Making a Little Go a Long Way: The Socio-economic Factors Influencing the Adoption of Fertilizer Microdosing in Northwest Benin

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ABSTRACT

Soil degradation and low crop productivity negatively affect the food security of smallholder farmers in West Africa. Various agricultural techniques have been developed as components of food security interventions, but their effectiveness in addressing food insecurity in part depends upon farmers' willingness to adopt these techniques. Likewise, adoption depends upon the effectiveness of these techniques in fulfilling farmers' objectives. The institutional and biophysical environments mediate not only the effectiveness of the techniques, but also how farmers value a technique.

This study examined the evidence for fertilizer microdosing as a form of agricultural intensification and the socio-economic conditions that influence its adoption among smallholder farmers. A census was conducted in one village in northwest Benin that had recently seen the introduction of fertilizer microdosing. Key household-level determinants of adoption identified in the literature—household resources, household demographics, and access to inputs— were included in the household surveys. Using partial budgeting analysis and yield data from demonstration plots, the relative profitability of fertilizer microdosing was calculated as a necessary condition of adoption. Drawing from farmers' stories, the potential value of microdosing was contextualized within the larger social and institutional context.

Based upon the village census, there was little adoption outside of the research project that introduced microdosing to the village. Households using microdosing (predominantly found within the research project) had, on average, higher socio-economic status, more cultivable land and larger labour forces. Profitability analysis indicated that microdosing was on average *less* profitable than the point-source application of the recommended dosage rate in Benin (the common alternative). However, farmers still expressed a desire to microdose, due to poorly functioning input markets, poor infrastructure, and lack of access to financial instruments, all of which limited the availability, access and utilization of inorganic fertilizer.

keywords: fertilizer microdosing, agricultural technology adoption, socio-ecological niche, sustainable intensification, demonstration trials, rainwater harvesting, development projects, maize, Benin, West Africa

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LIST OF ABBREVIATIONS

CARDER: *Centre d'Appui Régional au Développement Rural*

CEC: Cationic exchange capacity

CFA: *Communaute Financiere Africaine*

CIMMYT: International Maize and Wheat Improvement Center

CLCAM: *Caisse Local de Credit Agricole Mutuel*

CP: *Cordons pierreux*

DFATD: Department of Foreign Affairs, Trade and Development

ECOWAS: Economic Community of West Africa States

FAO: Food and Agriculture Organization (of the United Nations)

FECECAM-BENIN: *La Faîtière des Caisses d'Epargne et de Crédit Agricole Mutuel du Bénin*

GDP: Gross Domestic Product

GHI: The Global Hunger Index

ICRISAT: International Crops Research Institute for the Semi-Arid Tropics

IDRC: International Development Research Centre (of Canada)

INRAB: *Institut National des Recherches Agricoles du Bénin*

INuWaM: Integrated Nutrient and Water Management

LCN: *Labor en courbes de niveau*

LP: *Labor à plat*

MVCR: Marginal Value-to-Cost Ratio

PCA: Principal Components Analysis

SSA: Sub-Saharan Africa

SQI: Soil Quality Index

USDA: United States Department of Agriculture

Chapter 1. Introduction

1.1. Overall Context

1.1.1. Food Insecurity in Sub-Saharan Africa

One of the fundamental elements of social welfare is the physical and economic access to sufficient amounts of safe and nutritious food for all — a condition known as food security (FAO, 1996). Worldwide, there is great disparity in the realization of food security for all. Sub-Saharan Africa (SSA) remains one of the most heavily affected regions, with around one out of every four people suffering from food insecurity. Food insecurity constrains both social and economic development (Benson, 2004; Timmer, 2002). Improved agricultural productivity promises to not only help alleviate food insecurity, but can also lead to broad economic growth, through improved farm income, increased non-farm consumption, and the release of inputs for other economic activities. Investing in agriculture in SSA, and smallholder agriculture in particular, is considered a wise and necessary investment in the social and economic development of the SSA region (Africa Progress Panel, 2014).

For the majority of SSA, agriculture is the backbone of the economy, employing the majority of the population in smallholder farming operations (Delaney et al., 2011). Farmers work the land to provide enough for household consumption and ideally some surplus for sale at local markets. For resource-poor smallholder farmers, the quality of their soil and its productive capacity is integral to their ability to feed their family and create an income for their household, directly impacting their level of food security. For example, farmers in the Atacora region of Benin, where this research took place, farm on increasingly degraded soils. The geography of the region— characterized by sloping, rocky lands — means that declining soil fertility, erosion and nutrient run-off are severe problems (Saïdou et al., 2004). These conditions have traditionally resulted in low crop productivity, cycles of poverty, and household food insecurity.

1.1.2. Microdosing in West Africa

To increase output, and attempt to combat declining soil fertility, farmers in West Africa apply inorganic fertilizer. Fertilizer recommendations tend to be generic guidelines based upon limited crop response trials and are a poor guide to maximize the benefits to farmers operating in variable environments (Vanlauwe & Giller, 2006). In addition, farmers are constrained in accessing fertilizer in sufficient quantities at the appropriate time due to poorly functioning input markets (Morris et al., 2007). Aside from addressing the underlying institutional factors that contribute to these shortcomings, there is a need in the short term for a technique tailored to the needs of resource-constrained farmers operating under challenging environmental and market conditions.

With these considerations in mind, researchers at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) developed a technique called fertilizer microdosing, which is the precision (or point source) application of small (less than the recommended dosage) quantities of inorganic fertilizer at sowing or within a short time after sowing. The amount of fertilizer used under microdosing and the timing of application vary depending upon the target crop, region, planting density, and fertilizer formulation among other factors. Initial research on microdosing advised application of fertilizer at sowing time and set the microdosing rate at 60 kg ha^{-1} of NPK (Buerkert & Hiernaux, 1998; Buerkert et al., 2001; Tabo et al., 2006). Emerging literature continues to inform the practice of microdosing, as researchers study how a range of fertilizer quantities and application dates affect agronomic efficiency and profitability. For example, Sime & Aune (2014) investigated the effect of three separate 'microdosing' rates of 27, 50 and 80 kg ha^{-1} of NPK on maize in Ethiopia. Hayashi et al. (2008) investigated the effect of delayed application of microdose quantities upon millet production. However, based upon studies thus far, microdosing at its various rates and timing has in general shown to be an effective technique in SSA for enhancing crop production and profitability while also addressing limited access to fertilizer (Camara et al., 2013; Hayashi et al., 2008; Tabo et al., 2011; Twomlow et al., 2010). According to these same studies, microdosing can be an economically advantageous technique as compared to alternative fertilizer application techniques, such as broadcasting, or no fertilizer application.

While microdosing was introduced in Niger, Mali, and Burkina Faso as early as 1998 (Tabo et al., 2011), the technique was only introduced into Benin in 2011. Despite the economic potential of fertilizer microdosing as demonstrated through the aforementioned studies, reports indicate that fertilizer microdosing has not seen widespread adoption in the region. Thus, an examination of the factors that enable or constrain the adoption of fertilizer microdosing is of particular importance as researchers begin to promote fertilizer microdosing in Benin. Additionally, while researchers in Niger, Mali and Burkina Faso are contrasting microdosing against agronomically inefficient fertilizer application methods such as broadcasting, researchers in Benin are comparing the technique to a more efficient, precision application of fertilizer that the government has successfully promulgated throughout the country. This context changes the relative value of microdosing.

1.2. Objectives

The purpose of this research is to examine the factors that influence the adoption of fertilizer microdosing in the village of Koumagou B in northwest Benin. It is in this context that this research sets out to: 1) quantify the relative economic performance of maize production under microdosing as compared to recommended dosage application rates; and 2) identify the factors that influence the adoption of fertilizer microdosing, drawing from quantitative and qualitative data regarding household/farmer characteristics, soil quality, institutional context and development project implementation.

This research is part of a larger regional study carried out in Benin, Burkina Faso, Niger and Mali. Funded by the IDRC (International Development Research Centre), this project, entitled INuWaM (Integrated Nutrient and Water Management), involved the collaboration of West African research institutions and universities along with the University of Saskatchewan, Canada. The INuWaM project aimed to increase food security in the region by promoting the efficient use of soil nutrients and water so as to increase agricultural production and household income. To achieve this, the project promoted the use of fertilizer microdosing (along with *in situ* rainwater harvesting techniques and the *warrantage* system[1]). It also aimed to examine key social and economic variables that influence technological adoption. This thesis will contribute to this objective by analyzing the factors that promote or constrain the uptake of fertilizer microdosing. In so doing, it will add to the existing literature on the economic benefits of microdosing while taking into account relevant contextual factors at the individual, household and regional level.

This thesis is structured in the manuscript style, consisting of three chapters. The first chapter provides the larger context, identifies the research objectives, and includes the literature review. The second chapter is formatted for journal submission and includes an introduction (and

[1] Warrantage is a type of inventory credit system. Farmers store their crops immediately after harvest when prices are lowest, obtain credit using the stored crops as collateral to carry out productive dry-season activities, and then sell their stored crops when prices are higher.

synthesized literature review), conceptual framework, methodology and data collection, results, and a conclusion. The final chapter reviews the major results in the context of the relevant literature and expands upon the discussion of the findings and policy implications.

1.3. Conceptual Framework

There has been a veritable explosion of interest in socio-ecological systems and frameworks structuring the analysis of interactions between human society and the natural environment. See (Binder et al., 2013) for a description and comparison of some notable frameworks. Ojiem et al. (2006) in particular, described a socio-ecological niche as the complex set of social and biophysical factors that create the multidimensional environment for which a compatible technology can be selected. The adoption of that technology depends upon whether the characteristics of the niche are favourable towards said technology. An area or region of agricultural activities has spheres of influence that influence agricultural adoption: the agro-ecological sphere, socio-cultural sphere, economic sphere and local ecological sphere. Within these spheres is any number of factors that act as variables. These spheres make up the *socio-ecological niche*. For example, attitudes and values of the farmers are factors contained within the socio-cultural sphere that will be partly responsible for determining the compatibility of an introduced technology within the larger socio-ecological niche. Ajayi et al. (2007) used the language of 'biophysical and social niches' when discussing appropriate targeting of agricultural technologies. The overarching idea is one of contextualization along with a respect for the complexity of environments within which smallholder famers live and work.

This socio-ecological niche conceptualization allows for context specific assessment of new technologies and provides a framework upon which to evaluate the success or failure of a technology. In conjunction with Barth's (1967) theory of social change, farmers are not passive recipients but management agents that actively and dynamically reallocate their resources within a given context— a social and ecological context. This social and ecological context, along with the farmer's own decision making, creates a favourable or unfavourable environment for a new activity or technology.

The farmer at the center of the socio-ecological niche undertakes the decision-making process with the aim of optimizing their expected benefits (utility or profit), subject to constraints (Feder et al., 1985). Constraints to technology adoption commonly listed in the literature are credit constraints, size of landholdings, risk aversion, lack of extension support, low education levels and transportation infrastructure inadequacies. These constraints stem from the surrounding institutional and social environment that influences the process of decision-making on technology uptake.

It is within this framework[2] that this research undertakes the process of assessing the introduction of fertilizer microdosing in one village of Northwest Benin. See Figure 1.

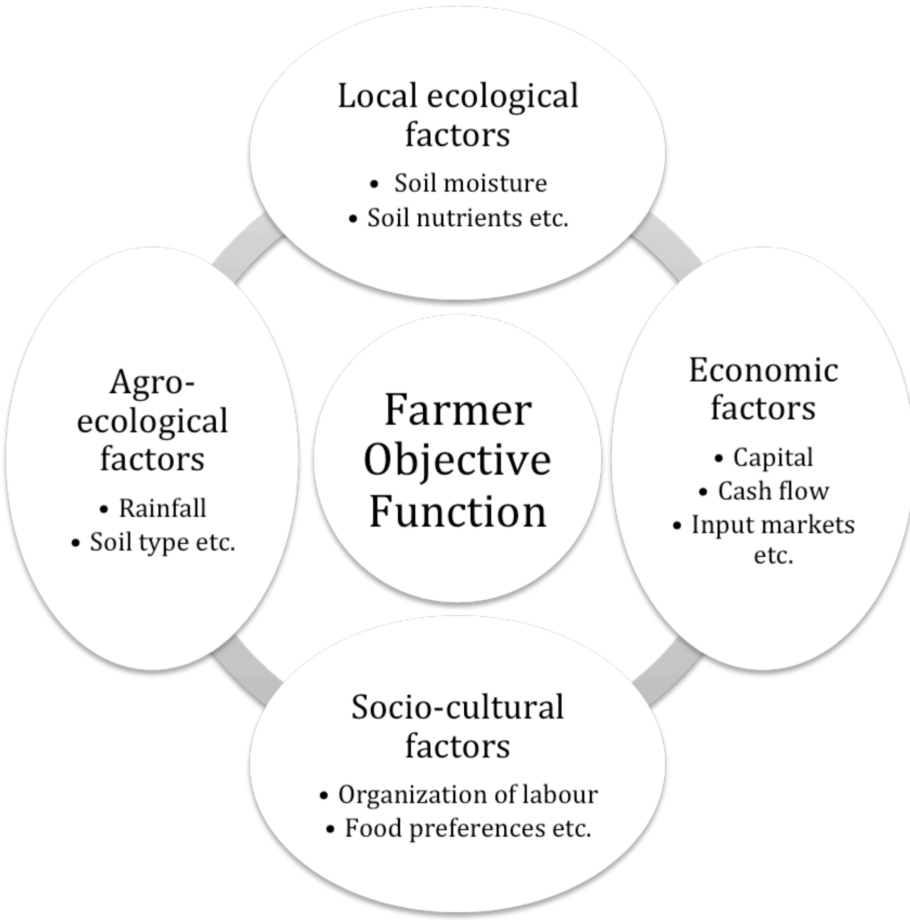

Figure 1-1 Socio-ecological niche framework

1.4. Literature Review

This thesis investigates the factors influencing the adoption of an agricultural technique designed for resource-constrained farmers, especially those confronted with the particular market challenges characterizing Sub-Saharan African agriculture. The agricultural technique in

[2] While there are many possible factors within each sphere, and while several have been listed here, not all are relevant or feasible in the context of this research and therefore not included in the analysis.

question is fertilizer microdosing— the strategic application of small quantities of inorganic fertilizer at specified times. The research for this thesis took place within a larger research and development project in West Africa, investigating the biophysical and economic impact of fertilizer microdosing, with the aim of increasing household income and improving food security for smallholder farmers.

This literature review will briefly describe the food security situation in Benin (the specific research area) and then proceed to describe some of the underlying reasons contributing to food insecurity in the wider region— namely, soil degradation and low agricultural productivity in West Africa and SSA at large. A brief discussion will follow on some of the more notable soil fertility management strategies presented as solutions to these problems and their assessment in the literature. These strategies will be situated within the Sub-Saharan African context by describing the constraints to input use (focusing on inorganic and organic fertilizer) that characterize much of the smallholder agriculture in the region. Fertilizer microdosing is one component of integrated soil fertility management that explicitly attempts to address the input constraints of smallholder farmers. The rationale and evidence for fertilizer microdosing will be explored using empirical studies conducted in the SSA region.

While an innovative agricultural technology may be good in theory, the real measure of its appropriateness for a specific locale should primarily be measured by the extent, intensity and duration of adoption by farmers. The literature on agricultural technology adoption is extensive, even when refined to the developing country context. This review presents an overview of some of the notable studies done on agricultural technology adoption in developing countries in the last 15 years, particularly those that look at: the influence of household characteristics of smallholder farmers on adoption; the adoption of low input, natural resource management technologies; and the role of the social and institutional context on influencing technology adoption. Finally, this review will make the case for contextualization and systems thinking when evaluating the impact of an introduced agricultural technology.

1.4.1. Food Insecurity and Agriculture in Sub-Saharan Africa

SSA is the region most severely affected by food insecurity, with the world's highest prevalence of undernourishment (FAO et al., 2013). Food insecurity as a condition is complex and multi-dimensional, resisting easy characterization. While prevalence of undernourishment is a widely used and simple food security indicator, multiple measures of food insecurity and nutritional status of a country's population exist. Different measures attempt to capture additional elements relating to food insecurity, such as utilization of available food or quality of food in terms of micronutrient provision. Often such measures focus on vulnerable populations, such as children under five years of age, as an indication of not only the country's overall capacity to provide adequate nutrition for all its population, but also the distribution and utilization of food amongst the population. The International Food Policy Research Institute (IFPRI) also notes that children are physiologically vulnerable to undernutrition, meaning that a lack of nutrients can lead to high rates of stunted development, illness and even death (Grebmer et al., 2013).

IFPRI developed the Global Hunger Index (GHI) to measure the severity of hunger and undernourishment throughout a country. This composite measure incorporates three equally weighted indicators: percent of undernourished people as a proportion of the population; proportion of children under 5 who are underweight; and under 5 child mortality. Conceptually, 1 is the best situation (no hunger, no children under-5 underweight and no under-5 child mortality) and 100 the worst. Benin has a Global Hunger Index (GHI) of 13.8. In comparison, Mali has a GHI of 14.8, Burkina Faso 22.2 and Niger 20.3. A range between 10 and 19.9 indicates a 'serious' hunger situation in a country, according to the brackets determined by IFPRI. Benin is ranked 30th of the 78 countries with a GHI greater than 5 (industrialized countries, countries with a GHI less than 5, and countries lacking data are excluded from the ranking system). Burundi is 78th on the list and has the highest GHI at 38.8 (Grebmer et al., 2013).

Addressing food insecurity requires understanding root causes so as to apply effective interventions. The good news is that effective policies aimed at increasing agricultural productivity and food availability, with a particular focus on smallholders, promise to improve the state of food security (FAO et al., 2013). Due to the importance of the agricultural sector in SSA, policies supporting smallholder farmers address the livelihood strategies of a large proportion of the general population. Smallholder farmers comprise the majority of SSA's farming population: 80% of farms are two hectares or less. And the rural population still outweighs the urban population in SSA, with agriculture the predominant livelihood of the general population, employing 62% of the population (Delaney et al., 2011). Thus, agricultural policies and management strategies are inextricably linked to food security and poverty reduction.

Improving agricultural productivity and increasing crop yields is an important element of food security strategies for smallholder farmers. In SSA, with low to moderate inherent soil fertility (Andre et al., 2006; Bationo et al., 1998) and low external input use (in terms of soil amendments such as inorganic or organic fertilizer), soil degradation is a serious issue. Addressing agricultural productivity and crop yields depends in part upon addressing soil fertility. Soil degradation is a contributing factor of food insecurity through both direct and indirect effects on farm incomes and food availability as crop production levels decline (Lal, 2009). Farmers in SSA have relied primarily upon a strategy of *extensification*, rather than intensification to increase agricultural production as the population increases (Delaney et al., 2011). Agricultural practices that fail to maintain the fertility on existing agricultural lands also drives the expansion of agriculture onto increasingly marginal lands. Increasing population pressure and degradation of fragile tropical soils makes this practice unsustainable (Morris et al., 2007). High rates of population growth in SSA (United Nations, Department of Economic and Social Affairs, 2013), which exacerbates land degradation as more land is pressed into producing greater amounts of food more intensively (Drechsel et al., 2001), means there is a pressing need for new approaches to improve crop production through sustainable and affordable agricultural practices.

Indeed, West Africa, which is more densely populated than other regions in SSA, shows a steady increase in net production per ha— a key measure of agricultural intensification (Delaney et al., 2011). But this intensification comes at a cost. Bationo et al. (1998) commented specifically on the increasing pressure on fragile West African soils due to population increases. In the past, farmers would have long fallow periods to let the soils naturally replenish. At higher population densities, shortened fallow periods and inadequate nutrient replenishment resulted in a decreased nutrient base in the soil (Bationo et al., 1998; Elbehri, 2013). At an even finer geographical focus, in the Atacora region of Benin (where the research for this thesis took place), fallow land is not common due to the pressure on the land. Farmers cited declining soil fertility as one of the major constraints on agricultural productivity in their farming systems (Saïdou et al., 2004). In essence, what is needed is the sustainable intensification of agriculture, a key component of which is appropriate nutrient and water management (Collette et al., 2011; Mueller et al., 2012).

1.4.2. Soil and Land Management Practices

Given that soil fertility directly affects food security, what options are available for addressing soil fertility concerns and sustainably intensifying agricultural production in SSA? There exist a number of agricultural practices, often grouped into packages or placed within frameworks, which address soil fertility management. Two of the more prominent frameworks carrying considerable clout in the research and development community, Conservation Agriculture (CA) and Integrated Soil Fertility Management (ISFM), will be discussed in this review.

Conservation agriculture, actively promoted by the FAO, (FAO, 2014a) is an umbrella category bringing together various soil conserving techniques. The central tenets are minimal soil disturbance, the use of cover crops and crop rotations. The idea is to protect the soil through a range of options that cover and feed the soil's biota. Studies have shown positive environmental and economic benefits for farmers transitioning away from machine intensive, tillage systems (Hobbs, 2007). But what are the benefits for labour-intensive smallholder farms in Sub-Saharan Africa?

Knowler & Bradshaw (2007) reviewed the evidence for conservation tillage across a broad range of studies and notes that even in the developing world conservation tillage has been demonstrated to have net positive returns for farmers. They did note however, that for smallholder farmers who work by hand, conservation agriculture can increase costs due to the need for specialized no-till machinery and pesticide application. However, when the authors broadened the scope and reviewed studies on practices *associated* with conservation agriculture techniques (eg. fallowing, intercropping, cover crops, legume rotation) they found a positive net present value in 10 of the 11 studies examined (90.9% of the time).

Giller et al. (2009) took issue with the promotion of conservation agriculture among smallholders in Africa, citing concerns over increased labour burden (especially for women), a decrease in yields, and a high opportunity cost for the mulch and organic matter used as ground cover. The authors were especially concerned with the selling of conservation agriculture as an inseparable package of techniques. Farmers are constrained in the adoption of such a total package by lack of access to external inputs (e.g. herbicide or cover crop seeds). As such, they argued that it is important to review the evidence for individual techniques, rather than sell the benefits of the total package to farmers unable to incorporate all principles. Valbuena et al. (2012) examined the feasibility of developing country farmers adhering to one principle of CA in particular— the maintenance of soil cover. Looking at studies done in developing countries throughout SSA and South Asia, they investigated the effect of competitive uses for crop residue. Crop residue can be used as a mulch to maintain soil cover in accordance with the principles of conservation agriculture. The authors group study sites into a gradient of combined population and livestock density. They found that areas of low and medium density— given relatively low supply of biomass— see high opportunity cost for crop residue as a mulch in conservation agriculture techniques, thereby making it less attainable for farmers. Ultimately, context determines the viability of using crop residue for conservation agriculture among mixed crop-livestock systems.

Integrated Soil Fertility Management (ISFM) is another suite of techniques designed to address the need for sustainable intensification through soil fertility management. It is championed by Alliance for a Green Revolution in Africa (AGRA) as the foundational component for one of their core programs addressing poverty and food insecurity (Alliance for a Green Revolution in Africa (AGRA), 2014). Vanlauwe et al. (2010) provides an operational definition of ISFM:

> A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles. (p. 195)

Efficient use of scarce inputs, namely, organic and inorganic fertilizer, is a key component of ISFM. Fertilizer microdosing is cited as a practical example of ISFM principles, especially in combination with rainwater harvesting techniques (Sanginga & Woomer, 2009; Vanlauwe et al., 2010). Efficiency also stems in part from the complementarity of inorganic and organic inputs. There is a positive relationship between the uptake of nutrients from inorganic fertilizer and the use of organic fertilizer, due to the beneficial nature of organic matter on soil properties that contribute to nutrient holding capacity and water infiltration.

Organic contributions (such as manure) decompose and leave a stabilized amount of soil organic matter in the soil. Not only do organic resources contribute nutrients directly to the soil, they also have a beneficial effect on soil properties. It contributes to nutrient release, stimulates microbial activity and improves soil structure (Marenya & Barrett, 2007). For example, organic matter increases the water holding capacity and infiltration rate of the soil (Mafongoya et al., 2006). In addition, organic matter buffers against the acidification of soils that can occur with the prolonged use of inorganic fertilizers (Adams & Peak, 2014; Buresh et al., 1997; Tabo et al., 2007). Thus, there is a well-established scientific foundation for the complementarity of inorganic and organic fertilizer in maintaining soil fertility and agricultural productivity (Vanlauwe et al., 2010; Vanlauwe et al., 2001). Adoption studies corroborate this complementarity: researchers have found a strong positive relationship between the use of organic fertilizer and use of inorganic fertilizer in SSA (Marenya & Barrett, 2007; Wubeneh & Sanders, 2006).

1.4.3. Constraints on External Input Use in Sub-Saharan Africa

Mafongoya et al. (2006) concentrating on Southern Africa, describe the need for a mix of inorganic and organic inputs to bolster crop productivity through improved soil fertility. However, each input has its own particular limiting factors for uptake. Organic fertilizers can be of varying quality and also be labour and transport intensive. Additionally, on their own, they may not provide enough nitrogen for the crop, due to low nitrogen availability for the plant. Likewise, the sustained use of inorganic fertilizers on their own can lead to nutrient imbalance in the soil and even chemical soil degradation, such as the acidification of the soil (Buresh et al., 1997). The authors concluded that a mix of inorganic and organic inputs is required for sustainable crop production (Mafongoya et al., 2006). Place et al. (2003) and Vanlauwe et al. (2001) agree, noting that inorganic and organic inputs should be used in conjunction for Sub-Saharan African crop production.

Despite the need for a mix of organic and inorganic inputs, the use of inorganic fertilizers is limited by availability of input markets, affordability, and timely, efficient distribution.[3]

[3] Ultimately, these factors contribute to a situation where inorganic fertilizer use in SSA is lowest of all regions in the world, and less than half that of all other developing regions (Druilhe & Barreiro-Hurlé, 2012).

Fertilizer markets in SSA suffer from problems on both the demand and supply side, where weak and punctuated demand reinforces poor and inadequate supply (Morris et al., 2007).

Subsistence farmers often lack the economic means to provide these inputs to enhance and sustain the fertility of their soil. Inorganic fertilizers can be relatively expensive given high rates of poverty in West Africa (Elbehri, 2013) and as such, economic access to sufficient amounts of inorganic fertilizer is limited for subsistence farmers. Inflexible marketing systems where fertilizer is only available in 50 kg bags can also deter farmers who cannot afford the considerable up front cost of such an investment (Place et al., 2003). A study on farmers' perceptions of soil management techniques and land use in northwest Benin overwhelming cited the cost of inorganic fertilizer as the primary constraint on its use. However, they ranked it highest in the most desirable technique for addressing soil fertility, which the authors concluded is due to the importance of short-term production for the farmers (Adegbidi et al., 1999).

Liquidity and the cyclical nature of agricultural production and lean times play a role in financial constraints for purchasing agricultural inputs. Just before planting when farmers need to buy fertilizer is also when food supplies have run low and cash is needed to buy food for the household (Hayashi et al., 2008; Moser & Barrett, 2003). A lack of insurance and other consumption-smoothing mechanisms contributes to farmer reluctance to purchase fertilizer. The consumption risk is too great for poor households (Dercon & Christiaensen, 2011). This contributes to the weak and punctuated demand for fertilizer, and reduces market incentives for supply responses.

In addition, poor infrastructure and inefficient input markets affect the physical access to fertilizer. Lack of rural development and poor infrastructure means transportation and distribution costs are significant components of the total cost of fertilizer (Bumb et al., 2011; Druilhe & Barreiro-Hurlé, 2012). Poorly developed distribution networks mean that farmers in rural areas may incur substantial additional costs in terms of transportation and travel time. This can also create a psychological barrier to fertilizer use (Gregory & Bumb, 2006).

Organic matter, while sorely needed in poor, over exploited soils, has competing uses in subsistence farmer household economies. Farmers will remove crop residue from fields to use as livestock feed, fuel or construction material (Giller et al., 2009; Lal, 2009). Manure from livestock is a valuable source of nutrients and organic matter for farmers, though poverty means the ownership of large livestock, such as cows, is often out of reach. In addition, a study in the

Atacora department of Benin found that farmers cited a decline in the use of manure, as their cows had been stolen or died from disease (Adégbidi et al., 2004). Another study in Benin (also in the Atacora department) found that only farmers owning cattle applied cow dung to their fields (Saïdou et al., 2004). In fact, the relationship between crop production and the use of manure from livestock is complicated and dynamic, shifting as population densities and livelihood strategies change (Powell et al., 2004).

1.4.4. Fertilizer Microdosing

1.4.4.1. History in West Africa

As mentioned above, soil degradation is a crucial element contributing to the specter of food insecurity throughout SSA. To feed a growing population, farmers must sustainably intensify food production, and this includes the judicious use of mineral fertilizers (Alexandratos & Bruinsma, 2012; Collette et al., 2011). However, subsistence farmers are constrained in the application of soil enhancing inputs. Driven by the motivation to improve farmer livelihood through better soil nutrient practices, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) developed a precision fertilization technique called fertilizer 'microdosing'. Quantities applied under this technique are relatively small: less than six grams of fertilizer (equivalent to a bottle-cap full or a three-finger pinch) at the base of each plant. This can be as little as a third to a fourth of the recommended rate (Camara et al., 2013).

1.4.4.2. Rational and Evidence

Microdosing was designed to address the disjoint between the fertilizer recommendations that optimized yields/profits and the economic reality for many smallholder farmers with scarce resources. Microdosing is meant to maximize return on investment (i.e. an investment in small quantities of inorganic fertilizer) so that farmers will be more willing to take the risk of using inorganic fertilizer in very risky growing conditions. However, there are multiple barriers to adoption of this technique. These include poorly functioning input markets throughout SSA, credit constraints, liquidity constraints, information flows and inappropriate policies (ICRISAT, 2009).

In this context, ICRISAT promotes fertilizer Microdosing in conjunction with complementary interventions such as the *warrantage* system. The *warrantage* system allows farmers to store crops, using them as inventory credit at a time when crop prices are low, typically right after harvest, and then to resell the safely stored crops when prices are higher. With money borrowed from the *warrantage* shop, farmers can undertake income-generating activities during the dry-season. In addition, this system provides a means of offering fertilizer in affordable quantities and at group rates to resource poor farmers lacking the capital to individually buy the 50kg sacks of fertilizer typically sold at input shops (ICRISAT, 2009).

Studies on microdosing have compared microdosing against no fertilizer, traditional farmer practices, and conventional fertilizer application techniques such as banding or broadcasting. While studies in SSA have shown microdosing advantageous from an economic perspective even against conventional fertilizer application techniques that use considerably more fertilizer, many factors influence the relative profitability of microdosing, two of which are soil types and crop choice. Several studies have been done on the effect of microdosing on millet and sorghum yields in various agro-ecological zones and on different soil types. Hayashi et al. (2008), working in Niger, found that microdosing on millet increases yields and is more profitable than the control (no fertilizer) regardless of different application dates for the microdose quantities. Palé et al. (2009), investigating the effect of different fertilizer application rates and rainwater harvesting techniques on millet in Burkina Faso, found that a modified form of fertilizer microdosing (microdose of 4g NPK per planting hill + 20P ha^{-1} + 30N ha^{-1}) was successful in increasing grain yields over the recommended dosage rate. Tabo et al. (2006), working in Burkina Faso, Mali and Niger, found that microdosing could increase yields of millet and sorghum by 44 to 120% in comparison with traditional farmer practices or recommended rates. Shifting focus to Southern Africa, Twomlow et al. (2010) using data from broad scale, on-farm trials across Zimbabwe on millet, sorghum and maize, found that microdosing could increase yield by 30 to 100% compared to alternative farmer practices.

1.4.4.3. Evaluating the Economic Performance

Profitability is an essential condition for adoption of an agricultural technique. Beyond this, relative profitability matters as farmers make comparisons between alternative techniques. Tabo et al.(2011) used a net gain approach, calculating the difference between revenue minus cost for three techniques. This particular study looked at Niger, Mali and Burkina Faso, where the techniques were farmers' traditional practices and broadcasting fertilizer as well as fertilizer microdosing.

Hayashi et al. (2008) in a study in Niger on millet comparing microdosing and a control (no fertilizer), used a budget analysis and a Marginal Value to Cost ratio (MVCR). Through the budget analysis they recorded average yields and calculated a net return. From that, they used the MVCR defined as the net revenue of the microdosing minus the control, divided by the net cost of microdosing minus the control. The benchmark for a treatment to be considered profitable is a MVCR of 2, drawn from CIMMYT's influential work from the 1980s (CIMMYT, 1988). Twomlow et al. (2010) used the same value-to-cost ratio technique to assess the effectiveness of microdosing, also with the commonly accepted 2:1 ratio set as the minimum ratio needed for risk-averse farmers to adopt a particular technique.

Camara et al. (2013) took into account the increase in average yields, using a partial budgeting analysis, calculating only the difference between application and fertilizer costs (this is similar to the initial cost calculation conducted in this thesis, as the difference between other costs for the techniques are negligible).

Most of the studies done on microdosing approached the problem from a multi-disciplinary perspective, using soil science, economics and other social science techniques to examine the biophysical impact and the socio-economic impact of microdosing on the land and the farmers. In this respect, this thesis is in line with the current standard for microdosing studies, drawing from multiple disciplines to create a holistic picture of the impact microdosing has on farmers' lives.

1.4.5. The Adoption of Agricultural Techniques in Developing Countries

1.4.5.1. General Theoretical Considerations

The oft-cited work on agricultural technology adoption in developing countries by Feder et al. (1985) is useful in explicating the theory of technology adoption at both the farm-level and the aggregate level. The analytical framework centered on the farmer's decision making regarding the extent and intensity of adoption, the objective of which is generally considered to be the maximization of expected utility (or expected profits) subject to constraints, in a given period. This decision making process is dynamic and influenced by the act of information gathering, learning by doing and the farmer's changing balance of resources. Foster and Rosenzweig (2010) emphasize the maximization of profit, noting that as an important determinant of adoption, net gain to the agent of adoption must be assessed and measured carefully. Besley and Case (1993) argue for rigorous theoretical choice-based model of decision making underpinning empirical adoption models.

1.4.5.2. Factors Influencing Agricultural Technology Adoption

Complex socio-economic and environmental factors affect the adoption of agricultural technologies. One can view the factors affecting technology adoption at different levels of influence: those stemming from farmer/household characteristics and those driven by the social, institutional and biophysical environment, though the interplay between these levels of influence is complex and differentiations are not always distinct.

Micro-level: The Farmer and Household

Smallholder farmers may be less likely to adopt new agricultural technologies due to an aversion to risk. A household's willingness to engage in riskier ventures may in fact be a function of their wealth and asset holdings, as wealthier farmers (or those with non-farm sources of income) are more likely to adopt technologies that have uncertain returns (Foster & Rosenzweig, 2010). This means conversely, poorer farmers are less likely to adopt technologies with uncertain returns, particularly if the downside risk is very great. Using panel data, Dercon and Christiaensen (2011) examined the impact of consumption risk on inorganic fertilizer use in Ethiopia. They found that the potential negative impact on consumption did indeed decrease the use of inorganic fertilizer and that the effect was not trivial. Lack of insurance or consumption-smoothing options contribute to a situation where poor farmers who may benefit the most from yield increasing agricultural inputs are the least willing to adopt, due to the devastating potential of the downside risk. Households existing on the edge of adequate consumption do not necessarily have the luxury to take risks in their livelihood strategies. Therefore the relative riskiness of a technology will be important in adoption decisions (Buerkert & Schlecht, 2013). Technologies that increase a farmer's vulnerability to biophysical, agro-ecological shocks may also see lower rates of adoption (Muzari et al., 2012).

Wealth is consistently positively associated with adoption (and early adoption) of new technologies, though the nature and direction of causality is difficult to determine from many standard estimation models (Adolwa et al., 2012; Akinola, 2010; Foster & Rosenzweig, 2010). Foster and Rosenzweig (2010) note that it may be imperfect credit and insurance markets that contribute to the phenomenon of wealthier households greater adoption levels. As noted before, poorer households are potentially less willing to take the risk of investing in profitable fertilizer technologies because of the unacceptably high downside risk on household consumption (Dercon & Christiaensen, 2011). But even if they were willing to take on the risk, they may not have the physical, social and human capital to overcome barriers to accessing inputs or may be less connected to those with resources (Larson & Gurara, 2013). Moser and Barrett went as far as to call it an "empirical regularity" that poorer households are the last to adopt improved agricultural techniques (Moser & Barrett, 2003, p.1093). To increase adoption rates, agricultural technologies aimed at poor farmers should have low asset/cash requirements (Buerkert & Schlecht, 2013). Understanding the mix of livelihood strategies for smallholder farmers can be important in determining technology suitability. Income from other non-farm sources in household can improve ability to purchase inputs, increasing probability of adopting new technology that may require additional inputs (Akinola, 2010; Marenya & Barrett, 2007). In addition, it can provide a buffer from negative effects on consumption of failed experimentation, help ease working-capital constraints and finance a fixed-investment innovation (Feder et al., 1985).

As wealth is consistently positively associated with adoption, and since wealth and income are two important components of socio-economic status (Morris et al., 2000) it is expected that the relationship of socio-economic status will be similar to that of wealth on adoption. As total cultivable land increases, farmers have more land upon which to experiment. In addition, farmers with greater cultivable land are expected to have higher socio-economic status and greater wealth, both factors that positively influence the probability of adoption (Larson & Gurara, 2013). Household size, another characteristic associated with greater wealth in certain developing country contexts, is also positively associated with the adoption of agricultural technologies (Larson & Gurara, 2013; Marenya & Barrett, 2007; Mignouna et al., 2011).

Since household size may also indicate greater labour availability, the size of household labour force can be an important determinant in technology adoption— especially for low-external input, labour intensive technologies. One innovative quasi-panel data analysis of a low-external input, highly profitable technique with great potential for poor farmers in Madagascar concluded that the seasonal nature of labour and income demands negated benefits of the technique and led to low adoption rates. When financial markets do not function for the rural poor, labour markets can act as a stopgap measure as farmers sell their labour for money during lean times (Moser & Barrett, 2006). In fact, a systematic review on technology adoption in developing countries found that the "operative constraint" in African agriculture was peak season labour shortages (Feder et al., 1985). Therefore, the nature and timing of labour demands associated with an agricultural technology will affect its appeal to smallholder farmers.

The effect of age on the probability of adoption has mixed results in the literature, as the direction of influence on adoption can be specific to the location or the technology (Akinola, 2010). For example, age was found to be positively correlated with the adoption of improved maize varieties in Kenya (Mignouna et al., 2011), but negatively correlated with the adoption of improved natural resources management practices in Kenya (Marenya & Barrett, 2007)In addition, it was shown to have no statistically significant effect on adoption of nutrient management technologies in Nigeria (Akinola, 2010) and a threshold effect with the uptake of improved rice varieties in Côte d'Ivoire, indicating that after a certain point its direction of influence on adoption reverses (Beke, 2011). One study found that age had no effect on probability of adoption of dairy technology in Ethiopia (Amlaku et al., 2012), whereas another study of hybrid cocoa adoption in Ghana found that younger farmers were more likely to adopt the hybrid crop, possibly due to their longer planning horizons (Boahene et al., 1999).

Education level, on the other hand, has a more consistent relationship with adoption in the literature. Education, especially basic literacy in the context of low educational attainment, has a significant effect on adoption. Bandiera and Rasul found that literate farmers (as compared to illiterate) are more likely to adopt a new crop in Mozambique (Bandiera & Rasul, 2006). Yengoh et al.(2010) drawing from their research on technology adoption in small-scale agriculture in Cameroon and Ghana, recommend that governments improve basic education to increase literacy levels so that farmers can better access information about agricultural techniques. Adolwa et al. (2012) noted that low literacy levels among farmers in SSA has been identified as a constraint to access knowledge on soil fertility, which hinders the adoption of soil fertility management techniques. Education level can also have an indirect effect on technology adoption; Beke (2011) found a negative relationship between education level and the probability of facing a credit constraint, and credit constraints in turn hinder adoption. Numerous other studies have found a positive effect of education level on the diffusion and adoption of agricultural techniques in developing country context (Larson & Gurara, 2013; Mignouna et al., 2011; Moser & Barrett, 2006).

Gender presents a particular dimension for technology adoption that cuts across the different levels of influence. Gender affects the individual decision making process and household dynamics: there are questions raised in the literature related to different preferences and degrees of risk aversion. Gender also plays into the way institutions help or hinder technology adoption. Female farmers face different constraints and barriers than do male farmers. For example, female farmers may face different access to credit than male farmers. Additionally, male farmers may have greater access to land, information, and technology (Muzari et al., 2012) Doss and Morris (2001) suggested that women are less likely to adopt new technologies, in part because of their limited access to and control over the factors of production that enable adoption. [4] For example, a study in Western Kenya on the adoption of natural resource management practices found women were less likely to adopt, but once controlling for other factors such as off-farm income and livestock holdings, gender alone does not appear to affect adoption. Hence, the authors surmised that it is women's lack of off-farm income that prevent them from acquiring the capital required to purchase inputs, in this case in particular, inorganic fertilizer (Marenya & Barrett, 2007).

While most surveys record the gender of the head of household, to obtain a more accurate picture on the effect of gender on technology adoption researchers should ensure correct specification. For example, it may be important to record the gender of the head of household along with the gender of farmers *within* the household. A study by Doss and Morris (2001) in Ghana on the effect of gender on the adoption of improved maize technology illustrates the importance of conducting analysis using properly specified gender variables. Initially, the researchers used a simple gender variable and the results showed no difference in adoption rates. After specifying the variable in a different manner (the gender of farmer in combination with the gender of the head of household), they found that female farmers living in female-headed households are significantly less likely to adopt modern varieties of maize than are female farmers living in male-headed households.

[4] This is the case in Benin, which is a patriarchal society (Kinkingninhoun-Mêdagbé et al., 2010).

Organic fertilizer, through the provision of organic matter, exhibits a complementarity with inorganic fertilizer in terms of crop yields (Place et al., 2003). This complementarity could increase the marginal value of product for the inorganic fertilizer, making fertilizer microdosing more profitable. In addition, as microdosing decreases the use of inorganic fertilizer in soils with declining soil fertility, there may need to be a commensurate increase in organic fertilizer as farmers attempt to sustain soil fertility. In fact, proponents of fertilizer microdosing cite the need for increasing organic matter in the soil alongside fertilizer microdosing to improve soil properties and increase soil fertility (Tabo et al., 2011; Tabo et al., 2007). Thus, use of complementary inputs can be predictive in technology adoption.

Social, Institutional and Environmental factors

Small-holder farmers in SSA face numerous challenges including declining soil fertility, input market failures, erratic rainfall, increasing population pressure on land, inadequate agricultural financial services, not to mention systemic poverty. The literature acknowledges the importance of context and understanding the lived realities of farmers when promoting and disseminating agricultural technologies designed to improve the lives of those farmers. The context must be broad enough to include the social, cultural, biophysical, institutional and environmental realms and the complex interplay between these realms, as well as specific enough to understand the important differences between farmers and individual plots, even within the same agro-ecological zone. Giller et al. (2011) in particular note the "bewildering complexity" associated with smallholder farming systems across Africa. Factors such as highly variable resource endowments, the diversity of agro-ecological zones that give rise to very different agricultural systems, and rapid demographic changes are just some examples of the drivers that contribute to this complexity.

Vanlauwe et al.(2010) noted that ISFM must consider the significant variability of soil fertility status between farmers' fields, claiming that this may be as great a difference as the difference between agro-ecological zones. Kassie et al. (2013) included plot level characteristics, such as slope of plot, perceived fertility of plot, depth of soil, as independent variables when evaluating the adoption of interrelated sustainable agricultural practices (which included the use of chemical fertilizer and soil and water conservation). They found a significant effect of such plot level variables on the farmers' adoption decisions for particular agricultural techniques.

Knowler and Bradshaw (2007), in their review of the past studies on the adoption of conservation agriculture, concluded that there are “few if any universal variables” that can explain adoption. This led the authors to the conclusion that strategies promoting conservation agriculture must be designed with the particular context in mind. Indeed, they even suggest that more studies done on finding universal factors promoting adoption may be energy misspent. Rather, studies examining management strategies for the local context may yield higher returns on research investment.

The broad context related to government policies and institutional factors also have important consequences on adoption and directly affect farmers’ livelihoods. Infrastructure development is key for reducing transportation costs of key inputs to rural areas, where farmers reside. It is also important in increasing market access for farmers. The price ratio of inputs to outputs influences farmers’ decisions. These prices can be influenced by government policies pertaining to fertilizer subsidies, infrastructure development and structural changes that modify the business environment in which farmers operate (Abdoulaye & Sanders, 2005; Larson & Gurara, 2013). Food related policy measures, such as taxes and subsidies or input/output quotas, play an important role in the process of technology diffusion and adoption (Feder et al., 1985).

Kristanjson et al. (2005) constructed socio-economic domains based upon population density and access to markets to stratify sub-populations in their analysis of adoption of an improved crop variety in Nigeria. They concluded that these village level spatial and social variables of market access and population densities are significant determinants of adoption.

Financial institutions and their capacity to respond to the needs of smallholder farmers play an important role in the dissemination and promotion of agricultural technologies as well as directly affecting the rates of adoption. By determining eligibility, formal lending agencies can determine who receives credit, and access to credit affects adoption of agricultural technologies (Muzari et al., 2012). The literature is replete with evidence that credit constraints limit adoption of new technologies (Abdulai & Huffman, 2005; Akinola, 2010; Druilhe & Barreiro-Hurlé, 2012; Feder et al., 1985; Moser & Barrett, 2003) Informal mutual help systems can sometimes fill the gap for formal institutions: Honlonkou (2004) found that participation in informal mutual financial systems positively affected the intensity of adoption of natural resources management technologies.

1.5. Summary

A variety of soil and land management techniques have been promoted as ways of sustainably intensifying agricultural production in SSA. One such technique is the efficient use of small quantities of inorganic fertilizer, or fertilizer microdosing. However, the adoption of such techniques depends upon many variables acting at different levels. For a few of these variables, the nature of how they influence adoption is consistent throughout the literature; for others it appears to vary widely depending upon context. However, it is clear that understanding the broader social, economic and institutional context is crucial for an appropriate assessment of how and why some technologies flourish and why others are never adopted (or abandoned soon after adoption).

Farmers in many developing countries are faced with a multitude of interrelated institutional and biophysical challenges. Thus, the study of agricultural decision-making in low-resource settings is inherently complex and nuanced. The complexities of farming decisions in low-resource settings mean that there are many interrelated and multi-faceted factors influencing the adoption/non-adoption of new agricultural technologies. Assessing the nature of technology uptake in such a context then is best undertaken by using a holistic framework to examine the factors that mediate the viability of a particular technology within the larger biophysical and institutional environment. It is with this understanding that the following research on the adoption of fertilizer microdosing in Benin was undertaken.

1.6. Chapter Transition

Chapter one has presented the overall context and background for the research conducted through this thesis, as well as a review of the literature that informed the analysis. Chapter two serves as the research manuscript where a detailed methodology and the research results are presented. It is formatted for submission to the International Journal of Agricultural Sustainability. Chapter two will be followed by a discussion of the research results in the context of the wider literature, as well as study limitations and areas of further research.

Drawing from detailed household surveys and plot-level data on farmer demonstration plots, this research will identify the rate of adoption of fertilizer microdosing in one village in Benin, as well as the relative economic performance of fertilizer microdosing in comparison to the recommended dosage. Farmer comments and stories from the surveys will be used to paint the broader picture of the various factors influencing the adoption of fertilizer microdosing. In sum, this research sets out to understand to what extent farmers living in one village of northwest Benin have adopted fertilizer microdosing, and what factors have limited or encouraged adoption.

Chapter 2. Making a little go a long way: Socio-economic factors influencing the adoption of fertilizer microdosing in Northwest Benin

2.1. Abstract

Soil degradation and low crop productivity negatively affect the food security of smallholder farmers in West Africa. Various agricultural techniques have been developed as components of food security interventions, but their effectiveness in addressing food insecurity in part depends upon farmers' willingness to adopt these techniques. Likewise, adoption depends upon the effectiveness of these techniques in fulfilling farmers' objectives. The institutional and biophysical environments mediate not only the effectiveness of the techniques, but also how farmers value a technique.

This study examined the evidence for fertilizer microdosing as a form of agricultural intensification and the socio-economic conditions that influence its adoption among smallholder farmers. A census was conducted in one village in northwest Benin that had recently seen the introduction of fertilizer microdosing. Key household-level determinants of adoption identified in the literature—household resources, household demographics, and access to inputs— were included in the household surveys. Using partial budgeting analysis and yield data from demonstration plots, the relative profitability of fertilizer microdosing was calculated as a necessary condition of adoption. Drawing from farmers' stories, the potential value of microdosing was contextualized within the larger social and institutional context.

Based upon the village census, there was little adoption outside of the research project that introduced microdosing to the village. Households using microdosing (predominantly found within the research project) had, on average, higher socio-economic status, more cultivable land and larger labour forces. Profitability analysis indicated that microdosing was on average *less* profitable than the point-source application of the recommended dosage rate in Benin (the common alternative). However, farmers still expressed a desire to microdose, due to poorly functioning input markets, poor infrastructure, and lack of access to financial instruments, all of which limited the availability, access and utilization of inorganic fertilizer.

2.1. Introduction

For the majority of Sub-Saharan Africa (SSA), agriculture remains the backbone of the economy, employing the majority of the population and provides roughly 70% of Africa's food supply (IFAD & UNEP, 2013) Smallholders- generally defined as having two hectares or less-comprise 80% of the farms in Africa (Delaney et al., 2011). These farmers work the land to provide enough food to satisfy domestic household needs and ideally, some surplus for sale through local or regional markets. Increasing population pressure in West Africa has, however, meant that farmers cannot rely upon agricultural extensification or long fallow periods to increase agricultural production, but rather must intensify production on existing agricultural lands (Bationo et al., 1998). While intensification is seen increasingly as a necessary progression for SSA agriculture (Vanlauwe et al., 2010), intensive agriculture is also linked to serious environmental problems, such as decreasing water quality in ground and surface water, pest and disease resistance, and notably for this research, declining soil fertility (Tilman et al., 2002). The un-sustainable intensification and resulting loss of soil fertility has in turn led to the depreciation of the farmers' 'natural capital' in ways that threaten both the regenerative capacity of the land and puts the sustainable livelihoods of farming households at risk. To avoid these conditions, farmers struggle to find a balance between the intensification of agricultural production while minimizing soil degradation.

Farmers use a number of techniques to enhance production and limit soil degradation. These strategies include crop rotation, the use of nitrogen fixing crops, increasing organic matter in the soil, and minimal tillage, among others. In terms of fertilizer applications, the United Nation's Food and Agriculture Organization (FAO) recommends the "judicious use of mineral fertilizers," using precision approaches to promote soil health (Collette et al., 2011). Similarly, the targeted application of small quantities of fertilizer has been promoted as a sustainable 'step up the ladder' of agricultural intensification (Aune & Bationo, 2008). While recommended dosages have been determined through government-sponsored research,[5] these recommended doses are often unaffordable for the rural poor or unattainable given limited availability. In response, researchers at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) developed a technique known as fertilizer microdosing, involving the precision application of small (less than the recommended dosage) quantities of inorganic fertilizer. Previous studies in SSA, and West Africa in particular, have found microdosing to be an economically advantageous technique, while also addressing limited access (both physical and

[5] For example, in Benin, the *Institut National des Recherches Agricoles du Bénin (INRAB)* provides farmers with a technical report detailing recommended agronomic practices.

economic) to inputs, as compared to alternative fertilizer application techniques, such as broadcasting at recommended dosages (Camara et al., 2013; Hayashi et al., 2008; Tabo et al., 2011; Twomlow et al., 2010).

Microdosing was introduced in Niger, Mali, and Burkina Faso as early as 1998 (Tabo et al., 2011) but reports indicate that microdosing has not been widely adopted in other regions of SSA. To investigate factors influencing the adoption of microdosing and the biophysical implications of microdosing on the soil, a multidisciplinary research team from West African research centres and universities from Benin and Canada collaborated on the **In**tegrated **N**utrient and **Wa**ter **M**anagement research and development project (INuWaM) in Niger, Mali, Burkina Faso and Benin. (See figure 2-1) This project involved introducing the fertilizer microdosing technique to six villages in two districts in northern Benin. (See Figure 2-2) The two districts were chosen as they represent two major agro-ecological zones of the Sahel region. As well, the districts had previous research pertinent to microdosing and rainwater harvesting; they hosted sizeable local and regional markets; there was determined to be a need for intensification due to the high rate of soil degradation within, and there was a network of rural development and farmers' organizations that were deemed important in maximizing the approach and results of the project. Fertilizer microdosing for the maize demonstration trial in Benin was defined as the strategic (point source) application of small quantities of inorganic NPK fertilizer between one and 15 days after sowing, along with an amendment of urea 45 days after sowing.

In 2013, two years following the project's inception, a follow-up study was conducted in one of the six project villages — Koumagou B — to determine rates to which microdosing had been adopted by village farmers. This paper presents the results of that research and reports on the social and economic factors that influenced the adoption and non-adoption of microdosing among Koumagou B households. Specifically, this paper: 1) assesses the relative economic performance of maize production under microdosing as compared to recommended dosage application rates; and 2) identifies the factors that influenced the adoption of fertilizer microdosing, drawing from quantitative and qualitative data on household/farmer characteristics, soil quality, institutional factors, and the design and implementation of the original demonstration project. The objective was to identify key social and economic variables that influence the adoption of micro-dosing technologies while elucidating the socio-ecological factors that either promote or constrain the uptake of fertilizer microdosing. In so doing, this research adds to the existing literature on the economic benefits of microdosing while drawing attention to the complexity and multidimensionality of factors that influence the decision-making of rural farmers.

Figure 2-1 West Africa

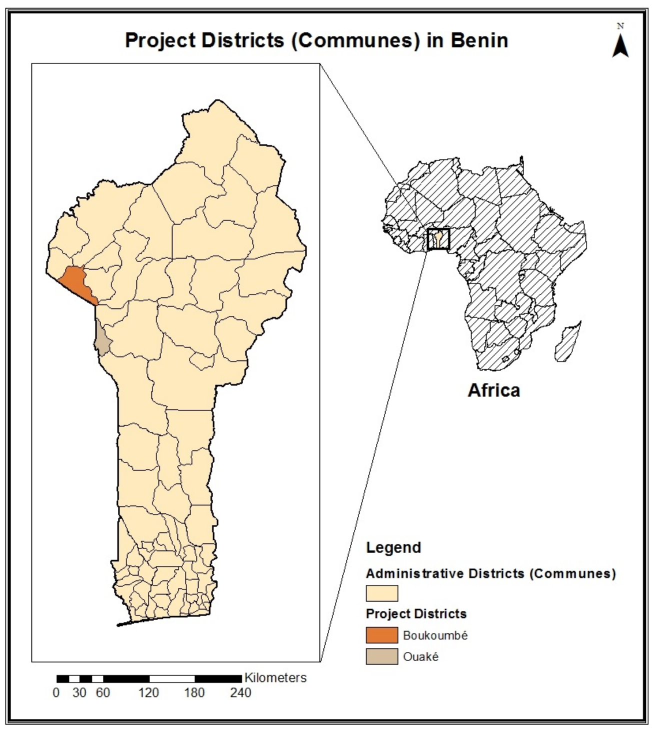

Figure 2-2 INuWaM Project Districts in Benin

2.1.1. Agricultural Technology Adoption

The sustainable intensification of agriculture generally requires the adoption of improved agricultural techniques. The literature on the topic of technology adoption, even limited to developing country context only, 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 findings that are most relevant to our research. Feder et al. (1985) for example, offer one of the first multi-country assessments on the adoption of agricultural innovations. They emphasize the importance of developing a strong theoretical foundation by modeling the individual/household decision-making as a dynamic process with parameters that change as the farmer adapts to changing situations. The core of the model is a temporal utility maximization problem: in a given time period, farmers attempt to maximize utility (or expected profits) subject to constraints.

In terms of empirical findings, Feder et al. (1985) reduce the vast quantity of research done on technology adoption by examining the following key explanatory factors: farm size, risk and uncertainty, human capital, labour availability, credit constraints, tenure, supply constraints, and aggregate adoption over time. Farm size is positively associated with adoption, though it may be a proxy for other factors such as capacity to bear risk, wealth, and access to credit, information, and inputs, among others. Risk and uncertainty are difficult to measure and they find a lack of strong empirical work done to validate or refute theoretical models. Human capital (primarily education in this case) is positively correlated with adoption and earlier adoption. Labour availability is a critical issue for technology adoption and they state that the "operative constraint" in African farming systems is labour availability at peak times. Credit constraints were found to hamper the adoption of new technologies. In regards to tenure, they find mixed results and suggested more research needs to be done. Supply constraints are more straightforward: clearly key inputs need to be available for a technology to be adopted. Aggregate adoption patterns begin to touch upon the effect of social learning and knowledge diffusion in technology adoption. Importantly for this research, the authors discuss the importance of context in the pace and nature of diffusion, as farmers adapt the technology for their purposes under local conditions (Feder et al., 1985).

Foster and Rosenzweig (2010) provided a more recent survey on the determinants of technology adoption in developing countries. Their examination looked at the adoption of welfare-increasing innovations in general, rather than just in the agricultural realm. However, they noted that most of the studies they reviewed still focus on agriculture, given its importance and the relative ease of measuring inputs and outputs. Their major findings indicated that education and schooling, size and relative wealth of farm households, and the extent of adoption among neighbours are all positively correlated with adoption.

In the intervening years between these two major reviews, there have been a number of studies done on the subject of agricultural technology adoption. Collectively, these studies emphasize profitability as foundational in agricultural technology adoption, either explicitly or implicitly in their model specification. This is the optimization assumption that Besley and Case (1993) referred to in their influential work on modeling technology adoption in developing countries. Shiferaw et al. (2009) in their review on the adoption of natural resource management innovations noted that farmers must see economic benefits in the short run in order to adopt a technique.

In addition, context matters. Government policies, the biophysical environment and social structures, among many others, 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 fertilizers 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). Therefore, site-specific knowledge dependent upon soil quality and soil type, while taking into account current farmer practices and local knowledge, is key to improving crop production through the promotion of technological innovation.

2.1.2. Research Site

Benin is a small country of 10.05 million people (as of 2012), bordered by Nigeria to the East, Togo to the West, Niger and Burkina Faso to the North and by the Atlantic Ocean to the South. (See Figure 2-1.) Agriculture is the predominant sector, employing nearly half the workforce population. However, it only accounts for about 36% of GDP. Farming is predominantly small scale and the average size of the small-scale farm is 1.7 hectares (Bio Goura et al., 2013).

Koumagou B is a small, rural village, situated in the Boukoumbé *commune* (administrative district) in Northwest Benin. It is situated roughly 50 km from the paved road that connects to the larger centre of Natitingou to the East and 16 km from the Benin/Togo border to the West. It is only a few kilometers from the town of Boukoumbé (which is both the name of the *commune* and the major town in the commune) but retains its distinct rural identity. There is no electricity in Koumagou B, but several enterprising households own a generator to charge cellphones (ubiquitous in the village) for a fee. Villagers collect water from communal wells, pumps or streams, as there is no piped water. The land tenure system is based primarily on inheritance (Aregheore, 2009). Crops grown include grains such as maize and sorghum, legumes such as cowpea and voandzou, tubers such as yam, and the occasional vegetable, such as chilli peppers. While cotton is a major cash crop throughout Benin, cotton is not grown in Koumagou B, due to the unsuitability of the soil and land constraints (i.e. Farmers lack sizeable plots of cultivable land with soil of a minimum fertility level). Only one farmer in the village claimed to be growing cotton, and only on a very small plot at that, claiming it was simply to experiment with the crop. Farmers in Benin are advised to apply recommended quantities of fertilizer using point source application (placing the fertilizer in a hole near the plant) (Saidou et al., 2012).[6] This conventional form of fertilizer application is called either "CARDeR" (in reference to the name of the government agricultural extension organization) or *la dose recommandée* (recommended dosage) and is the strategic application (sometimes with a bottle cap) of recommended quantities of inorganic NPK fertilizer 15 days after sowing, along with an amendment of urea 45 days after sowing. Thus the primary differences between microdosing in the Benin trial and the recommended dosage are the quantity (microdosing uses nearly half the amount) and the timing (microdosing requires an earlier application of fertilizer).

The ethnic group in Koumagou B is the *Batammariba (Otamari).* Polygamy is an accepted practice and men derive social importance from the number of their wives and children. Fetishists, traditional healers and current and former chiefs of the village hold particular prestige (Central Bureau for Projects & Multinational Agribusiness Systems Ltd., 1983) A village secretary assists the chief of the village. Traditional (animist) beliefs dominate the religious landscape, though Christianity and Islam are also represented, (République du Bénin, n.d.) but are more commonly practiced in nearby larger centers. The older generation primarily speaks the *Ditammari* language but French, as the national language, is used in schools. Those formally educated (primarily the youth) will speak French as well as *Ditammari*.

Boukoumbé's sudanian climate is characterized by one rainy season from April to October and a dry season from November to March. On average there is 800 to 1100 mm of rainfall per year (Adegbidi et al., 1999). A hot, dry wind called the *Harmattan* blows through the region from November to February. Sloping, rocky lands characterize the geography of the

[6] Saidou et al. (2012) note that farmers often don't use the recommended *quantity* of fertilizer, though they make no reference to alternative *application* techniques in Benin. Judging from experience in the field, discussions with researchers and available literature, the standard method of applying fertilizer in Benin is the precision (point source) application.

study region contributing to erosion and nutrient run-off. The sloped landform coupled with intensive agriculture leads to declining levels of soil organic matter and a decrease in the water-holding ability of the soils (Saidou et al., 2012).

The INuWaM project was presented to the community at an initial meeting with village representatives. After the initial formal meeting with the INuWaM research team, the chief of the village held another meeting to discuss the project. After this, those interested in the project volunteered to be demonstration farmers and the village chief and secretary put forth a list for the research team. One of the requirements was that the demonstration plot of land had to be near a road to maximize visibility of the project, so as to encourage information dissemination on the technique. Though the exact number varied, 20 farmers participated each year. (Four of the initial 20 farmers left half-way through the project and were replaced; one farmer left for family health reasons, two farmers left for Nigeria to work, and one farmer found the project and the microdose technique too bothersome.) These farmers, called "*producteurs,*" were the farmers who hosted the demonstration trials on their land. Each farmer divided a parcel of land into two equal plots, one for the microdose technique and one for the recommended dosage technique. Maize was chosen for the demonstration trials. In the first year of the project, a control plot was also included, with no fertilizer application. However, there was total crop failure across control plots and it was subsequently discontinued.

Understanding the impact of microdosing on the maize crop is particularly important for the country of Benin, as maize is the country's staple cereal grain. In 2012, maize was the 3rd most important *commodity* in terms of production quantity, at 1,174,563 tons. However, maize is the most important *cereal grain* grown in terms of production quantity. Maize is the 6th most important crop grown in terms of production value, but yet again the most important *cereal grain* on the list. In terms of per capita supply of food energy however, maize is the most important commodity, providing 455 kcal per capita per day in 2009 (FAO, 2014b).

Farmers did not receive improved seed from the research project—they had to source seed on their own— but were provided fertilizer sufficient for the demonstration plots at no cost. In addition, the *producteurs* received technical visits from the project coordinator, trained in the microdosing technique. The project researchers prescribed the management of each demonstration plot in an attempt at standardization; thus, the primary differences were to be soil and rainwater harvesting techniques present on the land. At the end of each growing season, the yields from the two demonstration plots were weighed for the community to see. The intention was for the *producteurs* to train interested village farmers, who were not part of the project, on the microdosing technique. Villagers who saw the demonstration plots and were interested in the technique were expected to ask the *producteurs* to teach the technique. In this way, the technique was expected to spread throughout the village through informal networks.

2.2. Methodology and Data Collection

This research was informed conceptually through a socio-ecological niche framework of analysis (Ojiem et al., 2006). In addition, the seminal work of the anthropologist Fredrik Barth influenced the conceptualization of farmer economic decision-making within a social context. Barth (1967) was one of the first to emphasize the processual nature of social change. Individuals make decisions according to their own purposes, and allocate their time and resources accordingly. The ecological and strategic constraints that form their external environment reward or punish the decision makers based upon these allocations, thereby channelling and directing the process of change. In this vein, introducing an agricultural technology involves a reallocation of time and resources on the part of the farmer, the potential adopter of the technology. The success or failure of that technology depends upon the ecological and social environment. Ajayi et al. (2007) framed this in the language of biophysical and socio-cultural niches, arguing that using such a framework is important for successful targeting of renewable soil fertility replenishment technologies.

2.2.1. Household Surveys

A census was conducted of one project village, treating the project village as the 'population' of interest. As the research had both an anthropological and economic approach, the smallest of the six project villages — Koumagou B — was selected so that a census could be conducted of all the households. The census approach was chosen so as to determine the exact number of microdose users within the project village. Although conducting a census of one village meant a more context specific data set and a smaller number of potential adopters, it was deemed the most appropriate method for a number of reasons. For one, the length of time spent in one village provided the basis for respectful engagement with the community. In addition, as noted by Moser and Barrett (2003), conducting a census-style survey of a village and enumerating the precise number of adopters, non-adopters and dis-adopters obviates the possibility of selection bias, which they claim is common in adoption studies.

The field research took place between May and August 2013. A detailed household survey was administered to 73 households within the village of Koumagou B. All surveys were administered in person by the author with the assistance of a translator. This allowed for a high response rate and additional information gathering as surveys were based on a semi-structured interview format.

Survey respondents were drawn from a list of names created by the chief and the secretary of the village. The list provided by the village was updated as the survey unfolded according to the reality on the ground. Of the 103 names, 20 were ineligible for various reasons (death, living in same household as another respondent, not currently living in village etc.), four refused, two were not contacted in time, and four were not available when contacted. The total response rate was 95% after excluding those that were ineligible, missed or not present at time of attempted contact (73 out of 77 contacted respondents).[7]

The survey included detailed questions on household demographics, household assets, awareness of the INuWaM project and knowledge diffusion, experience with the microdosing technique, crop production and land tenure, access to inputs, and credit availability. (See Appendix A for survey.)

2.2.2. Soil Sampling and Creating a Soil Quality Index

Soil samples were collected from each household after the survey was administered in 2013. For farmers that *had* used the microdosing technique in 2012, a soil sample was taken from the plot of land that had been used for the microdosing trial for 2012. Separate soil research done through the INuWaM project in Benin on the short-term effects of microdosing versus recommended dosage show only very small effects on soil parameters after two years of microdosing (the only statistically significant change is in available phosphorus increasing in recommended dosage vs. microdosing and only at a 90% confidence level.) In addition, due to the high turnover rate for nutrients in the soils and the prevailing tillage systems, the residual fertility changes would be minimal (Derek Peak (soil scientist), personal communication,

[7] Response rate was calculated as total interviewed divided by total eligible (and excluding those not contacted.)

February 25, 2014). Thus, a sample taken from the microdosed side of the demonstration plot is broadly comparable to the soil used for the entire demonstration plot.

The sample was taken 30 cm away from a stalk of maize remaining from the 2012 growing season. For farmers who had *not* microdosed but *were* using inorganic fertilizer, and who grew maize, a soil sample was taken from the fertilized, non-microdosed maize plot of 2012. For farmers *not* using inorganic fertilizer, and who did not grow maize but rather sorghum, soil samples were taken from the sorghum plot of 2012.

The survey unfolded as the agricultural season progressed and some of the soil samples taken from the end of the planting season (July –August 2013) were taken from plots that had already been tilled under and/or had maize growing in them from that season. Soil analysis provided measures of various soil characteristics: organic carbon, pH, total nitrogen, total phosphorous, total available phosphorous, and cationic exchange capacity (CEC).[8] (See Appendix B.)

Principal Components Analysis (PCA) has been used to develop soil quality indices to reduce the dimensionality and redundancy in a dataset and produce an index that can be deployed to assess soil quality.[9] Thus, PCA was used to ascertain if certain soil characteristics (indicators) were more influential in determining soil quality. PCA works by capturing the variation found in the original dataset variables in new variables called "principal components." Each principal component is uncorrelated to all the other principal components and each explains successively less of the variation found within the original dataset. Each of the principal components has an associated eigenvalue that indicates the amount of variance it explains in the original variables. According to the Kaiser criterion, only principal components with eigenvalues greater than one need be used, as principal components with eigenvalues less than one capture less variability than a single original variable (Kaiser, 1960).

The analysis showed that each of the soil characteristics was an important element of soil quality as each of the six soil characteristics had similar weightings. In addition, all were highly correlated. The first principal component explained the majority of the variability from the

[8] The Soil Science department at the University of Saskatchewan, led by Dr. Derek Peak, conducted the soil analysis.

[9] See (Armenise et al., 2013, Bastida et al., 2008) for a review on the creation of soil quality indices.

original data set and was the only one with an eigenvalue greater than one. (See Appendix C.) The indicator values across all observations for each soil characteristic were standardized using a standard scoring function. (For the standard scoring function equation see (Li et al., 2013).) The resulting standardized scores were weighted according to principal component analysis and then summed across the indicators within each sample, resulting in a final value for each soil sample that provides a relative measure of the soil quality. The sums across all the soil samples provide a Soil Quality Index (SQI) that represents soil quality[10] according to the formula: (Masto et al., 2008).

$$SQI = \sum_{i=1}^{n} W_i S_i \tag{2.1}$$

Where W is the weighting for a characteristic derived from the principal component analysis and S is the score of the respective soil characteristic.

2.2.3. Creating a Socio-Economic Status Indicator

As noted with the creation of a soil quality index, PCA is used to create an index capturing information found in multiple, highly correlated factors. It is useful to reduce the dimensionality while preserving the original information. PCA has been used as a tool to create socio-economic status indices for communities for which available survey data contains household assets and characteristics, rather than income or expenditure data (Vyas & Kumaranayake, 2006). Rather than being simply a data limitation, there are a number of theoretical and practical advantages to using asset indicators to proxy wealth and socio-economic status over, say, consumption data, particularly in developing countries. McKenzie (2005) provides an assessment on the benefits of asset-based indices of socio-economic status.

Household survey included data on household assets and access to water. As there was no income, expenditure or consumption data collected to reflect household status, PCA was chosen as the methodology by which to construct an indicator of relative socio-economic status for each household within the community. Variables included in the analysis were 13 categories of household assets, use of communal water as opposed to private water source, and number of spouses. In other domains, common practice is to retain all principal components with an eigenvalue greater than one. However, only the first principal component is considered necessary in deriving a socio-economic status index that is indicative of wealth level effects within a

[10] These summed values are, of course, relative to all the other soil samples taken from the village and thus the values on their own have no meaning.

community (McKenzie, 2005). Thus, the factor loadings within the first principal component were used to weight each asset. (See Appendix D.)

2.3. Data Analysis and Results

2.3.1. Data Analysis

Based upon household survey data and project documentation, we first quantify the rate of adoption of the introduced technique— fertilizer microdosing— in one INuWaM project site in Northwest Benin. Descriptive statistics were used to examine the distribution of individual and household characteristics across microdose adopters and non-adopters. While there is a considerable amount of literature on the characteristics of adoption among smallholder farmers, we also consider the tension inherent within research *and* development projects on the diffusion of technological innovations and adoption.

As profitability is a necessary, though not sufficient, condition for adoption, we estimate the relative profitability of microdosing against the recommended dosage of fertilizer for maize, and regress it against various independent variables hypothesized to directly impact the relative profitability. In addition, we examine the social, institutional and environmental context, in so far as it affects fertilizer microdosing and farmer preferences. Comments from household surveys and key informant interviews were used to provide necessary context to situate the quantitative data derived from household surveys.

Due to the inherent complexity governing the interactions between agricultural systems, social and political processes, the environment, and smallholder farmer objectives, a multidisciplinary assessment of the technology at hand that covers several scales (individual, household, regional, national etc.) is crucial for an informative analysis.

Drawing from the extensive adoption literature, questions pertaining to the key socio-economic variables hypothesized to influence adoption were included in the household survey. The resulting data were then analyzed using test of equality of the means and a two-proportion test to determine if the difference observed between adopters and non-adopters is significantly different than zero. Given that a near-complete census of the village was undertaken, the population parameters are believed to be known and thus a z-test was used.

2.3.1.1. Hypothesized Variables

The hypothesized relationship between microdose adoption (project participation) and key household characteristics includes: gender; age; labour and household size; education level attained; household assets as a proxy for household status and wealth; total cultivatable land; credit; and access to inputs. (Further details are shown in Table 2-1.)

Table 2-1 Household Characteristics and hypothesized distribution amongst adopters versus non-adopters

Household characteristics and hypothesized distribution amongst adopters versus non-adopters			
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 cited difficulty finding labour	Household size positively associated with adoption; 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	Wealth consistently positively associated with adoption; 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)

2.3.1.2. Results

In total, 21 of the 22 microdose users were part of the INuWaM project. There has been little adoption outside of the development project that has introduced this technique to the community. Only men participated in the project at this site. While attempts were made to survey women within male-headed households, social norms made this nearly impossible. (One woman in a male-headed household asked why she should be discussing her husband's business while he was not present.) Due to this, only one female within a male-headed household was surveyed. Women head of households were surveyed and represented fewer than 10% of the total survey respondents (seven of the total 73 households).

Only socio-economic status, total cultivable land and household labour force were different at a statistically significant level. (See Table 2-2.) However, the significance of total cultivable land was not surprising, considering the construction of the socio-economic status index, which included total cultivable land and showed a significant weight for the indicator. Thus, it was expected that total cultivable land would be significant in addition to socio-economic status. In addition, while household labour force was not included in creating the SES index, household size (number of wives and children) is an indication of social status and wealth in the society (Central Bureau for Projects & Multinational Agribusiness Systems Ltd., 1983).

Household size, while directly related to the pool of available family labour, is also a proxy for other household characteristics such as wealth (as noted above) thus making it hard to tease out the association between availability of family labour and adoption. Essentially, households that are better off in terms of social and economic capital are better represented within the adopter category.

Interestingly, adopters of microdosing were more likely to cite difficulty finding additional labour, though the difference between the two groups was not statistically significant. It is possible that the adopters of microdosing, as they have greater cultivable land in general, have increased their production levels to a point where household labour is no longer sufficient.

Table 2-2: Distribution of household characteristics, comparing microdose users and non-microdose users

Distribution of household characteristics, comparing microdose users and non-microdose users										
	Microdose Users n=22			Non-Microdose Users n=51			Village Total n=73			Difference between groups
	Mean	Proportion	St Dev.	Mean	Proportion	St Dev.	Mean	Proportion	St Dev.	Statistical Sig. (P Value)
Household Demographics										
Gender of Respondent										
Male		1.00			0.84			0.89		
Female		0.00			0.16			0.11		
Age	40.77		12.22	41.12		12.40	41.01		12.35	0.912
Labour (Active Members of Household)	4.73		2.14	3.78		1.81	4.06		3.84	**0.070**
Gender of Household Head										
Male		1.00			0.86			0.90		
Female		0.00			0.14			0.10		
Education of Respondent										
Some education=1 Illiterate=0		0.32	0.47		0.29	0.46		0.30		0.837
Socio-economic status (Index: Min=1.93 Max=18.28)	10.78		3.45	8.21		3.27				**0.003**
Total Cultivable land (ha)	2.84		1.04	2.24		1.11	2.41		1.11	**0.020**
Access to inputs										
Use of Organic fertilizer (2012) 1=Yes		0.91	0.29		0.75	0.44		0.79	0.40	0.112
Use of Inorganic fertilizer (2012) 1=Yes		1.00	0.00		0.59	0.49		0.71	0.45	N/A
Difficulty finding additional labour 1=Yes		0.41	0.49		0.27	0.45		0.32	0.46	0.256
Currently a member of credit org. 1=Yes		0.18	0.39		0.18	0.38		0.18	0.38	0.956
Access to credit 1=Yes		0.55	0.50		0.43	0.50		0.47	0.50	0.370

It is important to note that there exists a social support system whereby farmers will work on neighbouring farms in exchange for food (system of invitation/trade). In this manner, farmers will cycle around the neighbouring farms spreading the labour force throughout the community. However, there were farmers who stated that they lacked the financial means to provide the food required for the system of invitation/trade. This is indicative of how the poorest households in the community have the least capacity to finance the inputs associated with technology adoption, even within existing social support systems that are designed to alleviate constraints.

Education was not statistically significant between the two groups. This was unexpected as the literature notes the consistent influence of education on adoption (Beke, 2011; Foster & Rosenzweig, 2010; Larson & Gurara, 2013; Moser & Barrett, 2006). However, education status was low at a village level. More than two thirds of the surveyed farmers were illiterate. This has important implications for the diffusion and uptake of technology for the village: low levels of literacy in SSA have been shown to inhibit the process of dissemination of soil fertility information, influencing farmers' access to the information (Adolwa et al. 2012 citing Ofuoku et al., 2008; Sanginga & Woomer, 2009).

Credit constraints may hinder the process of technology adoption, as is noted in the literature (Abdulai & Huffman, 2005; Akinola, 2010; Beke, 2011). However, there was no statistically significant difference between the two groups in terms of membership in a credit-granting organization. Membership in a credit-granting organization was also low at the village level— only 18% of all surveyed farmers were members— and this relative homogeneity may help explain the lack of difference between the groups. However, the impact of credit constraints on microdosing adoption in particular may differ depending upon the baseline. For those not using any fertilizer due to binding credit constraints, credit constraints may hinder the adoption of microdosing, as they cannot access even the small quantities required for the technique. However, for those already using the recommended dosage on a small plot of land, credit constraints and lack of access to greater quantities of fertilizer may in fact *encourage* the use of microdosing, as they can fertilizer greater area with a smaller amount of fertilizer (with the additional benefit that this spreads risk). This is cited in the literature (Camara et al., 2013; Kaizzi et al., 2012) and backed up by farmer comments. In fact, the most frequently cited positive characteristic of microdosing among microdose users was that it allowed one to increase the cultivable area fertilized. (Cited by 10 out of 24 farmers who had experience with microdosing.)

A conceptual challenge remains— how does the research and development project change the nature of adoption? How does a researcher distinguish between adoption of a technique and participation in a research and development project, where opportunity for participation is determined within the existing social hierarchy? It is noted in the literature that the 'adoption' of a technique can simply be the effect of project support, where the technique is discontinued after the sustaining influence of the project has ended (Giller et al., 2009). In addition, Twomlow et al. (2010), when examining the evidence for microdosing across broad scale trials in Zimbabwe, caution that the real challenge is moving farmers from free fertilizer handouts to buying fertilizer at a retail store each year. Although farmers in the research site were accustomed to buying fertilizer rather than receiving it for free, the vast majority of the microdose adopters were project participants receiving free fertilizer for the microdose demonstration plots. This lessens the risk involved with experimentation with fertilizer microdosing. On the other hand, project-based assistance may increase not only initial adoption of a technique, but also improve the longevity of use as it did for soil and water conservation techniques in Ethiopia (Teshome et al., 2012).

Kiptot et al. (2007) address some of these definitional and conceptual challenges in their discussion of adoption of improved tree fallows in Kenya. "Adoption" stemming from research or development projects comes in various forms, one being 'pseudo-adoption': the adoption of an introduced technique not for its own value, but for the sake of prestige associated with being part of a project, free inputs, participation in seminars, or other benefits associated with project participation. Another potential 'adoption' category is 'experimenters' (those in the process of testing a technology), a category that researchers have only began to use. Adoption should not be used as a uniform category; rather, the various forms of adoption should be defined and used to differentiate between farmers' experiences with a new technique. To a great degree, this requires the study of changes in behaviour over time. As well, as the authors note, a richer understanding of adoption requires an examination of the broader socio-political dimensions that influence adoption.

2.3.2. Relative Profitability of Microdosing as Compared to Recommended Dosage

A partial budget was created for each of the 17 demonstration plots for which yield and survey data were available for 2012. Net benefits were determined using secondary and primary project data. Revenue was calculated as grain yield/ha multiplied by average market price in Malanville market in the north of Benin in September 2012 (Rondon, 2013). The main cost that varied between microdosing and recommended dosage was due to the different quantity of fertilizer required for each technique. Data were taken from household surveys on fertilizer cost and were averaged across all survey responses to determine the price of fertilizer in 2012 (NPK and urea were the same price). (See Table 2-3.)

Of the 17 demonstration plots, 13 (76%) experienced microdosing as less profitable than recommended dosage. While previous studies have shown microdosing as more profitable (on average) than recommended dosage, the context is important. In Mali, Niger, Burkina Faso and other countries with experience in microdosing, the starting point for fertilizer application is often broadcasting. This is an inefficient method of fertilizer application, whereas the targeted application of fertilizer involved with fertilizer microdosing is a more efficient use of the input (Tabo et al., 2007). In Benin, government extension agents have successfully promoted the strategic application of fertilizer at the base of every plant for the recommended dosage rates and few farmers broadcast fertilizer in the area. Thus, it is not surprising that microdosing is not on average more profitable than recommended dosage in the Benin context. To understand what might drive the differences between profitability at a micro-level (farmer and plot characteristics), we modeled the relationship between the difference in net benefits and environmental and household factors.

Table 2-3 Figures used for partial budget analysis

Figures used for partial budget analysis		
Maize demonstration plots	Microdose	Recommended Dosage
Revenue		
Yield (kg/ha)	Plot dependant	Plot dependant
Market Price 2012(CFA/kg)	230	230
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
CFA is the Beninese currency, where 1 CFA BCEAO = 0.0019 US Dollar as of Oct 31, 2014		

2.3.2.1. Empirical Model

A multivariate regression was estimated using difference in net benefits (referred to from here on as 'profit' for simplicity) between microdosing and the conventional alternative (recommended dosage) as the dependent variable (in CFA, the Beninese currency). The dependent variable, *RelprofMD_RD*, is calculated as the difference between the profit per hectare derived from the microdosing trial plot and the profit per hectare derived from the recommended dosage trial plot, where profit is revenue minus cost (as laid out in the partial budget analysis).

This dependent variable was selected because when growing maize, farmers must chose between different levels of fertilizer application; growing maize without fertilizer is not an option due to the high nutrient requirements of the maize crop and poor soil quality in the area.[11] Microdosing represents a potential alternative to recommended dosage and farmers will naturally compare the relative profitability of microdosing to recommended dosage, within the constraints of the institutional environment and economic situation.

While the term 'profit' is used, a more accurate term may be 'net benefits' as not all costs are captured in the analysis. In particular, the cost of labour is difficult to approximate in developing countries with notoriously incomplete labour markets and where smallholder farmers rely upon family labour. The USDA foreign agricultural service in their Coarse Grains Report for Benin explicitly state that they don't include the cost of labour when calculating the production costs of maize because it is typically family labour used on small farms (Rondon, 2013).[12] Such difficulties in accurately capturing the opportunity cost of labour have been noted in the literature (Foster & Rosenzweig, 2010). However, as the dependent variable is the *difference* between the net benefits, and as there is minimal difference between the two techniques in regards to labour requirements, labour costs are effectively cancelled out with this calculation. Thus the dependent variable does approximate the difference in profit. The difference in profit was hypothesized to be a function of various biophysical independent variables: soil quality (using the soil quality index), soil type, and plot level rainwater-harvesting techniques. (See Table 2-4 for summary of variables.)

As noted earlier, soil samples were taken throughout the growing season and a few of the plots had been tilled under or had 2013 season maize growing in the field prior to sampling. Dummy variables were introduced to account for this variation in soil sampling across the growing season. While many factors, such as available labour, farm size etc. influence the profitability of an agricultural technique in general, as the data came from standardized

[11] As noted before, during the first year of the project, the project design included a control plot where maize was grown without fertilizer. Due to total crop failure, this element of the design was abandoned in the subsequent years of the project. In addition, farmers consistently noted that maize required fertilizer, and required it at a higher level than the other cereal crops.

[12] They also note that independent small-scale farmers produce 90% of the total corn output in Benin.

demonstration plots, these factors were not hypothesized to directly influence the resulting net benefits and were therefore not appropriate to use as independent variables.

Soil type did not vary enough across the observations (only one farmer's plot was of a different soil type) and the coefficient was highly insignificant in the initial regression and therefore removed.

Thus, the final model is represented by the equation:

$$RelprofMD\_RD = \beta_0 + \beta_1(CP) + \beta_2(LCN) + \beta_3(LP) + \beta_4(Cultivated) + \beta_5(Maisgrow) + \beta_6(SQI\_SSF\_PCA) \quad (2.2.)$$

Table 2-4: Independent variables hypothesized to affect relative profitability of fertilizer microdosing

Independent variables hypothesized to affect relative profitability of fertilizer microdosing	
Variable	Variable Description
CP (*Cordons pierreux)*	Rainwater harvesting technique-"Ridging" soil with rocks 1 if farmer was using CP technique, 0 otherwise
LCN (*Labor en courbes de niveau)*	Rainwater harvesting technique using contouring 1 if farmer was using LCN technique, 0 otherwise
LP *(Labor à plat)*	Rainwater harvesting technique- Flat field 1 if farmer was using LP technique, 0 otherwise
Cultivated	Field tilled up before sample taken Dummy variable: 1 if field had been cultivated prior to sampling, 0 otherwise
Maisgrow	Maize growing in field when sample taken Dummy variable: 1 if maize was growing in the field during sampling, 0 otherwise
SQI_SSF_PCA (Soil quality index, standard scoring function, principal component analysis)	Soil quality index value (using principal component analysis and standard scoring function)

2.3.2.2. Results of Empirical Analysis

When explaining the difference in profit between the microdose trial and recommended dosage trial, the constructed soil quality index was significant ($P<0.05$) and negative. (See Table 2-5.) As soil quality increases, the difference between the net benefits on a plot of land decreases. However, the underlying relationship between soil quality and the net benefits of microdosing versus recommended dosage *across* farmers is not clear. There appears to be no obvious relationship between the net benefits of microdosing across better or worse soils and the same holds true for recommended dosage. (See Appendix E) This is in apparent contradiction to farmer comments: A consistent theme was the need for a minimum soil quality for microdosing to 'work'. Suspecting a possible threshold effect, the square of soil quality was also used in the regression analysis but turned out to be highly insignificant. This warrants further research with a larger sample size, ideally across time, and more precise soil sampling techniques.

Despite microdosing being on average less profitable than recommended dosage, 21 of the 22 microdosers said they would continue using microdosing. However, when asked if they would expand (or restart, for the one who planned to abandon the technique) the use of microdosing if the price of fertilizer fell, 14 of the 22 (64%) said they would instead use the recommended dosage (or a more general response of "would use lots of fertilizer".) Seven of the 22 (32%) said they would continue using microdosing, often with the response that they could use fertilizer over more of their fields. Only one farmer said it would depend upon the soil whether he would expand the use of microdosing.

Table 2-5: Estimation output for factors influencing relative profitability of microdosing

Dependent Variable: RELPROFMD_RD
Method: Least Squares
Sample: 1 17
Included observations: 17

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	67690.46	81902.45	0.826477	0.4278
CP	4698.551	86016.21	0.054624	0.9575
LCN	139905.2	63159.01	2.215126	0.0511
LP	65569.04	92935.80	0.705531	0.4966
CULTIVATED	-528526.2	119703.0	-4.415314	0.0013
MAISGROW	156237.1	85912.22	1.818566	0.0990
SQI_SSF_PCA	-280564.9	117242.2	-2.393037	0.0378

R-squared	0.828088	Mean dependent var	-109631.2
Adjusted R-squared	0.724941	S.D. dependent var	156499.5
S.E. of regression	82077.86	Akaike info criterion	25.76163
Sum squared resid	6.74E+10	Schwarz criterion	26.10471
Log likelihood	-211.9738	Hannan-Quinn criter.	25.79573
F-statistic	8.028211	Durbin-Watson stat	2.498826
Prob(F-statistic)	0.002316		

The constraints on fertilizer use due to institutional factors (inadequate rural financial services, poor infrastructure, input market failures) and farmers' willingness to continue with microdosing provide reason 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 microdose instead of use the recommended dosage despite loss in potential profit, one can calculate a minimum shadow value for fertilizer by finding 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 per ha 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:

$$p \cdot y_{md} - w_f \cdot f_{md} \geq p \cdot y_{rd} - w_f \cdot f_{rd} \tag{2.3}$$

Solving for the price of fertilizer (w_f), there is an average shadow value of 3,820 CFA/kg across the 16 farmers from whom yield data was available and who stated a desire to continue microdosing. This is the lower bound of a shadow value for fertilizer. (See Appendix F for the range of shadow values across farmers.) The market price for fertilizer was 240 CFA/kg for both NPK and Urea, which makes the shadow price of fertilizer almost 16 times that of the actual price of fertilizer. This difference speaks to the number of constraints on fertilizer use for farmers in this region. The correlate is that if fertilizer were cheaper and more available, microdosing would be less attractive to farmers. We now turn to the social and institutional environment that creates these constraints.

2.3.3. Social and Institutional Environment

It is helpful to view the factors relating to the adoption of fertilizer microdosing in the common food security paradigm: availability, access, and utilization but with regards to inorganic fertilizer rather than food. As with most explanatory constructs, these categories are flexible and some factors could arguably fit into more than one category.

2.3.3.1. Fertilizer Availability

An interview with a technician at the Boukoumbé branch of the CARDER[13] revealed that truck drivers transporting fertilizer from the south of Benin were reluctant to brave the road to Boukoumbé due to its poor condition. As a result, the technician concluded that the fertilizer did

[13] CARDER (*Centre d'Appui Régional au Développement Rural*) is a regional rural development agency that provides extension services.

not meet the needs of the population in Boukoumbé due to the inaccessibility of the area and difficult route.

Fifty-six of the 73 households surveyed knew of a place other than CARDER where to buy fertilizer. The vast majority of the time (41 of the 56 respondents) they cited a market in Togo, just across the border from Benin. When asked about their primary place to buy fertilizer, 34 of the 56 said that they bought primarily at CARDER. An additional 14 of the 56 households said that they bought first at CARDER and then Togo and only two said that Togo was their primary place. Purchasing fertilizer at the local CARDER is clearly the first choice, despite availability problems. In fact, when asked about trouble travelling to their primary place of fertilizer purchase, farmers wanted instead to discuss availability as a concern. They complained that fertilizer was rare at CARDER, and that sometimes they would have to return multiple times to look for fertilizer. Fertilizer application is time-sensitive and farmers voiced their frustration that fertilizer was not always available when they needed it. During the field season, researchers on the INuWaM project experienced this first hand, as fertilizer delivery was delayed and there was concern that the fertilizer would not be available in time for the demonstration farmers' microdose plots. Microdosing in particular requires not only the availability of fertilizer, but also the timely availability of fertilizer. Research done in Niger investigated the effect of delayed application timings for fertilizer microdosing on millet and found that regardless of timing, microdosing was relatively more profitable compared to the control, where no fertilizer was used (Hayashi, Abdoulaye, Gerard, & Bationo, 2008). However, the results are not generally applicable for this research as maize is not grown without fertilizer and timing is one of the two key differences that distinguish microdosing from recommended dosage in Benin.

2.3.3.2. Access

Physical Access

Farmers most frequently cited impassable roads when asked about difficulty accessing their primary input shop. Poor transportation infrastructure has been implicated in hampering the adoption of new technologies and constraining fertilizer use through increased costs and decreased market access (Beke, 2011; Morris et al., 2007).

Buying fertilizer from Togo was problematic in a different regard. Despite a porous border between the two countries and shared membership in the regional economic union (ECOWAS), farmers complained of difficulty purchasing and transporting fertilizer from the market in Togo back to Benin. According to farmers, the Togo government has regulations to prevent Beninese farmers from purchasing fertilizer in Togo. One farmer said that it is “very difficult to buy in Togo; venders ask where you are from and *gendarmeries* (police) can confiscate your fertilizer.” Another farmer complained of harassment from the border police and his 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. While one farmer did explain that it was possible for Beninese to buy fertilizer in Togo, the process involved procuring papers certifying the individual intending to purchase fertilizer had a relative residing in Togo. Ideally then, farmers would be able to find fertilizer available on a consistent basis through the CARDER.

However, farmers routinely said that the CARDER would sell fertilizer first to farmers incorporated into groups and only afterwards to individuals. While group membership has advantages in terms of accountability and mutual assistance, it also has a time cost for farmers. In addition, groups can suffer from poor management and financial difficulties. Of all respondents, only 18% were currently part of a group for access to inputs (13 of 73 households). However, 44% of the respondents who were not currently part of a group had *previously* been part of a group. There was a variety of reasons for why they were no longer a member, including poor management, theft and group disbandment (after a development project finished or a notable extension agent left, for example). Farmers also chose to leave a group because it was not functioning according to their needs or required too much of their time.

Economic Access

According to the technician at the Boukoumbé branch of the CARDER, the government demonstrates fiscal support for fertilizer use through subsidies: while the unsubsidized market price of fertilizer would be between 17,500 and 18,000 CFA per 50 kg sac the government subsidizes it so that it is only 10,500 and 11,000 CFA.[14] However, fertilizer subsidies alone do not ensure access for farmers. (See Larson and Gurara (2013) for an analysis on the inadequacy of fertilizer subsidies to ensure access to fertilizer for poor farmers.) Despite the substantial

[14] Responses from the household survey indicate that farmers are paying more than the subsidized rate of 11,000 CFA/50kg sack quoted by the CARDER agent: on average, farmers claim they paid 12,100 CFA/50 kg sack in 2012.

subsidization, there were several farmers who could not afford to buy fertilizer. Twenty of the 21 respondents who did not use inorganic fertilizer in 2012 said it was on account of not having enough money. And of the 52 farmers using inorganic fertilizer, 50 did not use it on all their cultivated land. Of those 50 respondents, 26 (or 52%) said it was because they did not have enough money to do so.

Liquidity and Credit

Credit constraints reduce effective demand for fertilizer, as farmers who desire to purchase fertilizer on credit (and not all do, given the risky nature of the investment and lack of insurance schemes) cannot access credit and buy fertilizer during the narrow window of time for fertilizer application. Farmers said it was hard to find the money to buy fertilizer or finance agricultural activities when they are required— at the beginning of the farming season. In fact, the vast majority of households (89%) had difficulty with short-term agricultural funding in 2012. However, only 40% of those were able to access credit of some form (either formal or informal). The other 60% either tried and could not access (26%), or did not try (34%).

For those farmers that could not access credit, the reasons varied. Some stated that the conditions for borrowing money from a formal organization are difficult,[15] or that one must be in incorporated into a group to borrow. In terms of informal lending, several farmers claimed they could not borrow from their neighbours or even that their neighbours would 'run away' when they saw them, as a way of indicating their refusal to lend money. Another respondent said that "we're all in the same boat; you cannot lend money if you don't have it." However, it is particularly telling that so many households would not even attempt to access credit despite the need for short term agricultural funding. The common refrain was a fear of acquiring debt to invest in an uncertain activity (agriculture) due to the consequences of defaulting on that debt. Of all those who would not try to access credit, 68% said they were afraid to borrow because they didn't know if they'd be able to reimburse. Farmers mentioned a fear of the police and jail, or of having their possessions confiscated as a penalty of default. One respondent said he had borrowed from a microcredit institution in the past and could not repay. As a result the institution

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[15] The main formal organization farmers referred to was CLCAM (*Caisse Local de Credit Agricole Mutuel*), the local branch of the national microfinance institution FECECAM-BENIN (*La Faîtière des Caisses d'Epargne et de Crédit Agricole Mutuel du Bénin*)— a cooperative savings and credit organization.

took some of his possessions. On a more positive note, a few of the farmers mentioned alternatives to borrowing as a way of addressing short-term funding needs. One respondent said that he exchanged a goat and received labour for his field instead of having to borrow money to finance the help. Another farmer said his wife helped him buy fertilizer so he didn't have to borrow.

Opportunities to buy fertilizer on credit appear to be limited to farmers in groups or those growing cotton (or at least those purporting to grow cotton.) One farmer recounted his experience buying fertilizer from someone who had gone to the CARDER and received a large quantity fertilizer on credit, claiming he was growing cotton. This enterprising farmer then turned around and resold the fertilizer he had received on credit. A study done for the World Bank on the cotton sector in Benin noted that farmers "tend to overestimate their need for cotton fertilizers, in order to benefit from credit on fertilizers for their other crops, in particular, for maize" (Gergely, 2009). Another study found that the fertilizer distribution system in Benin suffered from high transaction costs and poor market service delivery, due to institutional failures and perverse incentives within the cotton sector (Honfoga, 2013).

2.3.3.3. Utilization

Risk

As mentioned above, even if credit and liquidity constraints are not present, farmers still face considerable risk involved with investing fertilizer (a sunk cost) into what is the inherently risky venture of agricultural production under uncertain weather conditions (Dercon & Christiaensen, 2011). The fact that all of the farms surveyed were exclusively rain fed makes the venture even riskier, as the moisture level in the soil, which affects the timing and effectiveness of inorganic fertilizer as well as the crop yield, is ultimately weather dependent (Winterbottom et al., 2013). (The farmers practice rainwater harvesting to trap water and minimize erosion and while this influences how the soil retains moisture, it does not change the initial provision of water).

While the household survey did not explicitly include measures of risk aversion, it would be remiss to exclude it from the discussion on the social and institutional environment. Due to the lack of insurance schemes or a government safety net for the farmers, crop failure can be financially or socially devastating for the farmer and his/her family. One farmer said that he wasn't sure if his field would yield well and if it didn't, he would not be able to pay back and the lender could "bring the brigade."

One notable instance (mentioned by four different farmers) of a failed investment was a project organized by the CARDER. Fertilizer was provided on credit for rice production and farmers were expected to repay after harvest. An extension agent provided information on fertilizer application but the poorly formulated fertilizer ended up 'burning' the rice, destroying the farmers' harvest. Another farmer mentioned this instance when asked about borrowing money: the farmer had refused to pay back the money borrowed for the poor fertilizer and CLCAM (the local agricultural credit bank) subsequently refused to lend him money the following year. This is exemplary in that even projects organized by government extension agents may fail and leave the farmers arguably worse off than before, as farmers have little recourse when faced with crop failure and unpaid debts.

Soil health

Microdose users often mentioned the synergistic relationship between organic matter and microdosing. In fact, when asked about the two most important negative characteristics of microdosing, farmers cited 'dependency on soil condition' most commonly, claiming that microdosing needed the soil to be a little rich in order to work. Organic matter is critical for maintaining soil health and for ensuring that inorganic fertilizer can deliver nutrients to the plants. However, an important contributor of manure (i.e. livestock) is associated with wealthier farmers (Adolwa et al., 2012); poorer households are less likely to have the means to amend their soil and improve soil quality through the addition of manure. When asked about the use of organic fertilizer several farmers commented on their lack of livestock. Only 12 out of the 73 households surveyed (16%) owned draft animals (large livestock). Small livestock such as guinea fowl or chicken provide only small quantities of organic fertilizer.

Labour

Microdosing is a labour intensive endeavour. However, the standard alternative- recommended dosage- is almost equally intensive by most accounts. Additionally, labour does not appear to be the constraining factor in the adoption of fertilizer microdosing. There is a system of trade and invitation amongst neighbours that relieves labour shortages at peak times and is demonstrative of how community adaptive strategies can work to alleviate important constraints in innovative ways. Fifty of the 73 households claimed they did not have trouble finding enough labour when needed. Of those 50 respondents, 20 (or 40%) specifically cited the system of invitation/trade as a way of finding the additional labour needed. This system entails farmers coming together as a group and working on each other's farms, being repaid in food during the workday. However, there is one important caveat. The poorer households who cannot even afford to provide food for the workers are not able to benefit from this adaptive community strategy.

Family Health

Unexpectedly, farmers frequently cited family health problems when asked about trouble buying fertilizer or about problems with short term agricultural funding. Of the 73 households, 30 provided an explanation of their short-term agricultural funding needs. Eight of these 30 cases (or 27%) were related to family health. Resource-constrained farmers must focus their limited resources on the most pressing needs, and when basic health care requires immediate monetary outlay, farmers may choose not to purchase fertilizer, opting instead to deal with acute medical problems. This revelation was especially key in understanding the complexity of farmer decision-making and the importance of examining smallholder technology adoption within a systems framework. When institutional support in terms of basic health care provision and insurance schemes are lacking, farmers are faced with an increased number of urgent and variable demands on their meagre cash reserves, or in some cases, their limited ability to borrow money. One farmer in particular had to borrow money to pay for his daughter's health care (the costs apparently surpassed 60,000 CFA) and therefore could not afford fertilizer. He managed to borrow a portion of the money, through his wife, from a *tontine* (savings group). The *tontine* is organized by Plan Benin and has a system for lending out money, interest free, on urgent cases such as his.

2.4. Conclusion

In the stratified society of rural Benin, with benefits accruing unequally among segments of the population, in an area with a long history of development projects, the process of technology adoption is mediated through the implementation strategy of development projects and the existing social hierarchies. The results show that farmers with higher socio-economic status, as determined by household assets, labour force, access to water and number of spouses, were more likely to be involved with the INuWaM project and by extension more likely to be using fertilizer microdosing. This suggests that those with more economic and social resources can take advantage of opportunities to experiment with productivity increasing technologies. While economists may accept that market forces and economic realities determine the process of technology adoption, projects with ostensible development goals often dictate the implementation so that they promote equity.

The INuWaM proposal submitted to the IDRC had an overall objective of improving food security through increased crop production and household income, whilst promoting gender equality and environmental sustainability. These are clearly motivated by larger development concerns. In addition, the IDRC publishes 'outcome stories' on the research, highlighting how the research has achieved objectives related to such concerns as improved food security and equitable growth and impact on target populations, such as women farmers. For example, the outcome story published for the larger research project on microdosing in the Sahel region was part of an IDRC series of outcome stories titled "Engage, enhance and empower: Research that makes a difference for African women." In the introductory article to the series (Sanginga et al., 2014) the authors state:

> The research is designed to have a direct impact on smallholders - with an emphasis on women farmers - and consumers, and is expected to contribute to the food security needs of vulnerable populations in an environmentally sustainable way. (p. 4)

This then, is about more than conducting research, reporting 'objective' research results and allowing economic principles to guide implementation, but also about how researchers fit their work into the larger social goals promoted by the IDRC. In particular, they aim to impact vulnerable populations, women farmers in particular.

However, the poorest households are least able to adopt a technology like microdosing for a multitude of reasons. They are less able to absorb the potential downside risk of investments in fertilizer if crops fail, which also means they are less likely to be able to benefit from the upside of productivity-enhancing, fertilizer-dependent agricultural technologies. They are less likely to be able to afford to finance agricultural help, making labour intensive activities like the targeted application of fertilizer less feasible. Furthermore, they are excluded from an already poorly functioning credit market, precluding them from investing in new technologies that may increase their income.

In part, because of this reinforcing nature of poverty, the development agenda looks to reduce extreme poverty and inequality by assisting the poorest and most marginalized. With this in mind, it is important to think critically about the implementation of development projects and the resulting distribution of the benefits accruing from interventions prior to project implementation. Targeted interventions are necessary to avoid inadvertently perpetuating existing social inequality. Farmers with greater economic and social capital are better positioned to take advantage of new techniques that promise to improve agricultural productivity. But if the purported goal of development interventions is to improve the lives of members across the social classes (and within vulnerable populations), and to address underlying economic disparities, then development practitioners should take care when implementing projects within existing social hierarchies. Relying upon the community to produce volunteers for a project may mean that the poorest and most marginalized, including women, are underrepresented. Care must be taken to construct projects so that those lower on the socio-economic scale are given equal chance to participate. A caveat: projects promoting technologies that may expose participants to more risk, but hold the promise of an escape from the cycle of low return, low productivity activities, should be evaluated with opportunities for risk mitigation strategies bearing in mind institutional and social constraints.

Because the data were collected in the early phase of introducing microdosing to the community, and because adoption is a dynamic, time-dependent process, more research will need to be done after the technology has diffused throughout the community and farmers have had the chance to experiment over several seasons. Farmer experimentation is critical; a technology is only as good as its performance in a given context. While research trials may provide standardized results on the *potential* of a given technology, the acid test is how well the technology performs under the challenging and variable conditions in a farmer's field (Sileshi et al., 2010).

In terms of the economic value of microdosing, results suggest that the technique can be a short-term measure for smallholder farmers operating in a challenging environment. Given inadequate, unpredictable fertilizer supply and low household income, microdosing can address some of the constraints surrounding fertilizer use in northwest Benin. If the context changes (that is, if fertilizer becomes more consistently available and more affordable for a greater proportion of the population), the value of microdosing on maize will decrease relative to that of recommended dosage, given the poor soil quality and heavy nutrient requirements of maize. Thus, given the current context of incomplete input markets and rural poverty, microdosing is a cost-saving technology that has the potential to improve the lives of subsistence farmers in food insecure areas. Ultimately, however, farmers want a fertilizer distribution system that can provide sufficient quantities of fertilizer to meet market demand in an efficient, timely and cost effective manner. In addition, farmers need a rural financial system that provides them the means of accessing credit to address seasonal liquidity problems so that they can purchase fertilizer.

Inorganic fertilizer alone will not sustain agricultural production. The farmers surveyed consistently voiced the need for organic matter as supplemental to the microdosing technique and this is also repeatedly stated in the literature. Increasing organic matter is critical for maintaining the fertility of the soil over time and for complementing inorganic fertilizer. Innovative approaches are needed to ensure that even the poor, without oxen or other livestock, can find ways 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.

These policy implications are not new. There are many voices calling for increased access to credit for the rural poor, the provision of insurance schemes and increased the availability of key inputs along with the promotion of integrated soil fertility techniques. But the urgency of the issue only increases as farmers in Benin specifically, and SSA more generally, struggle to eke out a living on increasingly degraded soil in a region that faces increased population pressure and the uncertain vagaries of weather and climate change.

Chapter 3. Conclusion

3.1. Review of Research Objectives and Results

Fertilizer microdosing has been promoted as an accessible technology for increasing the agricultural productivity of resource-constrained smallholder farmers. While numerous studies have indicated its potential for increasing yields and household income in several West African countries (Camara et al., 2013; Hayashi et al., 2008; Tabo et al., 2007), microdosing was only recently introduced into Benin through the INuWaM research and development project beginning in 2011. Consequently, the literature on the adoption of microdosing in the Beninese context is scant. In particular, its relative value against an existing precision application technique of the recommended dosage of fertilizer had not yet been evaluated. In addition, this research focused on the various contextual factors that influenced this relative profitability, in particular, the market failures that constrained the availability of and farmers' access to fertilizer. The context was also unique in that previous fertilizer microdosing studies with farmer demonstration plots have tended to concentrate on millet and sorghum (Camara et al., 2013; Hayashi et al., 2008; Tabo et al., 2007). Studies involving microdosing and the maize crop in West Africa have predominantly involved researcher-led field experiments (Buerkert & Hiernaux, 1998; Buerkert et al., 2001). One large-scale trial involving farmer plots was carried out on maize and microdosing, but was undertaken in Zimbabwe (Twomlow et al., 2010). As such, this research represents a novel study on the economic value for farmers of fertilizer microdosing on maize in Benin in the context of serious input market failures.

Through this research, the extent of adoption of fertilizer microdosing was determined in one community in northwest Benin. Factors associated with 'adoption' (or pseudo-adoption) were analyzed using two different methods. Firstly, household characteristics were recorded to determine if there was a pattern in the distribution of characteristics across 'adopters' and non-adopters of fertilizer microdosing. Secondly, the profitability of fertilizer microdosing was compared to the conventional alternative (point source application of recommended dosage) to determine the relative economic value of the new technology for farmers. As institutional constraints affect input availability, accessibility, and utilization— and consequently, the economic decision making of farmers— qualitative data was used to capture elements of the social and institutional environment that influence the relative value of fertilizer microdosing.

Farmer stories from the survey data were used to draw out key themes related to the institutional constraints.

Of the total, 22 farmers from the village reported using microdosing in 2012. All but one of the microdose users was part of the research and development project that introduced the technique to the village. Following Kiptot et al. (2007), this type of 'adoption' may be classified as 'pseudo-adoption', or adoption for the sake of benefits stemming from project participation. Using household demographic data from the village level census, the results suggest that households with higher socio-economic status and total land holdings and household size were better represented amongst project participants, who comprised the majority (95%) of the 'adopters'. This may indicate that households with greater social and economic capital have greater access to development projects, as the project relied upon a list of community volunteers mediated through the village chief and secretary.

An alternative explanation is that farmers with greater social and economic capital are more willing to take on the risks involved with new agricultural techniques. This would be in line with the literature that indicates they have a better cushion to withstand the downside risks of failed experimentation (Dercon & Christiaensen, 2011). However, considering that through the INuWaM project, fertilizer was provided free for the farmers' demonstration plots, and that fertilizer was a scarce resource, limiting farmers' ability to use a demonstrably profit-increasing input (Duflo et al., 2008), inclusion in this project appears to be less of a risky venture and more of a low-risk way to experiment with a valuable resource. Thus, it is reasonable to conclude that the microdose users (predominantly involved in the project) were privileged by relatively higher socio-economic status to experiment with the microdosing technique through the auspices of the INuWaM project.

The results show that based upon the demonstration plots of farmers participating in the project, fertilizer microdosing is on average less profitable than recommended dosage. While the literature has consistently demonstrated the superiority of fertilizer microdosing for increasing yields and farmer incomes against *conventional* agricultural techniques such as broadcasting, this is not the case in Benin. Due to successful government extension work in Benin prior to the introduction of microdosing, farmers typically use point source application of inorganic fertilizer for the recommended dosage rates. Thus, farmers in Benin are not comparing microdosing to relatively inefficient forms of fertilizer application, but instead, against a considerably more efficient approach than what is common in other West African countries. Previous research in West Africa has compared the treatment effect of fertilizer microdosing to no fertilizer application, fertilizer broadcasting of recommended dosages and/or an undefined ‘farmer practice’ (Camara et al., 2013; Tabo et al., 2011).

Despite the inconsistent and lower than average performance of microdosing as compared to recommended dosage, microdose users overwhelmingly (21 of 22 microdose users) stated a preference to continue using the microdosing technique. Based upon contextual questions from the survey and the literature on fertilizer use in Africa, institutional constraints on fertilizer access and availability are such that there is a high shadow value (at least seven times that of the average market price) for fertilizer, making microdosing an attractive option for farmers, *given the current context*. If fertilizer were to become more available and/or more accessible to farmers, fertilizer microdosing would lose its value relative to recommended dosage. Thus, the existence of serious constraints on availability and access to inorganic fertilizer increases the value of the fertilizer microdosing technique for smallholder farmers attempting to maximize a scarce resource.

3.2. Limitations

The research was conducted through the assistance of a translator, who translated from the local language, Dittamari, to French, and then the responses were translated to English for the purpose of analysis and presentation. It is likely that some of the nuances from the original language were lost in translation. However, this is an expected limitation of any multilingual research work and every attempt was made to address potential confusion in translation through iterative questioning and contextualization.

The research conducted in Koumagou B on the adoption of microdosing was a cross-sectional study- a snapshot of the community at a point in time. As Moser and Barrett note, static, cross-sectional models of adoption can be useful if the adoption process is already well underway: i.e. the technology has had time to diffuse and the process of adoption is more or less ‘complete’ (Moser & Barrett, 2006). However, if the process is still underway, a static model may miss crucial parts of the process and such models may result in biased coefficients, as is commonly cited in the literature (Besley & Case, 1993). Hence, in certain contexts, panel data (or quasi-panel data, for example, using recall data as illustrated by Moser and Barrett (2006)) can be desirable to capture the dynamic, time-dependent process of adoption. Despite these limitations, cross-sectional snapshots of adoption may still be useful in determining which groups are confronting barriers to adoption and thus can guide policy makers (Moser & Barrett, 2006).

The research in Koumagou B, Benin can be seen as the first step in a commitment to understanding the process of technology diffusion and adoption in the region. As the research was conducted only two years after microdosing was introduced into the village, the process of technology diffusion was in the early stages. Future studies are warranted to measure adoption, non-adoption and dis-adoption as the technology diffuses throughout the community. However, the current research is useful in providing insights into the development process and the effect of community stratification on initial adoption, or 'pseudo-adoption'.

The study design- a community census in one project village and the use of project data- meant that the number of observations for the profitability analysis was limited to the number of adopters of microdosing within the community for which we had yield data. There were 17 demonstration farmers in the village for which we had yield data- a number that precludes wide-ranging inference into the profitability of microdosing versus recommended dosage. However, the use of mixed methods and considerable time invested in one community allowed for a more nuanced understanding of the contextual issues affecting the adoption of fertilizer microdosing. Future studies would benefit from larger study sizes of plot-level data comparing fertilizer microdosing to the recommended dosage.

3.3. Areas for Future Research

One of the limitations of this research— the small number of observations upon which to study profitability— could be remedied by including the other five INuWaM Benin project villages in future research studies. The INuWaM project villages were spread out over two communes and will have different environmental contexts (soil type, physical geography, rainfall etc.). In addition, one of the study sites mandated that women be involved as *producteurs*, changing the social dimension of the project. The increase in potential variables and variation attained by using data from across all six INuWaM project villages would provide a rich data set for adoption research. In combination with a time element — fieldwork could be conducted across all villages at distinct intervals over a period of time — researchers would have a valuable panel data set for strong future empirical work.

One biophysical concern raised with fertilizer microdosing is soil mining of nutrients, creating problems for long term sustainability. Ongoing research is finding that soil fertility does not decline faster on microdosed soils than on recommended dosage soils (Adams & Peak, 2014). It is important to note, however, that this does not make microdosing 'sustainable' in the more general sense. Intensive agriculture puts pressure on the fragile soils of the region and contributes to declining soil fertility. Data from long term trials in Burkina Faso show declining soil fertility across both microdosing and recommended dosage demonstration plots. The use of organic matter however, acted as a buffer to the acidification of the soil with long-term inorganic chemical use (Adams & Peak, 2014). Extensive research and considerable investment is needed to address the serious consequences of intensive agriculture on inherently low fertility soil in the wider context of an increasing population in Benin. Addressing the need for the sustainable intensification of agriculture will require a greater understanding of the complex dynamics between agronomic practices and changing soil fertility over the long term.

In line with the literature (Camara et al., 2013; Mafongoya et al., 2006; Tabo et al., 2011; Vanlauwe et al., 2001) and farmers' feedback, fertilizer microdosing should be implemented in tandem with application of organic matter to sustain soil fertility and improve crop production over a wide variety of soils. However, the low levels of cattle ownership in the community limit the amount of sizeable quantities of organic manure available to households. Additionally, cattle are markers of wealth, indicating a positive relationship between access to organic fertilizer and wealth. The complementary nature between microdosing and organic fertilizer may mean fertilizer microdosing is less sustainable for poorer households with limited access to organic soil amendments. Promoting a technology like fertilizer microdosing does not happen in a social vacuum and the benefits of technology adoption may accrue disproportionately to one group due to the complementary nature to inputs, the accessibility of which is a direct function of household wealth. If the goal of projects such as the INuWaM project is to introduce a widely accessible and sustainable technology for smallholder farmers, including a sociological and anthropological perspective on technology adoption that is cognizant of how power dynamics and wealth effects mediate the adoption process would be important.

Connected to the need for more research on increasing organic matter in soils, is the need to examine the interrelated adoption of multiple, synergistic agricultural techniques, including fertilizer microdosing. Kassie et al. (2013) conducted notable research on this topic when they examined the simultaneous, interrelated adoption of seven different sustainable agricultural practices using a multi-variate probit model. While this study incorporated the effect of different rainwater harvesting techniques on the relative profitability of fertilizer microdosing, there are many opportunities for examining the simultaneous decision making on the use of rainwater harvesting techniques, organic matter, agroforestry, intercropping, and other sustainable land management techniques present in the area.

Recently, there has been a particular interest in the way information on new technologies spreads and the role of social learning in technology diffusion (Abdulai & Huffman, 2005; Maertens & Barrett, 2013). Future studies could examine the role that social networks play in who adopts fertilizer microdosing at what point in the process of diffusion. As there was little formal extension support for farmers in Koumagou B, mapping the complex linkages within informal social networks would be key to understanding how information spreads. In addition, understanding the dynamics of power and identifying the arbiters of information within the community would once again require an anthropological/sociological viewpoint. In combination with an economic evaluation of the technology regarding profitability and impact on household income, this research would provide valuable insights for policy makers on the complexity of technology adoption.

Understanding how and why farmers choose to adopt new technologies for the sustainable intensification of agriculture is particularly pressing in sahelian West Africa, which is grappling with the serious impacts of climate change and increasing population pressure. One of the farmers surveyed (aged 60) talked about the impact on soil fertility of a growing population. “When our parents were here, they didn’t work a large field, just a small field. The people weren’t very numerous. They had soil and trees. They didn’t have a problem with fertility of the soil. The soil wasn’t poor.”

3.4. Policy Implications

Understanding and appreciating the complexity of smallholder livelihood strategies is foundational in addressing food insecurity in the rural population of the region. Part of this complexity connects to how the environment is both shaped and shapes the farmer. Despite the complexity and interconnectedness of the challenges facing smallholder farmers in Northwest Benin, there are concrete steps that can be taken to address underlying problems of widespread environmental degradation and limited market access for key inputs. Four key policy areas present themselves from this research.

The first area relates to the availability of inorganic fertilizer. Here 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 with urban areas, is likely a long term goal for the government. However, in the near term, improving market access to key agricultural inputs such as inorganic fertilizer for the farmers of all food crops, not just cash crops such as cotton, would go a long way to improve food security amongst some of the most vulnerable segments of the population. Rather than retaining the current system that prioritizes and subsidizes fertilizer for cotton growers, a properly implemented and administered voucher system amongst the rural poor could provide the foundation for a more equitable outcome. At the same time this would serve to strengthen the private sector by providing a market incentive for fertilizer distribution in underserved areas.

The second policy area involves access to credit. Many project interventions and market access schemes hinge upon farmer communication and 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 into solidarity groups. However, years of mismanagement, outright fraud and defaults have made farmers suspicious or despairing of the effectiveness of such strategies. Ongoing management training to increase the effectiveness of such groups should be a complementary strategy to promoting farmer groups. But this does not address some of the underlying causes of default, namely crop failure and extreme poverty. Government insurance schemes that protect smallholder farmers from some of the downside risks of investing in agricultural inputs, (especially those that affect the basic food security of their households), will improve the willingness of individual farmers to join cooperative farmer groups and invest in techniques that improve productivity and ultimately food security.

The third policy concern relates to the soil quality of the study region. Low levels of organic matter in the soil is a limiting factor in improving soil fertility and therefore agricultural productivity. Agroforestry and mixed farming systems that include livestock provide valuable sources of organic matter. In addition, they offer a host of other benefits to smallholder farmers. For example, certain trees provide medicines for endemic diseases, firewood, and fruits, as well as organic matter in the form of leaves. But other trees are damaging to the soil and not well suited for the particular climate. Identifying the most appropriate tree species must involve farmer experimentation and feedback. Cows and small ruminants such as sheep and goats, offer a multitude of benefits, including food, dry season income, as well as organic matter in the form of manure. Pertinent projects would include the provision of trees, education in the care and maintenance of trees, and indigenous research projects on the most effective tree species. While the complexity of human and environmental systems create challenges when designing effective interventions, the upside of this complexity lies in the possibility of single interventions serving multiple purposes. For example, research in Mali[16] showed the benefits of agroforestry for the fattening of small ruminants. Thus, agroforestry together with livestock would provide multiple benefits: tree leaves create organic matter directly, as well as offer a source of fodder for livestock, and the livestock in turn provide organic matter to the soil in the form of manure.

Finally, researchers should ensure efforts to improve agricultural productivity are grounded in a holistic, integrated understanding of the contextual challenges facing smallholder rural farmers in adopting and adapting new agricultural technologies.

The problems facing smallholder farmers in Northwest Benin are complex, and inevitably so are the solutions. But this complexity indicates the potential for synergistic and mutually reinforcing solutions. Meaningful community engagement across all socio-economic levels to promote equitable change should be a marker of interventions designed to improve social welfare and food security.

[16] See the IDRC-supported project documentation at http://bit.ly/1ctHeIG and http://www.plg.ulaval.ca/giraf/projet_trop_securite_alim.html.

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APPENDIX A

Household Survey

INTEGRATED NUTRIENT AND WATER MANAGEMENT FOR SUSTAINABLE FOOD PRODUCTION IN THE SAHEL

PROJET IDRC /CIDA N° 106516-002

TECHNOLOGY ADOPTION AND KNOWLEDGE DIFFUSION STUDY

Household Survey

INFORMED CONSENT

Hello, my name is Erika Bachmann. I am a student from Canada working with Dr. Baco and his team from the Universite de Parakou. Dr. Baco and his team work very closely with the INuWaM project, which you may have heard about it. I am interested in understanding your experience with this project. I would like to ask you some questions related to how to improve food security in the Sahel through efficient use of soil nutrients and water to increase production of staple food crops and household income.

The information you provide will be useful in understanding the pathways out of poverty and food insecurity and what interventions are appropriate for sustainably intensifying (increasing productivity per unit area) farming systems in your village.

The interview may take about 1h 15 minutes and participation is voluntary, and you can choose not to take part. All the information you give will be confidential. The information will be used to prepare general reports, but the reports will not include any specific names. There will be no way to identify that you are the one who gave this information.

If you have any questions about the survey, you can ask me or my survey field supervisor who is here with the survey team. At this time do you have any question about the survey? Can we continue with the interview?

If yes, continue.

If No, stop and ask why?

General Information to be recorded by enumerator

Instructions	Response
Date of Survey	
Name of Enumerator	
Village	
GPS Coordinates	

Demographic

1. What is your name?
2. Name of Household Head
/____
______________/
    2.1. Sex of Household Head [1]: Male [2]: Female
    2.2. Age of Household Head /____________/ years old
    2.3. Education level of Household Head
        [1]: Illiterate [2]: Primary school [3]: Secondary school [4]: University
        [5]: Non formal study
    2.4. Did you engage in paid work outside of farming during the 2012 season (June to November)? [1]: Yes [0]: No
        2.4.1. If yes, what other paid work did you engage in?
/____
______________/
        2.4.2. About how many hours per week did you spend on this other work during the 2012 season? /___________/ hours per week
3. Total members of household (including yourself): /___________/
    3.1. Number of wives /__________ /
    3.2. Number of children /__________/
    3.3. Number of active members of household (active farmers) /___________/
        3.3.1. Of which are men: /___________/
        3.3.2. Of which are women: /___________/
4. Number of meals per day /_____________/

Household resources

5. What kind of house do you live in?
    [1]: House built with clay [2]: Clay brick house [3]: Cement brick house
    [4]: Other (to specify) /_____________/

6. *Among the following equipment, how many does your household have?*

Items	Number

Items	Number
Transportation	
Automobile	
Motorbike	
Bike	
Agriculture equipment	
Tractor	
Plow	
Harrow	
Draft animals	
Cultivator	
Wheelbarrow	
Daba, Houe, Coupe-coupe	
Communication	
Television	
Radio	
Phone	
Water and power resources	
Well, water pump (and sinking)	
Generator	
Others:	

Awareness of Project and Microdosing Technology

7. Do you know of the INuWaM Project, which promotes fertilizer microdosing and water conservation? [1]: Yes [0]: No
   7.1. If yes, from whom, or where, did you first learn of the project?
   /____
   ____

____
_______________/

7.2. How did you learn of it?

[1]: Demonstration

[2] Formal meeting

[3]: Discussion

[4]: Observation

[5]: Radio

[6]: Received training

[7]: Other /______________________________/

Crop Production, Land Tenure and Soil Fertility

8. What crops did you grow in the 2012 season?

Crop	Maize	Sorghum	Millet	Cowpea	Groundnut
Size of land					

Crop	Yam	Fonio	Rice	Voandzou	Other /________/
Size of land					

8.1. If the wife(s) cultivates and sells the voandzou, does she keep the money or give it to the head of household? [1]: The wife [2]: The head of household [3]: Other situation /____/

8.2. Did you practice intercropping? [1]: Yes [0]: No

8.2.1. If yes, which crops did you plant together?

/____
______________/

/____
______________/

/____
______________/

9. Of your total area of farmland, how much is devoted to each of the following uses (in the farming season 2012).

	Size of parcel of land (*corde*)	Ownership/Management System (See codes)
Abandoned plot		
Fallow plot		
Pasture land		
Traditional agroforestry (indigenous trees retained when clearing land)		
Introduced agroforestry (trees planted specifically for beneficial nature of trees on soil)		
Cultivated plot		

Land code

1=gift ; 2=let; 3=sharecropping 4= family land ; 5= others

10. Does any portion of your land suffer from low productivity? (I.e. is any portion of your land poor?) [1]: Yes [0]: No

    10.1. If yes, what proportion of your land is poor?

    /______________________________/

    10.2. If yes, how does the poor land affect your crop production?

    [1]= very negatively

    [2]= negatively

    [3]= slightly negatively

    [4]= no impact

Soil Fertility and Water Conservation Management Practices

11. What practices of soil fertility management and water conservation do you know? (Don't necessarily have to use)

	Practice	**Advantages**	**Disadvantages**
Local or traditional			

practices			
	Practice	**Advantages**	**Disadvantages**
Adopted practices (introduced practices that have been well integrated into traditional practices)			
	Practice	**Advantages**	**Disadvantages**
Introduced practices			

12. Of the above practices of soil fertility management, which do you use? Please indicate why you use the ones you do, and why you choose not to use the ones that you don't.

Practices used	**Reasons**
Practices not used	**Reasons**

13. Do you use organic fertilizer on your fields? [1]: Yes [0]: No

14. Do you use chemical fertilizer on your fields? (Any part of any field) [1]: Yes [0]: No

    14.1. If yes, which crops do you use chemical fertilizer on?

    /____

    ___________________/

    14.2. If no, why not?

    /____

    ___________________/

15. If yes to Question 14, do you use chemical fertilizer on **all** of your cultivated plots? [1]: Yes [0]: No

    15.1. If no, why not?

    /____

    ___________________/

16. Do any of the female members of your household use chemical fertilizer on their own fields? [1]: Yes [0]: No

    16.1. If yes, Number of Women? /__________ /

    16.2. If no, why do you think the women don't?

    /____

    ______________/

17. Of the land that you cultivate, do you use RWH techniques? [1]: Yes [0]: No

    17.1. If yes, what area of cultivated land is watered using RWH? (*corde*)

    /__________ /

    17.2. If no, why not?

    /____

    ___________________/

18. Do any of the female members of your household practice RWH on their own fields? [1]: Yes [0]: No

    18.1. If yes, Number of Women? /__________ /

18.2. If no, why do you think the women don't?

/____

______________/

Access to inputs

19. Aside from the *carder*, do you know of any other places to buy fertilizer? [1]: Yes [0]: No

20. If you buy chemical fertilizer, what is the main place that you buy chemical fertilizer?

/____

______________/

(If not applicable, continue to question 20)

20.1. How long does it take you to get to the main place where you buy fertilizer?

/_____________/ hours

20.2. By what mode of transportation do you usually travel to the main place where you buy fertilizer? /______________________________/

20.3. During the 2012 season, did you have trouble for any reason traveling to the main place where you buy fertilizer?

[1]: Yes [0]: No

If yes, please give the reason why:

[1]: Roads impassable

[2]: Form of transportation stopped working (e.g. bicycle broke down)

[3]: High cost of transportation

[4]: Taxes en route

[5]: Government regulations

[6]: Too much too transport on the return trip

[7]: Other /_____________/

21. During the 2012 season, did you have trouble finding enough labour for farming activities?

[1]: Yes [0]: No

/____

____

____/

Adoption choice (and willingness to pay)

22. What is your experience with fertilizer Microdose technology (MD)? (If the farmer has never used microdosing, continue to question 22.)

<table>
<tr><th>Experience</th><th>Crops</th><th>Area</th><th>Years</th><th>Strategy before MD</th><th>Difference in yields?</th><th>Comments</th></tr>
<tr><td rowspan="4">Currently using MD and intend to continue using</td><td></td><td></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4">Use on same crops, different crops? Land use: less, same, more?</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="4">Currently using and intend to stop</td><td></td><td></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4">Why do you intend to stop? See coding</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="4">Used in the past and stopped using</td><td></td><td></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4">Why did you stop? See coding</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

22.1. How much did fertilizer cost you in: (CFA per kg)

Price CFA/50 kg	2011	2012	2013
NPK (and Urea)			

22.2. Would you be willing to expand (or start again) the use of microdosing if fertilizer was cheaper? [1]: Yes [0]: No

What is the maximum amount you could afford for a bag of fertilizer? /_________ /

****

23. If you have never used microdosing, are you interested in the technique? [1]: Yes [0]: No

Yes	1	Why are you not currently using MD?	See coding* if 4 ask 24.2
No	0	Why are you not interested in using MD?	See coding* if 4 ask 24.2

Coding:

[1]: Fertilizer unavailable locally

[2]: Too risky

[3]: Satisfied with current practices

[4]: Fertilizer too expensive

[5]: Have been informed of MD (through demonstrations, radio, tv etc.) but not convinced of its superiority

[6]: Haven't been informed of MD (through demonstrations, radio, TV etc.)

[7]: Too labour intensive

[8]: Soil unsuitable

[9]: Other (specify)

23.1. How much did fertilizer cost you in (CFA per kg)

Price CFA/50 kg	2011	2012	2013
NPK and Urea			

23.2. Would you be willing to start using microdosing if fertilizer was cheaper? [1]: Yes [0]: No

What is the maximum amount you could afford for a bag of fertilizer? /_________ /

Access to Credit

24. Were there times in the 2012 season where you faced problems with short-term funding for agricultural purposes? [1]: Yes [0]: No

24.1. If yes, were you able to access credit for agricultural purposes?
[1]: Yes [0]: No

24.1.1. If yes, from what source?

Type of credit	Amount (local money)/quantity(kg)	Source 1= formal 2= informal	Amount/quantity repaid	Was the credit given in a timely fashion? *Yes = 1No=2*
Credit in general				
Credit for seeds				
Credit for fertilisers				

24.1.2. If no, why not?
/____
____________________/

25. Are you currently a member of a local warrantage organization (any organization promoting commercialization, offering access to credit or access to inputs)? Discuss with technician in field appropriate description) [1]: Yes [0]: No (If no, continue to question 29.2)

25.1. If yes, for how many years have you been a member? /____________/

25.1.1. And what role do you play in the warrantage organization?
[1]: Member [2]: Keyholder [3]: Other /____________/

25.2. If no, were you ever a member? [1]: Yes [0]: No

25.2.1. If yes, how long were you a member? /____________/ (Months, years etc.)

25.2.2. If you have never been a member of a warrantage organization, can you state your reasons for why not?

/____

____

Networks

26. *{If the farmer is currently using Microdose technique, continue to question 28}* Could you list the top three (or less) people with whom you discuss **farming in general**?

a. Name or Position	**b. Organisation or relationship**	**c. Gender**	**d. Distance for meeting (in hours)**	**e. Topic(s) discussed**

27. In the last two years, have you discussed **farming in general** with any of the people listed below?

a. Position	**b. Name**	**c. Gender**	**d. Distance for meeting (in hours)**	**c. Topic(s) discussed?**
producteurs in INuWaM project				
Extension Agent				
INuWaM Project				
NGO				
Government				
Scientist				

a. Position	b. Name	c. Gender	d. Distance for meeting (in hours)	c. Topic(s) discussed?
Scientist				
Personal Contact				
Neighbour				
Parent or Relative				

28. *{Ask this question if the farmer is **currently** practicing Microdosing}* Could you list the top three (or less) people that you talk to about **microdosing in particular**?

a. Name or Position	b. Organisation or relationship	c. Gender	d. Distance for meeting (in hours)	e. Topic(s) discussed

29. In the last two years, have you discussed **microdosing in particular** with any of the people listed below?

a. Position	b. Name	c. Gender	d. Distance for meeting (in hours)	c. Topic(s) discussed?
Producteurs in INuWaM project				
Extension agent with INuWaM project				
Scientist /_________________/				
Neighbour				

a. Position	b. Name	c. Gender	d. Distance for meeting (in hours)	c. Topic(s) discussed?
Parent or relative				

General Attitudes towards the technology

30. If you use microdosing, what are the two most important positive and two most important negative characteristics of microdosing?

    Positive characteristics:

    /____

    ____

    ____/

    Negative characteristics:

    /____

    ____

    ____/

31. Please write down any general comments you have regarding microdosing.

/____

____

____/

32. If you don't use Microdose, please write down any general comments you have regarding the technique.

    /____

    ____

    ____

    ____

    ____

    ____/

APPENDIX B

Results of Soil Analysis

Soil analysis conducted by the Soil Science Department at the University of Saskatchewan under the leadership of Dr. Derek Peak.

SURVEY NUMBER	pH	OC	TOTAL P	AVAILABLE P	TOTAL N	CEC
		%	mg/kg	mg/kg	mg/kg	cmolc/kg
1	5.15	1.23	134.58	4.71	756.26	1.99
2	6.00	1.58	477.57	42.09	1341.21	4.22
3	5.64	1.11	188.21	10.71	700.76	1.99
4	6.07	1.21	265.84	8.32	1041.62	3.58
5	6.37	1.27	241.92	6.05	912.54	2.83
6	5.52	1.18	289.50	12.99	1348.37	3.12
7	6.11	1.80	174.16	5.26	838.89	2.29
8	6.20	1.40	328.53	8.65	1843.73	5.25
9	6.62	2.28	350.82	18.73	1153.37	4.91
10	6.43	1.30	160.63	3.93	944.36	2.65
11	6.24	1.34	296.92	7.01	994.25	3.46
12	5.78	0.44	101.41	2.45	429.20	1.42
13	5.46	0.43	114.72	1.77	301.85	1.18
14	5.54	1.38	202.79	4.12	811.59	2.57
15	5.55	1.98	277.19	2.95	1120.43	3.54
16	6.39	1.65	259.75	14.31	1049.94	3.96
17	6.55	1.25	232.69	9.49	913.29	3.73
18	6.48	0.38	99.23	1.50	324.39	1.10
19	6.84	0.69	160.50	8.41	593.22	2.08
20	5.87	0.59	106.86	2.48	435.39	1.02
21	6.12	1.07	171.03	2.29	709.68	2.37
22	6.41	2.15	366.68	6.33	1426.14	4.79
25	6.65	1.44	357.30	37.32	943.82	3.43
24	5.11	1.40	155.65	10.71	1011.51	1.77
23	6.58	1.26	207.10	6.26	1044.66	3.97
26	5.54	0.51	127.31	5.98	415.20	1.35
27	6.12	2.41	245.19	9.03	1284.39	5.04

28	5.99	0.87	131.88	3.79	957.12	2.03
29	5.82	0.75	127.77	2.96	539.39	1.78
30	6.27	1.03	181.37	9.50	635.87	2.74
31	7.29	1.85	500.46	121.71	1050.35	7.84
32	5.99	1.31	153.01	6.07	778.11	2.04
33	6.55	1.13	138.71	9.96	716.54	2.75
34	6.91	3.94	850.04	206.26	2254.79	8.71
36	6.38	0.77	177.10	22.25	533.70	2.46
35	5.64	0.82	134.39	3.70	548.13	1.55
37	6.27	1.50	199.46	5.43	844.29	3.56
39	6.13	1.04	126.53	4.08	659.45	2.24
38	5.19	0.90	175.17	3.47	712.76	2.35
40	7.24	1.38	163.77	8.22	777.09	3.70
41	7.11	1.10	241.39	38.61	700.50	4.33
42	5.73	1.49	165.66	6.68	950.15	2.49
44	4.86	0.66	133.35	3.31	908.97	2.13
43	5.65	1.52	116.56	2.08	481.59	1.64
45	5.69	0.85	136.62	2.20	613.68	1.68
46	5.54	1.11	144.71	5.83	725.75	2.62
47	5.87	1.03	151.98	2.67	1023.11	3.06
48	5.85	0.98	206.39	5.48	1009.53	2.48
49	6.73	1.05	244.86	8.75	1048.89	3.28
51	6.04	1.18	303.48	3.80	1318.82	3.59
50	5.94	1.20	262.15	15.49	1388.37	3.58
52	5.92	0.70	227.33	3.50	781.04	2.52
54	5.99	0.37	964.97	18.56	1457.24	4.72
53	5.63	1.38	98.91	1.72	392.15	1.16
55	5.70	0.52	151.41	1.81	576.56	2.45
56	5.39	0.92	186.47	3.54	1021.25	2.72
57	6.30	1.55	182.28	3.69	1212.93	3.61
58	5.71	0.69	235.75	14.68	900.11	3.47
60	5.48	0.89	153.70	1.81	1106.42	2.98
59	5.45	1.22	191.07	2.96	843.48	2.40
61	5.20	0.45	84.69	1.48	393.02	1.26
62	6.18	1.76	230.82	2.53	1446.59	4.08
63	7.24	1.32	422.88	32.28	1231.10	8.82

64	6.30	1.34	278.79	10.13	1224.48	3.76
65	6.38	0.88	188.93	3.16	870.99	3.12
68	6.86	0.61	401.60	20.21	1954.62	6.98
66	5.69	1.85	83.86	2.91	290.76	0.76
67	5.96	0.51	240.78	8.82	556.46	2.04
70	5.56	0.72	208.30	4.20	1152.05	2.68
69	6.08	1.40	220.45	4.29	713.61	2.74
72	6.19	0.83	443.52	24.35	845.93	3.64
71	5.87	0.86	264.33	5.46	872.99	2.80
73	6.38	1.47	446.03	12.65	1435.44	5.06

APPENDIX C

Principal Component Analysis Output for Creation of Soil Quality Index

Six soil characteristics — organic carbon (OC), pH, total nitrogen (TOTAL_N), total phosphorus (TOTAL_P), available phosphorus (AVAIBLE_P), and cationic exchange capacity (CEC) — were used in the construction of a soil quality index through principal component analysis.

Principal Components Analysis
Sample: 1 73
Included observations: 73
Computed using: Ordinary correlations
Extracting 6 of 6 possible components

Eigenvalues: (Sum = 6, Average = 1)

Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	3.781064	3.023833	0.6302	3.781064	0.6302
2	0.757231	0.078987	0.1262	4.538294	0.7564
3	0.678244	0.177737	0.1130	5.216538	0.8694
4	0.500507	0.316999	0.0834	5.717045	0.9528
5	0.183508	0.084062	0.0306	5.900554	0.9834
6	0.099446	---	0.0166	6.000000	1.0000

Eigenvectors (loadings):

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
OC	0.358736	-0.311631	0.720441	0.362593	0.340326	-0.088678
PH	0.327377	0.857934	0.073003	0.205747	0.144197	0.297186
TOTAL_N	0.419818	-0.363792	-0.379279	0.429867	-0.293725	0.525829
TOTAL_P	0.432931	-0.140853	-0.406661	-0.393513	0.686685	-0.031144
AVAILABLE_P	0.411774	-0.028807	0.357608	-0.680870	-0.433781	0.223560
CEC	0.480519	0.117566	-0.196281	0.151566	-0.342651	-0.759191

Ordinary correlations:

	OC	PH	TOTAL_N	TOTAL_P	AVAILABL E_P	CEC
OC	1.000000					
PH	0.320999	1.000000				
TOTAL_N	0.524992	0.316582	1.000000			
TOTAL_P	0.393503	0.400983	0.707323	1.000000		
AVAILABLE_P	0.587441	0.433714	0.458158	0.657235	1.000000	
CEC	0.540926	0.645566	0.792241	0.757500	0.656715	1.000000

APPENDIX D

Principal Components Analysis Output for Creation of Socio-economic Status Index

Fifteen household variables were used to construct a socio-economic status index. These variables were _0F_SPOUSES (number of spouses), TOTAL_CULTIVABLE_LAND, MOTORBIKE, BIKE, PLOW, DRAFT_ANIMALS__COWS, WHEELBARROW, DABA__HOUE__ETC (farm implements), TELEVISION, RADIO, PHONE, WELL, BOREHOLE, GENERATOR, COMMUNAL_WATER__ACCESS (communal access to water rather than private water source).

Principal Components Analysis
Sample: 1 73
Included observations: 73
Computed using: Ordinary correlations
Extracting 15 of 15 possible components

Eigenvalues: (Sum = 15, Average = 1)

Number	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
1	3.730014	1.836114	0.2487	3.730014	0.2487
2	1.893899	0.04934	0.1263	5.623913	0.3749
3	1.844559	0.288277	0.123	7.468472	0.4979
4	1.556282	0.54012	0.1038	9.024755	0.6017
5	1.016163	0.122946	0.0677	10.04092	0.6694
6	0.893216	0.123145	0.0595	10.93413	0.7289
7	0.770071	0.133271	0.0513	11.70421	0.7803
8	0.636801	0.097075	0.0425	12.34101	0.8227
9	0.539726	0.067292	0.036	12.88073	0.8587
10	0.472434	0.034591	0.0315	13.35317	0.8902
11	0.437843	0.063663	0.0292	13.79101	0.9194

12	0.37418	0.011394	0.0249	14.16519	0.9443
13	0.362785	0.109836	0.0242	14.52797	0.9685
14	0.252949	0.033872	0.0169	14.78092	0.9854
15	0.219077	---	0.0146	15	1

Eigenvectors (loadings):

Variable	PC 1
__OF_SPOUSES	0.366559
TOTAL_CULTIVABLE_LAND	0.333298
MOTORBIKE	0.359535
BIKE	0.16362
PLOW	0.17751
DRAFT_ANIMALS__COWS_	0.106258
WHEELBARROW	0.228522
DABA__HOUE__ETC_	0.366205
TELEVISION	0.117567
RADIO	0.393807
PHONE	0.312918
WELL	0.108879
BOREHOLE	0.093728
GENERATOR	0.284894
COMMUNAL_WATER__ACCESS_	-0.02743

APPENDIX E

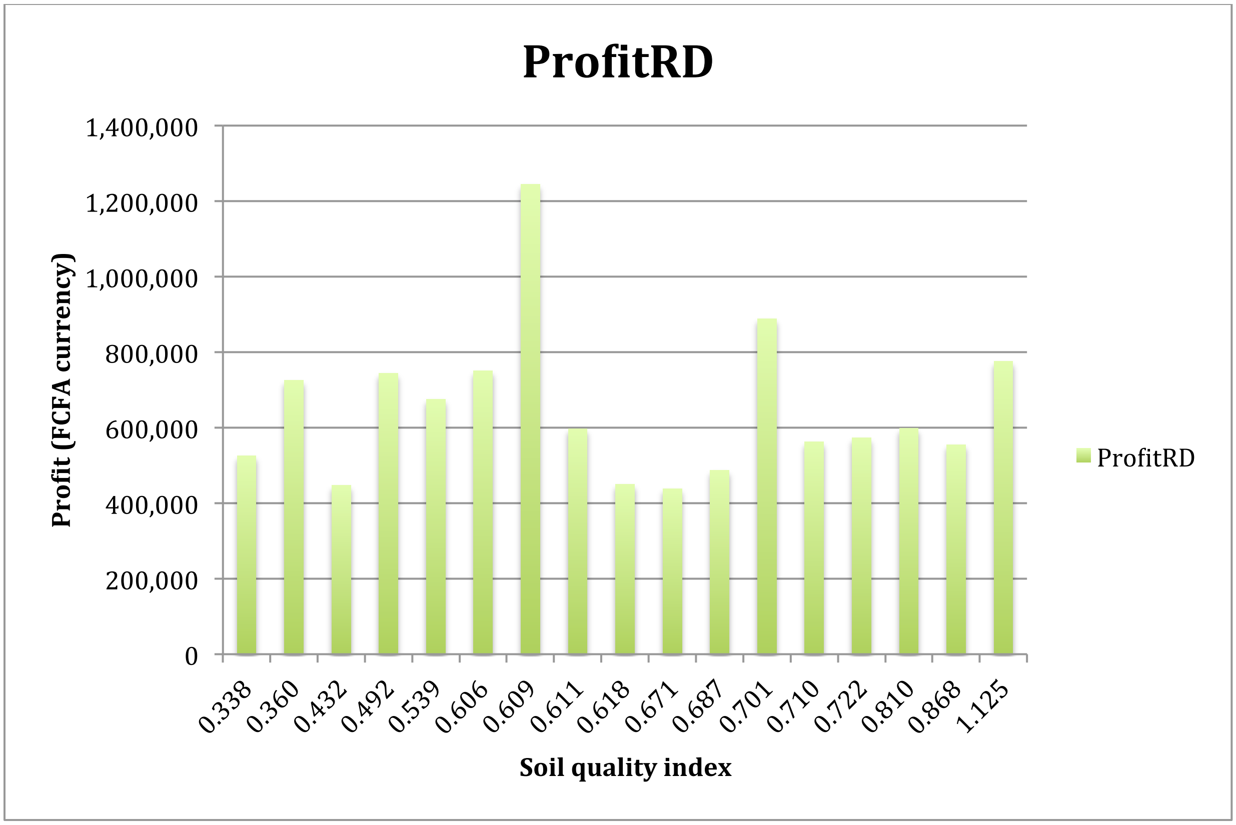
Relationship between Net Benefits (Profit) under Fertilizer Application and Soil Quality Index

E.1 Recommended Dosage

Dependent Variable: PROFITRD
Method: Least Squares
Sample: 1 17
Included observations: 17

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	480640.1	127771.6	3.761713	0.0037
CP	139858.5	134189.2	1.042248	0.3218
LCN	-129164.2	98530.96	-1.310899	0.2192
LP	166761.4	144984.1	1.150205	0.2768
CULTIVATED	465796.5	186742.2	2.494330	0.0318
MAISGROW	-163244.2	134027.0	-1.217995	0.2512
SQI_SSF_PCA	215789.9	182903.1	1.179804	0.2654

R-squared	0.746968	Mean dependent var	649431.9
Adjusted R-squared	0.595149	S.D. dependent var	201240.7
S.E. of regression	128045.2	Akaike info criterion	26.65106
Sum squared resid	1.64E+11	Schwarz criterion	26.99414
Log likelihood	-219.5340	Hannan-Quinn criter.	26.68516
F-statistic	4.920120	Durbin-Watson stat	2.528565
Prob(F-statistic)	0.013592		



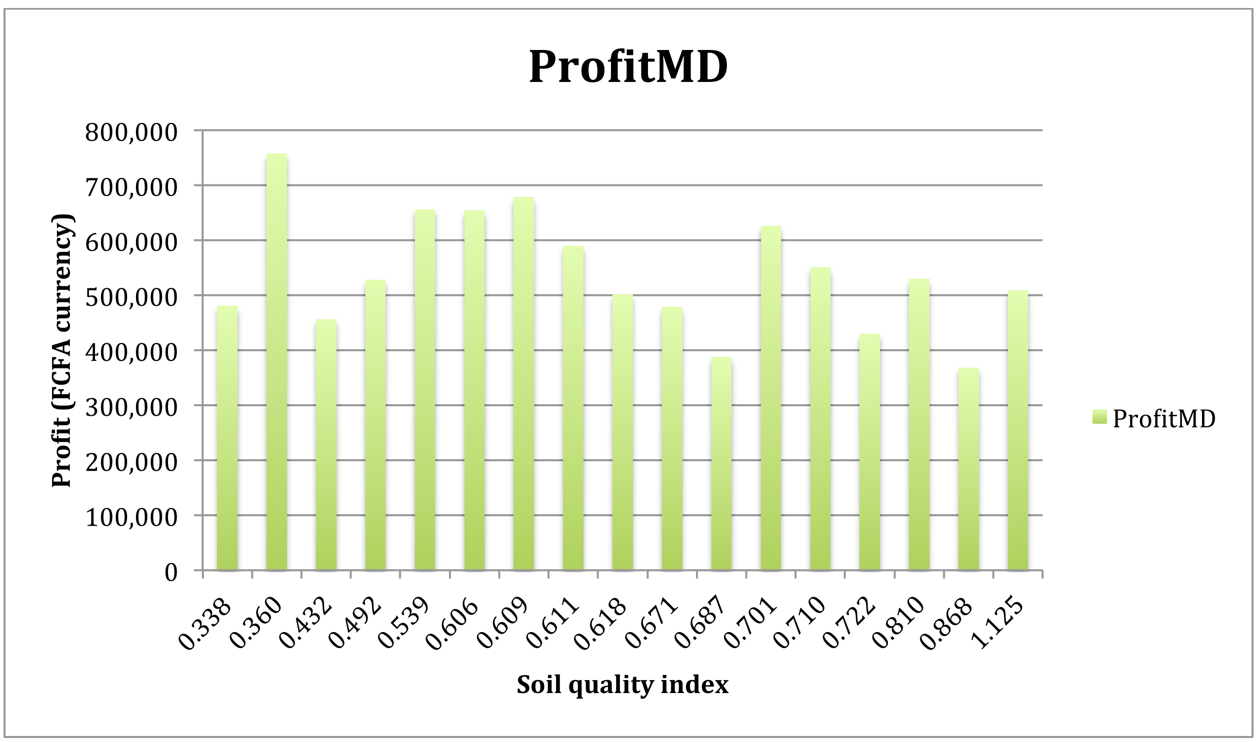
The graph above depicts the relationship (or lack thereof) between increasing soil quality index and net benefits (profits) from the recommended dosage demonstration plot across the 17 observations (*producteurs*).

E.2 Microdosing

Dependent Variable: PROFITMD
Method: Least Squares
Sample: 1 17
Included observations: 17

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	548330.5	93379.94	5.872038	0.0002
CP	144557.0	98070.18	1.474016	0.1712
LCN	10741.00	72009.86	0.149160	0.8844
LP	232330.5	105959.5	2.192636	0.0531
CULTIVATED	-62729.74	136477.7	-0.459634	0.6556
MAISGROW	-7007.109	97951.62	-0.071536	0.9444
SQI_SSF_PCA	-64774.97	133672.0	-0.484581	0.6384

R-squared	0.526883	Mean dependent var	539800.7
Adjusted R-squared	0.243013	S.D. dependent var	107556.9
S.E. of regression	93579.93	Akaike info criterion	26.02392
Sum squared resid	8.76E+10	Schwarz criterion	26.36701
Log likelihood	-214.2033	Hannan-Quinn criter.	26.05802
F-statistic	1.856069	Durbin-Watson stat	1.255895
Prob(F-statistic)	0.184865		



The graph above depicts the relationship (or lack thereof) between increasing soil quality index and net benefits (profits) from the microdosing demonstration plot across the 17 observations (*producteurs*).

APPENDIX F

Estimation of Shadow Values of Fertilizer

Below are the individual shadow values of fertilizer for *producteurs.* These are the 16 *producteurs* for whom there was survey and yield data available for, and who in addition stated their desire to continue microdosing. A negative shadow value indicates that microdosing actually performed better than recommended dosage on their demonstration plots.

Shadow values for those that would continue microdosing*	
Survey ID	**(ω) Shadow value in CFA/ kg of fertilizer**
1	1,456
2	10,988
3	1,008
5	3,349
7	10,838
12	377
13	-535
14	-826
15	7,925
19	4,533
36	9,044
38	-1,237
47	6,221
48	1,172
60	4,461
61	2,448
Average	3,826
Median	2,899
Min	-1,237
Max	10,988