TECHNOLOGY ADOPTION WHEN RISK ATTITUDES MATTER: EVIDENCE FROM INCENTIVIZED FIELD EXPERIMENTS IN NIGER

By

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ABSTRACT

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Fertilizer micro-dosing is a precision fertilizer application technique with the potential to improve agricultural productivity and livelihoods in the semi-arid-tropics. Despite more than two decades of disseminating the technology in Niger, micro-dosing adoption rates remain low with evidence of dis-adoption. Since fertilizer is a risk increasing technology, this paper estimates the effects of risk attitudes on fertilizer use and the practice of micro-dosing. I use different methods to elicit measures of risk aversion and supplement those with measures of aversion to ambiguity and loss. I find that incentivized measures of risk attitudes have better predictive power than general measures based on hypothetical survey questions. Among the risk attitudes explored, risk aversion tends to matter in the decision to use fertilizer and in the choice of an application technique when fertilizer is used. This indicates that ex post programs like insurance could promote the use of fertilizer and fertilizer micro-dosing among risk averse farmers.

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CHAPTER 1: INTRODUCTION

1. Background and motivation

Inorganic fertilizer use across sub-Saharan Africa (SSA) is generally considered to be low. However, in Niger and other countries in the drier regions of the continent, inorganic fertilizer use is even lower (Morris, Kelly, Kopicki, & Byerlee, 2007). Compared to Tanzania and Uganda where about 16.9% and 3.2% of farming households use fertilizer at a rate of 95.6 and 37.5 kilograms (Kg) per hectares (ha), respectively, Sheahan & Barrett, (2014) show that 17% of farming households in Niger use inorganic fertilizer at a rate of only 26.3 Kg/ha. Traditionally in Niger, increases in agricultural production have been achieved through the cultivation of new land rather than increased yields. With increasing population density alongside limited supply of high quality land, the importance of agricultural intensification (including fertilizer use) is eminent. It is imperative for Niger and its farmers to focus on yield increasing intensive technologies like fertilizer micro-dosing. [1]Micro-dosing is a precision farming technique, where a small amount of fertilizer (2-6 g) is placed with the seed (separated by a thin layer of soil) (ICRISAT, 2012) thereby requiring about a third to a fourth of the usual fertilizer recommended by research or advisory services (Camara, Camara, Berthe, & Oswald, 2013). Thus, compared to traditional inorganic fertilizer application techniques such as line spreading and broadcasting, fertilizer micro-dosing is cost effective. Micro-dosing also enables efficient nutrient absorption and reduced soil degradation via soil nutrients replenishment, reduced soil erosion and enhanced use of water (Abdoulaye & Sanders, 2005; Pender, Abdoulaye, Ndjeunga, Gerard, & Kato, 2008; Tabo, Bationo, Maimouna, Hassane, & Koala, 2006).

[1] Fertilizer micro-dosing was developed by scientists at the International Crop Research Institute for the Semi-Arid tropics (ICRISAT) and partner organizations to address the cost constraints associated with fertilizer use in the Sahel

After over 20 years of micro-dosing promotion by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and its partner institutions, the use of this technology remains persistently low with some evidence of dis-adoption in Niger.[2] This is puzzling given the technology's potential to increase production thereby improve livelihoods for cash strapped smallholder farmers. Therefore, it is important to understand under which conditions farmers are willing to practice micro-dosing on scarce arable land for agricultural production. Anecdotal evidence and information from key informants indicate that a vast majority of farmers who apply some fertilizer mix the fertilizer with seeds at planting.[3] While mixing seeds with fertilizer is frequently interpreted as micro-dosing by some (Abdoulaye & Sanders, 2005; Pender et al., 2008; Tabo et al., 2006) I consider these application techniques to be different. Farmers mixing seed with fertilizer typically apply 2 to 8kg/ha of fertilizer (Abdoulaye & Sanders, 2005) compared to the 20 kg/ha – 60 kg/ha recommended for micro-dosing. This large difference in the quantity of fertilizer used is thus likely to have very different implications for profitability and production risk.

Inorganic fertilization strategies are risk increasing (since they introduce a higher variance in yield) and risk associated with innovative technologies can be a barrier to their adoption (Bocqueho, Jacquet, & Reynaud, 2014; Ghadim, Pannell, & Burton, 2005; Marra, Pannell, & Abadi Ghadim, 2003). Furthermore studies have shown the importance of farmers' risk preferences on the adoption of new farming technologies (Feder, Just, & Zilberman, 1985; Feder & Umali, 1993; Knight, Weir, & Woldehanna, 2003). However, there are limited empirical studies which actually elicit risk attitudes and integrate them in the technology adoption process. No study

[2] Niger is a big land locked country in West Africa. Though agriculture employs more than 80% of working age adults, agricultural productivity under mainly rain fed conditions is low.

[3] Liverpool-Tasie, Sanou, & Mazvimavi, (2015) show that the use rate of mixing seeds with fertilizer is much higher than micro-dosing among fertilizer users in Niger.

of micro-dosing was found that considered the effect of risk attitudes on adoption. Consequently this thesis explores the role of risk attitudes in the adoption of fertilizer micro-dosing in Niger. I elicit various types of risk attitudes using different elicitation methods. I supplement a traditional survey question on risk attitudes with incentivized experiments. There is an ongoing debate in the literature regarding the appropriateness of general survey questions versus incentivized/hypothetical experiment. While a few studies have used different elicitation methods to compare hypothetical and incentivized risk elicitation methods, this is the first study (I am aware of) that actually uses the exact same question for the hypothetical and incentivized elicitation methods in a developing country context. Using the exact question in both a hypothetical survey and an incentivized experiment, I am able to contribute to this debate by truly isolating the effect of incentives.

In addition to attitudes towards risk over gains, I also collect information on farmers' attitudes towards ambiguity and loss.[4] By collecting multiple measures I am able to test which risk attitudes (risk aversion, ambiguity aversion and loss aversion) most closely explains farmers' behavior in the sample. This is important since different risk attitudes call for different policy interventions. If risk aversion is key in farmers' decision to practice micro-dosing, then ex post risk-coping mechanisms, such as crop insurance, might be an appropriate policy response. On the other hand if ambiguity aversion matters more, then ex ante strategies, such as farm extension services and demonstration trials, may help increase familiarity with the technology and boost farmers' confidence about the technique.

[4] Ambiguity aversion is putting higher values on events with known probability than those with unknown probability.

2. Literature gap and study objectives

2.1. Study objectives

2.1.1. The importance of risk aversion in technology adoption

A significant number of studies have highlighted the important role that farmers' risk attitudes have on the adoption of new farming technologies. (Feder, 1980; Feder et al., 1985) conduct a review of studies that have attempted to explain patterns of technology adoption behavior. They find that risk aversion is one of the major impediments to the adoption and diffusion of new agricultural technologies. Moreover, the effect is even more pronounced when risk averse behavior occurs in the presence of other production constraints such as credit and access to complementary inputs. Binswanger (1980) is one of the first studies to provide empirical tests of risk aversion using a sample of farmers in a developing country. Although the findings were inconclusive with regards to the effect of risk aversion on technology adoption, the study found that most farmers were risk averse and the degree of risk aversion increased as the monetary payoffs of the lotteries increased. I interpret these findings to imply that the more important agricultural production is in sustaining livelihoods (through subsistence consumption or monetary income) the higher the degree of risk aversion exhibited by farmers. Consequently, I empirically test this hypothesis in the Nigerien context to determine if most farmers are risk averse and then explore how their risk attitudes impact their technology adoption decisions.

Risk aversion has also been shown to inhibit the adoption of new agricultural technologies by poor households. In their study disaggregating the effect of risk aversion by poverty status, Yesuf & Bluffstone (2009) used a dataset collected in Northern Ethiopia to show that poor households are reluctant to make investments in new technologies because of risk aversion. This is particularly relevant to the population of study in Niger where 93.6 % of rural residents are poor according to the FCFA 182,635.2/capita/year Nigerien poverty line (INS-Niger, 2013).

2.1.2. The importance of considering risk attitudes other than risk aversion

Risk aversion alone does not capture the full spectrum of the decision making process when farmers are confronted with new farming technologies. When farmers are not familiar with the distribution of a crop's yield associated with a new technology, this uncertainty is another potential barrier to its adoption. The strand of the literature relating risk attitudes to agricultural technology adoption addresses this concern. Engle-Warnick, Escobal, & Laszlo (2007) used a laboratory experiment in the field to distinguish empirically between risk aversion and ambiguity aversion in farmers' technology choices in seven rural communities in Peru. Using experimental data collected among mostly potato growers, they hypothesize that ambiguity aversion may also be a behavioral determinant of technology adoption since farmers may have less information about the distribution of yield outcomes with new technologies than traditional technologies. They find that ambiguity aversion predicts actual technology choices where more ambiguity averse farmers are less likely to diversify across crops. However, the payoffs in this study were hypothetical and may not reflect the individual's real willingness to pay to avoid ambiguous outcomes. Consequently, I conduct field experiments capturing ambiguity aversion using incentives.

Another risk attitude often considered by the literature characterizing an individual's behavior is loss aversion. Loss aversion is the tendency for people to strongly prefer avoiding losses than acquiring gains (Kahneman & Tversky, 1979). Liu (2013) estimates how Chinese cotton farmers risk attitudes are related to their decision to adopt Bt cotton, a new agricultural technology. The study uses an experimental method that elicits prospect theory parameters: risk aversion, loss aversion and nonlinear probability weighing. She finds that the more risk-averse or more loss-averse farmers adopt Bt cotton later and that those who overweight small probabilities are more likely to adopt Bt cotton earlier. In a poor rural agricultural setting with limited formal safety nets, like Niger, it would not be surprising if farmers are reluctant to invest their limited resources in a risk increasing agricultural technology, such as fertilizer. Although the experimental approach used in this paper does not assume that prospect theory drives the underlying decision process I am able to derive measures of risk aversion and loss aversion in a simple manner which I believe is more accessible with respect to Nigerien farmers' comprehension.

2.1.3. How is risk aversion measured?

Binswanger (1980) uses two methods: an interview method eliciting certainty equivalents and an experimental gambling approach (lottery choice) with real monetary payoffs with Indian Farmers.[5] The interview method is subject to interviewer bias and the results were totally inconsistent with the experimental measures of risk aversion (Binswanger, 1980). The elicited risk preferences were not correlated with demographic characteristics and did not demonstrate predictive power for the adoption of an agricultural technology. Thus, the ensuing research has focused on developing/refining risk elicitation methods that can be used to model farmers' adoption decisions. There is an ongoing debate on the suitability of various mechanisms for eliciting risk attitudes. The findings remain largely inconclusive as to which mechanism is more appropriate for field experiments in general and in developing countries in particular. In the following paragraphs, I focus on studies using elicitation methods similar to the ones in this thesis.[6]

[5] The Certainty Equivalent is the minimum sure/certain amount that an individual would take instead of a higher lottery amount.

[6] Specifically, I do not discuss the literature related to the balloon analogue risk task which measures risk preferences by presenting individuals with a computer simulation of pumping air into a series of balloons (Lejuez et al., 2002).

Ward & Singh (2014) elicit parameters of risk preferences consistent with cumulative prospect theory in rural India and relate them to the decision to adopt drought-tolerant rice seeds. Similarly to Liu (2013), in the field experiments participants are presented with two series of games with 35 choices between two options. A notable difference between the two experimental designs is that in Ward & Singh (2014) each experiment involves choices between a certain payment and a risky prospect in order to ensure the participants understand. In addition, they derive an experimental measure of ambiguity aversion and administer a discrete choice experiment over new and traditional rice seeds.[7] To capture measures of ambiguity aversion, participants were given two series of games with 11 pair-wise choices between a riskless option and a risky option comprised of a winning draw and a losing draw. In the first experiment respondents do not know the probability of winning and losing draws in the risky option but in the second they do. The study finds that individuals with a greater degree of risk aversion and loss aversion are more likely to switch to the new, risk reducing variety while ambiguity aversion appears to be a negligible determinant. These findings contrast with the belief that individuals with higher degrees of ambiguity aversion are less likely to deviate from status quo. As a non-traditional fertilizer application technique, it is possible that ambiguity aversion would matter in the adoption of micro-dosing. However, this hypothesis has not been tested. Hence I examine the effect of ambiguity aversion on the decision to use fertilizers.

There is evidence that Nigerien farmers' technology adoption behavior is conditioned by their attitudes toward risks. An *ex-ante* risk programming study in Southern Niger found that highly risk averse farmers may adopt fertilization but on a limited crop area while adoption among farmers with lower risk aversion is higher but limited by cash and seasonal labor constraints

[7] A discrete choice experiment predicts/explains choices between two or more discrete alternatives

(Adesina, Abbott, & Sanders, 1988). The empirical approach in their study is a variation of the MOTAD model which takes into account farmers' risk preferences and simulates farm production of millet, sorghum and cowpeas (in pure standing and intercropping) based on two alternative technologies – no fertilizer and with fertilizer (urea and simple-superphosphate).[8] Unlike the present study, Adesina et al., (1988) did not elicit risk attitudes through field experiments . Their results are programming solutions using MOTAD under different levels of constraints and risk preferences which are measured by the maximum amount of negative deviation allowed (Adesina et al., 1988). One obvious shortcoming of arbitrarily setting degrees of risk preferences is the inability to confirm whether they indeed depict farmers' true attitudes toward risk in a specific context, which is one of the objectives of this study.

Dohmen et al., (2011) used a survey question from the German Socio-Economic Panel (SOEP) to evaluate the determinants of individuals' willingness to take risks. The survey question asked people their willingness to take risks "in general" on a 10-point scale with 1-completely unwilling and 10-completely willing. They added a complementary experiment conducted with a sample of respondents similar to the SOEP. The experiment used paid lottery choices to test the behavioral validity of the survey measure. These respondents also answered the same general risk question about their willingness to take risk. They find that the question about risk taking in general is a good predictor of behavior in the field experiment with real monetary stakes. Although the questionnaire has the advantage of being simple it is subject to the possibility of gratuitously-expressed preferences for risk (Charness, Gneezy, & Imas, 2013). The sets of experimental procedures used in this study will allow us to test whether responses from the questionnaire are compatible with those obtained from the incentivized experiments.

[8] Minimization of Total Absolute Deviations (MOTAD) where absolute deviation is the risk measure. The model depicts tradeoffs between expected income and the absolute deviation of income.

Hardeweg, Menkhoff, & Waibel, (2013) use a large sample of 934 respondents in rural Northeast Thailand to test the predictive power of a survey item (similar to Dohmen et al., 2011) and a risk experiment.[9] They used a large sample size since small sample sizes in most experiment studies do not allow for broader micro-econometric analysis. The survey item is a simple assessment of one's risk attitude while the field experiment is an incentivized Holt and Laury (2002) type (henceforth HL).[10] By implementing both techniques with the same individuals, they find that i) the self-assessed risk attitude is validated by the experiment and ii) the questionnaire predicts behavior better than the measures of risk attitudes provided by the experiment in the domain of purchasing lottery tickets. Moreover, Hardeweg et al., (2013) performed robustness tests to ensure that respondents did not have any comprehension problems with either elicitation method. Overall, their results remain qualitatively unchanged to variations of the sample, and they do not identify which of the two methods is more subject to comprehension related distortions. However, though they find the two measures to be compatible, the fact that they use a general question that is not incentivized and a HL field experiment that is incentivized, it is hard to be sure if these results are truly comparing incentives to non-incentives or general questions to HL experiments since the context within which the general risk attitudes were collected and that for the incentivized experiments are not exactly the same.

Charness & Viceisza (2012) test the comprehension and degree of meaningful responses to three distinct risk elicitation mechanisms including the HL task, a simple binary mechanism modeled after Gneezy & Potters (1997) and a non-incentivized willingness to take risk similar to the general survey question in Dohmen et al. (2011). The HL task presents participants with a list

[9] Rural Northeast Thailand is the poorest among the five large regional areas of Thailand.
[10] The Holt-Laury task is a multiple price list method which presents participants with a list of 10 decisions between systematically varied paired gambles. For every decision row, the participant chooses which gamble he/she prefers to play from each pair.

of 10 decisions between systematically varied paired gambles. For every decision row, the participant chooses which gamble she prefers to play from each pair. In the original Gneezy and Potters method, the decision maker receives a real monetary endowment and is asked to choose how much of it to invest in a risky option and how much to keep. The expected value of investing is greater than the expected value of not investing and the choice of the amount to invest is the only decision the participant make in the experiment (Charness et al., 2013). For the purpose of their study, Charness & Viceisza (2012) provided participants with a simple choice of how much to invest in a risky asset with a positive expected profit from investing. The field experiments and the questionnaire were implemented in rural Senegal. The results showed a low level of understanding with the Holt and Laury task and largely inconsistent predictive power with the general risk question. The study postulates that the Gneezy and Potters mechanism might be more suited for measuring preferences in the rural developing world because it is not sophisticated and it is incentivized. Charness et al. (2013) take on the task to conduct a desk review of the prevailing experimental methodologies for eliciting risk preferences by highlighting the advantages and disadvantages. They find that general willingness to take risk questions are simple to understand but due to the lack of monetary incentives, it is debatable whether they reflect individuals' true attitudes toward risks. The Gneezy and Potters method is also simple with the additional advantage of being incentivized. The study concludes that the choice of the elicitation method is dependent on the context as well as the question of interest. However, it falls short of comparing the same method implemented with monetary stakes and without monetary stakes due to the lack of such studies in the literature.

2.1.4. Gaps that remain in the literature

Despite the vast body of literature demonstrating the important role that risk preferences play in technology adoption, its inclusion into the specification of adoption processes is often confronted with the challenge that risk attitudes cannot be directly observed from surveys. In particular, there has been a considerable lack of analyses that elicit preference parameters using both hypothetical and incentivized elicitation techniques and then integrate them in an analysis of the technology adoption process for micro-dosing. There is also a gap in the literature since no study in the developing country context asks the exact same elicitation question with and without incentives in the field, leading to the current inability to clearly disentangle the role of incentives versus context.

Consequently, this study contributes to the literature by addressing these two issues. I use both hypothetical and incentivized techniques to elicit risk attitudes and I am able to truly test for the effect of incentives by using the exact same risk elicitation question with and without incentives. I use experiments to elicit different risk attitudes and explore how variation in risk attitudes among farmers relates to the technology adoption decision. This will enable us to test the predictive power of hypothetical versus incentivized methods of eliciting risk attitudes. Finally, this study expands on the existing literature by adopting a methodological design that provides several measurements of risk preferences which are subsequently used to understand how risk attitudes affect the adoption of fertilizer and the practice of a particular fertilization strategy: micro-dosing.

2.2. Research questions

The overarching objective of this study is to understand the role of risk attitudes in the decision to adopt new technologies. It will inform how risk attitudes encourage or constrain the widespread adoption of fertilizer micro-dosing on scarce fertile arable land in agricultural production.

The study will address this research objective through the following questions:

1. How similar are the measures of risk aversion generated using the different elicitation measures/approaches?
   - Which elicitations methods most closely capture similar states of risk aversion among respondents?
   - How does the hypothetical context specific fertilizer question relate to the incentivized context specific fertilizer question and do incentives matter?
2. How do risk attitudes influence adoption decisions?
   - Which measures of risk attitudes explain farmers' decision to use fertilizer generally and then specific fertilizer application techniques? In particular, here I focus on which of the hypothetical and incentivized fertilizer variable better predict farmer behavior? For instance, could ambiguity aversion be more important for fertilizer use generally (or mixing seeds with fertilizer) but risk aversion more important for micro-dosing?

2.3. Study contributions

This study makes several contributions to the existing literature. First, it leverages a unique data structure and the use of simple framed field experiments to demonstrate the importance of incorporating risk preferences into the design and evaluation of programs promoting new technologies. The framed field experiment is easy to implement in a rural context with low literacy rates when one wants to ensure that participants understand the task. It has the advantage of being able to elicit attitudes toward risk over gain, ambiguity and losses without using lotteries with varying probabilities as in previous studies (Liu, 2013). Instead, each experiment involved choices between a certain payment and a risky prospect. Charness & Viceisza (2012) tested respondents' understanding of and the level of meaningful responses to three distinct risk elicitation mechanisms in rural Senegal. Their findings show that individuals may have a much more difficult time with varying probabilities than with varying payoffs.

Second, I provide empirical evidence that incentives matter and risk attitudes elicited with incentives better predict behavior. The study also contributes to the limited empirical evidence that exists on farmers' understanding and consequent experience with the practice of fertilizer micro-dosing in Niger.

Finally, collecting farmers' risk attitudes using both incentivized and hypothetical context-specific experiments to frame a familiar decision terrain for farmers is the first of its kind in the literature to my knowledge. While previous studies have been concerned with comparing distinct risk elicitation mechanisms or using student populations in lab experiments, I compare the same risk elicitation mechanism without monetary stakes and with monetary stakes in the field in a developing country.[11] I will thus be able to more accurately identify if incentives matter and the potential consequent effects this has on being able to identify the effect of risk attitudes on fertilizer micro-dosing adoption.

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[11] This refers to the elicitation method using fertilizer with and without payoff.

3. Background on modern inputs use and micro-dosing in Niger

This section presents an overview of the existing literature on inorganic fertilizer use within the realm of sustainable intensification in SSA generally and then Niger, more specifically. Sustainable intensification has gained prominence as a response to the challenges of increasing global food demand alongside limited supply of land, water, energy and other inputs (The Montpellier Panel, 2013). Within this context, methods that increase the efficiency of fertilizer use while minimizing the potentially negative effects of its use on the environment is a top research and policy concern. This is one reason why it is important for countries with low fertilizer use rates, to take advantage of opportunities that can increase fertilizer use in a sustainable manner. In this section, I discuss the relevance of inorganic fertilizer as the technology of interest with a focus on micro-dosing, a sustainable intensification technique. I also describe national and regional inorganic fertilizer use in Niger.

3.1. Modern input use in Niger

Close to 84% of Niger's population lives in rural areas, of which 65% are poor compared to 41% in urban settings (The World Bank, 2013). With 80% of the labor force engaged in agriculture countrywide, it follows that this sector constitutes the principal livelihood of most of the rural poor. Even though over 60 % of farming households are active in subsistence farming, the majority of them are net buyers of food.[12] They do not produce enough to meet their consumption needs, meaning they are subject to food insecurity. They also do not produce enough to make a profit that could enable them to improve their situation. Fertilizer adoption rates are generally low in Niger. This contributes to the pervasive state of low productivity in the

[12] The World Bank, 2013a

agricultural sector which translates into high poverty rates as presented in Table 1. In addition, the devaluation of the FCFA in 1994 had a detrimental effect on the country's agricultural sector. Inputs, such as fertilizers, which are imported became unaffordable for cash strapped smallholder farmers following an increase in price.

Table 1: Poverty status across the regions of study in Niger

Region	Poverty Rate
All regions	48.2
Dosso	52.9
Maradi	57.8
Tillabéri	56.0
Zinder	47.7

Source: Niger LSMS (2011/2012) and L'enquête Nationale sur les conditions de vie des ménages et l'agriculture au Niger (ECVMA).

3.2. Government/NGO efforts to increase input use

Confronted with the aforementioned challenges, the government of Niger (GoN) has launched a number of country wide programs on food security and sustainable agricultural development in its effort to alleviate the hardships faced by farmers. The latest of such an undertaking is "*Initiative 3N*", Nigeriens feed Nigeriens which was launched in 2011. Prior to this, in 2006, the government of Niger adopted the National Inputs Procurement Strategy for Sustainable Agriculture in Niger (SIAD).[13] The main objective of the SIAD was to facilitate access to and the use of good quality modern agricultural inputs at affordable prices. Thus, in line with its agricultural development agenda, and in partnership with development partners, the GoN has implemented a number of key interventions aiming to improve input markets and smallholder farmers' access to modern inputs. In 1999 in partnership with the Food and Agriculture (FAO) the GoN introduced *"Projet Intrants",* or *"Project on inputs"* in English (Salmou & Sidi, 2012) which

[13] Stratégie nationale d'approvisionnement en Intrants pour une Agriculture Durable Au Niger

later become the Project on the Intensification of Agriculture and Input Supply Shops(IARBIC) (FAO, 2013).[14] The impact of these interventions are yet to become tangible on a larger scale and begs the need to further explore the sources of the low level of productivity in the agricultural sector.

Moreover, cognizant of the state of low fertilizer consumption in Niger, the GoN established a state owned enterprise, Centrale d'Approvisionnement en Intrants et Materiel Agricoles (CAIMA) to ensure the procurement of modern agricultural inputs such as fertilizers, improved seeds etc. Although there is a nascent small private input supply sector, CAIMA remains the major player. According to CAIMA's officials, national fertilizer demand, during the 2013 agricultural season was estimated to be about 70,000 tons. CAIMA funded and supplied less than 30% of this amount or approximately 20,000 tons. The country relies on other supply channels to cover the gap but the needs are often times not met. Development partners, such as the Alliance for a Green Revolution in Africa (AGRA), supplied about 25,000 tons or 36% of demand. Thus, only about 65% of the estimated national demand for fertilizers in 2013 was satisfied – even with the contribution of donors. A fertilizer bag of 50 kg was sold to farmers through their farmer organizations for FCFA 13500 though the actual price of fertilizer was FCFA 19000; indicating a subsidy of about 30%.

Traditionally in Niger, increases in agricultural productivity were achieved through the cultivation of new land, a process that is known as the frontier model (Eicher & Staatz, 1998). It has been documented that farmers would expand areas cultivated by clearing the land (Abdoulaye & Lowenberg-DeBoer, 2000). Besides being land using, the characteristics of this extensive and unsustainable agricultural pathway include low labor requirement and minimal capital. However,

[14] Intensification de l'agriculture et des boutiques d'intrants Coopératives

with increasing population pressure, fertile new cropland is becoming scarce in Niger and the rest of the Sahel (Ramaswamy & Sanders, 1992). In a context of already constrained arable land surfaces, overtime, agricultural activities also contribute to declining soil fertility. The induced innovation model, as described by Ruttan & Hayami, (1984), predicts that technical change in agriculture occurs under changes in resource endowment and growth in output demand. Within this context, the relative factor scarcity determines the nature of the technology adopted to save the scarce factor of production. Consequently, as the supply of higher quality land become more inelastic and population density increases, it is imperative for Niger and its farmers to focus on yield increasing intensive technologies like fertilizer micro-dosing instead of cultivating new land.

3.3. Why micro-dosing?

The traditional inorganic fertilizer application techniques in Niger are line spreading and broadcasting. These techniques have not proven to be cost effective and efficient as they require the use of large quantities of fertilizers. With the use of micro-dosing there is an increase in productivity through fertilizer use efficiency (Liverpool-Tasie, Sanou, & Mazvimavi, 2015). Micro-dosing as initially developed by scientists at ICRISAT, consists of applying small quantities of fertilizer with the seed in the planting hole at planting.[15] Arguably due to labor constraints, farmers modified the technique to include two variants that are less labor intensive. The first consists of applying the fertilizer as top dressing 3 to 4 weeks after the plant emerges and the second method is to bury the fertilizer next to the plant after it emerges. I consider all three application types as micro-dosing in this study.

[15] The fertilizer is separated from the seed by a thin layer of soil.

There are significant yield increases associated with the practice of micro-dosing over no inorganic fertilizers. From a crop science point of view, the positive yield impact of micro-dosing results from better exploitation of soil nutrients because of the higher root volume, and pearl millet plants receiving micro-dosing export 5 to 10 times more phosphorus from the soil than the amount added through fertilization (Ibrahim, Pasternak, & Fatondji, 2014). With current millet yield averaging less than 398kg/ha (INS-Niger, 2014), ICRISAT estimates that the potential yield increase could range from 44% to 120% (ICRISAT, 2009). Micro-dosing also has the potential to serve as a famine mitigation strategy in case of late sowing. Recent experiments on demonstrations plots in western Niger showed that the positive yield response to micro-dosing increased with later sowing while late sowing tended to reduce yields on unfertilized control plots (Bielders & Gérard, 2015).

Furthermore, Nigerien farmers traditionally used fallowing as a soil fertility maintenance technique. However, with the supply of land becoming more inelastic, fallowing time has gradually declined and has become extinct in some areas (Sutter, 1979). Thus, the practice of micro-dosing is well suited to address both the yield and soil fertility management concerns. In fact, in addition to being a precision farming technique, micro-dosing is a sustainable intensification technique through efficient nutrient absorption and reduced soil degradation via soil nutrients replenishment, reduced soil erosion and enhanced water usage (Tabo et al., 2006). The recommended fertilizer application rate for micro-dosing of 20-60 Kg/ha is only slightly higher than the national fertilizer application rate of 26.3 Kg/ha. Consequently, it is likely that those who use fertilizers in Niger (largely for production of food crops such as millet) are likely to practice micro-dosing or a variant of the application technique that uses similar or less quantities of inorganic fertilizer Since it is more affordable than applying larger amounts of fertilizer, resource-poor and credit constrained farmers are likely to adopt micro-dosing (or mixing) in the first instance compared to traditional fertilizer application. Also, the lower expenditure associated with micro-dosing (or mixing) also removes some of the risk associated with poor crop yields in the event of inadequate rainfall. In spite of the proven benefits associated with the technique, the adoption rates remain low and there is even evidence of dis-adoption among fertilizer users. Thus it is important to understand what factors could explain farmers' reluctance to using the technology.

3.4. Why is it important to focus on farmers' risk attitudes?

The process of switching from using no inorganic fertilizer to adopting micro-dosing (or mixing) is a risky one. There is evidence that the degree of yield variability increases with the amount of fertilizer (Just & Pope, 1979). It follows that the increase in productivity associated with micro-dosing is also tied to the risk of a higher yield variance in the event of poor rainfall. Also, there is no return to the investment without optimal growing conditions. This is particularly important because Nigerien farmers face multiple markets failures, such as the lack of formal insurance systems or savings agencies, to protect them against potential crop failures. The practice of micro-dosing requires a minimum monetary investment, the loss of which can have irreversible adverse consequences for the less well-off farmers in the event of crop failures. In effect, the possible low consumption outcomes when harvests fail discourage the application of fertilizer and the lack of insurance or alternative means of consumption smoothing leave some trapped in low return, lower risk agriculture (Dercon & Christiaensen, 2011). Empirical evidence from a study in Ethiopia indicates that households are reluctant to adopt fertilizers when they are unable to cope with ex-post consumption risks (Dercon & Christiaensen, 2011).

Taken altogether, unfamiliarity and uncertainty related to the use of micro-dosing or mixing is higher compared to no fertilizer, which means that the farmer's risk attitudes might influence the adoption decision. Similarly, differential risk levels associated with each technique might also help explain why a greater proportion of fertilizer users practice mixing rather than fertilizer micro-dosing.

There appears to be a consensus in the literature that farmers living in rural areas of developing countries exhibit higher degrees of risk aversion. However there is limited empirical evidence on the topic in Sub-Saharan Africa. This can be partly attributed to the fact that risk preferences/attitudes are not easily observable and the ability to adequately capture these using a traditional survey question on risk attitudes is under debate. Yet when studying technology adoption, failing to account for risk preferences potentially introduces bias in the estimated effects of other determinants of adoption (Ward & Singh, 2014). I use framed field experiments because they are potentially a better elicitation method than traditional household surveys using general or hypothetical questions to capture farmers' true attitudes toward risks.

Since the use of micro-dosing is associated with a significant yield increase, knowing how farmers practicing subsistence agriculture make decisions can inform strategies for agricultural policies in Niger. Empirical evidence demonstrates that risk aversion is associated with the use of less land and less fertilizer in crop production than is risk neutrality (Hiebert, 1974). I also capture attitudes towards uncertain outcomes as it has been shown that people with lower degrees of ambiguity aversion own the most innovative firms (Rigotti, Ryan, & Vaithianathan, 2008). Hence it can be instructive to examine and understand the effect of ambiguity aversion on technology adoption. A better understanding of the role of farmers' risk attitudes in the adoption decision can help design targeted mechanisms that both eliminate sources of risk and encourage those engaging in low return, lower risk agriculture to adopt the practice of micro-dosing as a means to potentially break away from a cycle of poverty perpetuated by their current practices.

CHAPTER 2: CONCEPTUAL FRAMEWORK AND METHODOLOGY

1. Theoretical framework for micro-dosing adoption in Niger

In order to model the adoption of micro-dosing among Nigerien farmers, I consider a standard household utility maximization problem subject to cash/credit and labor constraints.

In rural Niger, like elsewhere in developing countries, farmers face multiple imperfect or missing markets including land, labor, and credit. Using country representative data, Dillon & Barrett (2014) test for factor market failures in rural parts of Niger and other countries in SSA. They find that although agricultural households actively participate in labor and land markets, their endowments influence factor demand in a way that is inconsistent with a separable household model. In effect, liquidity position and seasonal labor constraints were identified as major bottlenecks in fertilizer use in Niger (Adesina et al., 1988). Moreover, the rate of hiring for non-harvest activities is almost twice that for the harvest, indicating that the seasonal labor constraint is most likely binding in the harvest period (Dillon & Barrett, 2014). Consequently, it is appropriate to use a non-separable agricultural household model where household production decisions(including the adoption decision of a new technology) are simultaneously made with consumption and household labor supply decisions (Singh, Squire, & Strauss, 1986). The non-separable household model enables us to account for individuals' characteristics such as risk attitudes, my variables of interest, which might influence production decisions.

The use of fertilizer exposes a farmer to a higher yield variance compared to a farmer's traditional practice. This is largely due to uncertainty associated with rainfall and other agro ecological factors beyond the farmer's control. This study assumes that farmers' risk attitudes influence their fertilizer allocation decisions. I incorporate measures of risk aversion, ambiguity aversion and loss aversion. Risk aversion is the aversion to a set of outcomes with a known probability distribution while ambiguity or uncertainty aversion is the additional aversion from being unsure about the probabilities of outcomes. Farmers' experience in seeing the results of fertilization in the field has been shown to be a determinant of micro-fertilization (Abdoulaye & Sanders, 2005). If I assume that the dissemination of micro-dosing was effective and allowed the farmer to learn about the probability distribution of the yields associated with its use, then the low adoption rate can most certainly be explained by risk aversion. However, I cannot rule out ambiguity aversion because the farmer may not know the probability of high and low yields associated with the technology (Engle-Warnick et al., 2007). Although this is a plausible proposition in the Nigerien context with regard to the adoption of micro-dosing, the opposite could also be argued because the technology has been rolled out to farmers for close to two decades now. Nevertheless, I allow for ambiguity aversion in case some farmers are still learning about the technology. Farmers' decisions can further be explained by the endowment effect which indicates an individual's aversion to changing from an established behavior (Liu, 2013). Since there are potential monetary losses connected to the use of micro-dosing when growing conditions are not optimal, I also elicit a measure of loss aversion as one of my risk attitude measures.

I assume that at the beginning of each planting season, the farmer decides whether to use fertilizer or not then decides which fertilizer application method to use. The rainy season can be characterized by good or bad growing conditions. If growing conditions are good, the resulting yield with fertilizer is greater than with no fertilizer (Abdoulaye & Sanders, 2005). If growing conditions are bad, yields might be worse than under the status-quo of not using fertilizer and the farmer incurs a loss. If both the labor and cash/credit constraints are binding, which I expect in Niger, then the household's optimal choice of fertilizer level depends on a number of variables including the plot manager's attitude towards risk. I expect that farmers with higher tolerance toward risk, ambiguity and losses will be more likely to use fertilizer because they are less sensitive to the variability in yield introduced through the use of the risk increasing technology.

Consequently, the farmer's input demand for fertilizer takes into account risk attitudes along with other factors that affect the profitability of fertilizer use. These include manure use (desirable because it retains available water better), the price of fertilizer, the price of the crops on which fertilizer is applied, the availability and cost of both family and hired labor for the application of the input, as well as the size and agronomic characteristics of the plot allocated to the crop's cultivation, wealth (captured by value of assets), access to extension services, the level of education and the experience in farming contribute to the farmer's ability to use the technology well. Location specific factors that determine farmers' access to infrastructure and capture variations in administration and agro-ecological conditions are also likely to affect a farmer's input use decision. Conditional on these expected factors, I can empirically test for the significance of my variable of interest; risk attitudes and which attitudes, in particular, affect the farmer's decision to use fertilizer? I can also explore the effect that risk attitudes play on farmer's adoption of particular fertilizer application techniques, once the decision to use fertilizer has been made.

2. Estimation techniques

From the conceptual model I want to find out the effect of a change in risk attitudes on the probability that the farmer adopts fertilizer but I also need to account for potential confounding factors at a particular point in time. The decision to use fertilizer and to practice a particular application method depends on an unobservable latent variable (here the farmer's utility) which is determined by one or more explanatory variables such as the larger the farmer's utility, the greater the probability of a farmer adopting fertilizer. I do not observe the latent variable but I can measure the ultimate decision in terms of the farmer being a fertilizer user or not a fertilizer user.[16] Consequently, I adopt a binary response model to estimate the response probability of using fertilizer based on the set of explanatory variables described above i.e. $P(\boldsymbol{Y} = \mathbf{1}|\boldsymbol{X})$ (Wooldridge, 2010). I opt for a probit model where the response probability depends on a set of parameters which are a function of the standard normal cumulative distribution function. This ensures that the estimated response probabilities are strictly between zero and one. Since the data contains one plot manager for several plots in some instances, to obtain robust standard errors for accurate statistical inference, I cluster at the household level to allow for intragroup correlation.[17]

Given my focus on the practice of micro-dosing versus mixing seeds with fertilizer it is important to assess the heterogeneous factors associated with the decision to practice each technique. This heterogeneity may be driven by labor and non-labor input costs at the time of planting. Abdoulaye & Sanders, (2005) demonstrate that fertilization is a stepwise decision in Niger.[18] Once the traditional soil-fertility maintenance system breaks down due to population pressure, falling yields forces farmers to increase their consumption of organic fertilizer. Secondly, they move on to mixing small quantities of inorganic fertilizer with the seed in the seed pocket at planting (mixing fertilizer with seeds) and finally adopt a fertilizer application method that allows for the use of greater quantities of fertilizer applied to the plant outside of the seed pocket during side dressing (micro-dosing). This might mean that by the time the farmer starts practicing micro-dosing (and mixing to some extent) the learning and experimentation period is over. Thus I assume that fertilizer is not a new technology in Niger.[19]

[16] I focus on this binary decision first because all farmers mentally go through this process before choosing their preferred application method.
[17] I opt to cluster at the household level because I am interested in differences in plot management behavior across households. Results with standard errors clustered at the village level remain qualitatively unchanged.
[18] This is just one hypothesis of fertilizer adoption in Niger. Although it does not involve risk attitudes, it provides a good overview of the adoption process.
[19] Given that fertilizer is not a new technology in Niger, ambiguity aversion should not matter.

To further explore this idea, I explore the labor requirement, fertilizer quantities and costs associated with each technique. These results are presented in Table 2. They confirm that compared to mixing seeds with fertilizer, micro-dosing requires greater quantities of fertilizer and consequently greater monetary investment per hectare at planting.

From anecdotal evidence, the general belief is that micro-dosing is more labor intensive than mixing fertilizer with seeds. Thus, it is surprising that the median total man-days per hectare for fertilizer application is greater under mixing seeds with fertilizer in the study sample. These differences imply potentially different returns on investment and associated risk between micro-dosing and mixing fertilizer with seeds and the necessity of differentiating between them.

Table 2: Mean comparison of labor, fertilizer and yield across fertilizer application techniques

	Micro-dosing		Mixing	
	Median (SE)			
Total man-days per hectare for plot prep	4	(18.09)	3.6	(18.94)
Total man-days per hectare for planting	6.7	(11.06)	11.1	(17.31)
Total man-days per hectare for weeding	40	(17.97)	28	(19.18)
Total man-days per hectare for harvest	20	(19.03)	6	(19.33)
Total man-days per hectare for planting and harvest	300	(100.80)	300	(105.50)
Total man-days per hectare for all planting activities	100	(27.80)	100	(30.42)
Total quantity of fertilizer on plot (kilograms/hectare)	15.83	(71.01)	5.357	(57.30)
Yield in kilograms per hectare	375	(568.50)	399.2	(552.10)
Cost of fertilizer on plot (10000 FCFA/hectare)	0.121	(1.31)	0.121	(0.77)
Total man-days per hectare for fertilizer application	2.2	(13.36)	3	(15.84)
Number of observations	32		60	

Note: *This information is restricted to farmers using some fertilizer. Median values for mixing =1 and micro-dosing =1.*

Conditional on using fertilizer, the decision to use either micro-dosing or mixing could be made separately or jointly by farmers. If jointly made, a seemingly unrelated bivariate probit model would be the appropriate estimation technique to explore the effects of risk attitudes on the probability of using a particular technique. However if separately made, the conditional probit regression is more suitable.[20] With a rho value of -1 and p-value of 0.8 I fail to reject the null hypothesis that the decision whether to use micro-dosing and mixing are made separately. Thus a conditional probit regression is used to identify the effect of risk attitudes on the decision of which fertilizer application technique to use conditional on fertilizer use.

3. Identification strategy

The variable of interest in this study is the farmer's risk attitude. I conduct a series of field experiments to elicit farmers' risk attitudes. As mentioned earlier, I have two broad elicitation techniques, hypothetical and incentivized, which were collected roughly a month apart from each other. The timing of the surveys were strategically determined to minimize the likely exposure of respondents to shocks that would likely systematically affect their responses. I did not observe the occurrence of any exogenous shocks during the time gap between the data collection. Therefore, I am confident that differences in responses between the two experiments (hypothetical and incentivized) are most likely driven by the monetary stakes. Furthermore, risk attitudes are stable over time. Harrison, Johnson, McInnes, & Rutström, (2005) found that among students risk preferences are stable over a six month period; Love & Robison (1984) found that they are stable over a 2 year period for Midwestern farmers. Thus it is very unlikely that respondents' risk attitudes changed between the two experiments or that the adoption of the technology would have had any significant effect. Although, attrition (approximately 1%) between the two data collection is limited in the surveyed sample, I restrict the analysis only to those respondents for whom I have measures of risk attitudes for both the hypothetical and incentivized experiment.

[20] This is not to be confused with conditional probit estimations.

Thus, I use the risk attitude parameters elicited through the framed field experiments and relate them to the farmers' adoption decisions as outlined in the conceptual framework. As mentioned earlier, fertilizer is not a new technology in Niger and this is reflected in the sample. Using recall data from 2003/2004 to 2013/2014 agricultural season for the 237 plot managers in the study, I am able to identify whether a farmer used fertilizer for three, five and ten consecutive years.[21] Restricting the sample to the group of current fertilizer users, I am also able to evaluate whether they practiced micro-dosing for three, five and ten consecutive years. Table 3 below highlights that ten years ago almost 50% of plot managers in this analysis were using fertilizer. This numbers gets larger as I move closer to the 2013/2014 agricultural season to 76%. Moreover, when I look at the practice of micro-dosing, I see that the number of respondents who report consistently using the technique increases over time. This indicates that the majority of farmers are familiar with the use of fertilizer and many more have started using micro-dosing in recent years. The persistence of fertilizer use but not necessarily micro-dosing indicates that farmers are using alternative methods of fertilizer application techniques.

Table 3: Persistence of fertilizer use and practice of micro-dosing among current fertilizer users

Variable	Mean (N=640)	Standard Deviation
Used fertilizer consistently over the last 3 years	0.76	0.42
Used fertilizer consistently over the last 5 years	0.6	0.49
Used fertilizer consistently over the last 10 years	0.46	0.5
Used micro-dosing consistently over the last 3 years	0.07	0.26
Used micro-dosing consistently over the last 5years	0.06	0.24
Used micro-dosing consistently over the last 10years	0.03	0.17

Note: N is the total sample size.

[21] To address potential challenges with recall, enumerators used key events to help respondents identify specific years.

To accurately estimate and interpret the true effect of risk attitudes on the probability of using fertilizer and the decision to practice micro-dosing over mixing fertilizer and seeds, I need to be aware of the potential effect of confounding factors. I have to account for explanatory variables which could lead to biased and inconsistent estimates if they were omitted. The following paragraphs discuss some key variables that might be correlated with some of the variation in risk attitudes.

Following the literature on technology adoption, a key set variables that influence the adoption decision need to be controlled for more precise estimates. A growing literature (Marenya & Barrett, 2009; Sheahan, Black, & Jayne, 2013) supports the importance of soil characteristics, such as fertility status, in influencing the use of fertilizer. Marenya & Barrett (2009) found that western Kenyan farmers' fertilizer application behaviors differ markedly across plots of different soil quality. Thus, I control for this by including a proxy variable which is a dummy equal to 1 if the farmer believes his plot is fertile and equal to 0 otherwise. Interaction with extension agents and plot neighbors, participation in test and/or demonstrations also allow the farmer to gain information on micro-dosing; hence I include a variable to capture access to information.

Contrary to most studies in the literature of technology adoption, I can control for individual risk attitudes. Therefore, it is important to consider variables that are related to technology choice and also likely correlated with risk attitudes. First I consider demographic characteristics that may affect the decision to use fertilizer and also affect risk attitudes. An earlier study by Moscardi & Janvry (1977) using data from small Mexican subsistence farmers, suggested that risk attitudes might be a function of socioeconomic variables such as family size and age. More specifically, older people tend to be more risk averse (Binswanger, 1980; Yesuf & Bluffstone, 2009); Household size is associated with lower levels of risk aversion (Hardeweg et al., 2013; Wik, Aragie Kebede, Bergland, & Holden, 2004). Additionally, using data from rural Ethiopia, Knight et al. (2003) found that education encourages farmers to adopt agricultural innovations and decreases risk-aversion. Moreover, the literature of technology adoption often considers that family size, age and education influence farmers' technology choices (Feder et al., 1985). Education can be a proxy for exposure to information regarding new technologies, family size a proxy for family labor availability, and age may represent experience. Consequently, I will control for family size, age and education as they are potential confounders in this study.

A potential threat to the internal validity of this study is the effect of rainfall variability. Water availability affects the decision to adopt fertilizer but it can also be correlated with risk attitudes. Experimental results demonstrated that higher rainfall during the early growing season favored a positive response to micro-dosing (Bielders & Gérard, 2015). In addition, farmers' perception of the riskiness of fertilizer use is certainly related to their expectations about rainfalls in a given year. Indeed, risk preferences may be generally driven by psychological mindsets (Eckel, El-Gamal, & Wilson, 2009). Thus, it is possible that living in an area subject to high rainfall variability leads to more risk averse behavior. Additionally, rainfall variability might influence migration decisions. It is possible that those with higher risk tolerance might choose to remain in (or move to) places where there is more rainfall variability. To address this issue, I add annual precipitations as a control variable. This allows us to control for the exogenous variation in the availability of water but also capture regional variation in rainfall.

Furthermore, the degree of risk aversion is correlated with wealth, which also affects fertilizer use. Rosenzweig & Binswanger (1993) suggest that wealthier households invest in riskier agricultural activities and an experimental study in Zambia found that wealthier farmers tend to exhibit lower levels of absolute risk aversion (Wik et al., 2004). Since fertilizer is a costly input and requires complementary labor inputs that can be costly as well, it is evident that household's liquidity position also affects fertilizer use. I control for this by including livestock possessions which tend to be a good proxy for the poverty status of rural Nigerien households (INS-Niger, 2013).

I assume that the decision to use fertilizer is a two stage decision process. First, the farmer decides whether to use fertilizer or not on the plot. In the second stage, the farmer decides which fertilizer application technique to use. Following from Wooldridge (2010), the empirical specification for the binary decision is:

$$\mathbf{P}(y = 1|\boldsymbol{x}) = G(\boldsymbol{x\beta}) \quad (1)$$

where y is the binary variable of adoption taking the value of 1 if a farmer uses fertilizer on the plot. $\boldsymbol{G}$ is the standard normal cumulative distribution function. $\boldsymbol{X}$ is a vector of characteristics of a farmer in a specific household. It includes age, gender, formal education, household size, measures of risk attitude, and the number of years in farming. The risk attitude variables are continuous with higher values denoting lower degrees of risk aversion, ambiguity aversion or loss aversion. In addition, we add a vector of control variables that affect the decision to use inorganic fertilizer on a particular plot. These include the area allocated to crop production, use of organic fertilizer, soil fertility, wealth, indicators of climatic growing conditions, knowledge of inorganic fertilizer, distance to market, price of input, and regional characteristics. We also add village fixed effects to control for characteristics like infrastructure and administrative factors or production shocks that affect production decisions and input demand. The empirical model for the conditional probit is estimated only for those using some fertilizer. It is the same as above except that now the outcome variable y takes the value of 0 if a farmer mixes seeds with fertilizer on the plot, and the value of 1 if the farmer practices micro-dosing on the plot.

4. Experimental design and procedures

Risk elicitation methods can be broadly divided into hypothetical (non-incentivized) and incentivized methods. The hypothetical technique includes a general risk assessment question or hypothetical questions with context specific details relevant to farming activities that can improve the farmer's ability to understand the question and thus allow them to more readily place themselves on the risk scale. In effect, the hypothetical context specific method models real life agricultural decisions related to the use of inorganic fertilizer. The literature also suggests that if measures of risk preferences are to be associated with actual risk-taking behavior, their elicitation should be incentivized in order to ensure that choices more accurately reflect true underlying attitudes toward risk (Charness et al., 2013; Holt & Laury, 2002). Consequently, the second elicitation approach I use includes an incentivized contextualized framed field experiment (with fertilizer). By including both hypothetical and incentivized fertilizer context specific assessment experiments I am able to explore whether contextualized questions and/or incentives matter when eliciting risk preferences in rural agricultural settings. More specifically, comparing the hypothetical and incentivized versions of the fertilizer question provides a unique opportunity for a true comparison of the effect of incentives when eliciting risk attitudes without confounding factors from changing contexts associated with previous comparisons observed in the literature (Charness & Viceisza, 2012; Dohmen et al., 2011; Hardeweg et al., 2013).

I also conduct incentivized HL-like experiments to elicit risk over gains, risk over ambiguity and risk over losses. These elicited measures of loss aversion and ambiguity aversion enable me to better understand how each type of aversion influences (or does not influence) the farmer's behavior and the subsequent adoption decision. All the experiments were implemented by individual explanation provided by enumerators in the relevant local language: Haoussa, Zarma or Fulani. Each interview lasted between thirty to forty minutes. The enumerators were trained beforehand in French then in the local language and proceeded to a testing of the instrument to ensure they would communicate the tasks appropriately and uniformly to participants. Each respondent was presented with visual aids depicting all the possible choices to facilitate a good grasp of the games.

The general hypothetical risk question is inspired by Dohmen et al. (2011) which requested that respondents give an assessment of their general willingness to take risks on a 0-10 scale. In this study, I simply ask that participants give an assessment of their general willingness to take risks on a 4-point Likert scale where the value 1 means "avoids risk most of the time" and the value 4 means "take risk most of the time". This approach has two main features: (1) there are no financial incentives provided, and (2) this question is not specific to any context.

The production specific questions implemented without monetary stakes (hypothetical) and with payouts (incentivized), are modeled after the experiments in Gneezy & Potters, (1997). Using real monetary payoffs, Gneezy & Potters, (1997) give respondents a simple choice of how much to invest in a risky asset with a positive expected profit from investing. For example each person is endowed with 100 cents. Any part of this amount could be invested in a risky asset and the rest is kept by the participant. The risky asset returns 2.5 times the amount invested with a probability of one-third and nothing with a probability of two-thirds.[22] The Gneezy and Potters experiment has the advantage of being easy to understand and has been previously implemented in a developing country setting (see Charness & Viceisza, 2012). I frame the experiments in this study in terms of "fertilizers" and "yields".

[22] The expected value of investing is higher than the expected value of not investing. A risk-neutral (or risk seeking) individual should invest the entire starting endowment.

In the task, I presented farmers with a scenario where they have to choose 10 sachets of fertilizer. I framed the decision in terms of how many of those 10 sachets will they choose to be of "risky fertilizer". As shown in Figure 1 farmers are told that the plot yields 500 kg (5 bags of 100 kg each) of millet without the use of fertilizer. At the conclusion of the game, the farmer payout was calculated at CFA 25 for each millet bag of 100 kg.[23] The traditional non-risky fertilizer (type 2) available in 2 kg sachets has a certain yield distribution. Specifically, it increases the yield of the plot by 100 kg (1 bag) for every sachet of fertilizer regardless of the growing conditions (temperatures). The new type of risky fertilizer (type 1) - also available in 2 kg sachets - generates higher yields than the traditional fertilizer under good conditions but significantly lower yields in bad conditions. Specifically, it increases the yield of the plot by 300 kg (3 bags) per sachet of fertilizer in good weather but increases the yield by only 10kg per sachet of fertilizer in bad weather. I simulate random growing conditions by flipping a coin. If the coin came up heads then conditions were good and bad otherwise (tails).

[23] At the time of the experiment US$1 was equivalent to CFA 470.

Figure 1: Incentivized and hypothetical fertilizer elicitation table

			Many days of good growing temperature 50% likely 				Many days of temperatures too hot for growing 50% likely 			
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Option	Fertilizer 1 (New) (2kg **sachets**)	Fertilizer 2 (traditional) (2kg **sachets**)	Plot yield with no fertilizer **(100 kg bags)**	Yield Increase from Fertilizer 1	Yield Increase from Fertilizer 2	Total Plot Yield **(100 kg bags)**	Plot yield with no fertilizer **(100 kg bags)**	Yield Increase from Fertilizer 1	Yield Increase from Fertilizer 2	Total Plot Yield **(100 kg bags)**
A	0	10	5	0	10	15	5	0	10	15
B	1	9	5	3	9	17	5	0.10	9	14.1
C	2	8	5	6	8	19	5	0.2	8	13.2
D	3	7	5	9	7	21	5	0.3	7	12.3
E	4	6	5	12	6	23	5	0.4	6	11.4
F	5	5	5	15	5	25	5	0.5	5	10.5
G	6	4	5	18	4	27	5	0.6	4	9.6
H	7	3	5	21	3	29	5	0.7	3	8.7
I	8	2	5	24	2	31	5	0.8	2	7.8
J	9	1	5	27	1	33	5	0.9	1	6.9
K	10	0	5	30	0	35	5	1	0	6

As shown in Figure 1, farmers were presented with a table including all possible combinations associated with the number of sachets of risky fertilizer and non-risky fertilizer that one might choose. The incremental yield observed from the use of fertilizer is added to crop production without fertilizer i.e. 5 bags of millet. The resulting table comprises 11 options. Suppose the farmer opts for 7 sachets of the new risky fertilizer and 3 sachets of the non-risky traditional fertilizer (which corresponds to option H in the table). If conditions are good, the field would yield 29 bags and pay FCFA 725. On the other hand, if conditions are bad, the field would yield only 8.7 bags and the consequent payout would be FCFA 217.5.[24] Clearly, a preference for more sachets of the risky new fertilizer indicates lower degrees of risk aversion.[25] The use of

[24] During the experiments the monetary payoffs were rounded up to the nearest FCFA 5 the smallest coin available.
[25] Note that in figure 1, option K denotes risk neutrality because it has the highest expected value.

monetary incentives in the incentivized fertilizer experiment is to encourage participants to reveal their true preferences (Andersen, Harrison, Lau, & Rutström, 2006).

A growing body of research cautions against imposing restrictive assumptions (i.e. using expected utility theory) on behavioral parameters in describing individuals' decision making process (de Brauw & Eozenou, 2014; Liu, 2013; Tanaka, Camerer, & Nguyen, 2010; Ward & Singh, 2014). In standard expected utility theory, risk aversion is the only parameter that determines the curvature of the utility function. In prospect theory (Kahneman & Tversky, 1979) the curvature of the utility function is jointly determined by parameters of risk aversion, loss aversion, and nonlinear probability weighting (the individual tendency of overweighing small probabilities and underweighting large probabilities) (Liu, 2013).[26] The experimental design does not make any assumptions about the underlying decision process (whether preferences conform to expected utility theory or cumulative prospect utility theory). For each experiment, I treat the elicited risk attitudes for each respondent relative to the responses provided by the other participants in the sample. This means that I do not calculate any coefficients of risk aversion but instead evaluate degrees/levels of relative risk attitudes. Nevertheless, the combination of three elicitation methods enables us to identify three different non-parametric measures of attitudes towards risk (degrees of risk, ambiguity and loss aversion) over a series of experiments.

Consequently, the final set of experiments were designed to elicit individuals' preferences toward (i) risk , (ii) ambiguity and, (iii) losses using a lottery choice mechanism similar to Holt & Laury (2002). In the typical Holt & Laury experiment, the participant is presented with a list of 10 to 20 decisions between paired gambles with changing probability distributions. For every decision row, the participant chooses which gamble he/she prefers to play from each pair. In contrast to

[26] Individuals' valuation of a particular prospect/lottery is conditioned by the asset position of the individual (personal reference point) and the change in the asset position from that reference point represented by the prospect.

Holt & Laury (2002), the experimental design used here asked participants to choose between a fixed lottery and a changing safe payoff. The lottery was presented to participants as 10 colored balls in a bag to facilitate a clearer sense of the gamble. The tables used for the elicitation of the HL measures of risk attitudes are provided in Appendix 1.

In the risk over gains experiment, participants were presented with a list of 20 choices between a varying safe payoff (Option B) and a fixed lottery (Option A). For every decision choice or row, the participant chooses which option (A or B) she prefers. To minimize potential inconsistencies in choices that could be linked to a lack of comprehension, I enforced monotonic switching. It is a common practice in the risk preference literature to ensure that results are not altered by a lack of understanding of the experiment (Liu, 2013; Tanaka et al., 2010). Specifically, respondents were asked to move down the list and once they switched from the risky option to the safe option they were not allowed to switch back. This is not to say that they were not allowed to change where they wanted to switch, but they were prevented from switching multiple times.[27] This is important since the "switching row" allows us to determine the respondent's relative risk attitude. While each of the 20 rows in the table constituted a choice, the participant was informed in advance that one pair of decisions would be randomly selected and played out for payment using a 20-sided die.

As the respondent moves down the table (see Appendix 1), the value of the safe payoff increases by an amount equal to FCFA 60 while the values for the fixed lottery could be either FCFA 0 or FCFA 1,200. The value of FCFA 0 corresponds to drawing a white ball and FCFA 1,200 corresponds to an orange ball draw. As shown in Appendix 1, the expected value of the safe payoff becomes greater than the expected value of the lottery. In all cases except risk over

[27] The options of never switching (always choosing A) or switching at row 1 (always choosing B) were available

ambiguity, participants were allowed to check that the bag contained five white balls and five orange balls. That is the probability of choosing a white ball or an orange ball is 50% chance. As shown in Appendix 1, the first 9 rows offer the choice of a higher expected payoff in the gamble relative to the certain payoff, while the final 10 choices offer an expected payoff lower in the gamble. In row 10, the expected value of the gamble is CFA 600 – the same as the 'safe' choice. The individual exhibiting lower degrees of risk aversion switches from choosing the lottery option (Option A) to choosing the safe payoff (Option B) further down the table (higher row numbers).The only difference between the risk over gains and risk over ambiguity experiment is the unknown probabilities in the gamble (i.e. the number of white versus orange balls in the bag).

In the risk over losses experiment, the gamble is not fixed while the safe payoff is For this choice experiment, the lottery choice involves a 50 % chance of winning FCFA 1,200 versus a 50% chance of losing an amount that increases as one moves down the rows. The safe option (Option B) is a zero payoff. As shown in Appendix 1, the first 9 rows offer the choice of a positive excepted payoff in the gamble relative to the zero payoff, while the final 10 choices offer a negative expected value in the gamble. In row 10 the expected value of the gamble is zero – the same as the 'safe' choice. Clearly, then switching from the lottery to the safe amount further down the table indicates a lower degree of loss aversion.

Note that it is possible to lose up to FCFA 2,400 in the risk over loss experiment. As such, participants were endowed with 2400 FCFA (about $5USD) to ensure that they could not end up owing the experimenters money. In order to avoid ordering or endowment effects due to earnings in the previous rounds, the outcomes were not determined until after all decisions had been made. The average payout was 4,159 FCFA for the 396 participants.[28] This average represents

[28] 4,207 FCFA for the 207 respondents and 4,176 FCFA for the 189 male respondents.

approximately four times the median daily wage of an agricultural laborer in rural Niger.[29] This average amount should thus be large enough to generate a less noisy risk attitude measure relative to a hypothetical payoff (Camerer & Hogarth, 1999; Holt & Laury, 2002).

[29] The median daily wage of an agricultural laborer is about 1094 FCFA (Dillon & Barrett, 2014).

CHAPTER 3: DATA, SAMPLE SELECTION AND SUMMARY STATISTICS

1. Data

The analysis in this study relies on two main data sources namely an agricultural household survey and data from risk preferences elicitation experiments administered in four regions of Niger – Dosso, Maradi, Tillabéri and Zinder. These four regions are mainly in the southern Sahelian, Sahelo-Sudanian and Sudanian agro-ecological zones, where crop production is most feasible. Although this is not a nationally representative sample, this group of regions capture the variation across important dimensions relevant to the adoption of a technology like micro-dosing such as rainfall, soils, population density, and access to markets, services, and assets. In addition, in the early 2000s, these regions were the first to see the establishment of input supply shops by a project funded by the Food and Agricultural Organization (FAO) and where the micro-dosing technology has been promoted through on-farm trials and demonstrations (Pender et al., 2008).

The agricultural household survey was designed to include questions on landholdings, resources such as labor, inputs for crop production, experience using modern and traditional inputs, and non-agricultural income sources. In addition, information was collected on demographic characteristics and risk attitudes using a general survey instrument and hypothetical experiments (i.e. without payout). Using the same respondents as in the household survey, I randomly select a subset to conduct incentivized field experiments (with monetary payoffs) to elicit farmers' risk attitudes. While the experiments yield information about farmers' risk attitudes, the household survey provides detailed information on agricultural production decisions useful to provide answers to the research objective outlined in this paper.

2. Sample selection

The sampling strategy and village selection for the primary data collection builds on the one adopted by a previous study conducted by the International Food Policy Research Institute in Niger between 2004 and 2005. The sample selection used in that study was both purposive and random. Of the 40 villages selected 10 were purposely selected because they had well-functioning input supply shops. In each of the selected villages, a random sample of 10 households was drawn from a listing of households in the village. In all 397 households were interviewed during the first round in 2004-2005. A follow up round administered by ICRISAT between April and May in 2014 collected data on about 800 households comprised of the same 400 households interviewed in 2005 and 400 new households. The new households were randomly selected from 40 villages (different from the ones included in the earlier survey) randomly selected in Dosso, Maradi, Tillabéri, and Zinder using the Repertoire National des Communes (RENACOM) database.

The framed field experiments were conducted from June 25, 2014 to July 3, 2014 at the onset of the raining season in the four regions to avoid that responses are influenced by the expectation of the outcome of the 2014 agricultural season. The subsample chosen for the incentivized field experiments is a randomly selected group of 20 villages from the larger sample of 80 villages included in the agricultural household survey. Figure A- 5 in Appendix 1 graphically shows the geographic location of the subsample in Niger. In each village, I elicited measures of risk attitude from the same respondents who completed the household survey, except for some female respondents who will be dropped from the analysis. In total, I conducted field experiments with 396 respondents including 198 male and 198 female .[30] Male respondents were consistently plot managers while some of the female respondents were not. For the purpose of this study I use

[30] 1 household in Marafa Koara and 1 in Winde-Beri were not available for the survey.

a combination of the field experiments and the agricultural household survey. This means that I can only use experimental measures for which I have both demographic and agricultural production data. As shown in Table 4 below, the plot level analysis in this paper will involve 237 plot managers responsible for a total of 640 plots.

Table 4: Description of the data used in the analysis

Elicitation method	Data collection method	Number of unique individuals	Number of plots by gender of plot manager
Hypothetical fertilizer	Household survey only	195 Male 43 Female	582 Male 62 Female
Hypothetical seed			
General risk assessment			
Incentivized fertilizer	Field experiments only	198 Male 198 female	
Risk over gain			
Ambiguity over gain			
Loss over gain			
Hypothetical fertilizer and Incentivized fertilizer combined	Combined household survey and field experiment	194 Male 43 Female	578 Male 62 Female

3. Summary statistics on fertilizer use trends as well as households and plot characteristics

In an earlier chapter, I presented the low rate of fertilizer use in Niger among farming households (17%) with conditional use rates of 26.3 kilograms of fertilizer per hectare. Using the Niger LSMS-ISA 2010-2011 data, Table 5 presents the proportion of fertilizer users and the mean quantity of fertilizer application across regions. On an aggregate level, the application rate per hectare is low but there exists some regional disparities as evidenced by rates greater than 50 kilograms per hectares in Agadez, Diffa and Niamey. The regions included in this analysis exhibit some of the lowest application rates at the plot level. Paradoxically in Dosso, the region with the greatest percentage of fertilizer users, the mean quantity of fertilizer applied per hectare is almost half of the rate observed at the national level (of 22.57 kilograms per hectare). I have demonstrated earlier that the fertilizer quantity requirement varies across application techniques. Thus, with no information on the prevailing fertilizer application technique in each region I cannot draw any strong conclusions from the descriptive statistics in Table 5 and I proceed to analyze fertilizer use trends in the sample used in this paper.

Table 5: General fertilizer use among farmers in Niger at the household level

	Number of observations	% using fertilizer	Mean quantity of fertilizer applied among users (kilograms/hectare)
All regions	2225	16.6	26.8
Agadez	89	16.8	94.3
Diffa	220	21.7	191.6
Dosso	384	34.7	16.8
Maradi	378	15.1	18.2
Tahoua	363	4.0	20.6
Tillabéri	351	20.4	15.7
Zinder	369	15.9	17.5
Niamey	71	35.4	120.7

Source: Author estimations from the Niger LSMS-ISA 2010-2011 data

Table 6 shows inorganic fertilizer use trends for the data. One of the advantages of this dataset is that it provides a breakdown of the fertilizer application methods thereby allowing for a more in depth analysis of farmers' behavior at the regional level. Farmers in Dosso mostly mix seeds with fertilizer. This might explain why the average quantity of fertilizer applied is relatively low in the nationally representative data (shown in Table 5). Micro-dosing is the application of choice among farmers in Zinder. For a region located in the drier part of the country and often confronted with erratic rainfalls, this trend confirms the claim by Bielders & Gérard,(2015) that micro-dosing can serve as a risk hedging technique in the event of late sowing due to the increased yield response. In Maradi, farmers seem to use both micro-dosing and mixing more than in any of the other regions. It is interesting to note that farmers in the two regions located in the western part of the country (Tillabéri and Dosso) use inorganic fertilizer the most and seem to prefer mixing to micro-dosing. The higher rate of use of inorganic fertilizer use might be explained by ease of access and lower transaction costs since both Tillabéri and Dosso are relatively closer to the capital Niamey. Micro-dosing appears to have appealing characteristics to both dry and more favorable agro-ecologies. In the eastern region of Zinder, also located in a drier part of the country where soils tend to have low nutrient content, a larger proportion of fertilizer users seem to prefer micro-dosing to mixing. The same holds true for Maradi, located in the south-center of the country, and gifted with very fertile soils and known for its agricultural production (Serra, 2015). Together, the patterns observed in Table 5 and Table 6 indicate that the diffusion of fertilizer in Niger is not uniform and is subject to regional specificities that may be linked to the agro-ecology of the regions or fertilizer dissemination strategies within the country.

Table 6: Inorganic fertilizer use trends at the plot level

	Tillabéri (N=168)	Dosso (N=223)	Maradi (N=158)	Zinder (N=91)	All (N=640)
Plots using inorganic fertilizer (%)	42.26	39.46	27.85	21.98	34.84
Fertilizer use across all households (includes zeros) (kilograms/hectares)	21.91	6.96	6.21	1.13	9.87
Fertilizer use across only fertilizer using households (excludes zeros) (kilograms/hectares)	51.85	17.64	22.31	5.15	28.33
Micro-dosing (excludes zeros) (%)	16.90	23.86	50.00	65.00	30.49
Mixing seeds with fertilizer (excludes zeros) (%)	54.93	61.31	25.00	15.00	47.98
Micro-dosing and mixing seeds with fertilizer (excludes zeros) (%)	14.08	9.09	22.73	15.00	13.90
Traditional application methods (excludes zeros) (%)	14.08	5.68	2.27	5.00	7.62

Note: N is the number of observations.

With this broad picture of fertilizer use across the regions, I turn to the farmers and their plots. Table 7 presents summary statistics on individual, household and plot characteristics by fertilizer use status.

It is not surprising that female plot managers use on average less fertilizer than men. One of the factors that explains the gender productivity gap in Niger, is linked to gender differences in the quantity and quality of fertilizer use with men using more inorganic fertilizer per hectare than women (McGee & Backiny-Yetna, 2015). The level of education also seems to be important in determining fertilizer use. On average, fertilizer users are more likely to have attended primary, and secondary school and in very few instances have completed some university level coursework. Additionally, fertilizer users tend to be wealthier than non-fertilizer users. This makes sense because most farmers tend to be cash strapped at planting time and only the relatively wealthier can afford the investment required to acquire the input.

Farmers who own relatively larger plot sizes are fertilizer users in the sample. However, it can be viewed as a proxy for wealth in which case it indicates the ability to afford inputs. The descriptive statistics also identify access to information about fertilizer as a factor that can potentially determine the use of the input. Most inorganic fertilizer users also use organic manure. This supports the theory of a stepwise fertilization strategy which stipulates that Nigerien farmers start using inorganic fertilizer only when organic fertilizer use becomes insufficient for crop production. As an important complementary input in the use of fertilizer, good precipitation is a key factor in rain-fed agriculture. This is illustrated in the table with fertilizer users experiencing on average greater precipitation. The significant difference in temperature experienced by users and non-users tells us that it is a factor that farmers take into account when making their production decisions with regards to the use of inorganic fertilizers. Lastly, the types of crops grown provide some useful information on the likelihood of fertilizer use on that plot. The millet-cowpea cropping system is indicative of fertilizer use while sorghum in pure standing or millet-sorghum-cowpea intercrop suggest the opposite. These observations are aligned with another study (see Pender et al., (2008)) in Niger which found that inorganic fertilizer applied using micro-dosing has a negative impact on yield of the millet-sorghum-cowpea intercrop.

Table 7: Descriptive statistics of difference in means at the plot level

	No fertilizer			Fertilizer		
Variables	N	Mean	Standard deviation	N	Mean	Standard deviation
Female plot manager (1/0)*	417	0.127	0.333	223	0.0404	0.197
Age	395	50.69	15.71	219	50.38	14.43
Household head received formal education (1/0)*	417	0.144	0.351	223	0.278	0.449
Household head received Koranic education (1/0)	417	0.348	0.477	223	0.291	0.455
Number of years engaged in farming	415	33.99	15.78	223	33	17.4
Household size	417	14.17	7.62	222	14.87	8.818
Average market value of livestock owned (in 10,000 FCFA)*	375	16.55	15.10	218	20.62	15.58
Farmer organization member(1/0)*	417	0.384	0.487	223	0.466	0.500
Millet (1/0)	417	0.139	0.346	223	0.112	0.316
Millet-cowpea (1/0)*	417	0.218	0.414	223	0.386	0.488
Cowpea (1/0)	417	0.655	0.476	223	0.713	0.453
Sorghum (1/0)*	417	0.405	0.492	223	0.305	0.461
Millet-Sorghum(1/0)	417	0.0408	0.198	223	0.0359	0.186
Millet-sorghum-cowpea(1/0)*	417	0.278	0.449	223	0.188	0.392
Hibiscus (1/0)	417	0.12	0.325	223	0.0852	0.28
Millet-cowpea-hibiscus(1/0)	417	0.0767	0.266	223	0.0673	0.251
Total area of plots owned (hectares)*	417	8.215	5.735	223	9.664	6.209
Number of plots owned	417	3.671	1.671	223	3.865	1.476
Plot area cultivated (hectares)	417	2.394	3.135	223	2.549	2.208
Millet area (hectares)	417	0.218	0.708	223	0.3	1.108
Millet-cowpea area (hectares)*	417	0.828	2.146	223	1.859	3.673
Millet-sorghum area (hectares)	417	0.148	0.886	223	0.148	0.935
Millet-sorghum-cowpea area (hectares)	417	1.951	6.281	223	1.249	3.332
Millet-cowpea-hibiscus area (hectares)	417	0.59	3.064	223	0.413	2.022
Fertile soil (1/0)	417	0.612	0.488	223	0.623	0.486
Main source of information about fertilizer is extension agent or development project*	417	0.396	0.49	223	0.475	0.501

Table 7 (cont'd)

Variables	No fertilizer			Fertilizer		
	N	Mean	Standard deviation	N	Mean	Standard deviation
Distance to/from plot to nearest market (kilometers)	414	6.218	5.079	223	6.02	5.106
Mean temperature of wettest quarter (10*C)*	417	277.5	4.245	223	278.6	5.3
Annual Precipitation (mm)*	417	447.7	128.8	223	498	100
Price of fertilizer at the village level (in 10,000 FCFA)	366	0.119	0.327	203	0.0903	0.272

*Note: Variables with * have significantly different means across fertilizer use status, N is the number of observations.*

4. Summary statistics of risk attitudes

This section briefly describes the various measures of risk attitudes elicited in this study. Table 8 shows mean coefficients for the measures of risk attitudes. Three out of the four measures of risk aversion are statistically significantly different between fertilizer users and non-users. In all the three cases, fertilizer users exhibit lower degrees of risk aversion compared to non-users. This provides some ground for the part of this study's objective which is to disentangle the effect of risk attitudes, in general, and risk aversion, in particular, on the use of fertilizer in Niger. Farmers in the sample do not seem to be different with regards to ambiguity over gains or losses over gains. The fourth measure of risk aversion, hypothetical fertilizer, does not indicate that risk aversion deters farmers from using inorganic fertilizer. Several factors, including inadequate elicitation methods can explain this paradoxical result and that is what I aim to explore in the next section.

Table 8: Descriptive statistics of difference in means for measures of risk attitudes

	No fertilizer			Fertilizer		
	N	Mean	Standard deviation	N	Mean	Standard deviation
Incentivized fertilizer*	164	7.317	2.751	73	7.562	2.858
HL-like risk over gains*	164	6.64	8.883	73	6.781	8.834
HL-like risk over ambiguity	164	7.945	9.358	73	6.863	9.086
HL-like risk over losses	164	8.457	9.448	73	9.507	9.446
General risk question*	144	1.604	1.059	67	1.94	1.153
Hypothetical fertilizer	141	6.858	3.352	66	7.348	3.873

*Note: General risk question is measured on a 4-point Likert scale ranging from 1 (avoid risk) to 4 (take risk). Incentivized and hypothetical fertilizer is measured on a scale ranging from 0 (unwilling to take risk) to 11 (risk neutral). HL-like risk over gain, ambiguity and losses refer to the row number (ranging from 0 to 20) of the lottery at which the respondent's preference changes from the lottery to the safe amount. Variables with * have significantly different means across fertilizer use status, N is the number of observations.*

CHAPTER 4: AN EVALUATION OF RISK PREFERENCES ACROSS ELICITATION METHODS

This chapter aims to provide answers to the first research question of this study, namely, how similar are risk attitudes generated from different elicitation measures/approaches? In order to evaluate similarities (or lack thereof) in the measures of risk attitudes elicited, I first analyze whether there is consistency across different elicitation methods for a particular measure of risk attitudes. I also explore how each measure is correlated with a set of socio-demographic previously tested in the literature[31]. I then employ statistical and econometric tools to identify which elicitation methods most closely capture similar states of risk attitudes in the sample. As part of this analysis, I examine the effects of incentives and context specific questions in the elicitation of measures of risk attitudes.

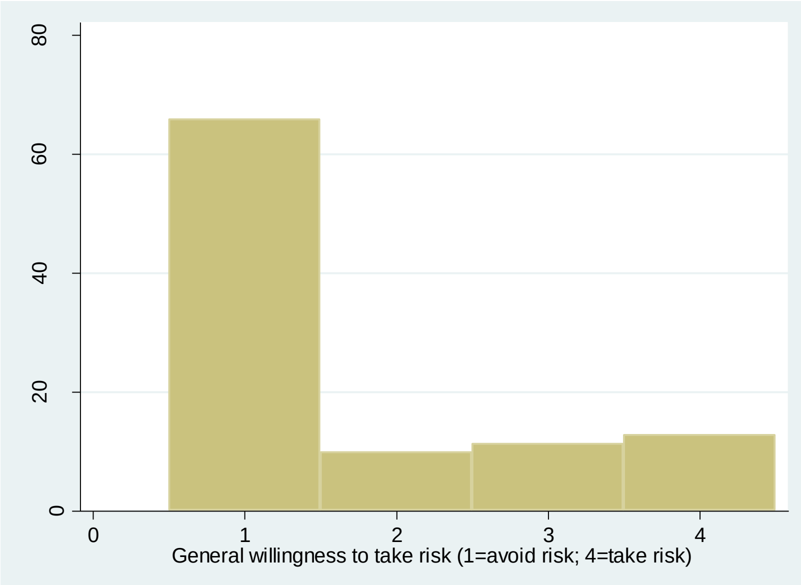
1. Distribution of responses and correlations across elicitation methods

1.1. Qualitative description of the responses

The general risk question is the simplest of the seven measures of risk attitudes in this analysis. The distribution of respondents' self-assessment to the general risk question is shown in Figure 2. Each bar indicates the percentage of respondents choosing a given number on the 4-point Likert scale. The mode of the distribution, represented by the highest bar on the left of the histogram, as well as the mean value of 1.71 which is slightly below the middle value of 2.0 suggest that respondents in the sample are risk averse on average. These descriptive statistics are qualitatively comparable to responses collected using an 11-point Likert scale in rural Thailand (see Hardeweg et al., (2013))

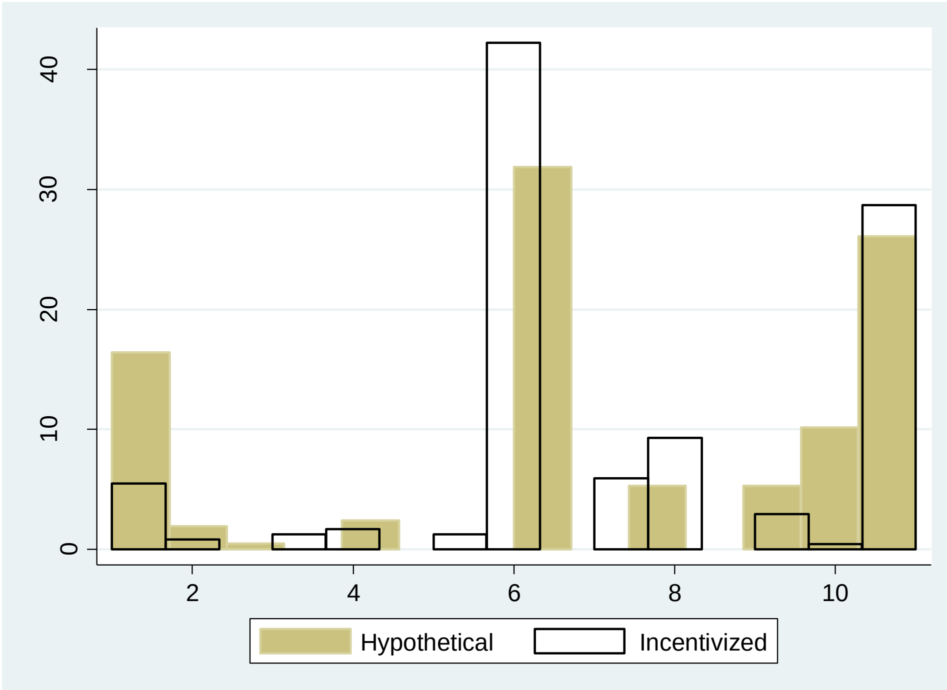
[31] This analysis is conducted at the individual plot manager level

Figure 2: General willingness to take risk



For the contextualized measures of risk attitudes using fertilizer elicited with and without monetary payoffs I immediately observe that there is some variation in responses when incentives are used compared to when none is given (see Figure 3). The horizontal axis in the histogram represents the number of bags of risky fertilizer chosen by the respondent (0 to 10 bags). With the introduction of monetary incentives, a greater proportion of respondents chose more bags of risky fertilizer over non risky fertilizer. That is, most participants shift to the right of the histogram. In fact, I see a tri-modal distribution in the hypothetical fertilizer game for responses involving 0, 5 and 10 bags of risky fertilizer. For the distribution in the incentivized fertilizer experiment I have two modes for choices involving 5 and 10 bags of risky fertilizers. Therefore, it is evident that respondents behave differently in the presence of monetary incentives.

Figure 3: Hypothetical and incentivized fertilizer



The experiments that elicit attitudes towards risk, loss and ambiguity (HL-like risk over gains, ambiguity and losses) are not directly comparable elicitation experiments but in all three cases, the higher the number of the switching row the less averse the subject is towards risk, ambiguity and losses. The histograms for the three elicitation tasks are provided in Appendix 1. All three distributions are bimodal with the peaks at the two extreme. In addition, approximatively 50% or more of the respondents chose the safe option for all the decision rows against about one-third choosing the risky option for all the decision rows. This confirms my earlier findings that the respondents in the sample are risk averse on average. They also have lower tolerance toward ambiguity and loss aversion on average.

1.2. Pairwise correlation across the measures of risk attitudes

In order to quantify how different measures of risk attitudes are related to each other, I perform a spearman's rank order correlation analysis. The spearman's correlation coefficient, denoted by $\boldsymbol{r_s}$, measures the strength of the association between two ranked variables for the same individual (Gujarati, 2003). It is defined as follows:

$$\boldsymbol{r_s = 1 - \frac{6\sum d^2}{n(n^2 - 1)}} \tag{2}$$

where $\boldsymbol{d}$ = difference in the ranks assigned to the same individual and $\boldsymbol{n}$= number of individuals.

Table 9 shows the spearman's correlation coefficients between pairwise measures of risk attitudes.

The incentivized fertilizer measure is positively and significantly correlated with both the HL-like risk and ambiguity measures. The correlation between the incentivized fertilizer measure and the risk measure is not surprising since both elicit known risk aversion when incentives are given. Perhaps somewhat surprising is the correlation between the incentivized fertilizer measure and the ambiguity measure, but this along with the correlation between HL-like risk measure and the HL ambiguity measure clearly implies that preferences toward risk are correlated with ambiguity. Finally, note that the HL measures are all significantly and positively correlated. This is somewhat surprising, but this may be more of a function of the fact that all the elicitation mechanisms were all incentivized and very similar.

Table 9: Spearman correlation coefficients across measures of risk attitudes

	Incentivized fertilizer	Hypothetical fertilizer	General risk	Risk over gains	Ambiguity over gains	Loss over gains
Incentivized fertilizer	1					
Hypothetical fertilizer	0.051	1				
General risk	0.0403	0.0781	1			
Risk over gains	0.1425**	0.0517	-0.0303	1		
	Incentivized fertilizer	Hypothetical fertilizer	General risk	Risk over gains	Ambiguity over gains	Loss over gains
Ambiguity over gains	0.1620**	-0.0369	0.1221*	0.4685***	1	
Loss over gains	0.0479	0.0598	0.0312	0.2613***	0.2943***	1

Note: **, ** and *** represent significance at 10, 5 and 1 percent level respectively*

2. Assessing the validity of each elicitation method

2.1. Spearman's rank correlations with socio-demographic characteristics

Some studies (see Dohmen et al., 2011; Hardeweg et al., 2013) suggest that a general risk question (or survey item), such as that, used here is a good predictor of risky behavior and as can be used for the elicitation of risk attitudes in the field instead of more complex incentivized and contextual mechanisms.[32] I follow their test of the predictive power of the general risk question (used as an explanatory variable) in explaining the more complex mechanisms in my thesis (i.e., the contextual questions and the HL-like risk experiments).[33]

We start with gender and age because they are largely exogenous with respect to risk attitudes (Hardeweg et al., 2013) and because, there is strong evidence from the literature that women and older people tend to be more risk averse (Charness & Gneezy, 2007; Donkers, Melenberg, & Soest, 2001; Gneezy, Leonard, & List, 2009). Moreover, I am also interested in how

[32] Although I used a 4-point Likert scale instead of an 11-point Likert scale as in Dohmen et al.(2011) and (Hardeweg, Menkhoff, & Waibel, 2013), the general risk question in this study is comparable to previous ones. See **Error! Reference source not found.**.

[33] I also used the ordered probit estimator as well as different specifications but the coefficients on the variables of interest don't change.

wealth and education affect risk attitudes in the sample. Livestock holding is the main source of wealth in Niger (Abdoulaye & Sanders,2005). As such I use the average market value of livestock owned by the household as a proxy for wealth. In previous studies, both wealth and education tended to be associated with lower degrees of risk aversion. Furthermore, the literature demonstrates that marital status and household size influence individuals' level of risk tolerance. Married individuals and larger household tend to be more risk averse. Finally, I include employment status, here described as the number of years the respondent has been actively farming, and leadership status. I expect that respondents with more farming experience and those holding leadership positions will be less risk averse.

Table 10 gives the coefficients of the spearman's rank correlation between selected socio-demographic variables and the four measures of risk aversion under scrutiny in this study. Although many of these coefficients are not statistically significant and do not have consistent signs across the different measures, I can check whether they have the expected signs. To this end, I proceed to an assessment of the spearman correlation coefficients between this study and Hardeweg et al., (2013). This analysis is based on the general risk question (column 1) and the common socio-demographic characteristics in both studies. It is important to note that although some of the variables are not measured in the same way they still capture similar socio-demographic characteristics.

Table 10: Spearman's rank correlation

Variables	(1) General risk question	(2) Hypothetical fertilizer	(3) Incentivized fertilizer	(4) Risk over gains	(5) Hardeweg et al (2013)
Age (years)	-0.0837	-0.0102	-0.0372	0.0315	-0.171***
Female (0/1)	-0.1463**	0.0313	0.0342	0.0049	-0.010
Formal education (0/1)	0.0895	-0.0922	-0.0371	-0.0405	0.146***
Value of livestock (in 10000 FCFA)	0.0482	-0.0555	0.0091	-0.0108	0.029
Married	0.0227	-0.0446	0.0186	0.0254	0.041
Leader in community (0/1)	0.1136*	0.0214	0.1636**	0.0992	
Household size	0.0633	0.1055	0.1032	0.0177	0.022
Number of years farming	-0.0806	0.0008	0.0065	0.0865	
Farmer organization member(1/0)	0.1873*	-0.0444	0.0209	-0.0429	

Note: *, ** *and *** represent significance at 10,5 and 1 percent level respectively. Column 5 represents Spearman rank correlation coefficients from Hardeweg et al. 2013.*

Similar to Hardeweg et al., (2013) I find that female and older respondents demonstrate more risk averse attitudes. The signs on the coefficients for wealth and education is consistent with both studies as wealthier and educated subject have a higher tolerance toward risk aversion. It is surprising that being married and living in a larger household is associated with lower degrees of risk aversion contrary to my expectations. Hardeweg et al., (2013) found a similar result and note that it may be because co-residence is a type of security blanket (Miyata, 2003).

We have established that the risk attitudes captured by the general survey question in this study broadly behaves according to my expectations and are similar to those in Hardeweg et al., (2013). Next I check if the coefficients of the other three measures of risk aversion behave similarly. Only the incentivized fertilizer measure (column 3) has more than two of the variables with the same sign as the general risk question. The incentivized fertilizer measure also suggests that older respondents are more risk averse while those who are wealthier, married and live in a larger household exhibit lower degrees of risk aversion. The hypothetical fertilizer and risk over gains measures are each similar to the survey item with regards to age, household size, and marital status, household size, respectively. Given that these coefficients only estimate pairwise correlations, I need to further investigate how the socio-demographic characteristics affect risk attitudes when considered together in a multivariate approach.

2.2. Ordered probit of measures of risk attitudes on socio-demographic characteristics

Setting the measures of risk attitudes as the response variables, I estimate the coefficients on socio-demographic characteristics using ordered probit regressions. Ordered probit is appropriate when the response variable has more than two ordered or ranked categories (Gujarati, 2003). There is indeed some level of ranking among the responses to the experiments I conducted because each number captures a different degree of risk attitude. Again focusing my analysis on the signs of the explanatory variables and considering the general risk question as outcome variable, I see in Table 11 that the ordered probit regression confirms that older and female respondents exhibit greater degrees of risk aversion while married, educated, and wealthier subjects living in larger households exhibit lower degrees of risk aversion. The measures of risk attitudes elicited using the general risk question, the incentivized fertilizer game and the HL-like risk over gains experiment seem to provide a sensible measure of individuals' risk attitudes given that they predict generally well behavioral responses often associated with certain socio-demographic characteristics. In fact, the types of behavior expected to be correlated with gender, age, wealth, and size of household holds for both column 4 and column 1. The results in column 3 and column 1 are also comparable. The measures of risk attitudes are correlated as expected to age, wealth, and size of household.

Table 11: Ordered probit regressions of socio-demographic correlates of measures of risk attitudes

Variables	(1) General risk question	(2) Hypothetical fertilizer	(3) Incentivized fertilizer	(4) Risk over gains	(5) Ambiguity over gains	(6) Loss over gains
Age (years)	-0.0053	-0.0001	-0.0061	-0.0058	-0.0147**	-0.0010
Female (0/1)	-1.035**	0.1090	0.0721	-0.1310	-0.508**	-0.2010
Value of livestock (in 10000 FCFA)	0.0009	-0.0074	0.0008	0.0008	0.0071	0.0119**
Formal education (0/1)	0.2430	-0.372*	-0.2170	-0.1170	-0.2230	-0.2400
Married	0.901*	-0.5170	-0.4760	-0.5740	0.4570	0.0392
Household size	0.0095	0.0134	0.0066	-0.0001	0.0028	0.0051
Number of years farming	-0.0032	-0.0027	0.0048	0.0109*	0.0077	0.0082
Leader in community (0/1)	0.471*	0.0318	0.389**	0.368*	0.1790	-0.0383
Farmer organization member(1/0)	0.329*	-0.1790	-0.0446	-0.1810	0.0898	0.0102
Number of observations	184+	181+	206	206	206	206

Note: **, ** and *** represent significance at 10,5 and 1 percent level respectively. + means respondents with missing values on the general and hypothetical fertilizer question were dropped from these regressions*

3. Testing whether one measure of risk attitude is a good predictor of another

This section explores whether contextualized questions or incentives matter in the elicitation of risk attitudes. Specifically, I want to know whether certain measures of risk attitudes are sufficiently related to be substitutable or used in conjunction for robustness tests when conducting field experiments to elicit the underlying risk attitudes in rural areas of developing countries. Table 12 below present the differences I seek to test. For instance, I compare the incentivized fertilizer (column 3, row 1) to the HL-like risk over gains variables (column 1, row3), to test whether the addition of context to an incentivized elicitation method generates different measures of risk aversion.

Table 12: Description of difference(s) between elicitation methods capturing risk aversion

		(1) General risk question	(2) Hypothetical fertilizer	(3) Incentivized fertilizer
(1)	Hypothetical fertilizer	Context		
(2)	Incentivized fertilizer	Incentives and context	Incentives	
(3)	HL-like Risk over gains	Incentives	Incentives and context	Context

As outlined in the review of the literature, some studies (see Dohmen et al., 2011; Hardeweg et al., 2013) suggest that the general risk question is a good predictor of risky behavior and as such can be used for the elicitation of risk attitudes in the field instead of more complex incentivized and contextual mechanisms. I repeat their test of the predictive power of the general risk question (used as explanatory variable) in explaining the more complex mechanisms in my thesis (i.e., the contextual questions and the HL-like risk experiments). I also use the ordered probit estimator as well as different specifications but the coefficients on the variables of interest don't change.

The results are summarized in Table 13. The coefficient on the general risk question is not statistically significant in any of the columns. In addition, the sign is not stable as I had already shown with the spearman correlation coefficients. In all, the general risk question does not appear to be a good predictor of the hypothetical fertilizer, the incentivized fertilizer and HL-like risk over gains experiments. These results indicate that the use of contextual questions and/or incentives lead to the elicitation of measures of risk attitudes that are not always compatible with those generated by the general risk question. This is contrary to the strand of the literature spearheaded by Dohmen et al., (2011) who found that the general risk question is a valid substitute for an experimental game of the Holt and Laury type.

A notable difference between the general risk question in this study and the one tested by Dohmen et al., (2011) is the scale. Dohmen et al., (2011) used an 11-point Likert scale whereas I used a 4-point Likert scale. While I recognize that this limits the possible variation in the sample (which is much smaller), this difference should not have any major implications on the interpretation of the question on the part of respondents. Furthermore, I was able to capture differences along socio demographic characteristics that were similar to their measures. Figure 2 above also shows that the 4 point-Likert scale generates a distribution similar to one using an 11-point Likert scale. Despite, the ease of elicitation and low implementation costs features that make the general risk question appealing, its ability to accurately capture the subject's true risk attitude is questionable. These results resonate with conclusions gathered from field experiments in Senegal (see Charness & Viceisza,(2012)).

Table 13: OLS regressions of measures of risk attitudes with the general risk question as the predictor variable

	Hypothetical fertilizer		Incentivized fertilizer		Risk over gains	
Variables	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
General risk question	0.2114	0.4250	0.0757	0.6962	-0.4693	0.4110
Age (years)	0.0020	0.9240	-0.0147	0.3509	-0.0366	0.4120
Female (0/1)	0.5346	0.5920	0.3380	0.6744	-2.9917	0.2200
Value of livestock (in 10000 FCFA)	-0.0220	0.2210	-0.0045	0.7412	-0.0132	0.7860
Formal education (0/1)	-1.24912*	0.0930	-0.1720	0.7252	-1.1755	0.4770
Married	-1.1727	0.5340	-1.0560	0.3909	-4.3595	0.3970
Household size	0.0479	0.1400	0.0280	0.3426	-0.0251	0.8030
Leader in community (0/1)	-0.0025	0.9970	0.981*	0.0503	2.7972	0.1010
Farmer organization member(1/0)	-0.7864	0.1810	-0.1480	0.7454	-0.8177	0.5670
Constant	8.4803***	0.0000	8.352***	0.0000	11.7768**	0.0380

Table 13 (cont'd)

Variables	Hypothetical fertilizer Coefficient	P-value	Incentivized fertilizer Coefficient	P-value	Risk over gains Coefficient	P-value
Number of observations	181		184		184	
R-squared	0.052		0.046		0.039	

Note: **, ** and *** represent significance at 10,5 and 1 percent level respectively*.

To identify the effect of incentives on risk attitudes as well as the effect risk attitudes have on fertilizer micro-dosing, I include an experiment framed around the adoption of an agricultural technology, namely fertilizer. Using OLS regression (see Table 14), I find that the hypothetical fertilizer measure is not any better than the general risk question at capturing risk attitudes. The coefficients on the hypothetical fertilizer variable are largely insignificant when the response variables are the HL-like risk over gains and incentivized fertilizer measures. This implies that the addition of context to a hypothetical elicitation technique does not necessarily strengthen the predictive power of that instrument.

Table 14: OLS regressions of measures of risk attitudes with hypothetical fertilizer as the predictor variable

	Incentivized fertilizer		Risk over gains	
Variables	Coefficient	P-value	Coefficient	P-value
Hypothetical fertilizer	0.014	0.822	0.073	0.7
Age (years)	-0.014	0.367	-0.02	0.671
Female (0/1)	0.352	0.666	-2.782	0.236
Value of livestock	0	0.845	0	0.844
Formal education (0/1)	-0.109	0.827	-1.088	0.511
Married	-0.192	0.874	-6.091	0.286
Household size	0.029	0.321	-0.027	0.791
Number of years farming	0.006	0.72	0.062	0.197
Leader in community (0/1)	1.025**	0.027	2.451	0.144
Constant	7.350***	0	11.415*	0.068
Number of observations	181		181	
R-squared	0.048		0.033	

Note: **, ** and *** represent significance at 10, 5 and 1 percent level respectively.*

Next, I test whether the incentivized fertilizer and the HL-like risk over gains measures are related in any way. The spearman correlation coefficient between both measures support that they are significantly and positively correlated. Based on the argument that context specific instruments are more appropriate in field experiments, I examine whether the HL-like risk over gains measure is a good predictor for the incentivized fertilizer and can thus be a valid substitute. Using an OLS regression (see Table 15), I find that the HL-like risk over gains variable does indeed predict risk attitudes collected using the incentivized fertilizer experiment.

Table 15: OLS regression of measures of incentivized fertilizer

	(1)		(2)		(3)	
Variables	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Risk over gains	0.041*	0.054	0.051**	0.017	0.057**	0.013
Age (years)			-0.002	0.843	-0.014	0.331
Female (0/1)			0.19	0.727	0.128	0.818
Value of livestock					3.25E-07	0.893
Formal education (0/1)					-0.456	0.327
Married					-1.066	0.454
Household size					0.019	0.481
Number of years farming					0.01	0.534
Leader in community (0/1)					0.805*	0.081
Constant	7.121***	0.000	7.194***	0.000	8.087***	0.000
Number of observations	237		226		206	
R-squared	0.017		0.027		0.07	

Note: **, ** and *** represent significance at 10, 5 and 1 percent level respectively.*

Incidentally, when I flip the question and use the incentivized fertilizer as a predictor for HL-like risk over gains, the coefficient on incentivized fertilizer is statistically significant at 5% and is greater in magnitude compared to when the HL-like risk over gains was the explanatory variable. This indicates that the incentivized fertilizer measure predicts fairly well the HL-like risk over gains experiments. It also supports the hypothesis that the incentivized fertilizer variable predicts behavior better than the HL-like risk over gains. Thus while context alone is not enough, having context in conjunction with incentives is more likely to elicit better measures of risk attitudes. This result is supported by the histogram (Figure 3) illustrating the distribution of responses for the incentivized fertilizer and the hypothetical fertilizer experiments. Given that there were no shocks between the two experiments, it seems that respondents behave differently due to the use of monetary stakes.

CHAPTER 5: TECHNOLOGY ADOPTION AND RISK ATTITUDES

This chapter uses plot level data to answer the second research question of this thesis - "How do risk attitudes influence the decision to use fertilizer?" In addition to the measures of risk aversion, I also explore the effect of aversion to ambiguity and loss on the decision to use fertilizer in general and then on the practice of a particular fertilizer application technique. This analysis informs which measure is a better predictor of farmers' fertilizer adoption decisions. Knowing this provides a clearer picture of the fertilizer adoption landscape in Niger to better inform future policy decisions related to the promotion of fertilizer and application techniques such as micro-dosing or mixing seeds with fertilizer.

1. Determinant of fertilizer use: binary decision

As described earlier, a probit regression model is used to estimate the binary adoption decision of using fertilizer. I estimate different models in which the response variable is an indicator variable taking the value of one (1) if the farmer uses fertilizer on the plot and zero (0) otherwise. In each model specification, the main explanatory variable is a measure of risk attitudes with additional controls variables for individual, household and plot level characteristics that may influence the adoption decision. A complete list and description of the variables used in the regression analyses is provided in Table 16. Summary statistics of the variables disaggregated by fertilizer use status are also available in Table 7 and Table 8.

Table 16: Definition of variables used in the analyses

	Definition
Explanatory variables	
General risk question	Equal to the number the respondent chooses on the 4-point Likert scale (no monetary payoffs)
Hypothetical fertilizer	Equal to the number of bags of risky fertilizer chosen by the respondent for a total of 10 bags (no monetary payoffs)
Hypothetical seed	Equal to the number of bags of risky seeds chosen by the respondent for a total of 10 bags (no monetary payoffs)
Incentivized fertilizer	Equal to the number of bags of risky fertilizer chosen by the respondent for a total of 10 bags (no monetary payoffs)
HL-like risk over gains	Switching row in the experiment from 0 to 20, where 0 is choosing the safe payoff for all decisions and 20 the risky option for all decisions
HL-like risk over ambiguity	Switching row in the experiment from 0 to 20, where 0 is choosing the safe payoff for all decisions and 20 the risky option for all decisions
HL-like risk over losses	Switching row in the experiment from 0 to 20, where 0 is choosing the safe payoff for all decisions and 20 the risky option for all decisions
Covariates	
Age	Age of plot manager
Formal education (1/0)	Equal 1 if household head received primary, secondary or university education
Active farming (years)	Number of years the farmer practiced farming
Household size	Number of people in household
Farmer organization member (1/0)	Equal 1 if the farmer belongs to a farmer organization
Area allocated to crop (hectares)	Plot area allocated to crops cultivation in hectares
Distance to market (Kilometers)	Distance from plot to nearest principal market (kilometers)
Value of livestock (‘000 FCFA)	Average current market value of livestock owned by the household in ‘000 of FCFA
Organic fertilizer (1/0)	Equal 1 if the farmer applies manure on the plot
Temperature (10*C)	Mean temperature of wettest quarter (10*C)
Annual precipitation (millimeters)	Annual Precipitation in millimeters
Fertilizer price (‘000 FCFA)	Price of fertilizer at the village level in ‘000 FCFA
Fertile soil (1/0)	Equal 1 if the farmer qualifies the soil as medium of good quality
Extension (1/0)	Equal 1 if the main source of information about fertilizer is from government extension agent or development projects

Table 18 presents the average marginal effects of the various factors affecting fertilizer use. These estimates are based on a probit model where the dependent variable is fertilizer use.

The magnitude of these estimates are similar to those reported in studies which tested the predictive power of measures of risk attitudes on real world behavior (Dohmen et al., 2011; Hardeweg et al., 2013). In column 1, I present results without the variables of risk attitudes to assess the effect of the observable characteristics on the use of fertilizer. The prevailing temperature during the wettest quarter is negative and significantly correlated with the use of fertilizer. Optimal growing temperatures are indeed an important complementary factor for the use of fertilizer in a Sahelian country like Niger. The availability of manure and interaction with government or development projects' extension agents does not appear to influence the use of fertilizer. As expected, the higher the price of fertilizer the less likely is the use of fertilizer.

Although columns 2 and 3 show that the measures of risk aversion elicited using the general risk question and the hypothetical fertilizer experiments have the expected signs, they are not statistically significant. Thus these variables cannot be used to explain the revealed behavior of using or not using fertilizer.

However, measures of risk aversion elicited using the incentivized framed field experiments are statistically significant. Farmers' level of risk aversion appears to be a barrier to the widespread adoption of fertilizer in the sample. The incentivized fertilizer variable in column 4 indicates that less risk averse farmers are more likely to use fertilizer at 15% significance level. This is confirmed by the significance of the coefficient on the HL-Like risk over gains variable in column 5 which is significant at the 1% level. These results are comparable to the behavior of Malagasy farmers whose risk aversion significantly reduces their likelihood of using the System of Rice Intensification (SRI) practices (Takahashi, 2013). The higher statistical significance for the HL-like might be due to the larger variation in this variable which goes from 1-20 compared to 11 for the incentivized fertilizer question. It also distinguishes between risk-seeking and risk-neutral preferences unlike the latter.

Column 6 indicates that ambiguity aversion is not an important parameter in the decision to use fertilizer. This result is similar to Ward & Singh, (2014) whose study among Indian farmers found that ambiguity aversion does not have any significant impact on the likelihood of choosing a new technology over the current one.[34] Considering that close to 50 percent of farmers in the sample have used fertilizer over the last ten years, the lack of explanatory power of the ambiguity aversion variable is not surprising. As discussed earlier, dissemination efforts in the regions of the study might have enabled farmers to learn about the probability distribution of the yields associated with the use of fertilizer.

Finally, column 7 indicates that loss aversion is not statistically significant and is not a good predictor of fertilizer use in the data. Other empirical studies however, have found loss aversion to be statistically significant for the adoption of new technologies. Liu (2012) found that if farmers perceive *Bt cotton* as ineffective at eliminating pests (as advertised by scientist), then more loss averse farmers tended to adopt the technology later. Hence, this result is not surprising because fertilizer is not a new technology.

For the response variables equal to one (1) when micro-dosing or mixing seeds with fertilizer is practiced, I also estimate marginal effects from probit regressions. The findings are summarized in Table 17 below. The checkmarks indicate the variables that are significantly associated with particular technology adoption variables at (15%) significance or lower.

[34] The discrete choice experiment for the adoption of new rice seeds in Ward and Singh (2014) was hypothetical.

Table 17: Summary of probit regressions results for fertilizer use, mixing, and micro-dosing

	General risk question	Hypothetical fertilizer	Incentivized fertilizer	HL-like risk over gains	HL-like risk over ambiguity	HL-like risk over losses
Fertilizer use			✓	✓		
Mixing			✓	✓		
Micro-dosing				✓		

Table 18: Probit regression results of the determinants of fertilizer use (use fertilizer=1)

	(1) No measure of risk attitudes	(2) General risk question	(3) Hypothetical fertilizer	(4) Incentivized fertilizer	(5) HL-like risk over gains	(6) HL-like risk over ambiguity	(7) HL-like risk over losses
Variables				Average marginal effects			
Incentivized fertilizer				0.01486+			
HL-like risk over gains					0.01135***		
HL-like risk over ambiguity						0.00279	
HL-like risk over losses							0.00165
Hypothetical fertilizer			0.01185				
General risk question		0.00873					
Age	-0.02185*	-0.0201	-0.01733	-0.02128*	-0.02510**	-0.02180*	-0.02062
Age squared	0.00014	0.00013	0.0001	0.00014	0.00017	0.00014	0.00013
Formal education (1/0)	0.09849	0.13711	0.13623	0.10635	0.10472	0.10439	0.0997
Active farming (years)	-0.00171	-0.00201	-0.00144	-0.00169	-0.00255	-0.0017	-0.00177
Household size	0.00011	0.00192	0.00047	-0.00061	0.00228	0.00027	0.00005
Area allocated to crop (hectares)	0.00239	0.00405	0.00608	0.00192	0.00627	0.00335	0.00238
Distance to market (Kilometers)	0.00784	0.00802	0.00807	0.00754	0.00839	0.00727	0.00803
Value of livestock (in 10000 FCFA)	0.00092	0.00114	0.00055	0.00142	0.00039	0.00071	0.00072
Farmer organization member(1/0)	0.10638	0.08916	0.07725	0.11306	0.11052	0.10689	0.11021
Temperature (10*C)	-0.06117**	-0.05697**	-0.05264**	-0.06676**	-0.06168***	-0.06345**	-0.06146**
Annual precipitation (millimeters)	-0.00237	-0.00212	-0.00166	-0.00282	-0.00228	-0.00256	-0.00235
Organic fertilizer (1/0)	0.05693	0.04281	0.06936	0.03932	0.01205	0.04139	0.05711
Fertilizer price (in 10000 FCFA)	-12.84499*	-12.13103*	-10.6452	-14.13439*	-11.72172*	-13.24527*	-12.61335*

Table 18 (cont'd)

	(1) No measure of risk attitudes	(2) General risk question	(3) Hypothetical fertilizer	(4) Incentivized fertilizer	(5) HL-like risk over gains	(6) HL-like risk over ambiguity	(7) HL-like risk over losses
Variables				Average marginal effects			
Fertile soil (1/0)	-0.05467	-0.05264	-0.02584	-0.06404	-0.0792	-0.06163	-0.05334
Extension (1/0)	0.10414	0.07017	0.052	0.11884*	0.12819**	0.10966*	0.10374
Number of observations	445	415	409	445	445	445	445

Note: +, *, ** *and* *** *represent significance at 15, 10, 5 and 1 percent level respectively*. *All regressions include village fixed effects.*

2. Micro-dosing versus mixing seeds with fertilizer adoption: conditional probit model

Table 19 presents the results from the probit regression conditional on using fertilizer. It reveals that risk attitudes significantly affect farmers' decisions on which fertilizer application technique to use. I restrict my analysis here to the incentivized fertilizer and incentivized HL-like measures of risk attitudes given that they were the measures with explanatory power in the fertilizer probit regressions. (see Table 17 above for a summary).

We investigate two model specifications – one that includes the three HL measures of risk attitudes (column 1) and another that replaces the HL measure of risk over gains with the incentivized fertilizer measure but keeps the HL measures of ambiguity and loss aversion (column 2). The reported results in columns 1 suggest that less risk averse farmers tend to practice micro-dosing over mixing seeds with fertilizer. Ambiguity aversion and loss aversion are not statistically significant. The results for the second specification are not statistically.

Table 19 also indicates that higher temperature reduces the likelihood of mixing seeds with fertilizer compared to micro-dosing. This might be due to fear of seed burning under high temperature conditions. (Abdoulaye & Sanders, 2005). Lastly, the high cost of fertilizer encourages farmers to practice mixing and discourages the practice of micro-dosing. Since micro-dosing requires higher quantities of fertilizer compared to mixing, these results support that high fertilizer costs appear to be a barrier to the practice of micro-dosing.[35]

[35] It is worth noting that when I estimate the results presented in Table 19 with regional fixed effects (instead of village fixed effects), farmers in Maradi and Zinder are more likely to practice micro-dosing.

Table 19: Probit regression results of the determinants of fertilizer application technique conditional on fertilizer use (use micro-dosing=1)

	(1) HL measures of risk attitudes		*(2) Incentivized fertilizer, HL-like risk over ambiguity and losses*	
Variables	Marginal effects	P-value	Marginal effects	P-value
HL-like risk over gains	0.01686**	0.025		
HL-like risk over ambiguity	-0.00792	0.253		
HL-like risk over losses	-0.00865	0.126		
Incentivized fertilizer			**-0.01556**	**0.472**
HL-like risk over ambiguity			**-0.00092**	**0.883**
HL-like risk over losses			**-0.00526**	**0.358**
Age	0.02314	0.186	0.02524	0.194
Age squared	-0.00018	0.189	-0.00020	0.173
Formal education (1/0)	0.04088	0.665	0.01340	0.889
Active farming (years)	-0.01350***	0.001	-0.00974**	0.019
Household size	-0.00229	0.797	0.00110	0.907
Area allocated to crop (hectares)	0.00468	0.795	-0.00135	0.944
Distance to market (Kilometers)	0.00306	0.741	0.00296	0.777
Value of livestock (in 10000 FCFA)	-0.00254	0.569	-0.00125	0.773
Farmer organization member(1/0)	0.08580	0.552	0.09409	0.499
Temperature (10*C)	0.19978*	0.056	0.12795	0.109
Annual precipitation (millimeters)	-0.00109	0.604	-0.00123	0.560
Organic fertilizer (1/0)	0.26363***	0.004	0.28455***	0.003
Fertilizer price (in 10000 FCFA)	-98.19181***	0.001	-67.21660***	0.003
Fertile soil (1/0)	-0.08706	0.346	-0.07416	0.454
Extension (1/0)	0.05561	0.613	-0.00413	0.970
Number of observations	142		142	

Note: **, ** and *** represent significance at 10, 5 and 1 percent level respectively. All regressions include village fixed effects.*

3. Other considerations

3.1. Randomly selected sample

One concern regarding the results of this study is that they might not be representative of the regions of study since the estimations are not based on a random sample. As described earlier, the sampling strategy for this study used both purposive and random sampling. In 2014, 400 more households were randomly selected and added to the initial sample. To confirm that my results are not driven by the non- random nature of the initial sample, I estimated the probit model using only the portion of the sample that was selected randomly. The results are presented in Table A- 3. As with the full sample, I first present the results without the variables of risk attitudes. Some of the variables that did not matter in the estimation using the full sample now become important in the decision to use fertilizer. In effect, I find that annual precipitation is significant and is negatively correlated with the use of fertilizer. This is not surprising since water availability is an important complementary factor in the use of fertilizer in general and even more so for a dry country like Niger. In addition, being member of a farmer organization appears to improve the likelihood of using fertilizer. The farmer's positive perception of the fertility level of his plot and interaction with extension agents both positively influence the use of fertilizer. The main study results for measures related to risk over gains are maintained. However, for this sub-sample, ambiguity aversion is positively and significantly correlated with the decision to use fertilizer at 5% significance level. This difference between the subsample and the larger sample is likely due to the fact that the initial sample (from 2004) was not random and those households have had more exposure to fertilizer than the rest of rural Niger. Thus, these results confirms the role that knowledge and experience with the technology plays on farmers knowledge about the distribution of outcomes under the technology. It indicates that ex ante strategies such as farm extension services and demonstration trials could potentially help increase the take up rate of the technology.

3.2. Using an instrumental variables approach to reduce measurement error

Since I have elicited risk aversion using more than one elicitation technique for this study, I can use an instrumental variable approach to reduce measurement error. I use the HL-like risk over gain variable as an instrumental variable for the incentivized fertilizer variable. Recall that in the probit regression results, the incentivized fertilizer variable was positive and only statistically significant at the 15 % level. The results are presented in Table A- 4. The coefficient of the incentivized fertilizer variable is larger in magnitude, positive and statistically significant at 1%. This lends credence to my earlier results and suggests that there might be value in eliciting risk aversion using more than one type of incentivized elicitation method to reduce potential measurement error.

3.3. Re-categorization of plots with both micro-dosing and mixing

Since I excluded plots with both micro-dosing and mixing for the estimation of the conditional probit, there might be concerns that my results are biased. Those concerns hold if I excluded plots with vastly different characteristics or if the plot managers behaved differently from the rest of the sample. In the survey I asked farmers for the first or main application method used on the plot as well as the second application method. Thus as a robustness check, I first re-categorize plots with both mixing and micro-dosing using the first application technique as the sole application method on the plot. The results presented in Table A- 5 show that the interpretation of the coefficients of the measures of risk attitudes from the main study results are maintained..

Second, I re-categorize plots with both methods as using micro-dosing and mixing. The results presented in Table A- 6 are also consistent with the main estimations in Table 19.

CHAPTER 6: SUMMARY AND CONCLUSIONS

1. Summary

Micro-dosing has the potential to transform Nigerien farmers' livelihood due to the yield increase associated with the technology. However, adoption rates remain low with evidence of dis-adoption among fertilizer users . Given the low level of nutrients in Nigerien soils, it is critical to find ways to encourage and support farmers to make the most of their investments in agricultural activities for improved food security and general wellbeing.

Going off the premise that fertilizer micro-dosing is a risk increasing technology, this thesis explored if the low adoption rates could be partially explained by farmer's risk attitudes. The study used a traditional household survey and framed field experiments to elicit different types of risk attitudes. The literature indicates that field experiments are potentially a better elicitation method than traditional household surveys using hypothetical or general questions to capture farmers' true attitudes toward risks. Thus, this thesis compared measures of risk aversion based on general and hypothetical questions to those elicited using incentivized field experiments. It examined the appropriateness of each measure and their ability to explain the technology adoption decision. Using measures of risk aversion based on the same question asked with and without incentives enabled me to compare the different elicitation methods more formally.

This research found that most of the measures of risk attitudes elicited are correlated as expected with socio-demographic characteristics as per previous studies on experimental measures. Moreover, some measures of risk attitudes are correlated pairwise while others stand out to be better predictors of behavior. I used Spearman's correlation coefficients to assess how different measures of risk attitudes are related to each other and how they relate to socio-demographic characteristics previously tested in the literature. Among the four measures of risk aversion surveyed in the study, the incentivized fertilizer question (which was a context specific incentivized experiment) and the traditional HL-like risk over gains measure tended to be good substitutes though the later was a better predictor of behavior. In addition, I found the hypothetical and incentivized elicitation techniques to be weakly correlated with the incentivized fertilizer variable being better predicted behavior. Thus, the use of incentives is highly recommended if one seeks to elicit risk attitudes that closely reflect individual's real life attitudes toward risk.

The analysis of the effect of risk attitudes on technology adoption confirms that in general, risk aversion undermines the use of fertilizer and any additional uncertainty associated with the use of the technology also negatively impacts the take up rate in areas less exposed to the dissemination of the technology. I used the HL-like risk over gains variable (which was the better predictor) and found that less risk averse farmers have a higher likelihood to use fertilizer, practice micro-dosing over mixing. While ambiguity aversion does not appear to matter in the decision process leading to the practice of micro-dosing or mixing seeds with fertilizer, my results indicate that it is likely to be important in areas where farmers have less experience using fertilizer. Although, high temperatures do not encourage the use of fertilizer, they encourage the practice of micro-dosing over mixing. The analysis further demonstrates that high fertilizer costs tend to dissuade farmers from using fertilizer in general and from practicing micro-dosing in particular. .

Overall, the results support the notion that the low adoption rate of micro-dosing is influenced by risk aversion. Given the differential effect of risk attitudes on the two fertilizer application techniques there might exist other factors that explain the lower adoption rate for micro-dosing. I conjecture that one such factor is the cost and consequent profitability of fertilizer micro-dosing. Compared to mixing, micro-dosing requires larger quantity of fertilizer which translates into larger monetary investments often not available to the farmer at planting time.

Further research on the profitability of micro-dosing versus mixing at the plot level would provide additional insights into the low adoption rates of micro-dosing. At least, it might enable us to understand whether most Nigerien farmers are not adopting micro-dosing because it is not an optimal investment decision given the profitability of its used within existing safety nets.

2. Limitations of the study

One of the main concerns of this study pertains to the use of ex-post cross sectional measures of risk attitudes. Indeed, in a cross-sectional data, any ex-post measure of covariates of interest could be affected by the adoption decision and is therefore endogenous (Besley & Case, 1993). Because I only have ex-post measures of risk attitudes, this could be problematic if attitudes toward risks have changed because of farmers' adoption decisions. That is the direction of the causality from the explanatory variable of interest to the dependent variable is questionable. However, I highly doubt that the adoption of fertilizer could have significantly altered individual's risk attitudes because previous studies (see Harrison et al., 2005; Love & Robison, 1984) have demonstrated empirically that risk attitudes are stable overtime. [36]

3. Conclusion

This thesis makes several contributions both to the existing literature on risk attitudes and technology adoption and the more general agricultural intensification agenda in SSA. First, the study provides empirical evidence that incentivized risk elicitation methods, whether general or context specific, are more suited tools to predicting individual's risk preferences in a rural agricultural setting of a developing country, compared to non-incentivized methods. The thesis

[36] In cases where risk preferences change, they do so slowly overtime and tend to be linked to age. Thus, I controlled for age in my estimation.

also speaks to the added value of simple field experiments that are easy to understand, to capture the true risk attitudes of respondents. This is particularly important if the elicited parameters are to be used to explain behavior and subsequently inform policy decisions. Secondly, I address an important methodological question by providing a true comparison of the effect of incentives in an experiment with the hypothetical and incentivized versions of the fertilizer question. Thirdly, the thesis contributes to the limited empirical evidence of the effects of risk attitudes on adoption of fertilizer micro-dosing.

These findings have important policy implications. First, I have shown that risk aversion matters among Nigerien farmers. Consequently, it is important to consider ex-post policies like crop insurance programs, to increase their likelihood of using fertilizer and promote the practice of fertilizer micro-dosing. In areas with low fertilizer use, it is also important to advocate for ex ante policies like such as farm extension services and demonstration trials to improve farmers' familiarity with the technology. Credit facilities and measures to solve the liquidity problem at planting could increase fertilizer use and enable farmers to take advantage of the higher yields resulting from the practice of micro-dosing. To allow farmers to take advantage of the higher yields resulting from the practice of micro-dosing Nigerien policy makers could develop or revive credit systems such as the warrantage or inventory credit system. The warrantage system provides credit to farmers at harvest time, using part of their production pledged as collateral (Pender et al., 2008). Such solutions have the potential to empower Nigerien farmers break away from the low productivity and low return agriculture.

It is also valuable to know that there exist important regional disparities with regard to fertilizer use. Farmers in the drier region of Zinder, characterized by poor soil quality, have a high predisposition to practice micro-dosing. Thus, farmers in these two regions can be targeted for the promotion micro-dosing. Targeted as opposed to blanket nationwide solutions to improve agricultural productivity are likely to be more effective given the specificities of each region, department, commune and sometimes village.

Further research on the profitability of micro-dosing compared to mixing fertilizer with seeds is necessary. This would provide additional insights into the low adoption rates of micro-dosing. At the least, it might enable us to understand whether most Nigerien farmers are not adopting micro-dosing because this is not an optimal investment decision given the profitability of its use within existing safety nets. Moreover, future research that uses a general and context specific incentivized risk elicitation method with the same number of decision rows will provide additional insights on the value of using framed field experiments.

APPENDICES

Appendix 1: Tables illustrating the elicitation of risk attitudes

Table A- 1: Elicitation of risk over gains and risk over ambiguity

Decision Number	Option A – Chance to draw a ball		Option B
	If Orange ball	If White ball	
1	CFA 1200	CFA 0	CFA 60 for sure
2	CFA 1200	CFA 0	CFA 120 for sure
3	CFA 1200	CFA 0	CFA 180 for sure
4	CFA 1200	CFA 0	CFA 240 for sure
5	CFA 1200	CFA 0	CFA 300 for sure
6	CFA 1200	CFA 0	CFA 360 for sure
7	CFA 1200	CFA 0	CFA 420 for sure
8	CFA 1200	CFA 0	CFA 480 for sure
9	CFA 1200	CFA 0	CFA 540 for sure
10	CFA 1200	CFA 0	CFA 600 for sure
11	CFA 1200	CFA 0	CFA 660 for sure
12	CFA 1200	CFA 0	CFA 720 for sure
13	CFA 1200	CFA 0	CFA 780 for sure
14	CFA 1200	CFA 0	CFA 840 for sure
15	CFA 1200	CFA 0	CFA 900 for sure
16	CFA 1200	CFA 0	CFA 960 for sure
17	CFA 1200	CFA 0	CFA 1020 for sure
18	CFA 1200	CFA 0	CFA 1080 for sure
19	CFA 1200	CFA 0	CFA 1140 for sure
20	CFA 1200	CFA 0	CFA 1200 for sure

Note: HL-like risk over gains - subjects choose between a risky Option A (CFA 0.00 or CFA 1,200 with 50% chance) or a safe Option B (a certain amount for sure) . HL-like risk over ambiguity- subjects choose between an ambiguous Option A (CFA0 0 or CFA 1,200 with unknown chance) or a safe Option B (a certain amount for sure)

Table A- 2: Elicitation of risk over losses

Decision Number	Option A – Chance to draw a ball		Option B
	If Orange ball	If White ball	
1	LOSE CFA 120	CFA 1200	CFA 0 for sure
2	LOSE CFA 240	CFA 1200	CFA 0 for sure
3	LOSE CFA 360	CFA 1200	CFA 0 for sure
4	LOSE CFA 480	CFA 1200	CFA 0 for sure
5	LOSE CFA 600	CFA 1200	CFA 0 for sure
6	LOSE CFA 720	CFA 1200	CFA 0 for sure
7	LOSE CFA 840	CFA 1200	CFA 0 for sure
8	LOSE CFA 960	CFA 1200	CFA 0 for sure
9	LOSE CFA 1080	CFA 1200	CFA 0 for sure
10	LOSE CFA 1200	CFA 1200	CFA 0 for sure
11	LOSE CFA 1320	CFA 1200	CFA 0 for sure
12	LOSE CFA 1440	CFA 1200	CFA 0 for sure
13	LOSE CFA 1560	CFA 1200	CFA 0 for sure
14	LOSE CFA 1680	CFA 1200	CFA 0 for sure
15	LOSE CFA 1800	CFA 1200	CFA 0 for sure
16	LOSE CFA 1920	CFA 1200	CFA 0 for sure
17	LOSE CFA 2040	CFA 1200	CFA 0 for sure
18	LOSE CFA 2160	CFA 1200	CFA 0 for sure
19	LOSE CFA 2280	CFA 1200	CFA 0 for sure
20	LOSE CFA 2400	CFA 1200	CFA 0 for sure

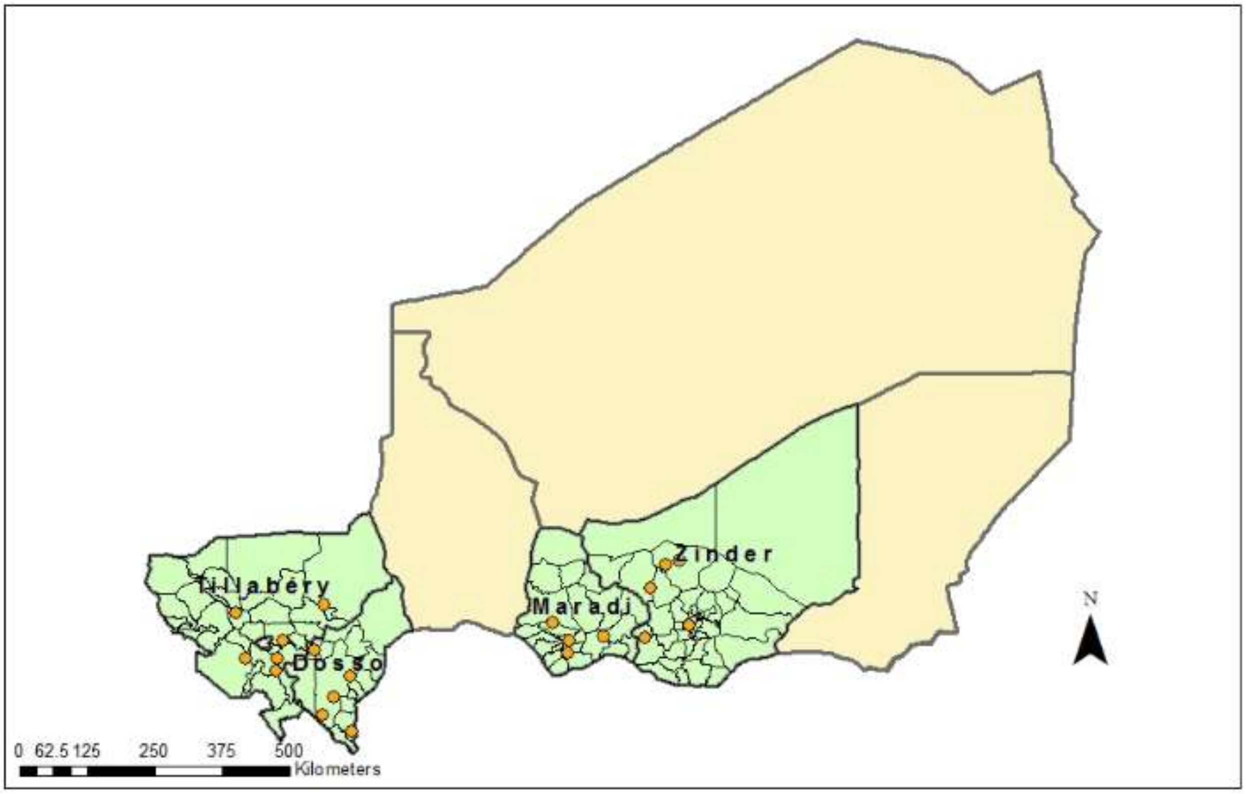
Note: Subject choose between a risky Option A (which has 50% chance of losing a certain amount CFA 1,200) or a safe Option B (CFA 0 for sure)

Appendix 2: Map of Niger and location of villages in the study

Figure A- 4: Map of Niger

Source: UNITED NATIONS (http://www.un.org/Depts/Cartographic/map/profile/niger.pdf)

Figure A- 5: Map of villages included in the study



Appendix 3: Histograms of HL measures of risk attitudes

Figure A- 6: Histogram of HL-like risk over gains

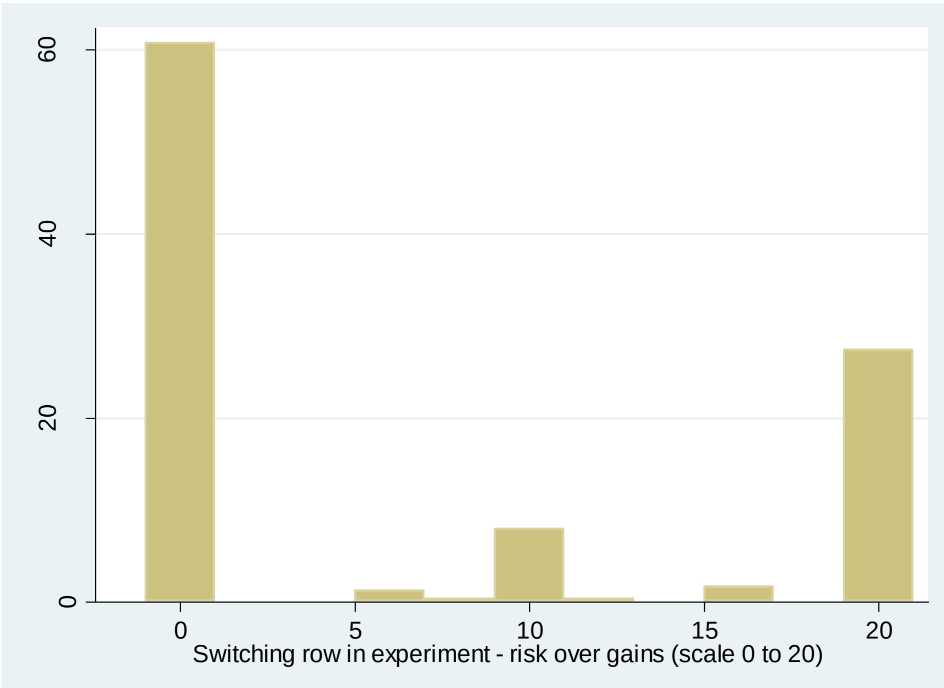


Figure A- 7: Histogram of HL-like risk over ambiguity

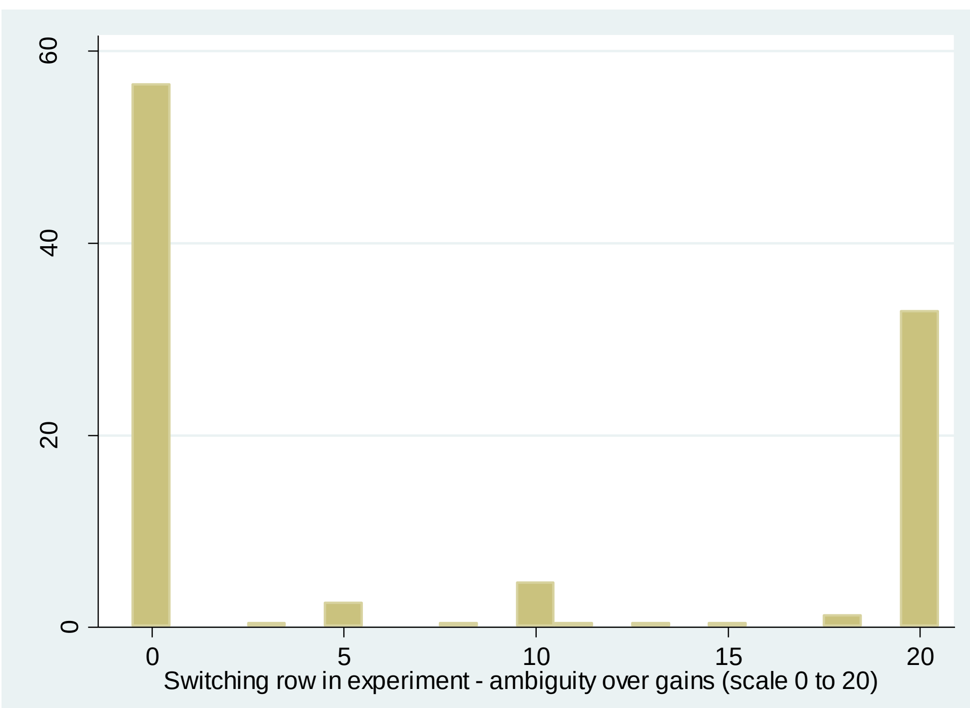
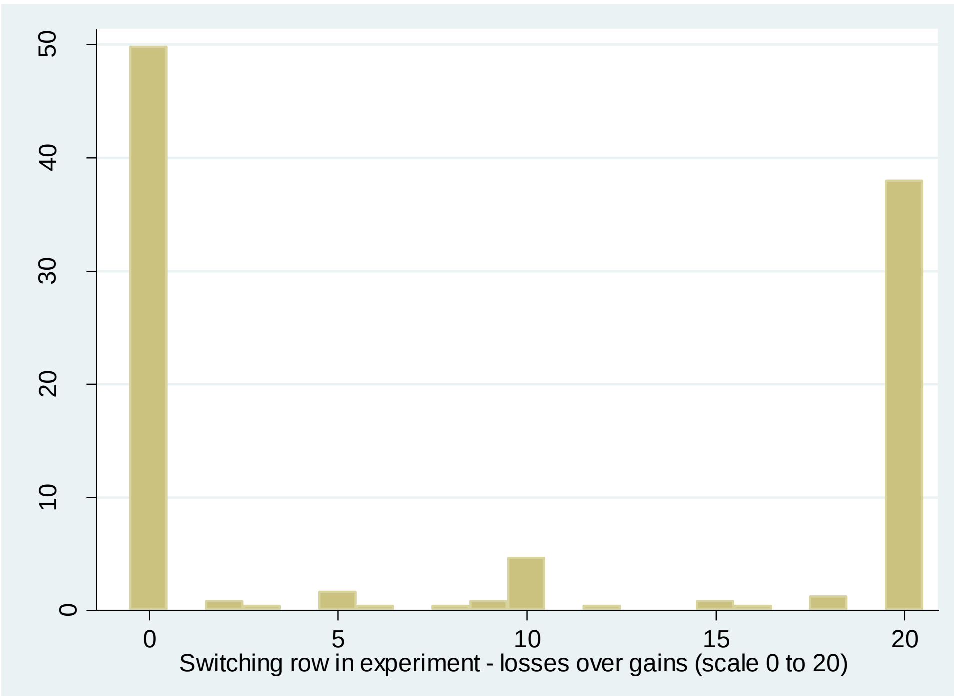


Figure A- 8: Histogram of HL-like risk over losses



Appendix 4: Robustness tables

Table A- 3: Randomly selected sample - Probit regression results of the determinants of fertilizer use (use fertilizer=1)

Variables	(1) No measure of risk attitudes	(2) General risk question	(3) Hypothetical fertilizer	(4) Incentivized fertilizer	(5) HL-like risk over gains	(6) HL-like risk over ambiguity	(7) HL-like risk over losses
	Marginal effects						
General risk question		0.01362					
Hypothetical fertilizer			0.00937				
Incentivized fertilizer				0.01750			
HL-like risk over gains					0.01380***		
HL-like risk over ambiguity						0.00886**	
HL-like risk over losses							-0.00690
Age	-0.03107*	-0.03316*	-0.03021	-0.03358*	-0.04707**	-0.03647*	-0.03525**
Age squared	0.00027	0.00028	0.00025	0.00029*	0.00038**	0.00032*	0.00030*
Formal education (1/0)	0.07945	0.06443	0.07382	0.10526	0.16648	0.13981	0.03846
Active farming (years)	-0.00559	-0.00555	-0.00546	-0.00490	-0.00334	-0.00467	-0.00600
Household size	0.00865	0.00822	0.00801	0.00812	0.01062**	0.00920*	0.01025*
Area allocated to crop (hectares)	-0.00288	-0.00316	-0.00216	-0.00196	0.00258	-0.00171	0.00053
Distance to market (Kilometers)	0.01216	0.01234	0.01239	0.01208	0.01260*	0.00944	0.01107
Value of livestock (in 10000 FCFA)	0.00412	0.00405	0.00348	0.00598	0.00866	0.00591	0.00392

Table A – 3 (cont'd)

Variables	(1) No measure of risk attitudes	(2) General risk question	(3) Hypothetical fertilizer	(4) Incentivized fertilizer	(5) HL-like risk over gains	(6) HL-like risk over ambiguity	(7) HL-like risk over losses
	Marginal effects						
Farmer organization member(1/0)	0.20360*	0.20202	0.18822	0.20134	0.12391	0.19428	0.17580
Temperature (10*C)	-0.04530*	-0.04768*	-0.04422	-0.04943*	-0.03733	-0.04835*	-0.03775
Annual precipitation (millimeters)	-0.00684**	-0.00692*	-0.00615*	-0.00771**	-0.00808***	-0.00821**	-0.00740**
Organic fertilizer (1/0)	0.02774	0.02834	0.04695	0.01487	-0.02108	-0.00033	0.02815
Fertilizer price (in 10000 FCFA)	-14.69205*	-15.28013**	-13.31944*	-16.05309**	-13.12194**	-16.04398**	-15.91638**
Fertile soil (1/0)	-0.17694*	-0.17756*	-0.15447	-0.17637*	-0.20426**	-0.19508**	-0.18723**
Extension (1/0)	0.17558*	0.19053*	0.14203	0.17713*	0.19274**	0.21817**	0.16842
Number of observations	194	190	187	194	194	194	194

Note: **, ** and *** represent significance at 10, 5 and 1 percent level respectively*. *All regressions include village fixed effects*.

Table A- 4: Instrumental variable approach - Probit regression results of the determinants of fertilizer use (use fertilizer=1)

Variables	Incentivized fertilizer	HL-like risk over gains	(Incentivized fertilizer=HL-like risk over gains)
	Marginal effects		
Incentivized fertilizer	0.01486+		
HL-like risk over gains		0.01135***	
(Incentivized fertilizer=HL-like risk over gains)			0.35896***
Age	-0.02128*	-0.02510**	-0.03539
Age squared	0.00014	0.00017	0.00033
Formal education (1/0)	0.10635	0.10472	0.33174
Active farming (years)	-0.00169	-0.00255	-0.00292
Household size	-0.00061	0.00228	-0.01392
Area allocated to crop (hectares)	0.00192	0.00627	-0.01614
Distance to market (Kilometers)	0.00754	0.00839	0.01093
Value of livestock (in 10000 FCFA)	0.00142	0.00039	0.01407
Farmer organization member(1/0)	0.11306	0.11052	0.29792
Temperature (10*C)	-0.06676**	-0.06168***	-0.24047***
Annual precipitation (millimeters)	-0.00282	-0.00228	-0.01516***
Organic fertilizer (1/0)	0.03932	0.01205	-0.30445
Fertilizer price (in 10000 FCFA)	-14.13439*	-11.72172*	-51.31266***
Fertile soil (1/0)	-0.06404	-0.0792	-0.39706**
Extension (1/0)	0.11884*	0.12819**	0.53601***
Number of observations	445	445	445

Note: *+, *, ** and *** represent significance at 15, 10, 5 and 1 percent level respectively. All regressions include village fixed effects.*

Table A- 5: Re-categorization using main application method - Probit regression results of the determinants of fertilizer use (use fertilizer=1)

	HL measures of risk attitudes		*Incentivized fertilizer, HL-like risk over ambiguity and losses*	
Variables	Marginal effects	P-value	Marginal effects	P-value
HL-like risk over gains	0.01756**	0.027		
HL-like risk over ambiguity	-0.00683	0.350		
HL-like risk over losses	-0.00783	0.175		
Incentivized fertilizer			-0.01278	0.577
HL-like risk over ambiguity			0.00043	0.947
HL-like risk over losses			-0.00401	0.505
Age	0.02663	0.164	0.03069	0.164
Age squared	-0.00024	0.103	-0.00028	0.100
Formal education (1/0)	-0.04805	0.622	-0.07291	0.463
Active farming (years)	-0.01133**	0.011	-0.00733*	0.086
Household size	-0.00335	0.717	0.00002	0.998
Area allocated to crop (hectares)	0.01068	0.544	0.00460	0.807
Distance to market (Kilometers)	0.00925	0.361	0.00913	0.418
Value of livestock (in 10000 FCFA)	-0.00364	0.451	-0.00257	0.589
Farmer organization member(1/0)	0.14848	0.301	0.15556	0.262
Temperature (10*C)	0.15966	0.161	0.08312	0.332
Annual precipitation (millimeters)	0.00008	0.970	-0.00000	0.999
Organic fertilizer (1/0)	0.26032***	0.008	0.27548***	0.006
Fertilizer price (in 10000 FCFA)	-88.94368***	0.008	-56.33822**	0.024
Fertile soil (1/0)	-0.01740	0.862	-0.00754	0.942
Extension (1/0)	0.07291	0.523	0.00836	0.943
Number of observations	149		149	

Note: **, ** and *** represent significance at 10, 5 and 1 percent level respectively. All regressions include village fixed effects.*

Table A- 6: Re-categorization as both mixing and micro-dosing - Probit regression results of the determinants of fertilizer use (use fertilizer=1)

	HL measures of risk attitudes		*Incentivized fertilizer, HL-like risk over ambiguity and losses*	
Variables	Marginal effects	P-value	Marginal effects	P-value
HL-like risk over gains	0.02000**	0.025		
HL-like risk over ambiguity	-0.00823	0.264		
HL-like risk over losses	-0.00900	0.140		
Incentivized fertilizer			-0.01935	0.388
HL-like risk over ambiguity			0.00029	0.963
HL-like risk over losses			-0.00464	0.446
Age	0.02378	0.210	0.02592	0.217
Age squared	-0.00020	0.157	-0.00024	0.148
Formal education (1/0)	0.05756	0.537	0.02681	0.775
Active farming (years)	-0.01249***	0.004	-0.00770*	0.067
Household size	-0.00386	0.672	0.00083	0.931
Area allocated to crop (hectares)	0.01078	0.531	0.00440	0.809
Distance to market (Kilometers)	0.00582	0.547	0.00637	0.558
Value of livestock (in 10000 FCFA)	-0.00272	0.553	-0.00149	0.734
Farmer organization member(1/0)	0.06860	0.643	0.06602	0.629
Temperature (10*C)	0.21024**	0.046	0.12494*	0.082
Annual precipitation (millimeters)	-0.00123	0.526	-0.00133	0.491
Organic fertilizer (1/0)	0.24096**	0.010	0.26528***	0.007
Fertilizer price (in 10000 FCFA)	-103.87283***	0.001	-66.55387***	0.001
Fertile soil (1/0)	-0.05621	0.564	-0.04177	0.678
Extension (1/0)	0.04991	0.655	-0.02090	0.854
Number of observations	149		149	

Note: **, ** and *** represent significance at 10, 5 and 1 percent level respectively. All regressions include village fixed effects.*

REFERENCES

REFERENCES

Abdoulaye, T., & Lowenberg-DeBoer, J. (2000). Intensification of Sahelian farming systems: evidence from Niger. *Agricultural Systems*, *64*(2), 67–81.

Abdoulaye, T., & Sanders, J. H. (2005). Stages and determinants of fertilizer use in semiarid African agriculture: the Niger experience. *Agricultural Economics*, *32*(2), 167–179.

Adesina, A. A., Abbott, P. C., & Sanders, J. H. (1988). Ex-ante risk programming appraisal of new agricultural technology: Experiment station fertilizer recommendations in Southern Niger. *Agricultural Systems*, *27*(1), 23–34. http://doi.org/10.1016/0308-521X(88)90077-7

Andersen, S., Harrison, G. W., Lau, M. I., & Rutström, E. E. (2006). Elicitation using multiple price list formats. *Experimental Economics*, *9*(4), 383–405. http://doi.org/10.1007/s10683-006-7055-6

Besley, T., & Case, A. (1993). Modeling Technology Adoption in Developing Countries. *American Economic Review*, *83*(2), 396–402.

Bielders, C. L., & Gérard, B. (2015). Millet response to microdose fertilization in south–western Niger: Effect of antecedent fertility management and environmental factors. *Field Crops Research*, *171*, 165–175. http://doi.org/10.1016/j.fcr.2014.10.008

Binswanger, H. P. (1980). Attitudes Toward Risk: Experimental Measurement in Rural India. *American Journal of Agricultural Economics*, *62*(3), 395–407. http://doi.org/10.2307/1240194

Bocqueho, G., Jacquet, F., & Reynaud, A. (2014). Expected utility or prospect theory maximisers? Assessing farmers' risk behaviour from field-experiment data. *European Review of Agricultural Economics*, *41*(1), 135–172. http://doi.org/10.1093/erae/jbt006

Camara, B. S., Camara, F., Berthe, A., & Oswald, A. (2013). Micro-dosing of fertilizer - a technology for farmers' needs and resources. *International Journal of AgriScience*, *3*(5), 387–399.

Camerer, C. F., & Hogarth, R. M. (1999). The Effects of Financial Incentives in Experiments: A Review and Capital-Labor-Production Framework. *Journal of Risk and Uncertainty*, *19*(1-3), 7–42. http://doi.org/10.1023/A:1007850605129

Charness, G., & Gneezy, U. (2007). *Strong Evidence for Gender Differences in Investment* (SSRN Scholarly Paper No. ID 648735). Rochester, NY: Social Science Research Network.

Charness, G., Gneezy, U., & Imas, A. (2013). Experimental methods: Eliciting risk preferences. *Journal of Economic Behavior & Organization*, *87*, 43–51. http://doi.org/10.1016/j.jebo.2012.12.023

Charness, G., & Viceisza, A. (2012). *Comprehension and Risk Elicitation in the Field: Evidence from Rural Senegal* (University of California at Santa Barbara, Economics Working Paper Series No. qt5512d150). Department of Economics, UC Santa Barbara.

De Brauw, A., & Eozenou, P. (2014). Measuring risk attitudes among Mozambican farmers. *Journal of Development Economics*, *111*, 61–74. http://doi.org/10.1016/j.jdeveco.2014.08.002

Dercon, S., & Christiaensen, L. (2011). Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. *Journal of Development Economics*, *96*(2), 159–173. http://doi.org/10.1016/j.jdeveco.2010.08.003

Dillon, B., & Barrett, C. B. (2014). Agricultural factor markets in Sub-Saharan Africa: an updated view with formal tests for market failure.

Dohmen, T., Falk, A., Huffman, D., Sunde, U., Schupp, J., & Wagner, G. G. (2011). Individual Risk Attitudes: Measurement, Determinants, and Behavioral Consequences. *Journal of the European Economic Association*, *9*(3), 522–550. http://doi.org/10.1111/j.1542-4774.2011.01015.x

Donkers, B., Melenberg, B., & Soest, A. V. (2001). Estimating Risk Attitudes using Lotteries: A Large Sample Approach. *Journal of Risk and Uncertainty*, *22*(2), 165–195. http://doi.org/10.1023/A:1011109625844

Eckel, C. C., El-Gamal, M. A., & Wilson, R. K. (2009). Risk loving after the storm: A Bayesian-Network study of Hurricane Katrina evacuees. *Journal of Economic Behavior & Organization*, *69*(2), 110–124. http://doi.org/10.1016/j.jebo.2007.08.012

Eicher, C. K., & Staatz, J. M. (1998). *International Agricultural Development*. JHU Press.

Engle-Warnick, J., Escobal, J., & Laszlo, S. (2007). *Ambiguity Aversion as a Predictor of Technology Choice: Experimental Evidence from Peru* (SSRN Scholarly Paper No. ID 1077656). Rochester, NY: Social Science Research Network.

FAO. (2013). Gestion des intrants et genre au Niger.

Feder, G. (1980). Farm Size, Risk Aversion and the Adoption of New Technology under Uncertainty. *Oxford Economic Papers*, *32*(2), 263–283.

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change*, *33*(2), 255–298.

Feder, G., & Umali, D. L. (1993). The adoption of agricultural innovations: A review. *Technological Forecasting and Social Change*, *43*(3–4), 215–239. http://doi.org/10.1016/0040-1625(93)90053-A

Ghadim, A. K. A., Pannell, D. J., & Burton, M. P. (2005). Risk, uncertainty, and learning in adoption of a crop innovation. *Agricultural Economics*, *33*(1), 1–9. http://doi.org/10.1111/j.1574-0862.2005.00433.x

Gneezy, U., Leonard, K. L., & List, J. A. (2009). Gender Differences in Competition: Evidence From a Matrilineal and a Patriarchal Society. *Econometrica*, *77*(5), 1637–1664. http://doi.org/10.3982/ECTA6690

Gneezy, U., & Potters, J. (1997). An experiment on risk taking and evaluation periods. *The Quarterly Journal of Economics*, 631–645.

Gujarati, D. (2003). *Student solutions manual for use with "Basic econometrics"* (4. ed). Boston: McGraw Hill.

Hardeweg, B., Menkhoff, L., & Waibel, H. (2013). Experimentally validated survey evidence on individual risk attitudes in rural Thailand. *Economic Development and Cultural Change*, *61*(4), 859–888.

Harrison, G. W., Johnson, E., McInnes, M. M., & Rutström, E. E. (2005). Temporal stability of estimates of risk aversion. *Applied Financial Economics Letters*, *1*(1), 31–35. http://doi.org/10.1080/1744654042000311576

Hiebert, L. D. (1974). Risk, Learning, and the Adoption of Fertilizer Responsive Seed Varieties. *American Journal of Agricultural Economics*, *56*(4), 764–768. http://doi.org/10.2307/1239305

Holt, C. A., & Laury, S. K. (2002). Risk aversion and incentive effects. *The American Economic Review*, *92*(5), 1644–1655.

Ibrahim, A., Pasternak, D., & Fatondji, D. (2014). Impact of depth of placement of mineral fertilizer micro-dosing on growth, yield and partial nutrient balance in pearl millet cropping system in the Sahel. *The Journal of Agricultural Science*, *FirstView*, 1–10. http://doi.org/10.1017/S0021859614001075

ICRISAT. (2009). Fertilizer microdosing - Boosting production in unproductive lands.

ICRISAT. (2012). *Fertilizer Microdosing*.

INS-Niger. (2013). *Profil et determinants de la pauvrete au Niger en 2011: Premiers resultats de l'enquete sur les conditions de vie des menages et l'agriculture au Niger (ECVMA)*.

INS-Niger. (2014). Le Niger en chiffre 2014.

Just, R. E., & Pope, R. D. (1979). Production Function Estimation and Related Risk Considerations. *American Journal of Agricultural Economics*, *61*(2), 276–284. http://doi.org/10.2307/1239732

Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, *47*(2), 263–291. http://doi.org/10.2307/1914185

Knight, J., Weir, S., & Woldehanna, T. (2003). The role of education in facilitating risk-taking and innovation in agriculture. *Journal of Development Studies*, *39*(6), 1–22.

Lejuez, C. W., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., … Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: The Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied*, *8*(2), 75–84. http://doi.org/10.1037/1076-898X.8.2.75

Liu, E. M. (2013). Time to Change What to Sow: Risk Preferences and Technology Adoption Decisions of Cotton Farmers in China. *Review of Economics and Statistics*, *95*(4), 1386–1403. http://doi.org/10.1162/REST_a_00295

Liverpool-Tasie, L. S. O., Sanou, A., & Mazvimavi, K. (2015). How profitable is sustainable intensification? The case of fertilizer micro-dosing in Niger.

Love, R., & Robison, L. (1984). An empirical analysis of the intertemporal stability of risk preference. *Southern Journal of Agricultural Economics*.

Marenya, P. P., & Barrett, C. B. (2009). Soil quality and fertilizer use rates among smallholder farmers in western Kenya. *Agricultural Economics*, *40*(5), 561–572. http://doi.org/10.1111/j.1574-0862.2009.00398.x

Marra, M., Pannell, D. J., & Abadi Ghadim, A. (2003). The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural Systems*, *75*(2–3), 215–234. http://doi.org/10.1016/S0308-521X(02)00066-5

McGee, K., & Backiny-Yetna, P. (2015). *Gender differentials and agricultural productivity in Niger* (No. WPS7199) (pp. 1–46). The World Bank.

Miyata, S. (2003). Household's risk attitudes in Indonesian villages. *Applied Economics*, *35*(5), 573–583. http://doi.org/10.1080/0003684022000020823

Morris, M., Kelly, V. A., Kopicki, R. J., & Byerlee, D. (2007). *Fertilizer Use in African Agriculture : Lessons Learned and Good Practice Guidelines* (World Bank Publications). The World Bank.

Moscardi, E., & Janvry, A. de. (1977). Attitudes Toward Risk Among Peasants: An Econometric Approach. *American Journal of Agricultural Economics*, *59*(4), 710–716. http://doi.org/10.2307/1239398

Pender, J., Abdoulaye, T., Ndjeunga, J., Gerard, B., & Kato, E. (2008). *Impacts of inventory credit, input supply shops, and fertilizer microdosing in the drylands of Niger*. Intl Food Policy Res Inst.

Ramaswamy, S., & Sanders, J. H. (1992). Population pressure, land degradation and sustainable agricultural technologies in the Sahel. *Agricultural Systems*, *40*(4), 361–378. http://doi.org/10.1016/0308-521X(92)90047-R

Rigotti, L., Ryan, M., & Vaithianathan, R. (2008). *Tolerance of Ambiguity and Entrepreneurial Innovation*.

Rosenzweig, M. R., & Binswanger, H. P. (1993). Wealth, Weather Risk and the Composition and Profitability of Agricultural Investments. *The Economic Journal*, *103*(416), 56–78. http://doi.org/10.2307/2234337

Ruttan, V. W., & Hayami, Y. (1984). An innovation development model. *Agricultural Development in the Third World*, 59.

Salmou, H., & Sidi, F. (2012). Le warrantage au Niger, une pratique adaptee aux besoins des petit producteurs et productrices.

Serra, T. (2015). Price volatility in Niger millet markets. *Agricultural Economics*, n/a–n/a. http://doi.org/10.1111/agec.12176

Sheahan, M., & Barrett, C. B. (2014). *Understanding the agricultural input landscape in Sub-Saharan Africa : recent plot, household, and community-level evidence* (No. WPS7014) (pp. 1–87). The World Bank.

Sheahan, M., Black, R., & Jayne, T. S. (2013). Are Kenyan farmers under-utilizing fertilizer? Implications for input intensification strategies and research. *Food Policy*, *41*, 39–52. http://doi.org/10.1016/j.foodpol.2013.04.008

Singh, I., Squire, L., & Strauss, J. (1986). Agricultural household models: extensions, applications, and policy., 343 pp.

Sutter, J. W. (1979). *Social analysis of the Nigerien Rural Producer* (No. Vol. II, Part D) (p. 79). USAID/NIGER.

Tabo, R., Bationo, A., Maimouna, K. D., Hassane, O., & Koala, S. (2006). Fertilizer micro-dosing for the prosperity of small-scale farmers in the Sahel: final report Jun 2002-Dec 2004 submitted to the United States Agency for International Development.

Takahashi, K. (2013). The roles of risk and ambiguity in the adoption of the system of rice intensification (SRI): evidence from Indonesia. *Food Security*, *5*(4), 513–524. http://doi.org/10.1007/s12571-013-0270-z

Tanaka, T., Camerer, C. F., & Nguyen, Q. (2010). Risk and Time Preferences: Linking Experimental and Household Survey Data from Vietnam. *American Economic Review*, *100*(1), 557–571. http://doi.org/10.1257/aer.100.1.557

The Montpellier Panel. (2013). *Sustainable Intensification: A New Paradigme for African African Agriculture*. London.

The World Bank. (2013). *Agricultural sector risk assessment in Niger : moving from crisis response to long-term risk management - technical assistance* (No. 74322) (pp. 1–90). The World Bank.

Ward, P. S., & Singh, V. (2014). *Risk and Ambiguity Preferences and the Adoption of New Agricultural Technologies: Evidence from Field Experiments in Rural India* (SSRN Scholarly Paper No. ID 2392762). Rochester, NY: Social Science Research Network.

Wik, M., Aragie Kebede, T., Bergland, O., & Holden, S. T. (2004). On the measurement of risk aversion from experimental data. *Applied Economics*, *36*(21), 2443–2451. http://doi.org/10.1080/0003684042000280580

Wooldridge, J. M. (2010). *Econometric Analysis of Cross Section and Panel Data*. MIT Press.

Yesuf, M., & Bluffstone, R. A. (2009). Poverty, risk aversion, and path dependence in low-income countries: Experimental evidence from Ethiopia. *American Journal of Agricultural Economics*, *91*(4), 1022–1037.