.2887
How plot acquired (cf. inherited)				
Rented	-0.2303	0.2384	0.0390	0.3205
Purchased	-0.2633*	0.1388	0.0301	0.1951
Sharecropped	-0.3962	0.3205	-0.5074	0.5187
Other	-0.3142**	0.1435	-0.1893	0.2273
Household/household head characteristics				
ln(value of traction animals)	0.0317***	0.0083	0.0333***	0.0127
ln(age)	0.7654***	0.2125	0.3098	0.3083
Member of a farmers' association	-0.3824***	0.1099	-0.5275***	0.1790
Region (cf. Dossa)				
Maradi	0.5188***	0.1680	0.7553**	0.3131
Tillabery	-0.1084	0.1427	0.1027	0.2106
Zinder	-0.2196	0.2041	-0.1859	0.3366
ln(dependency ratio)	0.7820**	0.3926	0.2194	0.6906
Intercept	1.7302*	0.9542	3.6781**	1.4298
Number of observations	243		269	
R^2/Pseudo R^2	0.4634		0.2841	
White/Koenker test of heteroskedasticity (P value)	0.2591			

[24] The coefficient of ln(number of household members in a farmers association) in Table 15 (–0.3824), represents dln(y) / dln(n + 1), where y is the millet yield and n is the number of household members in a farmers' association. It can be shown that the elasticity dln(y) / dln(n) = dln(y) / dln(n + 1) × (n / (n+1)). Using this formula and n evaluated at the mean in the data (approximately equal to 1), we obtained dln(y) / dln(n) = –0.19.

Table 15. Continued

Variable	GMM		Median regression	
Inputs	Coefficient	Std. error	Coefficient	Std. error
Wald test of excluded variables (P value)	0.2956			
Hansen's J test of overidentifying restrictions (P value)	0.6230			
C test of exogeneity of inputs (P value)	0.5616			
Relevance tests of excluded instruments (P values)				
ln(labor/ha)	0.0000			
ln(quantity of organic fertilizer/ha)	0.0000			
ln(quantity of traditional seeds/ha)	0.0000			
ln(quantity of improved seeds/ha)	0.7372			
Used pesticide	0.0000			
Fertilizer macrodosing used	0.0505			
Fertilizer microdosing used	0.0000			
Inorganic x organic fertilizer interaction	0.1342			
ln(value of inorganic fertilizer/ha.) x macrodose	0.9978			
ln(value of inorganic fertilizer/ha.) x microdose	0.0000			

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

6.6. Millet–Cowpea Production

Several variables have significant and robust impacts on the value of millet–cowpea production per hectare (Table 16), including amount of labor (+) and traditional seeds (+), the value of inorganic fertilizer used with microdosing (+), education (higher for households with other levels of education compared with none), age of the household head (+), distance to an input shop (+), participation in a fertilizer demonstration showing the line-spreading technology (+), and the labor-to-land ratio (+). Most of these results are consistent with our expectations, except the positive association of distance to an input shop with productivity. This regression controls for the level of use of inputs, so we expected no significant effect of distance, unless better access to an input shop improves farmers' ability to use inputs effectively as a result of better information. We do not have an explanation for this surprising result.

As for millet, the magnitude of the impact of inorganic fertilizer use under microdosing on millet–cowpea production is fairly small, with an estimated elasticity of 0.05. Considering the average value of millet–cowpea production (60,851 FCFA per hectare) and the average value of fertilizer application using microdosing on millet–cowpea intercrop (3.85 kg at 250 FCFA per hectare), this implies a VCR of 3.16 for fertilizer microdosing on millet–cowpea crops. In addition, demonstrations of the line-spreading technology have a large estimated impact on millet–cowpea production. The coefficient of this variable in Table 16 implies that participants in such demonstrations have yield values that are almost triple those of nonparticipants, even after controlling for input use and other factors.[25] Thus, training in optimal use of inputs appears to be more important for boosting yields than for simply increasing the amount of inputs used, at least for millet–cowpea production.

[25] This is calculated by exponentiating the coefficient of the dummy variable for whether the household participated in demonstrations of line spreading: exp(1.0589) = 2.883.

Table 16. Determinants of ln(value of millet–cowpea production per hectare), structural models

Variable	GMM		Median regression	
Inputs	Coefficient	Std. error	Coefficient	Std. error
ln(labor/ha)	0.2561***	0.0536	0.2448***	0.0712
ln(quantity of organic fertilizer/ha)	0.0256**	0.0121	0.0195	0.0147
ln(quantity of traditional seeds/ha)	0.1188***	0.0318	0.1160***	0.0422
ln(quantity of improved seeds/ha)	0.1124	0.0886	0.1214	0.1261
Used pesticide	0.3381***	0.0877	0.1565	0.1255
Fertilizer macrodosing used	0.2473	0.2235	0.8571	1.1042
Fertilizer microdosing used	-0.0706	0.1611	0.0117	0.1792
Inorganic x organic fertilizer interaction	-0.0050	0.0032	-0.0042	0.0038
ln(value of inorganic fertilizer/ha) x macrodose	0.0527	0.0455	-0.0039	0.1665
ln(value of inorganic fertilizer/ha) x microdose	0.0502*	0.0260	0.0520*	0.0281
Plot characteristics				
ln(plot area)	-0.1892	0.1246	-0.1631	0.1497
Soil type (cf. sandy)				
Clay	-0.2503	0.2203	-0.4307	0.3489
Sand and clay	0.1199	0.1104	0.0583	0.1363
Loam	0.3140*	0.1661	0.0422	0.3115
Sand and other	-0.1740	0.4665	0.3061	0.6379
Soil fertility (cf. poor)				
Average	-0.0879	0.0904	-0.0765	0.1298
Good	0.1981*	0.1122	0.0669	0.1643
How plot acquired (cf. inherited)				
Rented	-0.3895***	0.1337	-0.2155	0.1515
Purchased	0.0352	0.2113	-0.1119	0.3330
Sharecropped	0.3364*	0.1838	0.2991	0.2796
Other	-0.0415	0.1341	-0.1108	0.1694
Household/household head characteristics				
ln(value of traction animals)	0.0139*	0.0078	-0.0029	0.0081
Education (cf. none)				
Primary	-0.4117**	0.1665	-0.4010	0.3164
Secondary	0.0008	0.3101	0.3249	0.4082
Literacy training	-0.2091	0.1881	-0.5612***	0.2165
Other	0.7276***	0.2470	1.0983***	0.3908
ln(age)	0.3378*	0.1862	0.4533**	0.2218
Region (cf. Dossa)				
Maradi	0.1218	0.1867	0.2416	0.2489
Tillabery	-0.3427***	0.1172	-0.4292***	0.1421
Zinder	-0.4627***	0.1794	-0.4298*	0.2565
ln(distance to input shop)	0.2286***	0.0512	0.1788**	0.0866
Participation in fertilizer demonstrations				
Microdosing	0.2421**	0.1035	0.1641	0.1251
Broad spreading	-0.0565	0.1004	0.0457	0.1548
Line spreading	1.0589***	0.2084	1.3492***	0.4126
ln(labor-to-land ratio)	0.2858***	0.0656	0.3618***	0.0760
ln(dependency ratio)	-0.3244	0.2662	-0.1549	0.3466
Intercept	7.8958***	0.8027	7.6706***	0.9671
Number of observations	533		556	
R^2/Pseudo R^2	0.3063		0.2248	
White/Koenker test of heteroskedasticity (P value)	0.0069			
Wald test of excluded variables (P value)	0.2822			
Hansen's J test of overidentifying restrictions (P value)	0.6142			
C test of exogeneity of inputs (P value)	0.6366			

Table 16. Continued

Variable	GMM		Median regression	
Inputs	Coefficient	Std. error	Coefficient	Std. error
Relevance tests of excluded instruments (P values)				
lntotallabor	0.0000			
lnqtyorganic	0.0000			
lnqtytradseed	0.0000			
lnqtyimpvseed	0.4403			
pestusemill	0.0000			
macrodos	0.5953			
microdos	0.0000			
inorgorg	0.0000			
inorgmacro	0.8647			
inorgmicro	0.0002			

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

6.7. Millet–Sorghum–Cowpea Production

The factors having a statistically significant and robust impact on millet–sorghum–cowpea production (Table 17) include the amount of labor (+), traditional seeds (+), and pesticide used (+), plot size (–), soil fertility (higher on plots of average or good fertility than on plots with poor fertility), ownership of farm equipment (+), education of the household head (higher for heads with primary education but lower for heads with secondary education compared with none), whether the household head is a village leader (+), distance from an input shop (–), participation in microdosing demonstrations (–), and the labor-to-land ratio (+).

Most of these results are consistent with our expectations, except the negative association of participation in microdosing demonstrations. Contrary to our findings for millet–cowpea production, here we found that millet–sorghum–cowpea yields are 23 percent lower for households that participated in such demonstrations. We also found a statistically significant negative association of use of microdosing with millet–sorghum–cowpea yields in the GMM regression (the coefficient is also negative in the median regression but not statistically significant), and a statistically insignificant coefficient of the amount of fertilizer used under microdosing in both regressions. It seems that microdosing has not been effective in increasing yields among the sample households producing the millet–sorghum–cowpea crop mix. Further investigation of this is needed to understand why this is the case.

Table 17. Determinants of ln(millet–sorghum–cowpea production per hectare), structural models

Variable	GMM		Median regression	
Inputs	Coefficient	Std. error	Coefficient	Std. error
ln(labor/ha)	0.2942***	0.0751	0.4032***	0.0997
ln(quantity of organic fertilizer/ha)	0.0161	0.0133	0.0222	0.0187
ln(quantity of traditional seeds/ha)	0.1239***	0.0308	0.1304***	0.0419
ln(quantity of improved seeds/ha)	0.0873*	0.0454	0.0367	0.0592
Used pesticide	0.2993***	0.1097	0.3013**	0.1332
Fertilizer macrodosing used	0.1283	0.3400	0.5529	0.9881
Fertilizer microdosing used	-0.5588**	0.2456	-0.3186	0.2717
Inorganic x organic fertilizer interaction	-0.0021	0.0049	0.0028	0.0053
ln(value of inorganic fertilizer/ha) x macrodose	-0.0576	0.0657	-0.0790	0.2227
ln(value of inorganic fertilizer/ha) x microdose	0.0581	0.0437	0.0258	0.0500
Plot characteristics				
ln(plot area)	-0.4693***	0.0798	-0.3017***	0.1171

Table 17. Continued

Variable	GMM		Median regression	
Inputs	Coefficient	Std. error	Coefficient	Std. error
Soil type (cf. sandy)				
Clay	0.2151	0.2066	0.0759	0.4983
Sand and clay	-0.0205	0.1478	0.3464**	0.1723
Loam	-0.5353**	0.2434	-0.2391	0.3128
Sand and other	-0.1848	0.1863	-0.1999	0.2814
Soil fertility (cf. poor)				
Average	0.6674***	0.1364	0.5112***	0.1786
Good	0.5974***	0.1498	0.4595**	0.1982
Household/household head characteristics				
ln(value of equipment)	2.4589***	0.4102	1.7293***	0.5418
Education (cf. none)				
Primary	0.3291**	0.1587	0.4145*	0.2467
Secondary	-0.6712***	0.2168	-0.6292*	0.3706
Literacy training	-0.1972	0.1299	-0.2158	0.2339
Village leader	0.4797***	0.1700	0.4543**	0.2281
Member of a farmers' association	-0.3282**	0.1378	-0.1880	0.2060
Region (cf. Dossa)				
Maradi	0.3167	0.2757	0.3904	0.3790
Tillabery	0.5507***	0.2014	0.4164	0.2709
Zinder	-0.0272	0.2474	0.1463	0.3428
ln(distance to input shop)	-0.2328***	0.0510	-0.1860***	0.0696
Participation in fertilizer demonstrations				
Microdosing	-0.2634**	0.1120	-0.3173**	0.1320
Broad spreading	0.2375**	0.1184	0.0935	0.1628
Line spreading	0.1599	0.2886	0.6478	0.4509
Occupation (cf. agriculture only)				
- Nonagriculture	-0.9787	0.9828	-2.4254*	1.3241
Agriculture and nonagriculture	-0.5346	0.4140	-0.7954	0.7644
Agriculture and other	0.6855**	0.3174	0.7512	0.6919
ln(labor-to-land ratio)	0.2985***	0.0774	0.3929***	0.1189
ln(dependency ratio)	-0.9389***	0.2996	-0.2904	0.4596
Intercept	4.0261***	1.0977	4.8899***	1.3374
Number of observations	413		415	
R^2/Pseudo R^2	0.7504		0.4599	
White/Koenker test of heteroskedasticity (P value)	0.0376			
Wald test of excluded variables (P value)	0.8773			
Hansen's J test of overidentifying restrictions (P value)	0.8653			
C test of exogeneity of inputs (P value)	0.8267			
Relevance tests of excluded instruments (P values)				
lntotallabor	0.0000			
lnqtyorganic	0.0000			
lnqtytradseed	0.0000			
lnqtyimpvseed	0.0013			
pestusemill	0.0002			
Macrodos	0.4869			
Microdos	0.0771			
Inorgorg	0.1101			
Inorgmacro	0.8388			
Inorgmicro	0.0001			

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

6.8. Peanut Production

The variables having a significant and robust association with peanut production (Table 18) include the amount of labor used (+), plot size (–), soil fertility (higher for good than poor soils), education (– for other education compared with none), age of the household head (+), and access to inventory credit (–). Except for the unexpected negative association with inventory credit, these results are consistent with our expectations. As mentioned previously, we did not expect credit access to have a direct effect on crop production in the structural production functions, so this variable may be acting as a proxy for some other omitted factor. Our expectation was that access to credit would be associated with better access to technical information, which would tend to increase productivity. We do not have an explanation for this surprising result.

Table 18. Determinants of ln(peanut production per hectare), structural models

Variable	GMM		Median regression	
Inputs	Coefficient	Std. error	Coefficient	Std. error
ln(labor/ha)	0.1084***	0.0189	0.0657**	0.0324
ln(quantity of organic fertilizer/ha)	0.0359	0.0221	0.0003	0.1703
ln(quantity of traditional seeds/ha)	-0.0478**	0.0190	-0.0252	0.0416
ln(quantity of improved seeds/ha)	-0.0575**	0.0264	-0.0254	0.0457
Fertilizer microdosing used	2.9116***	0.4126	-0.1474	3.6062
Inorganic x organic fertilizer interaction	-0.0153***	0.0036	-0.0006	0.0279
ln(value of inorganic fertilizer/ha.) x microdose	-0.3604***	0.0542	-0.0013	0.4571
Plot characteristics				
ln(plot area)	-2.5863***	0.0687	-2.6907***	0.1444
Soil type (cf. sandy)				
Clay	-0.0683	0.0485	-0.0496	0.0729
Sand and clay	-0.1253***	0.0451	-0.0575	0.0572
Loam	0.0861	0.1604	0.0315	0.1447
Sand and other	-0.1013	0.0872	-0.1640**	0.0668
Soil fertility (cf. poor)				
Average	0.1127**	0.0478	0.0747	0.0568
Good	0.1503***	0.0530	0.1415*	0.0799
Household/household head characteristics				
Education (cf. none)				
Primary	0.1233	0.0840	0.1957*	0.1104
Secondary	-0.2664***	0.0749	-0.1549	0.1219
Literacy training	0.1719***	0.0641	0.1408	0.2931
Other	-0.2531***	0.0828	-0.2199*	0.1199
ln(age)	0.2418***	0.0784	0.2191**	0.1107
Village leader	-0.1518***	0.0506	-0.0990	0.0654
Region (cf. Dossa)				
Maradi	0.0531	0.1435	0.4292	0.3634
Tillabery	-0.2738***	0.0620	-0.1286	0.0991
Received inventory credit	-0.1608***	0.0524	-0.1631**	0.0777
Participation in fertilizer demonstrations				
Microdosing	0.0731*	0.0393	0.0526	0.0676
Broad spreading	-0.0213	0.0419	-0.0482	0.0563
Line spreading	0.1936**	0.0784	0.0804	0.1443
Occupation (cf. agriculture only)				
Nonagriculture	0.0068	0.0681	0.0865	0.0870
Agriculture and nonagriculture	0.0797*	0.0460	0.1419	0.0889
Agriculture and other	-0.0533	0.0453	-0.1032	0.0935
Intercept	0.5855**	0.2795	0.8462**	0.3877

Table 18. Continued

Variable	GMM		Median regression	
Inputs	Coefficient	Std. error	Coefficient	Std. error
Number of observations	211		245	
R^2/Pseudo R^2	0.9450		0.8048	
White/Koenker test of heteroskedasticity (P value)	0.0008			
Wald test of excluded variables (P value)	0.3341			
Hansen's J test of overidentifying restrictions (P value)	0.2060			
C test of exogeneity of inputs (P value)	0.3316			
Relevance tests of excluded instruments (P values)				
lntotallabor	0.0000			
lnqtyorganic	0.0106			
lnqtytradseed	0.1948			
lnqtyimpvseed	0.1555			
Microdos	0.0001			
Inorgorg	0.0000			
Inorgmicro	0.0008			

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

6.9. Reduced-Form Yield Functions

The results of estimation of the reduced-form yield functions [equation (17)] are presented in Table 19. As discussed in Section 5, the reduced-form functions estimate the total impacts of changes in explanatory variables, taking into account responses in different inputs. That is, the coefficients in these functions represent the total predicted effect of each variable on crop yield, accounting for the fact that these variables may influence yields indirectly, by affecting use of inputs, as well as directly, by affecting how productively inputs are used.

The only variable found to have a consistent significant effect for all crops is the size of the plot (–). As mentioned earlier, this negative plot size effect, which we observed in most of the input demand and structural production models as well, could be a result of decreasing returns to scale at the plot level, unobserved plot-quality characteristics that are negatively correlated with plot size, or error in measuring plot quality. We could not determine whether any or all of these explanations are valid without further investigation.

Other variables having consistent significant impacts on yields of at least two crop mixes include soil fertility (higher on good-fertility plots than on poor-fertility plots for millet–cowpea and millet–sorghum–cowpea), ownership of farm equipment (+ for millet–cowpea and millet–sorghum–cowpea), age of the household head (+ for millet and millet–sorghum–cowpea), membership in a farmers' association (– for millet and millet–sorghum–cowpea), and participation in demonstrations of fertilizer line spreading (+ for millet–cowpea and peanuts). All these results are consistent with our expectations, except the negative impact of membership in a farmers' association, as discussed earlier.

Several other variables have statistically significant impacts on yields of at least one crop, including soil type (– for loam soils for millet–sorghum–cowpea), average soil fertility (+ compared with poor fertility for millet–sorghum–cowpea), means of plot acquisition (– for other compared with inherited for millet), ownership of traction animals (+ for millet) and other animals (+ for millet–sorghum–cowpea), primary education (+ for millet–sorghum–cowpea), other education (+ for peanuts), household head a village leader (+ for millet–sorghum–cowpea but – for peanuts), distance to an input shop (+ for millet–cowpea but – for millet–sorghum–cowpea), participation in demonstrations of microdosing (+ for millet–cowpea and peanuts but – for millet–sorghum–cowpea) or broadcast spreading of fertilizer (+ for millet–sorghum–cowpea), occupation (nonagriculture, negative association with millet–sorghum–cowpea yields; agriculture and nonagriculture, negative association with millet yields;

agriculture and other, positive association with millet–sorghum–cowpea yields), labor-to-land ratio (+ for millet–sorghum–cowpea), and dependency ratio (– for millet–sorghum–cowpea).

These results do not support the part of hypothesis 1 arguing that access to inventory credit will increase yields (the impacts of inventory credit are statistically insignificant in all cases). Because our input demand results showed that inventory credit contributes to increased use of inorganic fertilizer and seeds but has insignificant impacts on other inputs or labor, and because these inputs are shown to have positive impacts on yields in some of the structural production models, we have indirect support for this part of hypothesis 1. It may be that our reduced-form yield models are not statistically powerful enough to discern the impacts of inventory credit (note the relatively large standard errors in these models).

The results are mixed with respect to hypothesis 2. Although the impact of access to input supply shops on millet–sorghum–cowpea yields is as expected, the impact on millet–cowpea yields is in the opposite direction. Perhaps farmers focus their scarce resources on providing more inputs to the millet–sorghum–cowpea crop mix and less to the millet–cowpea mix, if they have better access to input shops. Further investigation of this issue is needed.

Several of the results support the productivity implications of microdosing discussed in hypothesis 3. Both microdosing and line spreading (an alternative similar to microdosing) are found to have significant positive impacts on some crop mixes (millet–cowpea and peanuts). The exception is the millet–sorghum–cowpea crop mix, for which demonstrations of macrodosing using broadcast methods show more benefit than microdosing. Larger doses of fertilizer may be more efficacious when sorghum is part of the crop mix.

Table 19. Determinants of ln(crop production per hectare), reduced-form OLS models

Variable	Millet		Millet–cowpea		Millet–sorghum–cowpea		Peanuts	
Plot characteristics	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
ln(plot area)	-0.9177***	0.1640	-0.3585**	0.1589	-0.6200***	0.1024	-2.7649***	0.1665
Soil type (cf. sandy)								
Clay	0.0954	0.1723	-0.2248	0.2427	0.3757	0.3341	-0.0305	0.0829
Sand and clay	0.0263	0.2475	0.1456	0.1561	-0.1186	0.1748	-0.2005*	0.1042
Loam			-0.0152	0.2628	-0.4178***	0.1513	0.0411	0.2252
Other			0.3613	0.6205	-0.1806	0.1194	-0.2441	0.2730
Soil fertility (cf. poor)								
Average	0.3280	0.1987	-0.0277	0.1325	0.7227***	0.1747	0.1122	0.0802
Good	0.3842	0.2380	0.3218**	0.1543	0.5628***	0.1662	0.1296	0.0802
Collectively owned plot	0.1185	0.2016	0.0852	0.1446	0.0869	0.1293	0.0829	0.1041
How plot acquired (cf. inherited)								
Rented	-0.2947	0.2701	-0.3806*	0.2113	-0.0041	0.2769	-0.0771	0.1280
Purchased	-0.3079*	0.1836	0.1577	0.2513	-0.2478	0.2331	0.2735	0.1924
Sharecropped	-0.6029	0.3996	-0.6962	0.9178			-0.1804	0.1658
Other	-0.5190**	0.2179	-0.0961	0.1784	-0.1733	0.1823	0.1143	0.0723
ln(distance from residence)	0.1804	0.1539	-0.1278	0.0986	-0.1752	0.1368	0.0748	0.0572
Household characteristics								
ln(value of assets)								
Farm equipment	-0.1174	0.8950	0.2544*	0.1479	2.5347***	0.7910	0.7606	0.6608
Durable assets	0.0194	0.0213	-0.0081	0.0321	0.0238	0.0183	-0.0088	0.0137
Traction animals	0.0422**	0.0181	0.0137	0.0129	0.0008	0.0147	-0.0095	0.0123
Other animals	-0.0211	0.0582	0.0164	0.0228	0.0435**	0.0199	-0.0138	0.0112
ln(land area cultivated)	-0.0332	0.1910	-0.2767*	0.1482	-0.1425	0.1013	-0.1051	0.1052
Characteristics of household head								
Education (cf. none)								
Primary	-0.3356	0.3166	-0.4118	0.2619	0.4228**	0.1897	-0.0291	0.1625
Secondary	-0.0231	0.4373	0.1551	0.2913	-0.2615	0.2455	-0.1414	0.1092
Literacy training	-0.2289	0.1796	0.1210	0.2966	0.0927	0.1456	0.2144**	0.0824
Other			0.3698	0.3548			-0.3379*	0.1943
ln(age)	0.9647***	0.3569	0.3893	0.3028	0.5746**	0.2575	0.1683	0.1845
Village leader	0.1141	0.3394	-0.0691	0.2473	0.3956**	0.1880	-0.3530**	0.1583
Member of a farmers' association	-0.3554**	0.1729	0.0083	0.1237	-0.3354*	0.1866	-0.0571	0.1117
Region (cf. Dosso)								
Maradi	0.1920	0.2784	-0.3038	0.2814	0.1360	0.3162	0.0222	0.2174

Table 19. Continued

Variable	Millet		Millet–cowpea		Millet–sorghum–cowpea		Peanuts	
Plot characteristics	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Tillabery	0.3354	0.2440	-0.1462	0.1944	0.6143**	0.2514	-0.0817	0.1804
Zinder	-0.1091	0.3203	-0.3796	0.3520	0.1569	0.2892		
ln(distance to input shop)	0.0969	0.1229	0.2435**	0.0956	-0.2433***	0.0755	-0.0030	0.0471
Received inventory credit	0.1973	0.1753	0.1530	0.1614	0.0250	0.1727	-0.0895	0.0835
Participated in fertilizer demonstrations								
Microdosing	-0.1195	0.2374	0.3061**	0.1527	-0.2568**	0.1231	0.2081**	0.0870
Broad spreading	0.0991	0.2057	0.0003	0.1737	0.3313**	0.1492	0.0443	0.0866
Line spreading	0.2859	0.4029	1.1989**	0.4917	0.0834	0.3596	0.2576**	0.1262
Occupation (cf. agriculture only)								
Nonagriculture	-0.0636	0.3279	-0.2690	0.2476	-0.8200***	0.2896	-0.0786	0.1126
Agriculture and nonagriculture	-0.7904**	0.3434	-0.1310	0.4854	-0.4344	0.4768	-0.0763	0.1950
Agriculture and other	0.1012	0.2903	0.4491	0.4414	0.9393***	0.2885	0.1027	0.1420
ln(labor-to-land ratio)	0.0321	0.1420	0.1690	0.1235	0.4309***	0.0672	0.0043	0.0767
ln(dependency ratio)	0.5892	0.5301	-0.5437	0.3742	-0.8801**	0.3547	-0.1783	0.2867
Intercept	2.1424	2.2117	8.8852***	1.3226	2.5244	1.9280	-0.0381	2.0382
Number of observations	250		542		420		214	
R^2	0.4151		0.2558		0.7225		0.9409	

*, **, *** = mean coefficient statistically significant at 10%, 5%, and 1% levels, respectively.

The results show that physical assets, especially farm equipment and animals, can contribute to higher crop yields, as expected. Education contributes to higher yields for some crops, contradicting the concern about this in hypothesis 4. However, nonagricultural employment reduces yields of some crops, consistent with hypothesis 4. Despite lower use per hectare of NPK, organic fertilizer, improved seeds, and labor on larger farms, we did not find that farm size had strongly statistically significant effects on yields in the reduced-form regressions [although we found a weakly significant (at the 10 percent level) negative effect of farm size on millet–cowpea yield], in contrast to our expectation of an inverse farm-size productivity relationship in hypothesis 5. As with the insignificant impacts of inventory credit, this may simply reflect the low statistical power of the reduced-form models to discern this impact. Note that all the coefficients of farm size in Table 19 are negative, but the standard errors are relatively large.

Although we did not find a significant inverse farm-size productivity relationship, the results for millet–sorghum–cowpea indicate that labor constraints are affecting yields of this crop mix, given the positive effect of the labor-to-land ratio and the negative effect of the dependency ratio. Thus, labor-constrained households find it more difficult to produce this crop mix than do other households.

7. CONCLUSIONS AND IMPLICATIONS

In our descriptive analysis, we found that use of inorganic fertilizer and microdosing is associated with access to inventory credit and input shops and participation in fertilizer trials, as are higher yields of several crops, consistent with several of our hypotheses. These hypotheses were tested using econometric analysis, and the results generally confirm them. Here we first recap our findings with regard to the hypotheses posed in Section 5 and then consider implications.

7.1. Main Findings

The qualitative results of the econometric analysis for key variables and their robustness to the statistical model used are summarized in Table 20.

7.1.1. Impacts of Inventory Credit (Hypothesis 1)

We found that access to inventory credit increases use of inorganic fertilizer and traditional seeds in Niger (results robust to statistical model). These results support the first part of hypothesis 1: inventory credit increases purchased input use.

We found that using a greater quantity of inorganic fertilizer leads to higher yields of millet and millet–cowpea if fertilizer is applied using □icrodosing (robust results). Greater seed use leads to greater yields of millet (not robust) and millet–cowpea and millet–sorghum–cowpea intercrops (robust results for intercrops). Surprisingly, however, greater use of seed and fertilizer applied through microdosing are associated with lower peanut yields (not robust). Taken together with the findings that inventory credit promotes greater use of fertilizer and seeds, these findings imply that inventory credit contributes to higher yields of millet, millet–cowpea, and millet–cowpea–sorghum, at least when fertilizer is applied using microdosing. This supports the second part of hypothesis 1 for these crop mixes, conditional on fertilizer being applied using microdosing. Our findings for peanuts contradict hypothesis 1.

As discussed in Section 5, we also tested the impacts of inventory credit and other factors using the reduced-form approach reported in Table 19. The reduced-form results show no statistically significant impacts of inventory credit on yields of any crop mixes, although the signs of the coefficients are consistent with the findings from the structural approach previously mentioned. The large standard errors of many of the coefficients in the reduced-form regressions limit the statistical power of those regressions to show the impacts. This does not refute hypothesis 1; it only fails to support it. A larger sample size would be necessary to have a better test of this hypothesis using the reduced-form approach.

Table 20. Summary of qualitative findings of the econometric models

Variable	Input use						Yields			
	Inorganic fertilizer	NPK	Organic fertilizer	Traditional seeds	Improved seeds	Labor	Millet	Millet–cowpea	Millet–sorghum–cowpea	Peanuts
Inputs and microdosing										
Labor/ha							++	++	++	++
Quantity of organic fertilizer/ha								+		
Quantity of traditional seeds/ha							+	++	++	-
Quantity of improved seeds/ha										-
Used pesticide								+	++	
Fertilizer macrodosing used										
Fertilizer microdosing used									+	+
Inorganic x organic fertilizer interaction										-
Value of inorganic fertilizer/ha if macrodose										
Value of inorganic fertilizer/ha if microdose							++	++		-
Access to inputs, credit, training										
Distance to input shop	--	--		--				++(+)	--(–)	
Received inventory credit	++	++		++		-				--
Participated in fertilizer demonstrations										
Microdosing	++	++	+	--		++		+(+)	--(–)	(+)
Broad spreading			+	--		++			+(+)	
Line spreading	+	+	-					++(+)		+(+)
Assets										
Farm equipment	+	+	+	+		+			++(+)	
Durable assets	-	-	++		+					
Traction animals	++	++	+	+			++(+)			
Other animals	+	-		+		-			(+)	
Land area cultivated		--	-	-	-	--				
Labor and human capital endowment										
Education of household head (cf. none)										
Primary		--		-				-	+(+)	
Secondary	+		-	+	-				-	-
Literacy training	+			+				-		+(+)
Other		-	+		-			++		-

Table 20. Continued

Variable	Input use						Yields			
	Inorganic fertilizer	NPK	Organic fertilizer	Traditional seeds	Improved seeds	Labor	Millet	Millet–cowpea	Millet–sorghum–cowpea	Peanuts
Occupation of head (cf. agriculture only)										
Nonagriculture	+	-	+	-	-				(–)	
Agriculture and nonagriculture	++	++	+	++	-		(–)			
Agriculture and other	-	++	+	+	-				+(+)	
ln(labor-to-land ratio)		-	+					++	++(+)	
ln(dependency ratio)		+	-	+		-	+		-(–)	

++ means the coefficient is positive, statistically significant (5% level) and robust across the different regression models (for yields, this refers only to the structural regression results presented in Tables 15–18).
+ means the coefficient is positive and statistically significant in some, but not all models (for yields, this refers only to the structural regression results).
-- means the coefficient is negative, statistically significant (5% level) and robust across the different regression models (for yields, this refers only to the structural regression results).
- means the coefficient is negative and statistically significant in some, but not all models (for yields, this refers only to the structural regression results).
(+) means the coefficient is positive and statistically significant (5% level) in the reduced-form yield models presented in Table 19.
(–) means the coefficient is negative and statistically significant (5% level) in the reduced-form yield model.

7.1.2. Impacts of Access to Input Shops (Hypothesis 2)

Like our finding for inventory credit, we found that having better access to input shops promotes greater use of inorganic fertilizer and seeds (robust results), supporting the first part of hypothesis 2. Because increasing these inputs leads to higher yields of millet, millet–cowpea, and millet–sorghum–cowpea (when fertilizer is applied using microdosing) but lower yields of peanuts, our finding tends to support the second part of hypothesis 2 for all crop mixes except peanuts. However, an additional impact that needs to be considered is the direct effect of access to input shops on crop productivity (controlling for input use), which was found to be significant for the millet–cowpea and millet–sorghum–cowpea intercrops. We found that households with better access to input markets obtain higher productivity of millet–sorghum–cowpea intercrops (possibly because of better access to information as well as inputs) but lower productivity of millet–cowpea (reasons for this are not clear). Combining these results with the impacts of inputs on these crops, we reached an unambiguous finding that access to input shops increases yields of millet–sorghum–cowpea intercrops but has ambiguous impacts on millet–cowpea because of competing effects. The total impact (combining the indirect and direct effects of access to input shops on yields), which we tested using the reduced-form approach, confirms that better access to an input shop increases yields of millet–sorghum–cowpea intercrops but reduces yields of millet–cowpea intercrops and has statistically insignificant impacts on millet and peanuts in sole stands. These results therefore provide robust support for the second part of hypothesis 2 only in the case of the millet–sorghum–cowpea intercrop and refute it for the millet–cowpea intercrop.

7.1.3. Impacts of Fertilizer Microdosing (Hypothesis 3)

Households that participated in fertilizer microdosing demonstrations use more inorganic fertilizer (robust result), consistent with the argument in hypothesis 3 that households that used little fertilizer before participating in microdosing are expected to increase fertilizer use. Participants in these demonstrations also use more labor (robust) and organic fertilizer (not robust) but fewer seeds (robust). The increase in labor use reflects the need for additional labor to apply seeds using microdosing (either to mix fertilizer with the seeds or to apply fertilizer as a side dressing at the planting mound). Organic fertilizer use with microdosing could increase because it is promoted by microdosing demonstrations or because organic manure is a complementary input to inorganic fertilizer. Other regression results did not support the assertion that inorganic and organic fertilizer are complementary, however, because we did not find a positive interaction between those two inputs in the yield functions for most crop mixes and did not find a negative interaction for peanuts. Thus, the impact of microdosing demonstrations on manure use appears more likely to result from the use of manure being promoted by the demonstrations. The negative impact of microdosing demonstrations on seed use also could be a result of the demonstrations promoting lower seed use per hole or lower planting density, or because fewer seeds are needed when microdosing is applied because of better performance of the seeds that are planted. We cannot determine whether any of these explanations is the reason for this finding, based on our evidence; this could be investigated in further research.

We found that use of microdosing has a positive impact on the yield response to fertilizer for millet and millet–cowpea (robust) but a negative impact for peanuts (not robust), as noted earlier. We also found that use of microdosing tends to increase yields of millet–sorghum–cowpea and peanuts, regardless of the level of fertilizer used (not robust), and that participants in microdosing demonstrations obtain higher yields of millet–cowpea (not robust) but lower yields of millet–sorghum–cowpea (robust), regardless of the particular practices used by the farmers.

These results suggest that microdosing demonstrations have complex impacts on crop yields through multiple mechanisms—for example, by affecting use of fertilizer and other inputs, the yield response to inputs, and farmers' knowledge and ability to be productive more generally. It is difficult to predict the net impacts of these complex effects using the structural models, because there are competing effects (e.g., an increase in fertilizer use but a reduction in seed use). The reduced-form models predict the total impacts of participation in microdosing demonstrations, and these are found to vary by crop mix, with positive impacts on yields of millet–cowpea and peanuts and negative impacts on millet–sorghum–cowpea. Therefore, we have mixed results concerning the impacts of microdosing demonstrations on crop yields, depending on the crop.

7.1.4. Impacts of Income-Generating Assets (Including Physical and Human Capital) and Activities (Hypothesis 4)

Physical assets used in farm production were found to contribute to increased input use and yields. For example, households that own more farm equipment use more inorganic fertilizer, organic fertilizer, seeds, and labor (none of these robust). Farm equipment contributes to increased yields of millet–sorghum–cowpea, both using the structural approach (robust) and the reduced-form approach. Similarly, greater ownership of traction animals is associated with greater use of inorganic fertilizer (robust) and manure and seeds (not robust) and with higher yields of millet (robust in structural regressions and reduced form).

By contrast, physical assets with uses outside crop production have more mixed impacts. For example, households with more durable assets were found to use less fertilizer (not robust) but more manure (robust) and improved seeds (not robust). We found no statistically significant impacts of durable assets on yields of any crop mixes. Ownership of other animals besides traction animals are associated with more use of inorganic fertilizer in total but less use of NPK, more use of traditional seeds but less labor (none of these robust), and a positive association with yields of millet–sorghum–cowpea (robust only in the reduced form).

Education also has mixed impacts on input use and yields. Household heads having primary education use less NPK (robust) and fewer traditional seeds (not robust) than uneducated heads and obtain lower yields of millet–cowpea but higher yields of millet–cowpea–sorghum (not robust). Household heads with secondary education use more inorganic fertilizer and traditional seeds, use less organic fertilizer and improved seeds, and obtain lower yields of millet–sorghum–cowpea and peanuts than do uneducated heads (none of these robust). Participants in literacy training use more inorganic fertilizer and traditional seeds and obtain higher yields of peanuts but lower yields of millet–cowpea (none of these robust).

Involvement in nonagriculture occupations also has mixed impacts. The household head whose main occupation is nonagricultural uses more inorganic fertilizer in total but less NPK, more organic fertilizer, and fewer seeds than does the household head whose main occupation is agricultural (none of these robust). The household head whose occupation includes both nonagricultural and agricultural work uses more inorganic fertilizer and traditional seeds (robust), uses more organic fertilizer but fewer improved seeds (not robust), and obtains lower millet yields (reduced-form regression only). The household head whose occupation includes agriculture and other activities uses less inorganic fertilizer in total (not robust) but more NPK (robust), uses more organic fertilizer and traditional seeds but fewer improved seeds (not robust), and obtains higher yields of millet–sorghum–cowpea (not robust in the structural regressions but also found in reduced form).

A larger labor endowment of the household contributes to more labor-intensive practices and higher yields of some crops. For example, households with greater labor-to-land ratios apply more organic fertilizer but less NPK (not robust) and obtain higher yields of millet–cowpea and millet–sorghum–cowpea (robust). Similarly, households with lower dependency ratios use more labor and organic fertilizer but less NPK and fewer seeds (none of these robust); they obtain higher yields of millet–sorghum–cowpea (not robust in structural model but also found in reduced form) and higher yields of millet in sole stands (not robust).

These findings support the argument in hypothesis 4 that the impacts of assets and activities on the use of inputs and yields are likely to be mixed, depending on whether households suffer from labor or capital shortages and the nature of the asset or activity. For assets focused on crop production, such as farm equipment and traction animals, the impacts on input use and yields are more generally positive.

Greater labor endowments promote increased use of labor-intensive inputs such as manure but reduced use of fertilizer, although they still lead to higher yields of some crops. Other endowments that increase labor opportunity costs and income, such as secondary education, cause farmers to substitute less-labor-intensive inputs (e.g., inorganic fertilizer) for more-intensive ones (e.g., organic fertilizer) and to be less productive with their inputs for some crops. Involvement in some nonagricultural activities stimulates increased use of inorganic as well as organic fertilizer, though the impacts on yields are not favorable, perhaps because farmers in this situation are able to devote less effort to managing their crops.

7.1.5. Impacts of Farm Size (Hypothesis 5)

We found that larger farms use less labor (robust), NPK (robust), and manure and seeds per hectare (not robust) than do smaller farms. This supports the argument in hypothesis 5 that larger farms will use fewer inputs per hectare if they face binding labor, capital, or other constraints. Despite this, we found no statistically significant impacts of farm size on yields in any of our regressions. This is a surprising result, given our findings of lower inputs per hectare on larger farms and the common finding in the literature of an inverse relationship between farm size and productivity. This could be an indication of greater land degradation on smaller farms—that is, larger farms may obtain comparable yields without as much inputs per hectare because they are more able to use fallowing to restore soil fertility. Therefore, more intensive use of inputs by smaller farms may act mainly to compensate for declining fertility resulting from declining use of fallowing, as argued originally by Boserup (1965).

7.1.6. Summary of Findings

Our findings relative to the hypotheses are summarized in Table 21, based on the robust statistical results (statistically significant in more than one model specification). The portions of hypotheses 1, 2, 3, and 5 related to the impacts of inventory credit, input shops, microdosing demonstrations, and farm size on input use are well supported by the evidence. The hypothesized impacts of these factors on crop yields are less well supported, with insignificant impacts in many cases and conflicting negative impacts in some cases. For example, better access to input shops is associated with higher yields of the millet–cowpea–sorghum intercrop and lower yields of millet–cowpea intercrop, while participation in fertilizer microdosing demonstrations is associated with higher yields of millet–cowpea and lower yields of millet–sorghum–cowpea. Apparently, microdosing has unfavorable impacts when sorghum is in the crop mix, while simply having better access to inputs is important for sorghum. Insignificant yield impacts may result because such impacts are difficult to detect with our sample given large variability in yields. In the case of the effects of farm size on yields, the lack of significant impact despite greater input use per hectare on smaller farms suggests that soil fertility may be more depleted on smaller farms because of their inability to fallow the land, and that small farmers are compensating through a Boserupian intensification response. More direct evidence on fallowing practices and soil quality would be needed to verify this explanation, however.

With regard to hypothesis 4, we found that different assets and activities have different impacts on input use and yields, and that impacts also vary by crop type. Ownership of traction animals contributes to greater use of inorganic fertilizer and higher millet yields, while farm equipment contributes to higher yields of the millet–sorghum–cowpea intercrop. Involvement of the household head in both nonagricultural and agricultural employment contributes to greater use of inorganic fertilizer and higher yields of millet–sorghum–cowpea. A greater endowment of labor per unit of land and a lower dependency ratio also contribute to higher millet–sorghum–cowpea yields.

7.2. Implications

Our findings support the FAO Projet Intrants approach of promoting increased input use through development of inventory credit and input supply shops and demonstrations of fertilizer microdosing. Access to inventory credit increases the predicted value of inorganic fertilizer use by between 1,600 and

3,200 FCFA per hectare (across the various models in Table 10), and given that the estimated VCR for fertilizer use (using microdosing) is greater than 3 for millet and millet–cowpea production, the predicted impact of access to inventory credit on farmers' income (via impacts on fertilizer use) is between about 5,000 and 10,000 FCFA per hectare of millet or millet–cowpea cultivated. In addition, access to inventory credit increases farmers' use of seeds (by at least 16 kg/ha), which also has a positive impact on crop production. Similarly, being 10 km closer to an input shop increases farmers' use of fertilizer by 1,000 to 1,400 FCFA per hectare, leading to an increase in the predicted value of production of millet or millet–cowpea of at least 3,200 to 4,500 FCFA per hectare, plus positive impacts of increased seed use.

These positive impacts are linked to the use of fertilizer microdosing, which we have found increases the productivity impact of fertilizer applied to millet and millet–cowpea intercrops. Thus, a synergy exists among these various interventions, with inventory credit, input supply shops, and microdosing demonstrations combining to produce a stronger impact than would be possible by promoting any one of these activities in isolation. Our findings also imply that the degree of synergy among these approaches depends on the type of crops grown. We found that the impact of microdosing is less favorable when sorghum is part of the intercrop mix but that access to input shops is quite important for sorghum production. It thus appears that less emphasis should be given to promoting microdosing in sorghum production.

Other interventions that could help to boost input use and productivity include providing farmers with greater access to farm equipment and traction animals through programs designed to improve the supply of these capital items and the availability of credit to help farmers finance their purchases. Promotion of higher-value crops such as hibiscus (which was found to be associated with greater fertilizer use) through research, technical assistance, and market development programs could also be useful. Further research on these topics appears warranted. Research on the implications of inventory credit, input supply shops, microdosing demonstrations, and other interventions on land degradation would also be useful.

Table 21. Summary of findings relative to hypotheses

Hypothesis	Subhypothesis	Finding	Evidence (focusing on robust results)[a]
1	Inventory credit increases input use.	Supported.	Use of inorganic fertilizer and seeds increased.
	Inventory credit increases yields by increasing input use.	Partially supported.	Increase in fertilizer (applied with microdosing) and seed use increases yields of several crop mixes, except peanuts. Insignificant results using reduced form.
2	Access to input supply shops increases input use.	Supported.	Use of inorganic fertilizer and seeds increased.
	Access to input supply shops increases yields by increasing input use.	Partially supported, partially rejected.	Increase in fertilizer (applied with microdosing) and seed use found to increase yields of several crop mixes, except peanuts. Better access to input supply shops associated with higher yields of millet–sorghum–cowpea, but lower of millet–cowpea in reduced form.
3	Fertilizer microdosing demonstrations may increase fertilizer use, if little fertilizer used before.	Supported.	Value of inorganic fertilizer and quantity of NPK used both greater for participants in microdosing demonstrations.
	Use of fertilizer microdosing increases productivity of fertilizer use.	Partially supported, partially rejected.	Yield response to fertilizer greater for millet and millet–cowpea with microdosing. Participation in microdosing demonstrations associated with greater yields of millet–cowpea but smaller yields of millet–sorghum–cowpea.
4	Income-generating assets and activities may promote increased use of purchased inputs by relaxing cash constraints.	Mixed impacts, depending on asset or activity type and type of input.	Traction animals associated with greater use of inorganic fertilizer. Durable goods associated with more use of organic fertilizer. Primary education associated with less use of NPK. Involvement in both agriculture and nonagriculture occupations associated with more use of inorganic fertilizer and traditional seeds, while involvement in agriculture and other occupations associated with more use of NPK.
	The impacts of such assets and activities on crop yields is ambiguous, since they may compete with crop production for labor.	Mixed impacts, depending on asset or activity type, and on crop type.	Traction animals contribute to higher millet yields. Farm equipment contributes to higher yields of millet–sorghum–cowpea. Primary education associated with higher millet–sorghum–cowpea yields, while literacy training associated with higher peanut yields. Involvement in both agriculture and other occupations associated with higher yields of millet–sorghum–cowpea, as are a higher labor-to-land ratio and lower dependency ratio.
5	The amount of inputs used per hectare may be lower on larger farms as a result of cash or labor constraints.	Supported.	Larger farms use less NPK and labor per hectare.
	As a result, crop yields may be lower on larger farms.	Not supported.	No statistically significant impacts of farm size on yields in structural or reduced-form models.

[a] In this table, we consider only results that are statistically significant (at the 5% level) in more than one specification of the statistical model. For yield impacts, this includes significance in at least one specification of the structural model and in the reduced-form model.

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