How profitable is sustainable intensification? The case of fertilizer micro-dosing in Niger

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DRAFT

Abstract

This paper uses panel data techniques to identify the yield response to various fertilizer application techniques in rural Niger. Empirical evidence on the profitability of fertilizer micro-dosing is provided to confirm if the observed low adoption of the technique is contrary to what is expected given its expected profitability. Particular attention is paid to the effects of fertilizer micro-dosing on demand for complementary inputs such as labor. The study finds no empirical evidence that micro-dosing is more labor intensive than traditional methods of fertilizer application, as is conventionally thought. Study results indicate that while micro-dosing on its own is more profitable than using no fertilizer, other techniques such as mixing fertilizer with seeds at planting might be more attractive because they require significantly less fertilizer than the traditional approach or micro-dosing. Any yield returns from fertilizer micro-dosing compared to mixing do not appear to be sufficient to compensate for the higher costs associated with the higher quantity of fertilizer required

1. Introduction

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 domain, there is a particular interest in increasing food production using methods that increase the efficiency of fertilizer use in a manner that minimizes the potentially negative effects of its use on the environment. With very low fertilizer use rates generally, countries such as Niger are in a position to take advantage of opportunities that can increase fertilizer use in a sustainable manner; particularly if such environmental benefits occur alongside productivity gains.

The adoption rate of micro-dosing, like many other intensification techniques in sub Saharan Africa (SSA) is generally considered to be low. Yet, the notion that their adoption is low is predicated on the assumption that adoption is profitable. However, there is very limited empirical evidence to support this notion. Consequently, this paper uses a rich panel dataset on millet production in rural Niger to empirically explore the profitability of one such technique; fertilizer micro-dosing. Fertilizer micro-dosing[1] is a precision farming technique, where a small amount of fertilizer (1-4 g) is placed with the seed (separated by a thin layer of soil); typically at planting (Tabo et al., 2006, Twomlow et al., 2010, Bagayoko et al., 2011). Compared to the traditional fertilizer application techniques of broadcasting or line spreading, micro-dosing is a more targeted approach to fertilizer application; improving the efficiency of nutrient absorption. The quantity of fertilizer used for micro-dosing is also about a third to a fourth of the usual application rate recommended by research or advisory services (Camara et al., 2013).

[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. However, over the years various variants of the original practice have emerged.

Consequently, in addition to prospective productivity gains, there are potential cost reduction and environmental benefits (including the reduction of groundwater contamination) associated with the use of fertilizer micro-dosing (ICRISAT, 2009).

Despite the agronomic and potential low cost advantage of fertilizer micro-dosing, a long-standing puzzle is why farmers' adoption rate of the technology in SSA remains low. This occurs despite significant efforts by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and various partners to disseminate information about the technique (over the last two decades) and to make fertilizer more available to rural farmers. There is limited empirical evidence confirming that the limited adoption of fertilizer micro-dosing is unexpected given it's actually profitability for poor small holder farmers. Consequently, this study explores the profitability of micro-dosing independently and compared to other fertilizer application techniques used in Niger as a possible explanation for the low adoption rate. Some studies lump micro-dosing with other inorganic fertilizer application techniques using less fertilizer than traditional broadcasting and line spreading (Pender et al, 2008). We specifically distinguish between two different methods of fertilizer application commonly practiced in Niger. The first are methods that use about 30kg/ha (as recommended with micro-dosing) applied at different times or in different ways[2]. The second involves mixing fertilizer and seed at planting. We consider this distinction important because compared to 30kg/ha used for these methods, farmers mixing fertilizer and seeds typically use a much smaller amount; between 2-8kg/ha of fertilizer (Abdoulaye and Sanders, 2005). This is a very different amount of inorganic fertilizer likely to have very different implications for profitability and production risk.

[2] While fertilizer could be applied with seed at planting but separated by a thin layer of soil, it could also be applied later as top dressing placed at the side of the young plant or buried in a hole dug at the side of the young plant.

This paper addresses at least three gaps in the literature. First, using panel data techniques, we are able to more consistently identify the yield response to fertilizer micro-dosing by accounting for unobserved time invariant household characteristics likely to affect the adoption of fertilizer micro-dosing and yields. Most other studies have used cross sectional studies and not accounted for the endogeneity of the decision to adopt fertilizer micro-dosing. Second we are the first study (we know of) to explore more intentionally the labor effects of fertilizer micro-dosing using data on the man-days used for various activities in millet production during the agricultural season for micro-dosing compared to other practices. Third, we are able to contribute to a key gap in the sustainable intensification literature (and fertilizer use literature more generally) by providing empirical evidence on the profitability of fertilizer micro-dosing to confirm if the low adoption is indeed contrary to what is expected given the expected profitability of the technique.

The paper is organized as follows: Section 2 describes our data while section 3 discusses fertilizer and fertilizer application methods used by farmers in Niger. Section 4 presents our conceptual framework. Our production function estimates and profitability analysis are discussed in section 5. Section 6 concludes.

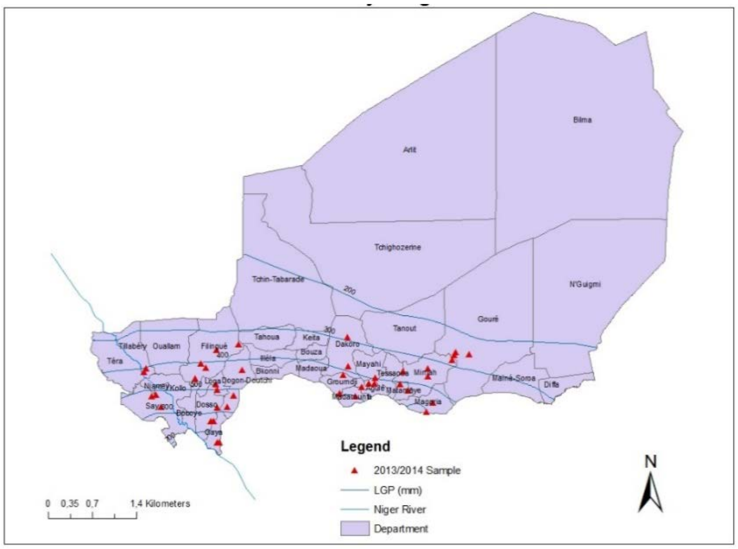
2. Data and Study sample:

This analysis is based on information gotten from several data sources. National data from the Living Standards Measurement Survey- Integrated Survey for Agriculture (LSMS-ISA) has been used to explore fertilizer adoption rates across Niger and how this correlates with expected need (poverty and agro ecology). This is supplemented by primary data collection in selected villages in the regions of Dosso, Maradi, Tillabéri, and Zinder in Niger, which are mainly in the southern Sahelian, Sahelo-Sudanian, and Sudanian agro-ecological zones, where crop production in Niger is most feasible. Though not nationally representative this group of villages capture the variation across important dimensions relevant to the adoption of a technology such as micro-dosing such as rainfall, soils, population density, and access to markets, services, and assets (see Figure 1).

The sampling strategy and village selection for our primary data collection builds on the sampling strategy adopted by a previous study conducted in Niger by the International Food Policy Research Institute (IFPRI) in Niger in 2004-2005. During that study, 400 households were randomly selected from 40 villages in the four regions of Niger mentioned earlier. Those villages were selected based on their proximity to areas in Niger that had been exposed to micro-dosing and other interventions; input shops and inventory credit systems. For this study, we administered household surveys to about 800 households; the same 400 households that were interviewed in 2004-2005 and an additional 400 new households. The new households were randomly selected from 40 new villages also randomly selected from the same regions (Dosso, Maradi, Tillabéri, and Zinder) using the Repertoire National des Communes (RENACOM) database.[3] We use agricultural, socioeconomic and agronomic information from the sample of 800 households for the primary agricultural seasons for 2013 and 2014. This contains detailed information on agricultural practices, input use (at the plot level) and prices of various crops and inputs.

[3] National database of all the communes (3rd level of administrative division) in Niger

Figure 1. Study villages



Source: Map generated by Ibro Madougou Abdoulaye (INRAN, Niger)

3. Fertilizer use and Micro-dosing in Niger

Over 80% of the Nigerien population live in rural areas and 80 percent of the labor force is engaged in agriculture. Despite the important role that agriculture plays in the livelihood of the majority of its citizen, agricultural productivity is low and the majority of rural households are net buyers of food. Niger is characterized by largely sandy soils with poor structural properties and low nutrient levels (Abdoulaye and Sanders, 2005; Adesina et al., 1988). Though the need for nutrient replenishment is clear, fertilizer adoption rates across Niger are low on average (see Table 1). This has been attributed to factors such as poverty (about 50%), low cereal prices (Abdoulaye and Sanders, 2005; ECVMA, 2011) and high prices for fertilizer[4].

[4] In 2014, a 50Kg bag of fertilizer in Niger cost about 19000CFA (about US$40).

Table 1: Fertilizer use across regions in Niger

	% using fertilizer	% of population resident here
All regions	12.8	100
Agadez	17.61	2.8
Diffa	13.59	3.4
Dosso	21.85	12.0
Maradi	10.36	19.9
Tahoua	3.84	19.2
Tillabéri	11.19	16.1
Zinder	8.78	20.6
Niamey	24.09	6.0

Source: Niger LSMS (2011/2012) and L'Enquête Nationale sur les Conditions de vie et des Ménages et l'Agriculture au Niger (ECVMA)

Fertilizer micro-dosing provides an opportunity to improve the productivity of poor farmers facing soil nutrient challenges, erratic rainfall and high price for fertilizer. Micro-dosing was developed over two decades ago by Scientists at ICRISAT and partner institutions. The goal of the technology is to ensure that poor farmers get the highest returns from the fertilizer quantities that they are able to purchase. Compared to line spreading and broadcasting (the traditional inorganic fertilizer application techniques in Niger), micro-dosing is said to be more efficient, using a fraction of the quantity of fertilizer that traditional practices use. Furthermore, while average millet yields amount to less than 398kg/ha (INS-Niger, 2014) the potential yield increase from micro-dosing could range from 44% to 120% (ICRISAT, 2009).

Farmers across Niger use different methods to apply their fertilizer. Though a nationally representative data for Niger finds that less than 20 % of Nigerien farmers used inorganic fertilizer, fertilizer use varies quite a bit across regions (Sheahan and Barrett, 2014). The study sample finds fertilizer use rates to be higher than the national average (about 40% on average) with significant variation across region[5]. Among fertilizer users in rural Niger, we also find significant variation in the method of application used by farmers.

Table 2: Fertilizer application methods across regions in Niger (2014)

Variables	Dosso	Maradi	Tillabéri	Zinder	Entire Sample
Any fertilizer (%)	61.46	28.26	43.56	27.73	42.77
Any type of micro-dosing (%)	**18.38**	**19.88**	**13.99**	**20.36**	**17.95**
Micro-dosing pure	1.85	3.11	4.48	1.61	2.75
Micro-dosing unburied at the side of budding plant	16.00	13.42	8.67	17.15	13.79
Micro-dosing buried at the side of budding plant	0.69	5.51	2.42	3.1	2.65
Broadcast application (%)	1.69	0.72	4.48	0.92	2.06
Line spread application	0.3	0.96	1.21	0.34	0.60
Fertilizer mixed with seeds (%)	*49.85*	11.85	31.06	9.43	28.5

Source: Authors estimations (from ICRISAT survey, 2014) using STATA.

One interesting observation from table 2 is that there are very few farmers in Niger practicing micro-dosing as originally defined and disseminated by ICRISAT (micro-dosing pure in table 2). This procedure required 3 people applying fertilizer at planting. One person dug the hole; one person put in the fertilizer and then a third person put in the seed and closed the hole. Less than 5% of respondents who indicated using a targeted approach of applying small amounts of fertilizer on their crop said they were using this method. Majority of respondents were actually

[5] This is likely due to the fact that the initial study sample was previously and more intensely exposed to fertilizer and fertilizer micro-dosing. Since we are interested in the profitability of fertilizer use under micro-dosing versus other techniques, the higher use rates of fertilizer is beneficial. However, to ensure that our results on the general profitability of the technique are externally valid, we run our estimations also only on plots from the truly random sample and the study results are maintained

applying fertilizer at the foot/base of the newly sprouted plant. Very few (also less than 5%) also placed the fertilizer on newly sprouted plants but actually dug a hole and buried the fertilizer. Given that these are all still targeted approaches to applying small quantities of fertilizer in line with the objective of the design and spread of micro-dosing, we have considered all of these to be micro-dosing.

The most prevalent method of fertilizer application being used in Niger is mixing of fertilizer and seed. Almost 30% of inorganic fertilizer application in our sample is done by mixing fertilizer with the seed. Anecdotal evidence on the field indicates that though common, it is actually not an ideal application method. However, there is limited empirical evidence on if it is better or worse than micro-dosing. Furthermore, as mentioned above the quantity of fertilizer used for mixing fertilizer and seed is less than half of the recommended rate for micro-dosing, likely having different effects on production risks and profitability.

Another interesting observation relates to the persistence of micro-dosing use by small holder farmers in Niger. When we asked farmers if they had used micro-dosing in the past, less than 20% of current plot managers who are using fertilizer indicated that they had used micro-dosing consistently over the last 3 years (Table 3). As the length of time increases, we see that this number drops to about 10% over the last 10 years. However, when asked whether they used fertilizer more generally (even if not applied using micro-dosing), we see that almost 90% of current fertilizer users report that they had applied fertilizer on their plots consecutively over the last 3 years.

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

Variable	Mean	Std. Dev.
Used micro-dosing consistently over the last 3 years	0.16	0.36
Used micro-dosing consistently over the last 5years	0.13	0.33
Used micro-dosing consistently over the last 10years	0.10	0.30
Used fertilizer consistently over the last 3 years	0.86	0.35
Used fertilizer consistently over the last 5 years	0.75	0.43
Used fertilizer consistently over the last 10 years	0.62	0.49

Source: Authors estimations (from ICRISAT survey, 2014) using STATA.

This proportion reduces to about 60% over 10 years. This indicates that fertilizer use has increased among farmers over the last 10 years and while the persistence of micro-dosing use is quite low, farmers' use of fertilizer more generally is largely maintained. It is therefore very important to distinguish between micro-dosing and other fertilizer application techniques as there are likely important reasons for this variation in fertilizer application methods.

Understanding the processes and implications of using these methods as well as their potentially different yield and profitability effects is important for appropriately designing and implementing programs to encourage the adoption of micro-dosing. Most fertilizer in Niger is applied on millet fields. We find that that the average millet yield for those practicing micro-dosing (about 553kg/ha) and those mixing fertilizer with seed only (about 640kg/ha) is statistically significantly higher than the average yield for plots on which no fertilizer is used (about 480kg/ha). Though the mean yield from mixing is higher, a test on the difference in mean yields across farmers using these different techniques indicates that the difference in means is not statistically significant.

4. Conceptual framework:

To explore the productivity and profitability effects of fertilizer micro dosing in Niger, we explore the agronomic and economic dimensions of the technique. The agronomic dimension involves the estimation of the yield response to fertilizer micro-dosing. In order to determine the yield response to micro-dosing, we first frame the decision on fertilizer use and application technique at the household level. We consider rural households in Niger to be involved in agricultural production as well as other non-farm or off-farm activities. Agricultural production is key to households' livelihood and thus even as the household optimizes over various income earning activities, the households need to decide the amount of risky inputs (including fertilizer) that will be applied on each of its plots.

The use of modern inputs such as fertilizer typically increase both the mean and the variance of the net returns to production (Just and Pope, 1979). Furthermore, the decision on whether to use such inputs and the consequent amounts needs to be made prior to rains being established and without complete information about output prices. In addition to incomplete information on price and water availability, the decision on input use is also taken in the presence of imperfect credit and insurance markets. Consequently, we model the fertilizer use decision of a farmer as a constrained utility maximization problem which yields reduced form specifications of input demands and technologies (Singh, Squire and Strauss (1986; Sadoulet and de Janvry 1995). Multiple market failures implies that input demand functions will be a function of not just input and output prices, but household characteristics as well as shown in equation 1:

$$x = x(\boldsymbol{P_x}, \boldsymbol{P_o}, \boldsymbol{Z}) \qquad (1)$$

where x refers to a vector of inputs whose demand depends on the vector of input and output prices as well as other household specific characteristics, **Z**).

Once the decision to use fertilizer and the amount and technique has been made, the yield response to fertilizer is driven by agronomic principles alongside management and other associated practices. Consequently a base empirical linear panel data model for the yield response to fertilizer use can be expressed as follows:

$$y_{ijt} = \boldsymbol{\beta_1} F_{ijt} + \beta_2 X_{ijt} + \beta_2 Z_{ijt} + \boldsymbol{\beta_3} M_{ijt} + \propto_i + \mu_t + \varepsilon_{it} \quad (2)$$

where y_{ijt} refers to millet yields on plot i of household j in time t. F_{ijt} refers to the quantity of fertilizer used by household i on plot j in time t . $X_{ijt}$is a vector of measurable farmer and plot characteristics that affect millet yields while Z_{ijt} captures exogenous factors such as weather and rainfall that affect production. M_{ijt} refers to a particular method of fertilizer application (micro-dosing, mixing fertilizer and seed or broadcasting and line spreading). $\propto_i$ are time-invariant unobserved household-specific characteristics (e.g. ability or motivation) while μ_t are year fixed effects to account for time specific production shocks; ε_{it} is the idiosyncratic error term. β_1, β_2 and β_3 are parameters to be estimated.

While agronomic conditions can be partially controlled for with measures of rainfall, temperature and soil characteristics, a key challenge when estimating yield response functions is the effect of unobserved farmer characteristics that could affect the decision to use fertilizer and the fertilizer application technique that could also affect crop yields. For example more motivated farmers might be more likely to adopt fertilizer, use more (or less) fertilizer or practice a particular fertilizer application technique but might also be more likely to have higher yields. Not accounting for such unobservable farmer characteristics could lead to biased estimates on our coefficient of interest which is the yield response to fertilizer use or the yield effect of using one technique over another.

To address this, we can employ a fixed effects model (FE) that exploits variation in fertilizer use within a household to consistently estimate the yield effects of fertilizer and micro-dosing in a production function framework. Though our key parameter of interest in equation (1) are β_1 and β_3, one challenge associated with the FE model is our inability to identify the coefficients of important characteristics which might not vary over time such as soil quality and location specific factors (e.g. market access). Consequently, we also employ the correlated random effects (CRE) model (which addresses the effect of time invariant unobservable factors (as does the FE) but enables us to identify the coefficients on time invariant variables important when measuring yield effects of fertilizer use. The CRE approach requires an additional assumption that

$$\propto_i = \varphi + \bar{X}_i \emptyset + a_i \tag{3a}$$

and

$$a_i \mid X_i \sim Normal(\varphi + \bar{X}_i \emptyset, \sigma_a^2) \tag{3b}$$

The CRE approach enable us to control for $\propto_i$ in equation (2) under this assumption by including, as additional controls, the household-level time averages of the observed explanatory variables ($\bar{\boldsymbol{X}}_i$). Controlling for time-constant unobserved effects via the FE or CRE approach should reduce the latitude for the amount of fertilizer applied (or the selected technique of fertilizer application) used by a household to be endogenous to crop yields. Consequently, we estimate both the household FE and the CRE version of the production function

The quadratic production function is generally viewed as a good approximation to the underlying functional form for yield response models (Traxler and Byerlee, 1993; Kouka et al., 1995 Sheahan et al., 2013; Liverpool-Tasie et al (2015)). We follow the literature to estimate a quadratic production function to capture the millet yield response to applied fertilizer in rural Niger. M_{ijt} captures the fertilizer application technique used on a plot in time t, to identify any yield differences across micro-dosing, mixing fertilizer and seeds, combining both micro-dosing and mixing and the traditional application methods of line spreading and broadcasting. We also include village dummies in the CRE models to capture any village characteristics or production shocks.

5.0 Production function estimates for millet production

Table 4 presents the fixed effects (FE) and CRE results for the quadratic production function estimation of millet yields as a function of applied fertilizer on millet plots. In both specifications. As expected, the yield response of millet to fertilizer is positive and significant. The yield response to applied fertilizer is decreasing as the quantity of fertilizer applied increases which is in line with decreasing returns to factors of production. The significance and sign of the base and squared fertilizer quantity variables indicate that the quadratic function is an appropriate specification. Labor and the seeding rate are other important inputs that are expected to affect millet yield. Higher seeding rates and labor are important for millet yields, consistent with the literature. While soil quality on its own appears to affect yields (as one would expect), we did not find the interactions between applied fertilizer and our soil group types to produce statistically significant estimates. This might be driven by limited variation in soil types and thus a limited ability to tease out how these soil types actually affect the fertilizer response differently. It might also be reflecting that though soil properties are important for determining yields, it might be the actual nutrient content of the soils that is important for the fertilizer response. (Marenya and Barrett, 2009). Higher annual mean temperature appears to reduce millet yields. Again we explored for differential effects on fertilizer response across rainfall and weather conditions and found them not to be significant[6]. We also explored the effect of different millet cropping systems on yields and the differential effect of applied fertilizer therein. Again we find no separate or jointly significant effects.

Comparing fertilizer application techniques, we do not find much heterogeneity in the effect of different application techniques on yields. However, where statistically significant, it appears that yields are relatively lower on plots where the traditional approach to fertilizer application is used (see table 4)[7]. As expected, regional and village characteristics are important determinants of millet yields. Compared to Dosso, where agro-ecological conditions are more favorable (and where fertilizer use is more prevalent) millet yields are lower in Maradi, Tillabéri and Zinder. The significance of village dummies indicates the importance of controlling for production shocks at such levels and likely captures the importance of differential levels of infrastructural development and access to information and complementary inputs.

[6] These results are not included but available from authors upon request

[7] We estimated a fuller quadratic model with interaction terms. Key interactions such as between fertilizer and application technique, labor and soil quality were not significant individually or jointly. Since they increase the yield response to applied fertilizer we chose to maintain the more parsimonious specification in table 4 as this is more conservative in terms of the yield response results thus likely to be a lower bound on the profitability effects as far as the fertilizer agronomics is concerned.

Table 4: Production function estimates for millet production across fertilizer use categories

VARIABLES	(1) Yield response- OLS	(2) Yield response- FE	(3) Yield response- CRE
Quantity of applied fertilizer (kg/hectare)	13.293***	13.789***	12.644***
	(2.483)	(3.284)	(2.576)
Squared quantity of applied fertilizer (kg/hectare)	-0.043***	-0.040***	-0.041***
	(0.008)	(0.010)	(0.008)
Female	-17.719	66.745	-3.379
	(35.286)	(76.811)	(35.724)
Age	2.132**	7.217	2.565***
	(0.917)	(5.998)	(0.970)
Clayey soil	-42.296	-90.323*	-38.538
	(30.116)	(49.459)	(30.788)
Sandy-clayey soil	-55.456*	-48.784	-61.147*
	(31.821)	(46.253)	(33.327)
Silty soil	1.208	-18.237	5.239
	(37.181)	(41.669)	(36.551)
Other soil types	-219.555**	-380.374*	-199.669*
	(104.573)	(217.958)	(105.725)
Crop area (hectares)	-55.006***	-77.141***	-50.560***
	(11.403)	(20.460)	(11.639)
Squared crop area (hectares)	1.585***	3.157***	1.397***
	(0.465)	(1.159)	(0.478)
Seeding rate (kg/hectare)	13.395***	10.555***	11.264***
	(3.359)	(2.871)	(2.756)
Total man-days per hectare for all planting activities	0.755*	1.167**	1.304***
	(0.420)	(0.498)	(0.423)
Quantity of organic fertilizer (kg/hectare)	0.152	0.175	0.200
	(0.236)	(0.221)	(0.238)
Intercropping millet with other crops (1/0)	-66.537	2.214	13.037
	(67.140)	(66.041)	(54.500)
Plot is a collective plot (1/0)	-15.778	16.694	42.333
	(26.695)	(58.045)	(48.872)
Improved seed used on plot (0/1)	18.634	32.401	-2.139
	(35.512)	(72.034)	(71.418)
Household asset value (000 CFA)	0.010	0.009	0.006
	(0.009)	(0.024)	(0.021)
2014 planting season	-140.430	-110.149	-121.891
	(154.894)	(173.246)	(160.911)
Micro-dosing	-42.118	-68.279	-41.684
	(34.897)	(46.990)	(34.613)
Mixing fertilizer and seed	-48.877*	-25.923	-42.918
	(27.838)	(55.542)	(29.241)
Traditional application (broadcasting and line spreading)	-143.949***	-84.967	-139.566***
	(49.991)	(74.910)	(48.409)

Dosso	-237.812		-287.888*
	(151.022)		(163.137)
Maradi	-611.282***		-659.323***
	(75.063)		(94.434)
Zinder	-124.216*		-138.366*
	(67.680)		(77.019)
Annual mean temperature	-30.449***		-34.410***
	(6.769)		(7.760)
Temperature seasonality (standard deviation*100)	0.038		0.032
	(0.050)		(0.051)
Annual precipitation	-0.224		-0.236
	(0.184)		(0.185)
CRE controls	NO	NO	YES
Village dummies	YES	NO	YES
Observations	5,803	5,803	5,803
R-squared	0.204	0.354	0.210

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.1 Profitability

To examine the profitability of intensification strategies such as fertilizer micro-dosing, it is necessary to consider both their agronomics and economics. Thus we combine the information from the yield response estimations above with information on the prices of relevant input and outputs. We first determine the expected marginal physical product of fertilizer (EMPP) and the expected average physical product (EAPP). The EMPP measures the additional millet gotten from an additional kilogram of fertilizer. It is calculated as the first derivative of the yield response function with respect to applied fertilizer as expressed in (4)[8].

$$EMPP_F = \frac{\partial Y(F,X,M,Z)}{\partial F} \quad (4)$$

[8] Since the results are so similar between the FE and CRE results, we proceed with the results from the FE models since it is not subject to the assumption about the distribution of the unobserved heterogeneity. However, the subsequent analysis was also conducted using the results from the CRE model and the profitability results are almost identical.

where Y is our millet yield and as expressed in (2) above is a function of our fertilizer (F), other inputs(X) and other factors also affecting millet yields as defined above. For this paper, we follow Sheahan et al. (2013) and Liverpool-Tasie et al. (2015) to calculate the average physical product as the gain in millet yield per unit of applied fertilizer relative to not using any applied fertilizer. We then calculate expected marginal and average value cost ratios (EMVCR and EAVCR) as the value of additional output divided by the price of fertilizer as expressed in (5) and (6) respectively

$$E\left(MVCR_{Fijt}\right) = \frac{E(p_{mt}) * E(MPP_{Fijt})}{p_F} \tag{5}$$

$$E\left(AVCR_{Fijt}\right) = \frac{E(p_{mt}) * E(APP_{Fijt})}{p_F} \tag{6}$$

where p_F is the price of fertilizer p_m is the expected price of millet at harvest. We use the average village fertilizer prices Missing village level prices were replaced with median department, and commune level prices respectively.[9] A farmer's decision to use fertilizer during the planting season is likely dependent on their expectation about prices in the harvest season and not actual prices. Consequently, we build an auxiliary model for price expectations for millet using FAO regional level retail prices. We follow Nerlove and Fornari's (1998) quasi-rational expectations model. We assume price expectations are formed using predictions from an optimal linear projection autoregressive model. The order of the auto-regression varies from 3 to 4 for the 4 regions included in our analysis and for each region takes the form:

[9] Department is the 2nd level of administrative division (equivalent to counties and cities in the US), commune is 3rd level (equivalent to municipalities in the USA).

$$P_t = a_0 + \sum_{i=1}^{k} a_i p_{t-i} + \upsilon_t \qquad (7)$$

where the a are parameters to be estimated, P_t is the price of output expected by producers, conditional on information available at planting, P_{t-i} is the observed price of output during planting time, and $\upsilon_t \sim N(0, \sigma_t^2)$ is the error term .

As most poor smallholder farmers are risk averse, we adjust our expected profit maximization criterion to account for the riskiness of the technique for smallholder farmers. We allow for uncertainty and additional input or other transactions cost to raise the expected marginal value cost ratio that farmers would require to consider fertilizer use profitable. Several studies apply a risk premium of 1 and a consequent MVCR of 2 as a threshold for profitability (Xu et al., 2009; Sauer and Tchale, 2009; Bationo et al., 1992; Kelly, 2005; Sheahan et al., 2013; Liverpool-Tasie et al., 2015). For this paper, we do not focus particularly on a specific threshold but recognize that MVCRs and AVCRs above 1 are likely to be necessary for smallholder farmers in Niger to consider fertilizer application for maize production profitable[10].

Table 5: Marginal and Average Physical Product of applied fertilizer across fertilizer application techniques

VARIABLES	MPP	APP
Micro-dosing	12.947***	13.09
	(3.088)	
Mixing Fertilizer and seed	13.457***	13.56
	(3.202)	
Traditional approach (line spreading and broadcasting)	13.088***	13.32
	(3.120)	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[10] There is a debate about the actual threshold for profitability that captures the likelihood that small holders are risk averse and also accounts for the fact that there are other costs associated with fertilizer use. The threshold of 2 commonly used in the literature has been critiqued to be too high. For this reason we have chosen not to focus on a particular threshold but to recognize that it is likely to be greater than 1.

Table 5 shows that the marginal physical products of fertilizer (MPPs) of applied fertilizer for millet farmers varies only slightly across different farming techniques. The MPPs are the Average partial effects (from the production function estimates) by fertilizer application technique. We derive the partial effect for applied fertilizer for every plot i at a particular time t in the dataset. The APE is just the average of all partial effects for every plot on which a particular technique was applied in the dataset. For farmers practicing micro-dosing, each additional kilogram of fertilizer applied yields about 13 kilograms of millet. For farmers practicing mixing where the average quantity of fertilizer is about half, each additional kilogram of fertilizer still yields about 13kg of millet, which is not expected in line with decreasing marginal returns. We also calculate the average physical product, measured as the additional yield gain per kilogram of applied fertilizer relative to not using any fertilizer[11]. We find the APP of applied fertilizer to be very similar to the MPP and across all the different fertilizer application techniques. It is also about 13kg.

Next we use estimated coefficients of the production function to determine the marginal physical product of fertilizer (MPP) for each plot to estimate the expected marginal value cost ratio associated with the various techniques. When $AVCR_{Fijt}$ is greater than 1, it implies that a risk neutral farmer could increase the income from his plot by using fertilizer. Consequently, we expect risk neutral households to use fertilizer if E(AVCRnijt)>1 and we expect their fertilizer application rate to be determined by E(MVCRFijt).

An important consideration of the economics of fertilizer application is the input/output price ratio (I/O ratio). This ratio captures the relationship between the output price and fertilizer

[11] This is not surprising given the quadratic functional form used where the MPP, defined as the first derivative with respect to a particular input is essentially equivalent to the APP, defined as the production function divided by the input.

price, expressed in units of output needed to purchase one unit of fertilizer. It shows the number of kilograms of output a farmer needs to purchase one kilogram of fertilizer (Morris et al, 2007). The lower the ratio, the higher the profitability (Yanggen et al, 1998). Table 6 shows the fertilizer/millet price ratios for 2013 and 2014 across the 4 study regions. It can be seen that fertilizer profitability is likely higher in Zinder and Tillabéri (with ratio's closer to 1) compared to Dosso and Maradi where the ratios are closer to 2 (Table 6)12.

Table 6: Input /Output price ratios across Nigerien regions

	Dosso	Maradi	Tillabéri	Zinder
Fertilizer price (2013)	374.338	371.141	251.06	124.002
Millet price (2013)	222.714	148.318	217.362	163.456
I/O ratio	1.68	2.502	1.156	0.761
Fertilizer price (2014)	394.526	370.434	247.985	123.832
Millet price (2014)	224.005	151.618	217.435	162.825
I/O ratio	1.761	2.443	1.142	0.762

Source: Authors estimations using STATA.

By virtue of the profitability measures considered above and based on economic profit maximization (where farmers choice of an input will be where the value of the marginal product of an input is equal to its price), it appears that the various fertilizer application techniques for millet production are profitable. One caveat worthy of note is that this analysis does not directly capture the effect of transactions or transportation costs on the true fertilizer acquisition costs and various studies have demonstrated that transportation costs are a key factor affecting the profitability and consequent use of fertilizer (Minten et al, 2013; Liverpool-Tasie et al, 2015). While, we expect that village and regional characteristics will affect the profitability of fertilizer use, our ability to speak

[12] Fertilizer prices in Tillabéri and Zinder are significantly lower than the price in other regions. For Zinder, particularly, the price is almost half of the expected price suggested by CAIMA. This might indicate access to subsidized fertilizer or might be driven by the regions close proximity to Nigeria from which a significant proportion of fertilizer in Niger originates. Millet prices are also quite low in communities in Zinder.

to the effects of transactions cost on the profitability of fertilizer use is limited. Thus we recognize that to account for these, the value cost ratio's required for a typical rural household who is likely risk averse or facing additional costs to use fertilizer such as increased labor costs, transportation costs and other transactions costs to consider fertilizer use profitable will be greater than 1. Furthermore, assuming that many of these effects are likely fixed at the household level, we can still compare the profitability of fertilizer use across plots within a household on which different fertilizer application methods were used.

Table 7 indicates that fertilizer use for millet production is profitable on average in the study sample. This is the case irrespective of the fertilizer application technique used by farmers.. Our AVCRs are much higher than 1or even 2, indicating that our conclusion would remain irrespective of whatever reasonable threshold was used. Though both are well above the threshold of 1.5 or 2 considered necessary for a risk averse farmer, the AVCRs are higher under mixing compared to micro-dosing.

Table 7: Expected marginal and average value cost ratios of fertilizer across fertilizer application techniques.

Fertilizer application technique	MVCR 2013	MVCR 2014	AVCR 2013	AVCR 2014
Micro-dosing	7.34	7.42	2.49	2.48
Mixing Fertilizer and seed	8.05	8.09	2.52	2.40
Traditional approach (line spreading and broadcasting)	7.63	7.69	2.72	2.31

Ultimately, average values across the different techniques masks the heterogeneity that is likely important at household and plot level. We thus compare the MVCRs and AVCRs at the plot level and compare the calculated AVCRs with the benchmark of 2 (for risk averse farmers) and estimate the number of plots on which fertilizer is currently applied but for which it appears not to be profitable by expected profit maximization conditions (i.e. when MVCR<2). Table 8 shows that across most fertilizer application techniques, it is profitable for over 95% or more farmers who apply fertilizer to do so[13].

Table 8: Farmer behavior and expected profitability

Fertilizer application technique	**percent of plots on which fertilizer is being used for which it is not profitable (MVCR<2)**
Micro-dosing	1.2%
Mixing Fertilizer and seed	<1%
Traditional approach (line spreading and broadcasting)	4.8%

Source: Authors estimations using STATA.

These results appear to indicate that at current input and output market prices, and given the response rate of fertilizer, both micro-dosing and mixing fertilizer with seeds are profitable. However, given the differential fertilizer quantity used for both techniques, the actual relative profitability might be quite different.

5.2 Relative profitability of fertilizer application techniques

Next we explore the relative profitability of fertilizer micro-dosing and mixing fertilizer and seeds as a potential explanation for the low adoption rates of micro-dosing. An important

[13] With such low numbers when the threshold 2(considered by some to be too high) is used, we are confident that these results will hold up for lower threshold values.

consideration when evaluating the profitability of fertilizer application techniques (and fertilizer use more generally) is the effect of fertilizer use (or a fertilizer application technique) on the need or demand for other inputs. Using the EMVCR and EAVCR ratios to evaluate fertilizer profitability assumes that there are no other major additional costs to the farmer in using fertilizer besides the cost of the fertilizer itself. Thus it is important to confirm if indeed the labor requirements for the various application techniques are significantly different. Furthermore, there is a general conception that intensification methods that focus on targeted fertilizer application such as fertilizer micro-dosing are more labor intensive than traditional application methods (Liverpool-Tasie et al, 2015) . This additional labor requirement is often offered as a reason for the low adoption of these strategies.

As mentioned earlier, the quantity of fertilizer applied for the different application techniques is usually very different (Pender et al, 2008; Abdoulaye and Sanders, 2005; Doumbia et al., 2005), likely affecting the relative profitability of the options and the likelihood of farmers choosing one over the other. This is particularly important given that we find no consistent evidence that micro-dosing or mixing seeds with fertilizer has a clear advantage in terms of yield gains. Thus it is important to confirm if the fertilizer quantity used on plots where different techniques are used is indeed different.

Consequently, we use detailed labor and input cost data on the various activities engaged in during the production process to explore the variation in labor use across activities and fertilizer application techniques. We also estimate the effect of the various fertilizer application techniques on the demand for various inputs, particularly labor and fertilizer. Table 9 provides the descriptive statistics on the use of some inputs across fertilizer application techniques. Three observations to note are: First there is no evidence that micro-dosing is more labor intensive than other fertilizer application techniques. While, on average, plot managers using the traditional application techniques report a mean of about 6 man-days used for fertilizer application , that for   micro-dosing is about 5.5 while mixing is over 7 man-days. The standard deviation of these measures are quite wide and thus it is not clear if these averages are truly different. When we look at the mandays required for weeding, we see that the number of man-days reported for weeding on plots where micro-dosing and traditional application methods are used are lower at 25 and 26 compared to almost 29 days for mixing fertilizer and seeds. A third point, evident from table 9 is the difference in the average quantity of fertilizer for this analysis stems from the quantity of fertilizer applied for the different techniques and the consequent cost associated with it. The mean quantity of fertilizer applied on plots on which mixing fertilizer and seeds is practiced is only about 11kg/ha, this increases to about 25g/ha for micro-dosing and about 30kg/ha for traditional line spreading and broadcasting. Table 9 displays the median quantity of fertilizer use which are lower than the means but with the same ordering.

Table 9: Labor use across various activities and fertilizer application techniques

Median Values			
	Mixing	Micro dosing	Broadcasting and line spreading
Total man-days per hectare for plot prep	4	3	2
Total man-days per hectare for planting	8	6	6.
Total man-days per hectare for fertilizer application	1	1	1
Total man-days per hectare for weeding	28	22	23
Total man-days per hectare for harvest	8	6	5
Total quantity of fertilizer used on plot (kilograms/hectare)	3.45	10.43	15.00
Number of observations	2,781	1,986	415

Source: Authors estimations (from ICRISAT survey, 2014) using STATA.

We supplement the descriptive analysis depicted in table 9 with a household fixed effect regression on the impact of the various fertilizer application techniques on the demand for various inputs. More specifically we focus on the quantity of fertilizer applied as well as the quantity of labor used for various activities. Column 1 and 2 of table 10 indicate that compared to micro-dosing (which is the base for that regression) plots on which mixing fertilizer and seed is the main fertilizer application technique, use significantly less fertilizer. However, columns 7 and 8 of table 10 show that there is no significant difference in man-days used for fertilizer application across fertilizer application techniques. These results indicate that the general perception that the low adoption rates of targeted fertilizer application techniques are because they are more labor intensive than traditional methods is not upheld in rural Niger[14]. Actually, plots on which mixing fertilizer and seed is practiced appears to actually require the most labor. Part of this is driven by the higher labor requirement for weeding. The higher weeding requirement supports the idea that fertilizer increases weed incidence and more targeted fertilizer application techniques (e.g. micro-dosing) allow for more efficient absorption of nutrients by the plant with less made available for weeds. However, these results suggest that the incidence of weeds is significantly more when fertilizer and seed are mixed.

On average, the total labor requirement is significantly higher for plots on which fertilizer is applied and this is not surprising. In addition to the labor requirement for fertilizer application, this appears to also be driven by labor for land preparation and weeding (particularly for mixing fertilizer and seed). This higher labor requirement is important to the larger debate about fertilizer use in general, in Niger. A revisit to our production function estimates indicate that the marginal

[14] While one would expect man-days for fertilizer application to be zero when fertilizer is mixed with seeds at planting, additional labor application might reflect that some farmers augment with additional top dressing later.

physical product of labor is about 1.5 and this does not vary significantly across fertilizer application techniques. Thus each additional man-day allocated to millet production yields about 1.5kgs of millet. Table 11 shows the typical daily wage across activities and regions in rural Niger. It is clear that the value of the marginal product of labor (millet price* additional output from a unit of labor) is not on average, covered by the cost of that additional unit of labor. This is likely a key factor affecting farmer's decisions to use fertilizer and might partially explain the generally low rates of fertilizer use in rural Niger. Fertilizer use does not only require a financial cost in terms of the direct cost of the input, it also requires additional labor which is very expensive, particularly if hired in.

Table 10: The effect of fertilizer application techniques on input use (Household Fixed Effects model)

VARIABLES	(1) Fertilizer quantity	(2) Fertilizer quantity	(3) Labor land prep	(4) Labor land prep	(5) Labor planting	(6) Labor planting	(7) Labor fertilizer	(8) Labor fertilizer	(9) Labor weed	(10) Labor weed	(11) Labor total	(12) Labor total
Micro-dosing	BASE	BASE	1.215***	1.228***	1.821	1.647	BASE	BASE	1.423	1.491	14.492***	15.256***
			(0.337)	(0.322)	(1.364)	(1.376)			(1.171)	(1.175)	(4.591)	(5.057)
Mixing fertilizer and seed	-4.174*	-4.760*	1.435**	1.203**	1.846	1.403	-1.543	-1.541	3.195***	3.397***	16.902***	17.692***
	(2.461)	(2.506)	(0.564)	(0.533)	(1.456)	(1.394)	(1.611)	(1.660)	(1.008)	(0.968)	(4.199)	(4.234)
Other fertilizer application	-1.251	-1.965	0.726	0.658	-1.812	-2.259	-3.734*	-3.675*	0.138	0.489	5.687	6.952
	(3.210)	(3.204)	(0.448)	(0.441)	(1.958)	(1.815)	(1.944)	(1.983)	(1.230)	(1.190)	(5.419)	(5.763)
Female		1.182		-0.374		5.832		0.730		-5.959		4.046
		(4.161)		(0.510)		(4.164)		(2.246)		(3.793)		(9.682)
Age		-0.116		0.017		-0.015		-0.021		0.124*		0.389
		(0.108)		(0.024)		(0.076)		(0.097)		(0.070)		(0.333)
2014 planting season		-25.037*		-0.676		-5.055		-0.144		-2.751		1.457
		(13.167)		(1.165)		(4.930)		(5.651)		(5.878)		(20.861)
Other controls	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES
Constant	20.054***	1094	5.709***	6094	14.722***	41162	8.255***	1,2240	26.419***	16652	69.820***	339163
	(1.713)	(2974)	(0.191)	(3705)	(0.557)	(1210)	(1.123)	(13787)	(0.381)	(1447)	(1.609)	(39619)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 11: Wage rates

	Dosso	Maradi	Tillabéri	Zinder
Average wage rate for all activities	1226.63	1131.08	1398.43	1474.74
Wage rate for harvest	378.847	523.115	377.932	1367.13
Wage rate for plot prep	1684.12	881.771	2326.28	1213.77
Wage rate for planting	1631.51	1451.12	1566.32	1539.54
Wage rate for weeding	1422.61	1390.53	1477.93	1578.71
Wage rate for fertilizer application	1462.15	1332.38	1577.19	1438.82

Finally, we compare the net revenue from millet plots on which various fertilizer application techniques are used. The major reported costs associated with millet production were labor and fertilizer (organic and inorganic). We explore the differential profitability of fertilizer application techniques using a household level fixed effects regression. This model captures the variation in net revenue across plots within a household on which different application techniques were used. We estimate two specifications of net revenue. One is the actual reported net revenue calculated as the difference between the value of millet produced and the reported expenses for labor and non-labor inputs (e.g seeds, organic manure, fertilizer etc). Here only hired labor cost was captured. In the second specification, we calculate net revenue as the difference between the value of millet yield and the total value of inputs used in production which included reported non labor costs and labor cost valued at the median community wage rate for all labor used for millet production on that plot.[15]

Table 12 indicates that compared to not using any fertilizer mixing fertilizer and seeds has the highest returns. While micro-dosing has a higher return compared to not using any fertilizer, this is small and not statistically significant. On the other hand the net returns to mixing fertilizer

[15] All labor includes family and hired labor

and seed is more consistently significant at 5% or below and is between about 7,000CFA (about $14) and 9,000($18) compared to between 2,500 (about $4) and 3,500($7) for micro-dosing. Traditional fertilizer application methods actually yields negative profits consistent with the production function results and likely partly responsible for the low observed use of the technique(less than 5% in any survey year).

Table 12: Net revenue on millet plots across fertilizer application techniques (Household Fixed Effects model)

	(1)	(2)	(3)	(4)
	Actual reported net revenue (Marginal effects)	Actual reported net revenue (Marginal effects)	Net revenue with cost of family labor valued at village median wage (Marginal effects)	Net revenue with cost of family labor valued at village median wage (Marginal effects)
Micro-dosing	1,650.475	3,753.541	775.394	2,523.134
	(4,319.122)	(4,449.352)	(4,983.716)	(4,640.579)
Mixing fertilizer and seed	7,872.215*	9,280.556**	5,700.372+	6,748.201*
	(4,165.950)	(4,111.730)	(5,741.170)	(4,206.796)
Traditional application methods	-10,942.128*	-8,732.728+	-10,750.327**	-8,933.117+
	(6,608.127)	(6,537.669)	(4,944.908)	(6,602.313)
No fertilizer use	BASE	BASE	BASE	BASE
Constant	67,187***	54,903***	40,286***	27,769*
	(1,383.577)	(15,811.386)	(1,801.769)	(16,257.036)
Other controls	NO	YES	NO	YES
Observations	8,454	8,257	8,454	8,257
R-squared	0.422	0.424	0.447	0.450

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1 + p<0.15

6. Summary and Conclusions:

This paper explored the profitability of micro-dosing as a fertilizer application technique in Niger. Our results indicate that millet yield response to fertilizer application are higher when fertilizer micro-dosing is used compared to no fertilizer. However, conditional on various agronomic and socioeconomic conditions as well as any unobserved household specific characteristic, we do not find evidence that millet yields are significantly different with micro-dosing compared to the other prevalent fertilizer application method; mixing the fertilizer and seeds at planting.

Assessing fertilizer profitability based on marginal and average value cost ratios indicated that at current fertilizer and millet prices, fertilizer use for millet production is profitable for many farmers. On average, the value of additional millet yield due to applying fertilizer was greater than the market price of the fertilizer. However, plots on which fertilizer is applied use more labor than those on which no fertilizer is applied. While this is not surprising, it indicates that profitability measures such as AVCRs and MVCRs might not be complete or appropriate in this setting. The high costs of labor in rural Niger indicate that the additional labor required for applying fertilizer is likely a binding constraint. A comparison of net revenue across the study sample indicates that mixing fertilizer and seeds yields the highest returns.

The study finds no empirical evidence that micro-dosing is more labor intensive than traditional methods of fertilizer application as is conventionally thought. Among different fertilizer application techniques, the study results indicate that total labor use is actually higher when fertilizer is mixed with seeds compared to that used on plots for which micro-dosing and traditional application such as broadcasting and line spreading are used.

Consequently, our analysis finds that while micro-dosing on its own is more profitable than using no fertilizer, other techniques such as mixing fertilizer with seed at planting (a method that appears to have been developed by farmers themselves) might be more attractive because it requires significantly less fertilizer than the traditional approach or micro-dosing. Any yield returns from fertilizer micro-dosing compared to mixing do not appear to be sufficient to compensate for the higher costs associated with the higher quantity of fertilizer required.

These findings indicate that additional research is necessary to understand the details of the fertilizer application techniques involving the mixing of fertilizer and seeds. There is much less information about this technique compared to micro-dosing. It is important to understand if there are any technique specific issues (in addition to the identified higher weed incidence) or risk trade-offs which might explain why some farmers still tend to practice micro-dosing over mixing.

One area for further consideration is the relative yield gains associated with micro-dosing . In addition to studies comparing the yield gains and other risk factors associated with micro-dosing compared to mixing seeds and fertilizer (for which there are almost no empirical studies), it is important to understand if the limited effects might be due to the nature of micro-dosing commonly practiced by farmers. We find that majority of those practicing micro-dosing in Niger place the fertilizer unburied at the side of the budding plant. This is not quite in-line with the original idea of targeted application at planting or buried at the side of the plant and might explain the limited yield gains associated with the practice compared to other methods.

These results also call for further attention as to the likely factors driving the low rates of adoption for micro-dosing particularly but fertilizer more generally in Niger. Further consideration of the potential effect of transactions and transportation costs on the profitability of fertilizer application (not explored in this study) are worthy of exploration given their established importance in the literature. Though fertilizer micro-dosing (and fertilizer more generally) has the potential to increase yields significantly (and this has been demonstrated in the study), fertilizer use is still a risk increasing technology. Sanou et al. (2015) demonstrate that risk aversion is a key determinant of the adoption of fertilizer and micro-dosing in Niger. This implies that there is likely a need for additional attention to be played to the possible role of ex-post coping strategies for farmers, such as crop insurance to encourage their adoption of fertilizer. Finally, the study results indicate the importance of labor constraints and high labor costs in the decision to adopt intensification techniques such as fertilizer use, when such techniques are labor using. Strategies to reduce the labor requirement of fertilizer application are one among several options worthy of further exploration.

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