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Profitability and Institutional Constraints to the Adoption of Fertilizer Microdosing in Northwest Benin

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Abstract

Various agricultural techniques have been developed as components of food security interventions, but their effectiveness in addressing food insecurity in part depends upon the effectiveness of these techniques in fulfilling farmers' objectives. This paper presents the results of research that examined the constraints that limit the adoption of microdosing by farmers in northwest Benin. The results of farmer field trials indicate that on average, microdosing produced lower yields and proved less profitable than recommended levels. In addition to reduced profitability, numerous institutional constraints were identified that further limit adoption. These constraints include poorly functioning input markets, inefficient distribution systems, limited affordability and credit constraints, liquidity constraints, and government policies that limit cross-border access to inputs as well as the prioritization of fertilizer for cotton production over food crops.

Keywords: agricultural technology adoption, food security, household decision-making

1. Introduction

Since the 1990s, fertilizer microdosing has been promoted in West Africa as an accessible technology for increasing the agricultural productivity of resource-constrained farmers. Microdosing, which involves the point-source application of small quantities of fertilizer, has been successful at increasing agricultural yields and household incomes (Camara et al., 2013; Hayashi et al., 2008; Tabo et al., 2007), has proven effective at overcoming constraints associated with fertilizer supply (ICRISAT 2009), and has promoted more efficient nutrient uptake (Tabo et al., 2006) while reducing risks associated with leaching and run-off (CGIAR 2011).

Notwithstanding these purported benefits, microdosing has yet to be broadly adopted in the country of Benin. While various constraints have been proposed, for instance, declines in yield relative to recommended rates and increased labour demand, no systematic investigation at the farm level has been conducted. In this context a multidisciplinary research team from Benin and Canada collaborated on an Integrated Nutrient and Water Management project (INuWaM). Initiated in 2011, the project set out to examine the constraints that may hinder the adoption of fertilizer microdosing by smallholder farmers in the village of Koumagou B, located in northwest Benin. Our approach was based on the understanding that in order to identify the factors that may impede the adoption of microdosing, it is necessary to employ a holistic, yet focused, research framework to account for the social, economic and biophysical constraints that influence the decision of farmers to trust a new technology.

The literature on technology adoption, even limited to agriculture in West Africa, is extensive. While it is beyond the scope of the paper to provide a comprehensive summary of this literature, it is possible to identify some of the key sources that proved most relevant to our research (see Table 1). This literature highlights the complexity associated with the introduction of new technologies and the socio-political dimensions that influence adoption. This literature also identifies the interplay between biophysical and socio-cultural constraints. Of particular value was the work of Feder et al. (1985), which represents one of the first, and perhaps most comprehensive, multi-country assessment on the adoption of agricultural innovations. Their results emphasize the dynamic nature of household decision-making and the fluidity of social and ecological constraints that farming households face. These constraints, according to Feder et al. (1985), include farm size, risk and uncertainty, human capital, labour availability, credit constraints, land tenure, supply constraints, aggregate adoption over time, education, and the pace and nature of knowledge diffusion among rural farmers.

In addition to these constraints, Feder et al. (1985) and others have found that the adoption of any new technology ultimately rests on the farmers need to maximize temporal utility (or expected profits) subject to constraints. A number of studies emphasize profitability as foundational in agricultural technology adoption. These include the optimization assumption that Besley and Case (1993) referred to in their influential work on modeling technology adoption in developing countries, as well as Shiferaw et al. (2009) in their review on the adoption of natural resource management innovations and the requirement that farmers realize tangible economic benefits in the short run before adopting a new technology.

Table 1. Factors influencing technology adoption

Variable	Hypothesized Relationship with adoption	Rationale	References
Gender	Fewer female adopters than male adopters	Women have limited access to and control over factors of production; Women have less off-farm income and thus less capital that is required to purchase inputs	Doss & Morris (2001); Marenya & Barrett (2007)
Age	Indeterminate	Effect of age has mixed results in adoption literature; direction of influence can be specific to location or technology	Akinola (2010); Beke (2011); Marenya & Barrett (2007); Mignouna et al. (2011)
Household size; access to labour	Adopters expected to have larger households, less difficulty finding labour	Labour is a complementary input to fertilizer microdosing	Larson & Gurara (2013); Marenya & Barrett (2007); Mignouna et al. (2011)
Education level	Higher education level amongst adopters	Direct relationship-- farmers can better access information on new technology; Indirect relationship-- better educated have better access to credit	Adolwa et al. (2012); Beke (2011)
Socio-economic status and wealth	Higher socio-economic status and greater wealth amongst adopters	Poorer households less willing to take risk of investing in uncertain technologies	Adolwa et al. (2012); Dercon & Christiaensen (2011); Moser & Barrett (2003)
Total cultivable land (Farm size)	Adopters will on average have larger farms (measured by total cultivable land)	Farmers with more land can more readily experiment with new technologies; Scale of production may matter for the technology; Farm size may be a proxy for wealth	Abdulai & Huffman (2005); Feder et al. (1985); Larson & Gurara (2013); Yengoh et al.(2010)
Use of organic fertilizer	Higher amongst adopters	Complementarity between organic fertilizer and inorganic fertilizer; increases value of inorganic fertilizer	Place et al. (2003)
Access to Credit	Greater access amongst adopters	Addresses liquidity constraints common to smallholder farmers in SSA (especially during lean period when fertilizer expenses compete with basic consumption needs)	Abdulai & Huffman (2005); Beke (2011); Feder et al. (1985); Moser & Barrett (2003)

In addition to social and economic constraints, the biophysical environment has also been shown to influence the nature and direction of technology adoption (Ajayi et al., 2007; Larson & Gurara, 2013; Moser & Barrett, 2006; Shiferaw et al., 2009). For example, the variable response rate to fertilizer across soil conditions means that adaptation to local conditions is a critical element of properly managing soil for efficient crop production (Vanlauwe et al., 2010). Site-specific knowledge of soil type and quality, together with current farming practices that are formed by local knowledge, are therefore critical to understanding technology adoption at the farm level. Based on the costs and benefits associated with a new technology, farmers make decisions according to their own purposes, and allocate their time and resources accordingly. The various social, economic and ecological constraints that form their external environment either reward or punish farmers based on the decisions made, thereby channelling and directing the process of change. The adoption of any new technology ultimately depends upon on a complex array of social, economic and ecological variables. In this paper we present the results of field trials that compared the yield and profitability of microdosing versus recommended levels of fertilizer applications. We then elucidate the social, economic and ecological factors that further constrained the adoption of microdosing by Koumagou B farmers.

2. Method

This research was conducted in the village of Koumagou B, located in Northwest Benin, roughly 16 km from the larger village of Boukoumbé on the Benin/Togo border (Figure 1). The population of Koumagou B is approximately 580 residents who reside in 83 households. The ethnic group in Koumagou B is Batammariba *(Otamari)* and the land tenure system is based primarily on inheritance (Aregheore, 2009). Polygamy is an accepted practice where men derive social importance from the number of wives and children they have. Fetishists, traditional healers and current and former chiefs of the village hold particular prestige. Animist beliefs dominate the religious landscape, though Christianity and Islam are also represented. The older generation speaks the *Ditammari* language but French, as the national language, is spoken increasingly by youth, and is the language of instruction in the village school.

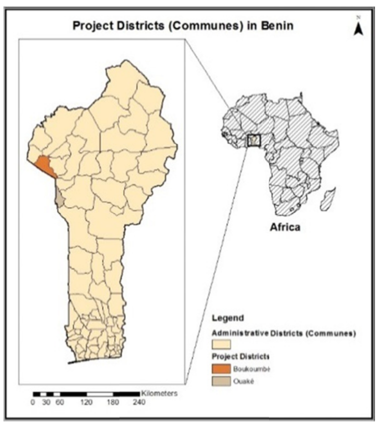

Figure 1. Location of project site in Benin

Koumagou B's Sudanian climate is characterized by one rainy season that extends from April to October. On average the region receives 800 to 1100 mm yr^{-1} of rainfall (Adegbidi et al., 1999). The remainder of the year consists of a dry season, and a hot, dry wind, known locally as *Harmattan,* blows from November to February. The local landscape is dominated by sloping and rocky terrain, which has contributed to soil erosion and nutrient run-off. The sloping landscape, coupled with a history of intensive agriculture, has led to declining levels of organic matter in the soil and a decrease in its water-holding capacity (Saidou et al., 2012). Local crops include maize, sorghum, cowpea, voandzou, yam, and vegetables such as chilli peppers. While cotton is a major cash crop throughout Benin, it is not grown in Koumagou B due to small land holdings of farmers and generally poor soil fertility.

The research project was initiated in 2011, and was launched through a village meeting in Koumagou B that included members of the research team, the village Chief and secretary, and representatives from village households. During this meeting the objectives of the project were presented, as was a request for participants to host demonstration plots on small parcels of their land. The only condition for participation was that the demonstration plot had to be near a road to maximize visibility and encourage information dissemination on the microdosing technique. Twenty farmers agreed to host demonstration plots. However, during the first year of the project two farmers left for employment opportunities in Nigeria, and one farmer chose to withdraw for personal reasons. The remaining 17 Demonstration Farmers (DFs) were given assistance in dividing a parcel of their land into two equal plots of $12m^2$ or $24m^2$, one for the microdosing technique and one for the application of recommended dosage. The project researchers prescribed the management of each demonstration plot to help ensure standardization. Maize was chosen for the demonstration trials. The participants received subsequent technical visits from the local project coordinator, who was trained in the microdosing technique. The primary differences between microdosing and the recommended dosage in this study were the quantity of fertilizer -less than six grams of fertilizer (equivalent to a bottle-cap full or a three-finger pinch) placed at the base of each plant under microdosing- and the timing-microdosing requiring an earlier application after planting. In the first year of the project (2012), a control plot was also included, with no fertilizer application. However, there was total crop failure across control plots and it was subsequently discontinued. Growing maize without fertilizer is not an option for Koumagou B farmers due to the high nutrient requirements of the maize crop and poor soil quality in the area. Microdosing could therefore serve as an effective alternative to recommended dosage levels. At the end of each growing season, the yields from the demonstration plots were weighed for the community to see and to compare the relative profitability. Revenue was calculated as grain yield.ha^{-1} multiplied by average market price in Malanville market in the north of Benin, in September 2012. The yield and relative profitability of microdosing versus the plots that received recommended dosage were then compared.

Concurrent to field trials, a census of Koumagou B households was completed. Household surveys were administered to 73 of the 83 village households (95% response rate of 77 contacted households with 4 abstentions). The survey included detailed questions on household demographics, household assets, knowledge of the microdosing technique, crop production, land tenure, access to inputs, and credit availability. These data were used to create indices of socio-economic status for all village households (Table 2). Comments from household surveys and key informant interviews were also used to provide necessary context and to illuminate the socio-ecological constraints that affect adoption.

Table 2. Household characteristics

Village Households (*n*=73)	Mean	Proportion	St Deviation
<u>Household Demographics</u>			
Gender of Household Head			
Male	--	0.90	--
Female	--	0.10	--
Age	41.01	--	12.35
Labour (Active Members of Household)	4.06	--	3.84
Some education=1 Illiterate=0	--	0.30	--
<u>Land and Fertilizer Use</u>			
Total Cultivable land (ha)	2.41	--	1.11
Use of Organic fertilizer (2012) 1=Yes	--	0.79	0.40
Use of Synthetic fertilizer (2012) 1=Yes	--	0.71	0.45

3. Results

The results of field trials, surveys and interviews indicate that the primary constraints to adoption include reduced yield and profitability, limited and inconsistent availability of fertilizer, cost of fertilizer, credit and labour constraints, and a general aversion to risk.

3.1 Profitability Comparison

The results of the trial plots indicate that 14 of the 17 trial plots that received microdosing application had lower yields than trial plots that received recommended dosage levels. The total yield for trial plots that received recommended dosage levels was estimated to be 22.5 percent greater than microdosed trial plots (Figure 2 and Table 3).

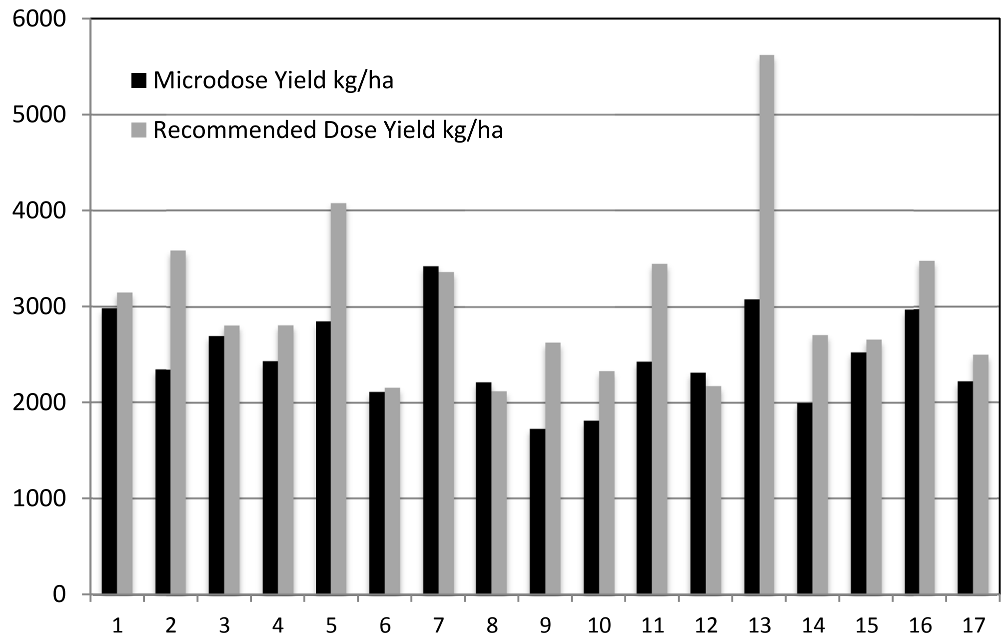

Figure 2. Yield results for microdosing and recommended fertilizer levels

While the term ‘profit’ is commonly used in adoption studies, in the context of this study a more accurate term may be ‘net returns over fertilizer costs’ as not all costs are captured in the analysis. This was a result of our inability to collect other cost data. In particular, the cost of labour is difficult to approximate since farmers rely heavily upon family and cooperative labour (discussed below). The USDA foreign agricultural service in their Coarse Grains Report for Benin explicitly state that they do not include the cost of labour when calculating the production costs of maize because it is typically family labour used on small farms (Rondon, 2013). Such difficulties in accurately capturing the opportunity cost of labour have been noted in the literature (Foster & Rosenzweig, 2010). However, because there is minimal difference in labour requirements between microdosing and applying the recommended dosage, the cost differences in labour for this study was essentially cancelled out. Estimated net returns over fertilizer costs are shown in Table 4 in Benin currency, the CFA (Communauté Financière Africaine) Franc, and the US dollar (USD). These yields resulted in a net return over fertilizer costs on a per hectare basis of 11,040,342 CFA ($20,976 USD) for recommended dosage plots, compared to 9,176,611 CFA($17,435 USD) for plots that received microdosing applications, a difference of 1,863,730 CFA ($3,541 USD) per ha.

Table 3. Yield and net returns over fertilizer cost comparison

Maize Demonstration Plots (n=17)	Microdosing Treatment	Recommended Dosage Treatment
Total Yield (kg/ha)	42,116	51,578
Market Price 2012 (CFA/kg)	230	230
Total Revenue (CFA/ha)	9,686,747	11,863,142
Costs		
Fertilizer amount (kg/ha)	83 kg/ha NPK; 41 kg/ha Urea	150kg/ha NPK; 50 kg/ha Urea
Fertilizer price 2012(CFA/kg)	240	240
Total Fertilizer Cost	510,136	822,800
Total Estimated Return over Fertilizer Cost (CFA)	9,176,611 (US$17,435)	11,040,342 (US$20,976)
Note: 1 CFA = 0.0019 US Dollar (as of October, 2014)		

While previous studies in other regions of West Africa have shown microdosing as more profitable on average than other forms of application, the context is important. In Mali, Niger, Burkina Faso and other countries with experience in microdosing, the starting point for fertilizer application is often broadcast application. This is an inefficient method of fertilizer application, whereas the targeted application of fertilizer involved with microdosing is a more efficient use of the input (Tabo et al., 2007). In Benin, government extension agents have successfully promoted the strategy in soil application of fertilizer at the base of every plant for the recommended dosage rates and thus few farmers broadcast fertilizer in the area. Thus, it is not surprising that on average microdosing is not more profitable than recommended dosage in the Benin context.

Despite microdosing being, on average, less profitable than recommended dosage, all but one DF indicated they would continue using the microdosing technique. However, when asked if they would expand the use of microdosing if the price of fertilizer fell, 14 DFs said they would instead use the recommended dosage (or a more general response of 'would use lots of fertilizer'). The remaining DFs (3) said they would continue using microdosing, noting that they could then use fertilizer over more of their fields. The willingness to continue with microdosing, despite being less profitable, provides reasons to believe that there is a shadow value for fertilizer that is not captured in the market price. The shadow value of fertilizer indicates the marginal value of fertilizer in increasing the farmer's objective function (profit maximization), subject to constraints. Thus, if farmers are willing to use microdosing instead of using the recommended dosage despite loss in potential profit, one can calculate a minimum shadow value for fertilizer by determining at what price of fertilizer microdosing would be equal to recommended dosage in net benefits: where p is equal to the market price for maize, y_{md} is the yield.ha^{-1} for microdosing, y_{rd} is the yield for recommended dosage per ha, f_{md} is the microdose quantity of fertilizer per ha, and f_{rd} is the recommended dosage quantity of fertilizer according to the formula:

$$p \cdot y_{md} - w_f \cdot f_{md} \geq p \cdot y_{rd} - w_f \cdot f_{rd}$$

Solving for the price of fertilizer (w_f), there is an average shadow value of 3,820 CFA.kg^{-1} (equivalent to US\$7.26.kg^{-1}) across the 16 farmers from whom yield data were available and who stated a desire to continue microdosing. This is the lower bound of a shadow value for fertilizer. The market price for fertilizer was 240 CFA.kg^{-1} for both NPK and urea, which makes the shadow price of fertilizer almost 16 times that of the actual price of fertilizer. Notwithstanding this value, numerous constraints were noted by farmers that, in general, limit their ability to access fertilizer.

3.2 Constraints to Fertilizer Use

Through interviews and conversations with village farmers, a number of constraints to accessing fertilizer were noted. The constraints cited most included limited and inconsistent availability of fertilizer, cost and credit constraints, and a general aversion to risk (see Table 4). In total, 36 households stated they had difficulties, aside from the cost, in accessing fertilizer in 2012.

Poor transportation infrastructure was also implicated in hampering regular access to fertilizer, a constraint not uncommon throughout Benin. Honfoga (2013), for example, found that the fertilizer distribution system in Benin suffers generally from high transaction costs and poor market delivery due to institutional and infrastructural failures. Farmers in Koumagou B confirmed that the limited and inconsistent availability of fertilizer was a significant deterrent. As noted above, the city of Boukoumbé is located approximately 16 kilometers northwest of Koumagou B. For Koumagou B farmers, Boukoumbé is the nearest center to purchase fertilizer. However, Boukoumbé is located nearly 600 kilometres north of Cotonou, Benin's port of entry and largest distribution center. This distance, coupled with poorly developed and seasonally variable transportation systems, has contributed to sporadic and inconsistent deliveries of fertilizer. Technicians with the Boukoumbé branch of the Regional Center for Rural Development (CARDER) confirm that deliveries from the south are often delayed due to impassable road conditions. Village farmers complained of inconsistent and unpredictable fertilizer availability in Boukoumbé, and even under the best of conditions they would often need to make multiple trips before acquiring sufficient quantities, a situation that is particularly problematic for fertilizer microdosing. The timely application of fertilizer is one of the principle requirements of the technique and one of the key differences that distinguishes microdosing from recommended dosage. If fertilizer is not available during critical times of production, its application has little benefit. Our research team experienced these logistical difficulties firsthand, as the delivery of project fertilizer was delayed to the point that the project's inception was nearly postponed. Fortunately, enough fertilizer arrived in time for use in the trials due to the influence of members of the Benin research team. Nonetheless, this situation highlighted the difficulties and time-sensitive nature of microdosing and the challenges faced by Koumagou B farmers. Infrastructure and transportation problems affected farmers at an individual level as well, with 14 of 36 (38.9%) stating that road conditions and 13 of the 36 (36.1%) stating transportation problems hindered their fertilizer purchasing.

Table 4. Constraints to fertilizer use

Cost	*n=73*		
Cost of fertilizer as major constraint (did not buy)		21	28.8%
Cost of fertilizer as a limiting constraint (couldn't buy as much as desired)		26	35.6%
Problems accessing fertilizer	*n=73*		
Yes		36	49.3%
No		14	19.2%
N/A (did not buy fertilizer or other circumstance)		23	31.5%
Problems with Access* (for those citing trouble accessing fertilizer aside from cost)	*n=36*		
Roads impassable		14	38.9%
Trouble with mode of transportation		13	36.1%
Regulations or harassment en route		7	19.4%
Availability		7	19.4%
Other (Family health etc.)		12	33.3%
**multiple responses possible per respondent*			
Short term financial difficulties	*n=73*		
Those stating problems necessitating short-term financing in 2012		65	89.0%
Those citing health problems as reason for financial difficulties		13	17.8%
Access to Credit (for those stating need for short-term financing)	*n=65*		
Able to access credit		26	40.0%
Unable to access credit		17	26.2%
Did not try to borrow		22	33.8%
Membership in credit-granting organization	*n=73*		
Current member		13	17.8%
Past member		32	43.8%
Never a member		28	38.4%

With limited and inconsistent availability of fertilizer in Boukoumbé, Koumagou B farmers often need to cross the border into Togo to purchase fertilizer. In fact, 41 of the 73 (56.1%) Koumagou B households identified a market in Togo as an alternative location to buy fertilizer, though most would try to buy fertilizer first at the CARDER in Boukombé. Forty of the 73 households said that their main location for buying fertilizer was at the CARDER with another 14 saying they would try the CARDER first, and then go Togo. Despite availability issues at the CARDER (with 19.4%, or 7 of 36 households, citing availability as a problem), buying fertilizer in Togo is also problematic. Although a generally porous border, and both Benin and Togo being members of the same regional economic union (ECOWAS), Koumagou B farmers noted considerable difficulty purchasing and transporting fertilizer from Togo markets back into Benin. Of the 36 households, 7 (19.4%) cited regulations or harassment en route to Togo. According to some farmers, the Togolese government has introduced regulations that prevent Beninese farmers from purchasing fertilizer in Togo. As noted by one farmer: "It is very difficult to buy in Togo. Venders ask where you are from and *gendarmerie* (police) can confiscate your fertilizer." Another farmer complained of harassment from border police and the need to avoid them, saying they could seize not only his fertilizer but also his bike or motorbike if they knew that he was a Beninese buying fertilizer from Togo. One farmer did explain that it was possible for Beninese to buy fertilizer in Togo, but the process involved procuring papers certifying the buyer had a relative residing in Togo. However, given the difficulties acquiring, completing, and submitting the necessary paperwork, most farmers choose to forgo this process and risk confiscation.

While limited availability of fertilizer was identified as formidable constraint to adoption, so too was affordability. A number of Koumagou B farmers noted that even if fertilizer was easily available, the costs would preclude its purchase. At the time of this research the Benin Government subsidized the price of fertilizer: the subsidized price for 50 kg of either NPK or Urea being between 10,500 and 11,000 CFA (Communauté Financière Africaine) Franc (equivalent to US$19.95 and US$20.90) compared to the unsubsidized price of between 17,500 and 18,000 CFA (equivalent to US$33.25 and US$34.20) for the same amount. Koumagou B farmers noted that they generally paid 12,100 CFA for 50 kg of either NPK or Urea (equivalent to US$22.99) fertilizer in 2012. However, as found by Larson and Gurara (2013), fertilizer subsidies alone do little to ensure access to smallholder farmers. Despite subsidization, this price was still beyond the purchasing capacity of most Koumagou B farmers. Twenty-one of the 73 (28.8%) households surveyed noted that the subsidization policies notwithstanding, cost was the single greatest constraint to adoption, in they simply could not afford to buy synthetic fertilizer, while another 26 households (35.6%) identified cost as a limiting factor in their fertilizer usage.

Farmers also noted that relative to individual farmers, it is easier for organized groups to purchase fertilizer. Several farmers complained that the Regional Center for Rural Development (CARDER) in Boukoumbé has a policy to first sell fertilizer to farmers incorporated into groups and only after to non-affiliated farmers. Yet among Koumagou B farmers, only 13 (17.8%) were members of cooperative groups. Thirty-two others (43.8%) acknowledged that they had in the past been part of various development or agricultural groups, but had given up their memberships for a variety of reasons. These reasons included: complaints of poor organizational management, theft and corruption, and group disbandment. Farmers also chose to leave groups because membership did not advance their immediate interests and membership demanded too great of a personal time commitment.

Credit constraints were also identified as hindrances to the purchase of fertilizer, as is often reported in other adoption studies (Abdulai & Huffman, 2005; Akinola, 2010; Beke, 2011). Among Koumagou B farmers, a majority noted difficulty, or were unable, to acquire credit in 2012-2013. Among the 73 households surveyed, 65 (89%) cited financial trouble requiring short-term financing. Of those 65 households, 26 (40.0%) were able to access credit (whether informal or formal), 17 (26.2%) households tried but were unable to access credit, and 22 (33.8%) households did not even try, often out of fear of default. For those farmers that could not access credit, the reasons varied. Some attributed it to having poor or no credit history, or as noted above, the requirement to be incorporated into a group-borrowing program. Farmers also mentioned fear of the police and potential incarceration, or having their possessions confiscated, as a penalty of default and thus many were dissuaded from even attempting to borrow. One farmer said he had borrowed from a microcredit institution in the past and could not repay. As a result, the institution confiscated some of his personal belongings to recover the costs. Another farmer noted that if he had borrowed money, but his crop yield was low, he would not be able to repay the loan and the lender would 'bring the brigade.' Other farmers said they managed without borrowing, by selling off livestock, trading with neighbours, or looking for work outside the village.

Opportunities to buy fertilizer on credit are typically limited to farmers growing cotton (or at least those purporting to grow cotton). Yet with the exception of one farmer who was growing a small plot of cotton on an experimental basis, no other farmers in Koumagou B grew cotton. One Koumagou B farmer recounted his experience buying fertilizer from someone who had gone to the CARDER and received a large quantity of fertilizer on credit, claiming he was growing cotton. This enterprising farmer then returned to Koumagou B where he resold the fertilizer to others at a profit, a situation that is reportedly not uncommon. A study commissioned by the World Bank on Benin's cotton sector found that farmers will often overestimate their need for cotton fertilizers, to benefit from resell or to use with other crops, especially maize (Gergely, 2009).

Opportunities for informal credit or financial lending are also limited. Several farmers noted that their neighbours would often hide or run away if they suspected a request for financial support is expected. In these cases, avoidance was a preferred option to direct refusal. Yet others acknowledged that informal lending was simply not a viable option and attributed it to their shared experience: "you cannot lend what you don't have." This statement in many ways highlights the fundamental challenge the Koumagou B farmers face, creating a constant pressure to allocate limited resources to more immediate needs. In several cases these more immediate needs involved family health concerns. Farmers frequently cited medical concerns and family health problems when asked about buying fertilizer or about problems with short-term financing. During the course of this research, 13 (17.8%) Koumagou B households needed to direct household resources to cover the medical costs of a family member. One farmer in particular had to borrow money to pay for his daughter's health care costs (the costs apparently surpassed 60,000 CFA or US$114) and was thus unable to afford fertilizer. In this case, the farmer was able to access funds through his wife's membership in a *tontine*, a savings group organized by Plan Benin that provides interest free lending in cases of urgent needs. These situations bring to life the complexity of household decision-making and the less observable demands placed on farming households. When institutional support in terms of basic health care provision and insurance schemes are lacking, farmers are often faced with urgent and variable demands on their limited cash reserves, resulting in their inability to exploit new innovations.

3.3 Farmers' Perceptions Related to Microdosing

When asked about the drawbacks of microdosing, many Koumagou B farmers noted the synergistic relationship between organic matter in the soil and the effectiveness of inorganic applications. Soil that is relatively high in organic matter is also more efficient for delivering inorganic nutrients through microdosing. However, as noted above, the soil fertility of Koumagou B land is generally low. This is due to the general characteristics of the landscape and a result of generations of agricultural intensification that has contributed to nutrient loss. With generally low soil fertility, farmers must find ways to introduce organic matter, either through minimal tillage or the addition of animal manure. However, in the case of minimal tillage, farmers most often remove crop residue from fields to use as livestock feed, fuel or construction material (Giller et al., 2009; Lal, 2009). The availability of organic matter (manure) is even more limited due to very few households owning livestock. Among Koumagou B farmers, only 12 out of the 73 households (16%) owned draft animals (large livestock). While small livestock such as guinea fowl or chickens were more commonly owned, these sources provide only small quantities of organic fertilizer and are thus insufficient for meeting the input needs of farmers. Manure from livestock is a valuable source of nutrients and organic matter for farmers, though for the majority of Koumagou B poverty means the ownership of large livestock, such as cows, is most often out of reach. In such cases, access is limited to those of relative wealth (Adolwa et al., 2012), where poorer households are less likely to have the means to amend their soil and improve soil quality through the addition of manure.

The vulnerability of the poor is also reflected in the availability of farm labour. Labour availability, in general, has been shown to be a critical factor for technology adoption and often serves as an operative constraint in African farming systems (Larson & Gurara, 2013; Marenya & Barrett, 2007; Mignouna et al., 2011), especially during peak periods of production. Microdosing in particular is a very labour intensive endeavour. However, in Benin the standard alternative—recommended dosage—is equally intensive. For this reason, labour was rarely identified as constraining factor to the adoption of fertilizer microdosing. In addition, within Koumagou B there is a system of cooperative labour among households. This cooperative system has adapted over time to relieve labour shortages during peak periods of production, and more recently to respond to the seasonal loss of male labour. Among the 73 surveyed households, 22 (30.1 %) specifically noted their involvement in cooperative labour networks as a way of addressing labour constraints. This system involves farmers coming together as a group and working reciprocally on each other's farms, or being repaid in food during the workday. However, there is one important caveat. The 'poorer' households that cannot afford to provide food in exchange for labour, or cannot contribute their own labour, do not benefit from this cooperative strategy. This situation is indicative of how the most vulnerable households in communities often have the least adaptive capacity and are left in positions of greatest risk (McKenzie, 2005).

3.4 Social, Institutional and Physiological Factors Affecting Adoption

Under the conditions described above, farmers in Koumagou B face considerable risks when deciding to invest in new technologies (a sunk cost) (Dercon & Christiaensen, 2011). Such risks are further compounded by the fact that all of the crops grown in Koumagou B are exclusively rain-fed. Because moisture levels in the soil affects the benefits of microdosing (Winterbottom et al., 2013), its application is ultimately dependent on the weather. While the household survey did not explicitly include measures of risk aversion, our interviews with farmers did explore the social, institutional and physiological factors that influence adoption.

During our interviews, farmers often noted that due to the lack of governmental or other forms of socio-economic safety nets, crop failure would be financially or socially devastating. One illustrative example was a project organized by the CARDER. In this recent case (2010), fertilizer was provided on credit for rice production and farmers were expected to repay after harvest. An extension agent from CARDER provided information on fertilizer application but the poorly formulated fertilizer ended up 'burning' the rice, and destroying the year's harvest for the farmers. In addition to the loss of their rice crops, several farmers noted that they were then unable to repay the money they had borrowed to purchase the faulty fertilizer. As a result, the local lender, in this case the Regional Agricultural Credit Union of Benin, refused to lend these farmers money the following year. With this experience fresh in the memories of Koumagou B farmers, the risks associated with another fertilizer project were for some, simply too great.

4. Conclusion

Fertilizer microdosing has been promoted in West Africa as an effective means to optimize agricultural yields, increase farm incomes, and maximize availability of fertilizer. However, adoption of the microdosing technique has been limited in Benin. Our research, conducted in the village of Koumagou B, provides some insight on the constraints that may be limiting adoption. The results of our field trials indicate that on average, microdosing produced lower yields and proved less profitable than recommended levels. Fourteen out of the total 17 demonstration farmers had yield lower under microdosing. Across demonstration farmers, total maize yields under microdosing were 42,116 $kg.ha^{-1}$, as against 51,579 $kg.ha^{-1}$ with application of recommended dose. Thus, producers could increase corn yield by 22.5 % by not adopting microdosing. This reduced yield lowered their net return over fertilizer cost by 16.9% compared to the recommended dose.

In addition to reduced profitability, numerous institutional constraints were identified that further limit adoption. These constraints include poorly functioning input markets, inefficient distribution systems, limited affordability and credit constraints, liquidity constraints, and government policies that limit cross-border access to inputs as well as the prioritization of fertilizer for cotton production over food crops.

Poor infrastructure and inefficient input markets were found to be a significant limiting factor to accessing fertilizer. Lack of rural development and poor infrastructure has meant that transportation and distribution costs are significant components of the total cost of fertilizer. Poorly developed distribution networks mean that farmers incur additional costs in terms of transportation, travel time, and production uncertainties. Liquidity and the cyclical nature of agricultural production during lean periods are further constraints. A lack of insurance, or other consumption smoothing mechanisms, also contributes to farmer reluctance to purchase fertilizer and consumption risk is too great for poor households to absorb. This contributes to the weak and punctuated demand for fertilizer, and reduces market incentives for supply responses.

Infrastructure is clearly an important element, and improving and maintaining road systems to connect the north of the country with the south, and rural areas to urban areas, was considered a long-term priority. However, in the near term, improving market access to key agricultural inputs, such as inorganic fertilizer for food crops, and not just cotton, is a necessary condition to improve food security amongst the most vulnerable segments of the Benin population. Rather than retaining the current system that prioritizes and subsidizes fertilizer for cotton growers, a properly implemented and administered system for food crops could provide the foundation for a more equitable income and food security. At the same time, this would strengthen the private sector by providing market opportunities for food crops while also creating greater incentives for fertilizer distribution in underserved areas.

Many project interventions and market access schemes hinge upon farmer cooperation. For example, in an attempt to increase access to credit for farmers with little formal collateral, formal micro-loans are restricted to farmers organized in solidarity groups. However, experiences with mismanagement, fraud, and default have made farmers suspicious or despairing of the effectiveness of such strategies. However, the benefits of such organizations, in terms of building community capacity, are also acknowledged. In this regard, management training to increase the effectiveness of such groups should be a complementary strategy to promoting group membership. But this does not address some of the underlying causes of default, namely crop failure and chronic poverty. Here, government insurance schemes that protect smallholder farmers from some of the risks of investing in agricultural inputs, especially those that affect the basic food security of households, would improve the willingness of individual farmers to join cooperative farmer groups and invest in techniques that improve productivity and ultimately food security.

Low levels of organic matter, coupled with decades of over-intensification, have taken a toll on soil fertility, agricultural productivity, and the livelihoods of Koumagou B households. However, inorganic fertilizer alone will not remedy the situation. Instead, the farmers who participated in this study were adamant about the need for organic matter to be used in combination with the microdosing technique. Increasing organic matter in the soil was considered a priority and microdosing considered complementary to that objective. Innovative approaches are therefore needed to ensure those who are most vulnerable have the means to increase the organic matter in their soil. The high opportunity cost of organic matter, given its many uses for the rural poor, must be accounted for when developing such approaches. Various agroforestry and mixed farming methods, that include livestock production, are potential opportunities for improving soil quality through organic inputs. Cows and small ruminants, such as sheep and goats in particular, offer a multitude of benefits, including food, dry season income, as well as organic matter in the form of manure.

Admittedly, these recommendations are not new or necessarily unique to the conditions of Koumagou B farmers. There have been others who have called for increased access to inputs, greater provisioning of credit and insurance schemes, and the promotion of integrated soil fertility techniques. But the urgency of this situation is only increasing as farmers in Benin, and SSA more generally, struggle to secure a living on increasingly degraded soil in a region that is facing increasing population pressure and mounting uncertainties in climate and weather variability. As researchers we must strive to ensure that our efforts to improve agricultural productivity are grounded in a holistic, integrated understanding of the contextual challenges facing smallholder farmers in adopting and adapting new agricultural technology. The challenges facing smallholder farmers in northwest Benin are complex, and inevitably so are the solutions. But this complexity offers potential for synergistic and mutually-supporting interventions. From our experience, meaningful community engagement is fundamental to promoting equitable change and should be a marker for any interventions designed to improve the social welfare and food security needs among those most directly affected by our research efforts.

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