IMPACTS OF INVENTORY CREDIT, INPUT SUPPLY SHOPS AND FERTILIZER MICRO-DOSING IN THE DRYLANDS OF NIGER

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Abstract

This study investigates the impacts of access to inventory credit (*warrantage*), input supply shops, fertilizer micro-dosing demonstrations, and other factors on farmers' use of inorganic and organic fertilizer in Niger, and the impacts on crop yields. We find that access to warrantage and input shops and participation in fertilizer micro-dosing demonstrations have increased use of inorganic fertilizer. Access to off-farm employment and ownership of traction animals also contribute to use of inorganic fertilizer. Use of organic fertilizer is less affected by these factors, but is substantially affected by the household's crop mix, access to the plot, ownership of durable assets, labor and land endowments, and participation in farmers' associations. Land tenure influences both inorganic and organic inputs, with less of both on sharecropped and encroached plots.

Inorganic fertilizer has a positive impact on millet yields, with an estimated marginal value-cost ratio greater than 3, indicating significant profitability. Organic fertilizer has a positive impact on millet-cowpea yields. We find little evidence of complementarity between inorganic and organic fertilizer.

Since warrantage, input supply shops and fertilizer micro-dosing demonstrations increase use of inorganic fertilizer which in turn increases millet yields, these interventions indirectly increase millet yields, although the impacts are relatively small. These findings support promoting increased input use through promotion of inventory credit, input supply shops and fertilizer micro-dosing demonstrations. Other interventions that could help to boost productivity include promotion of improved access to farm equipment and traction animals and improved access to land under secure tenure.

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1. Introduction

Niger is one of the poorest countries in the world. Only about one-eighth of the land area is suitable for cultivation, and this portion has fallen in the past several decades due to declining rainfall and land degradation (Abdoulaye and Sanders 2005). One critical manifestation of land degradation is depletion of soil fertility due to declining use of fallow resulting from rapid population growth and limited use of inorganic or organic fertilizers. Land degradation (together with climate change) has led to low and declining crop yields and increasing food insecurity. During the past two decades, yields of pearl millet (the dominant crop) have fallen 1% per year on average (FAOSTAT 2005).

To help address these problems, FAO and the government of Belgium initiated Projet Intrants ("inputs project") in 1999, which established a network of input supply shops and inventory credit (*warrantage*) schemes to promote farmers' use of fertilizer and other inputs and access to credit. The project is also promoting use of fertilizer "micro-dosing", an improved application method in which a small amount of fertilizer is combined with seeds before or during planting, and additional side dressing may be applied to the plant after emergence.

In this study we investigate the impacts of these innovations and other factors on farmers' use of inorganic and organic fertilizer and on crop yields, based on a survey conducted in late 2004/early 2005.

2. Study Regions and Data

The study was conducted in four regions of Niger where Project Intrants is active: Dosso, Maradi, Tillabery and Zinder (Figure 1). These regions are in the arable dryland zones of Niger, with annual rainfall generally ranging between 200 and 800 mm. Average rainfall is lowest in Zinder and highest in Maradi and Dosso. Soils are generally sandy with low inherent fertility and moisture holding capacity, except in river valleys where clay soils are found. Market access to the capital of Niamey is greatest in

Tillabery and Dosso, while Maradi is close to urban markets in Nigeria. About 70% of the population of Niger resides in these regions.

Forty study villages were purposively selected in the four regions, based on access to input shops. Ten villages were selected that have an input shop, and for each of these, three additional villages were selected from 5 to 20 km. away. In each village, ten households were randomly selected for the survey for a total of 400 households (three sample households did not complete the survey). All plots operated by each selected household were also surveyed.

The farming system in the study regions is dominated by intercropping of millet with various other crops (cowpea, sorghum, peanuts, hibiscus), though some pure stands of crops are also produced (especially of millet). Inorganic fertilizer is used on 23% of the plots surveyed. Inorganic fertilizer is most commonly used on the millet-cowpea-hibiscus intercrop (34% of plots) and least common on peanuts (4%). By far the most common fertilizer used is NPK (15-15-15) (18% of plots); other inorganic fertilizers used include urea and DAP (3%), PST (1.3%) and SSP (0.7%). On plots where NPK is used, the average amount used is only about 11 kg/ha. Micro-dosing is the most common method of applying inorganic fertilizer (90%), while broadcasting and line spreading are used on only 10% of plots.

Organic fertilizer is used on 32% of the plots. Organic fertilizers are most common on intercropped plots. Where organic fertilizers are used, the average amount used is 2.1 MT/ha.

Average crop yields in the survey were about 600 kg/ha each for millet, sorghum and cowpeas, across all crop systems. Interestingly, yields are higher in intercrop systems than in pure stands.

3. Empirical Model, Hypotheses and Econometric Approach

Empirical Model

Assume that production per hectare of crop mix C by household h on plot p (y^c_{hp}) is determined by the following production function:

(1) $$y^c_{hp} = f(C_{hp}, l_{hp}, x_{hp}, A_{hp}, z_{hp}, PC_h, HC_h, I_h, R, \theta)$$

C_{hp} is the crop mix produced on the plot; l_{hp} is the labor input per ha.; x_{hp} represents non-labor inputs per ha.; A_{hp} is the plot area;[1] z_{hp} represents plot quality characteristics; PC_h and HC_h represent household endowments of physical and human capital affecting productivity; I_h represents access to information and technical assistance affecting productivity; R represents regional factors such as agro-ecological potential affecting productivity; and θ represents unobserved random factors.

Assuming that the household maximizes expected utility subject to a liquidity and labor constraint, we derive the following form for input demands (see Annex):

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

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

T_{hp} is the tenure of the plot; SC_h represents social capital and OC_h represents other types of physical or human capital that influence income from non-crop activities; A_h is the household's total endowment of land and L_h is the total endowment of labor. We do not have wages, input and output price data at the household level. We assume that these prices will be determined by regional level prices (incorporated into R) as well as the access of the household and plot to the local markets (MA_{hp}).

Substituting equations (2) and (3) into (1), we obtain the reduced form equation for crop yield:

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

Equations (1) – (4) are the basis of the econometric estimation.

Hypotheses

Several hypotheses can be derived from this model (proofs not provided due to space limitation):

H1. By relaxing liquidity constraints and improving marketing of output, availability of warrantage credit should increase adoption of inorganic fertilizer and other purchased inputs, leading to higher yields.

H2. By reducing farmers' cost of purchased inputs, availability of input supply shops should increase use of purchased inputs and increase yields.

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[1] Plot area is included in the yield function to allow for non-constant returns to scale production at the plot level.

H3. Technical assistance promoting fertilizer micro-dosing may lead to either less or more use of inorganic fertilizer, depending on the level of fertilizer used and its profitability prior to such assistance. For households not previously using fertilizer, demonstrations of the effectiveness of micro-dosing may promote increased fertilizer use, while for those who had used fertilizer at larger doses, micro-dosing may reduce use. In either case, the marginal productivity of fertilizer use should increase.

H4. Income generating assets and activities may promote increased use of purchased inputs by relaxing liquidity constraints. The impact of such assets and activities on crop yields is ambiguous, however, since they compete with crop production for labor.

H5. The amount of inputs used per hectare may be lower on larger farms as a result of liquidity or labor constraints. As a result, crop yields may also be lower on larger farms.

Econometric Approach

In this paper we focus on estimation of equations (1), (2) and (4).

Production functions (equation (1)) and reduced form yield functions (equation (4))

In the specification of equations (1), we use a logarithmic functional form, in which the dependent variable and all of the continuous explanatory variables are transformed by their natural logarithms.[2] These transformations improve the performance of the regression model by transforming the variables towards normal distributions and reducing sensitivity to outliers (Mukherjee, et al. 1998). We include an interaction between inorganic and organic fertilizer to investigate cross-productivity effects, and interactions between the method of inorganic fertilizer application (whether micro-dosing or broadcast or line "macro-dosing") and the amount of fertilizer used, to investigate which approach is more productive. We also allow for different intercepts for micro-dosing vs. macro-dosing. The resulting production function specification is:

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

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

where α_{micro} and α_{macro} represent production intercept shifts, D_{micro} and D_{macro} are dummy variables indicating whether fertilizer micro-dosing or macro-dosing is used, β_{micro} and β_{macro} represent the response of production to the level of fertilizer used if applied using micro-dosing or macro-dosing, $inorg_{hp}$ is the value of inorganic fertilizer applied per ha., org_{hp} is the amount of organic fertilizer applied per ha., x_{hp}' is a vector of input amounts applied (other than inorganic fertilizer), K_{hp} is a vector of all other continuous variables in equation (1) (e.g., value of physical capital), and D_{hp} is a vector of all other dummy variables (e.g., plot level dummies representing different soil types).

In estimating equation (1'), the input variables may be statistically endogenous, leading to a bias. We use the generalized method of moments (GMM) estimator to estimate equation (1) and test for correlation between the error term and the explanatory variables using the C test for orthogonality (Davidson and MacKinnon 2004). We also test the validity of the overidentifying restrictions in the GMM model using Hansen's J test (Ibid.), and the relevance of the excluded instrumental variables as predictors of the potentially endogenous explanatory variables. The results of these tests are reported with the regression results. In all cases, the tests support the validity of the overidentifying restrictions in the regression models and the statistical exogeneity of the input variables. Thus we report only the results of the GMM models treating inputs as exogenous.[3]

The overidentifying restrictions imposed on the GMM models for equation (1) are based on theory and preliminary statistical testing of an unrestricted model. Theoretically, variables such as access to credit, ownership of assets not directly used in crop production and land tenure should not affect crop production directly (these are reflected in MA_{hp}, OC_h, and T_{hp}) in our model. However, if factors directly affecting production are not perfectly measured, such variables may have significant impacts on production in the structural model because they may act as proxies for other unmeasured factors that directly affect production. For example, plots of different land tenure may have different unobserved quality characteristics. Because of these considerations, we ran an initial unrestricted OLS regression for

[3] We also ran versions of the GMM models treating inputs as endogenous. In those models, almost all coefficients are statistically insignificant, due to the inefficiency of these models. Results available upon request.

equation (1'), including all of the exogenous variables and the potentially endogenous input variables. We used Wald tests in the unrestricted model to identify variables among those believed not to have a direct effect on production that were jointly statistically insignificant and which could be dropped from the model.

We also estimated the reduced form equation (4) using ordinary least squares (OLS), and report which results are robust in the reduced forms. We used the same type of logarithmic transformations of dependent and explanatory variables as for equation (1').

Input demand equations (equation (2))

In equation (2), the dependent variables include use per ha. of inorganic fertilizer, organic fertilizer, traditional seeds and improved seeds. In this paper we focus only on determinants of inorganic and organic fertilizer use. These variables are censored at zero; thus we use a Tobit model for estimation. A drawback of the Tobit model is its sensitivity to distributional assumptions. If the error term is not normally distributed and homoskedastic, as assumed by the standard Tobit model, this estimator yields biased parameter estimates. In the models for input use, we tested for normality and homoskedasticity using the test of Pagan and Vella (1989), and in all cases reject this assumption.

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

Another issue is the potential endogeneity of the crop mix in the input regressions. Because of the censored nature of the dependent variable, instrumental variables estimation is not appropriate for equation (2), and the methods of Smith and Blundell (1986) and Newey (1987) require that the endogenous regressors be continuous.

We address these issues by estimating several versions of the input use regressions: two Tobit models (one with and one without crop mix included), and censored quantile regressions at different quantile levels (we report results only of the 90th percentile regression; other quantile models that obtained convergence produced similar results). To save space, we report the coefficients of the Tobit model with crop mix, but only the statistical significance of the coefficients of the other two models. In the Tobit models, the coefficients are corrected to account for probability weights in the sample and robust standard errors are used. Because the dependent variables take zero values, we estimate these models using untransformed values of all variables.

Dependent variables

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

- Crop yield – for sole stands of millet, we used the quantity produced in kg. per ha. For intercrops (millet-cowpea and millet-sorghum-cowpea), we used the value of crops produced in CFA/ha, based on village level prices of crops. We did not estimate production functions for other crop mixes due to missing price information (e.g., for hibiscus) or a small number of observations.
- Inorganic fertilizer – total value of fertilizer used in CFA per ha.
- Organic fertilizer – quantity of organic fertilizer applied in kg. per ha.

Explanatory variables

The explanatory variables used in the input demand regressions and reduced form yield models included the following:

- Plot level variables: crop mix; area of the plot; soil texture categories (sand, clay, sand and clay, loam, sand and other); perceived soil fertility categories (poor, average, good); ownership of the plot (individual or collective by the household); how the plot was acquired (inherited, rented, purchased, sharecropped, other (mainly encroached)); and distance of the plot from the residence.

- Household level variables: value of assets owned (equipment, durable goods, traction animals, other animals); total area cultivated; labor/land ratio; dependency ratio; number of household members who belong to a farmers association; distance to the nearest input shop; whether household received warrantage credit in the past; whether household participated in fertilizer demonstrations in the past (micro-dosing, line spreading, broadcast spreading); characteristics of the household head - educational attainment (none, primary, secondary, literacy training, other); age; whether a village leader; occupation (agriculture only, non-agricultural work, agriculture and non-agricultural work, agriculture and other).
- Regional characteristics – dummy variable for each region.

To account for possible non-linear response of input demand to the age of the household head, we included age^2 as well as age.[4] Multicollinearity was not a serious problem (variance inflation factors (VIF) < 5) for any variables except age and age^2 (VIF > 50 for these).

4. Econometric Results[5]

Inorganic fertilizer use

Access to warrantage credit and better access to an input shop are significantly associated with greater use of inorganic fertilizer (Table 1), supporting hypotheses H1 and H2. These findings are robust for warrantage across all three regression models, and in two of the models for access to an input shop.[6] Participation in fertilizer demonstrations promoting fertilizer micro-dosing and line spreading are also associated with greater fertilizer use[7], consistent with the argument in H3 that prior to participating in such demonstrations farmers were not using fertilizer and that the demonstrations increased their awareness of profitable means of using it. By contrast, demonstrations on the broadcast method of applying fertilizer are not associated with greater use of fertilizer, suggesting that this method is not cost

[4] A squared transformation of ln(age) was not used in the other regressions because of very high multicollinearity in this case (variance inflation factors > 400 for ln(age) and $(\ln(age))^{2}$).
[5] Descriptive statistics are not reported due to space limitations.
[6] The statistical significance of the coefficients under each model is indicated in Table 1 using superscripts. In the remainder of this discussion we will focus on coefficients that are significant at the 10% level across all three models, unless otherwise noted.
[7] The effect of line spreading demonstrations is not significant in the censored regression model.

effective for farmers. Households involved in non-agricultural employment use more fertilizer, suggesting that liquidity constraints are important limitations to purchased input use (consistent with both H4 and H1).

We do not find support for any relationship between farm size and fertilizer use, as postulated by H5. Greater ownership of traction animals is associated with more fertilizer use[8], suggesting complementarity between traction and fertilizer inputs in production. We find no significant impact of the labor/land ratio or dependency ratio on fertilizer use, suggesting that labor constraints are not an important limitation on fertilizer use.

Other factors found to have significant and robust association (at 10% level across all three models) with fertilizer use include the region (lower use in Zinder than in Dosso), plot size (-), soil type (less on sandy/other than sandy soils), land tenure (less on sharecropped and other tenure (mostly encroached land) than on inherited, rented or purchased plots)[9], and crop choice (less on peanuts than millet)[10]. Lower use of fertilizer in Zinder is probably due to lower rainfall in this region. The negative association of fertilizer use with plot size could reflect diseconomies of scale, unobserved land quality factors that vary with plot size, or errors in measuring plot size. The negative association of sharecropping with fertilizer use is consistent with the Marshallian theory of sharecropping, which hypothesizes that farmers have less incentive to use inputs under sharecropping arrangements (Shaban 1987). The negative association of land encroachment with fertilizer use may be related to liquidity constraints faced by squatters and/or low quality of land occupied by squatters. Our productivity regression results (discussed below) support the explanation that such land is of lower quality than other land. The negative association of peanuts with fertilizer use is surprising, since peanuts are a higher value crop, but may be due to the fact that peanuts are a legume and thus require less nitrogen fertilizer.

Organic fertilizer use

Organic fertilizer use is not significantly and robustly affected by access to warrantage credit,

[8] Effect not significant in tobit model excluding crop mix.
[9] Effects of land tenure variables are not significant in censored regression.
[10] Effect of peanuts robust across only two models, since crop choice excluded from third model.

input supply shops, or fertilizer demonstrations; though a positive association with micro-dosing and line spreading demonstrations and negative association with broadcast spreading were found in the censored regression model. The latter findings (though not robust) suggest that fertilizer use in small doses may be complementary with organic fertilizer use, whereas application of larger doses may substitute for organic fertilizer. In general, however, such relationships between inorganic and organic fertilizer appear to be small, given the insignificant coefficient of several variables that promote inorganic fertilizer. We investigate this issue further below in our productivity regressions.

Not surprisingly, organic fertilizer use is lower on plots further from the household residence, due to the bulky nature of this input. Households owning more farm equipment and durable assets apply more organic fertilizer[11], probably because some of these assets are used to transport and apply organic fertilizer (like bicycles and carts).

Other fairly robust findings include associations of organic fertilizer use with region (more use in Tillaberi than Dosso), farm size (-)[12], land tenure (less use on plots acquired by sharecropping or encroachment)[13], membership in a farmers' association (+)[14], and crop mix (less use on peanuts and more use on all millet intercrops compared to sole millet). The negative association of farm size with organic fertilizer use is consistent with H5, and suggests that labor constraints are limiting use of this input. The censored regression results support this interpretation, showing that organic fertilizer use is greater for households with a larger labor/land ratio and less for households with a higher dependency ratio, though these results are not robust. The negative association of sharecropping and land encroachment with organic input use are consistent with the findings for inorganic input use. Together, these findings suggest that land tenure has substantial impacts on soil fertility depletion in Niger. The positive impact of farmers' associations on organic fertilizer use suggests that such associations are promoting organic practices. The negative association of organic inputs with peanut production is consistent with the results

[11] Effect of farm equipment is not significant in the tobit model excluding crop mix.
[12] Effect of farm size is not significant in the tobit model including crop mix.
[13] Effect of sharecropping is not significant in the tobit model including crop mix.
[14] Effect of farmers association is not significant in the tobit model excluding crop mix.

for inorganic fertilizer, while the positive association between millet intercrops and organic inputs suggests that organic practices are better suited to intercrops.

Crop yields

Greater of use of inorganic fertilizer applied via micro-dosing is associated with significantly higher yields of millet in pure stands (Table 2). Based on the estimated elasticity of millet yield to fertilizer micro-dosing (0.067), the average price ratio of NPK fertilizer to millet in the study villages (2.4), the average level of NPK fertilizer use on pure millet stands with micro-dosing (3.25 kg./ha.), and the average yield of millet in pure stands (388 kg./ha), the estimated marginal value cost ratio (VCR) of NPK fertilizer applied via micro-dosing is 3.35, indicating that fertilizer micro-dosing on millet is profitable for our sample farmers.[15] This result accords well with results of thousands of on-farm trials of fertilizer micro-dosing in Niger, which have found VCR's in the range of 2 to 4.

The quantity of organic fertilizer has a statistically insignificant impact on millet yield and a statistically weak and quantitatively small negative interaction with inorganic fertilizer. This suggests that complementarity between organic and inorganic fertilizer may be limited. There is a lack of consensus in the agronomic literature about whether and to what extent inorganic and organic fertilizer are complementary (e.g., Palm, et al. 1997).

Organic fertilizer use has a significant positive impact on millet-cowpea (M-C) yields, and inorganic fertilizer use has a statistically weak positive impact when applied using micro-dosing. Apparently organic inputs are more effective when applied in intercrop systems, consistent with the finding discussed earlier that use of organic inputs is greater in millet intercrops than pure stands. For the millet-sorghum-cowpea (M-S-C) intercrop, use of fertilizer micro-dosing is associated with lower yields. Apparently this technology is less well suited to sorghum than to millet.

Other inputs that have significant impacts (at 5% level) on crop production include labor and

[15] The VCR equals ε_{yx} (y/x)(p_y/p_x), where ε_{yx} is the elasticity of output (y) with respect to input (x), y is the quantity of output per ha., x is the quantity of the input used per ha., and p_y and p_x are the prices of the output and input per kg., respectively. A common rule of thumb is that VCR > 2 is needed for fertilizer to be widely adopted in a risky environment (CIMMYT 1988).

traditional seeds (positive for all crop systems), and pesticides (positive for M-C and M-S-C).

Controlling for input use, households that are closer to an input shop obtain better yields of M-S-C but worse yields of M-C. Prior participation in fertilizer demonstrations also has mixed associations with yields, as does access to input supply shops. Other factors that have significant impacts on crop production include plot size (- for M and M-S-C), soil type (mixed impacts), soil fertility (higher yields of M-S-C and M-C (weakly significant) on better soils), land tenure (lower millet yields on encroached land, lower M-C yields on rented land), ownership of traction animals (+ for M), equipment (+ for M-S-C), education (mixed impacts), age of the farmer (+ for M), household head being a village leader (+ for M-S-C) or a member of a farmers' association (- for M and M-S-C), the labor/land ratio (+ for M-C and M-S-C), dependency ratio (+ for M but – for M-S-C), occupation (higher yields of M-S-C if occupation is agriculture and other) and region (mixed). Almost all of these impacts are robust in the reduced form regressions.

Our results provide only mixed support for the positive impacts of access to warrantage, input supply shops and fertilizer micro-dosing demonstrations on yields postulated in H1, H2, and H3. The yield impacts of off-farm activities are also mixed, consistent with H4. We find little support for an inverse farm size-productivity relationship, as hypothesized in H5.

5. Conclusions

We find that access to warrantage and input shops and participation in fertilizer micro-dosing demonstrations have increased use of inorganic fertilizer in Niger. Access to off-farm employment and ownership of traction animals also contribute to use of inorganic fertilizer. Use of organic fertilizer is less affected by these factors, but is substantially affected by the household's crop mix, access to the plot, ownership of durable assets, labor and land endowments, and participation in farmers' associations. Land tenure influences both inorganic and organic inputs, with less of both on sharecropped and encroached plots.

Inorganic fertilizer has a positive impact on millet yields, with an estimated marginal VCR greater than 3, indicating significant profitability. Organic fertilizer has a positive impact on millet-cowpea yields. We find little evidence of complementarity between inorganic and organic fertilizer.

Since warrantage, input supply shops and fertilizer micro-dosing demonstrations increase use of inorganic fertilizer which in turn increases millet yields in pure stands, these interventions must indirectly increase millet yields. However, we do not find significant impact of these factors on millet yields in the reduced form regression; probably because these effects are quantitatively small. We do find significant impacts of access to input shops and fertilizer demonstrations on yields of different millet intercrops (both in production functions and the reduced form regressions), although though effects are mixed, probably because of differential effects of fertilizer on different crop mixes.

These findings support the Projet Intrants approach of promoting increased input use through development of inventory credit and input supply shops and demonstrations of fertilizer micro-dosing. However, the impacts on crop yields appear to be relatively small. Other interventions that could help to boost productivity include promotion of improved access to farm equipment and traction animals and improved access to land under secure tenure.

References

Abdoulaye, Tahirou, and John H. Sanders, 2005. Stages and determinants of fertilizer use in semiarid African agriculture: The Niger experience, Agricultural Economics, 32, 167-179.

Davidson, R. and J.G. MacKinnon. 2004. *Econometric Theory and Methods*. Oxford: Oxford University Press.

FAOSTAT database (2005), "Agricultural statistics," http://apps.fao.org.

Mukherjee, C., H. White, and M. Wuyts. 1998. *Econometric and data analysis for developing countries.* London Routledge.

Newey, W.K. 1987. Efficient estimation of limited dependent variable models with endogenous explanatory variables. *Journal of Econometrics* 36: 231-250.

Pagan, A. and F. Vella. 1989. Diagnostic tests for models based on individual data: a survey. *Journal of Applied Econometrics* 4: 29-59.

Palm, C.A., R.J.K. Myers, and S.M. Nandwa. 1997. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: R.J. Buresh, P.A. Sanchez, and F. Calhoun (Eds.), *Replenishing Soil Fertility in Africa.* Soil Science Society of America, American Society of Agronomy, SSSA Special Publication Number 51, Madison, Wisconsin.

Powell, J.L. 1984. Least absolute deviations estimation for the censored regression model. *Journal of Econometrics* 25: 303-325.

Shaban, R.A. 1987. Testing between competing models of sharecropping. *Journal of Political Economy* 95(5): 893-920.

Smith, R. and R. Blundell. 1986. An exogeneity test for the simultaneous equation tobit model with an application to labor supply. *Econometrica* 54: 679-685.

Table 1. Determinants of value of inorganic fertilizer use (CFA/ha) and organic fertilizer use (kg./ha) (tobit models)

Explanatory variable	**Inorganic fertilizer**		**Organic fertilizer**	
	Coefficient	Std error	Coefficient	Std error
Region (cf. Dosso)				
- Maradi	-2361^{**nnn}	1098	4734	3248.1
- Tillaberi	-738^{++nn}	723	3522^{*++ppp}	1953.6
- Zinder	-4899$^{***--nn}$	1150	4540^{++}	2875.9
Household characteristics				
Value of assets (CFA)				
- Farm equipment	205.34^{p}	197.21	776.3^{*ppp}	407.4
- Durable assets	-1.432E-03**	7.070E-04	4.2E-03$^{**++ppp}$	2.1E-03
- Traction animals	2.997E-03^{**ppp}	1.492E-03	4.6E-03*	2.7E-03
- Other animals	-1.739E-03^{ppp}	2.629E-03	7.3E-05	4.8E-03
Land area cultivated (ha.)	4.433	24.108	-136.35^{-nnn}	85.97
Distance to input shop (km.)	-140.2^{**nnn}	56.4	-21.7	85.7
Received warrantage credit	3209$^{***+++ppp}$	703	-1303.6	1142.6
Participated in fert. demonstrations				
- Micro-dosing	1243^{*++p}	741	640.0^{ppp}	1183.9
- Line spreading	2612^{**+}	1027	1029.5^{ppp}	2778.3
- Broad spreading	-183	640	1750.0^{nnn}	1265.2
Education of hh. head (cf. none)				
- Primary	-445	843	-1851.8	1762.2
- Secondary	1946**	974	-1694.0^{nnn}	1808.1
- Literacy training	903^{ppp}	991	-1373.4	2363.1
- Other	-1052^{-}	1836	6361.0^{+ppp}	3905.6
Age (years)	-228.8	152.9	235.5^{nn}	281.8
Age^2 ($years^2$)	2.318	1.467	-2.320^{p}	2.568
Village leader	-872	1071	-1988.9^{pp}	2988.1
Member of a farmers association	-252^{nn}	318	935.0^{*ppp}	549.0
Occupation (cf. agriculture only)				
- Non-agricultural worker	226	2332	3669.7^{++pp}	2630.8
- Agriculture and non-ag. worker	3838$^{***+++ppp}$	1174	1118.9^{ppp}	1638.3
- Agriculture and other	-842^{n}	1025	4422.6^{**+}	1883.9
Labor/land ratio (persons/ha.)	-22	209	841.5^{ppp}	639.9
Dependency ratio	1921	1875	-4176.9^{nnn}	2957.2
Plot characteristics				
Plot area (ha.)	-287$^{***---nnn}$	95	40.8^{nnn}	106.0
Soil type (cf. sandy)				
- Clay	-282^{+}	689	-3312.2^{nn}	2217.5
- Sand and clay	-1097^{nn}	669	-603.0^{nnn}	1725.0
- Loam	2031^{ppp}	1980	5948.2^{nn}	4161.8
- Other	-3067$^{**--nnn}$	1361	4076.6*	2351.1
Soil fertility (cf. poor)				
- Average	34	631	1800.5^{+ppp}	1101.6
- Good	590^{+pp}	848	745.6	1438.6
Collectively owned plot	52^{+++}	505	-646.2	1004.0
How plot acquired (cf. inherited)				
- Rented	974^{++}	740	-1318.0	2699.5
- Purchased	1169*	696	-5103.7^{-}	3382.7
- Sharecropped	-4182^{***---}	1483	-7036.0^{-nnn}	4584.4
- Other (mainly encroached)	-2176^{***---}	779	-5568.2$^{**---nnn}$	2202.5
Distance from residence (km)	88.0^{pp}	94.3	-2256.4$^{***---nnn}$	761.4

Explanatory variable	Inorganic fertilizer		Organic fertilizer	
	Coefficient	Std error	Coefficient	Std error
Crops produced on plot (cf. millet)				
- Peanut	-5945^{***nnn}	1759	-10634.4^{**nnn}	4406.1
- Cowpea	805^{pp}	3384	-2298.2	6064.9
- Millet-cowpea	351	764	5627.9^{***pp}	2062.2
- Millet-sorghum-cowpea	270	870	4278.6^{**ppp}	1724.0
- Millet-cowpea-hibiscus	916^{p}	847	3679.0^{**ppp}	1853.3
- Millet-sorghum-cowpea-peanut	480	1708	7453.5^{**ppp}	3016.0
- Other	158	1103	-133.7^{pp}	1430.8
Intercept	1415	4457	-24232.4^{**-}	11278.4
No. of uncensored obs/Total obs.	494/2052		620/2052	
Pseudo R^2	0.0423		0.0333	

$^{*, **, ***}$ mean that the coefficient is statistically significant at the 10%, 5%, 1% level, respectively.
$^{+, ++, +++}$ mean that the coefficient in the tobit model excluding crop mix is positive and statistically significant at the 10%, 5%, 1% level, respectively.
$^{-, --, ---}$ mean that the coefficient in the tobit model excluding crop mix is negative and statistically significant at the 10%, 5%, 1% level, respectively.
$^{p, pp, ppp}$ mean that the coefficient in the censored quantile regression (90th percentile level) is positive and statistically significant at the 10%, 5%, 1% level, respectively.
$^{n, nn, nnn}$ mean that the coefficient in the censored quantile regression (90th percentile level) is negative and statistically significant at the 10%, 5%, 1% level, respectively.

Table 2. Determinants of ln(crop production per ha.) – GMM model results

Variable	Millet		Millet-cowpea		Millet-sorghum-cowpea	
	Coefficient	Std. err.	Coefficient	Std. err.	Coefficient	Std. err.
Inputs						
ln(labor/ha.)	0.3100***	0.0652	0.2561***	0.0536	0.2942***	0.0751
ln(quantity of organic fertilizer/ha.)	-0.0155	0.0183	0.0256**	0.0121	0.0161	0.0133
ln(quantity of traditional seeds/ha.)	0.1116***	0.0407	0.1188***	0.0318	0.1239***	0.0308
ln(quantity of improved seeds/ha.)	0.0491	0.0497	0.1124	0.0886	0.0873*	0.0454
Used pesticide	-0.0343	0.0949	0.3381***	0.0877	0.2993***	0.1097
Fertilizer macro-dosing used	-0.1195	0.2645	0.2473	0.2235	0.1283	0.3400
Fertilizer micro-dosing used	-0.1465	0.1535	-0.0706	0.1611	-0.5588**	0.2456
Inorg. x org. fertilizer interaction	-0.0066*	0.0034	-0.0050	0.0032	-0.0021	0.0049
ln(value of inorg. fert./ha)x macrodose	0.0899*	0.0466	0.0527	0.0455	-0.0576	0.0657
ln(value of inorg. fert./ha) x microdose	0.0674***	0.0254	0.0502*	0.0260	0.0581	0.0437
Plot characteristics						
ln(plot area)	-0.5264***---	0.1241	-0.1892--	0.1246	-0.4693***---	0.0798
Soil type (cf. sandy)						
- Clay	0.2024	0.1601	-0.2503	0.2203	0.2151	0.2066
- Sand and clay	-0.0565	0.1542	0.1199	0.1104	-0.0205	0.1478
- Loam	NE		0.3140*	0.1661	-0.5353**---	0.2434
- Sand and other	NE		-0.1740	0.4665	-0.1848	0.1863
Soil fertility (cf. poor)						
- Average	0.0133	0.1363	-0.0879	0.0904	0.6674***+++	0.1364
- Good	0.2367	0.1537	0.1981*++	0.1122	0.5974***+++	0.1498
How plot acquired (cf. inherited)						
- Rented	-0.2303	0.2384	-0.3895***-	0.1337	I	
- Purchased	-0.2633*-	0.1388	0.0352	0.2113	I	
- Sharecropped	-0.3962	0.3205	0.3364*	0.1838	I	
- Other (mainly encroached)	-0.3142**--	0.1435	-0.0415	0.1341	I	
Household characteristics						
ln(value of equipment)	I		I+		2.4589***+++	0.4102
ln(value of durable assets)	I		I		I	
ln(value of traction animals)	0.0317***++	0.0083	0.0139*	0.0078	I	
ln(value of other animals)	I		I		I++	
ln(land area cultivated)	I		I-		I	
ln(distance to input shop)	I		0.2286***++	0.0512	-0.2328***---	0.0510
Warrantage credit	I		I		I	
Participation in fert. demonstrations						
- Micro-dosing	I		0.2421**++	0.1035	-0.2634**--	0.1120
- Line spreading	I		1.0589***++	0.2084	0.1599	0.2886
- Broad spreading	I		-0.0565	0.1004	0.2375**++	0.1184
Education (cf. none)						
- Primary	I		-0.4117**	0.1665	0.3291**++	0.1587
- Secondary	I		0.0008	0.3101	-0.6712***	0.2168
- Literacy training	I		-0.2091	0.1881	-0.1972	0.1299
- Other	I		0.7276***	0.2470	NE	
ln(age)	0.7654***+++	0.2125	0.3378*	0.1862	I++	
Village leader	I		I		0.4797***++	0.1700
Member of a farmers association	-0.3824***--	0.1099			-0.3282**-	0.1378
ln(labor/land ratio)	I		0.2858***	0.0656	0.2985***+++	0.0774
ln(dependency ratio)	0.7820**	0.3926	-0.3244	0.2662	-0.9389***--	0.2996
Occupation (cf. agriculture only)						
- Non-agricultural worker	I		I		-0.9787---	0.9828
- Agriculture and worker	I--		I		-0.5346	0.4140
- Agriculture and other	I		I		0.6855**+++	0.3174

Variable	Millet		Millet-cowpea		Millet-sorghum-cowpea	
	Coefficient	Std. err.	Coefficient	Std. err.	Coefficient	Std. err.
Region (cf. Dossa)						
- Maradi	0.5188***	0.1680	0.1218	0.1867	0.3167	0.2757
- Tillaberi	-0.1084	0.1427	-0.3427***	0.1172	0.5507***++	0.2014
- Zinder	-0.2196	0.2041	-0.4627***	0.1794	-0.0272	0.2474
Intercept	1.7302*	0.9542	7.8958***+++	0.8027	4.0261***	1.0977
Number of observations	243		533		413	
R^2	0.4634		0.3063		0.7504	
Wald test of excluded variables (P value)	0.2956		0.2822		0.8773	
Hansen's J test of overidentifying restrictions (P value)	0.6230		0.6142		0.8653	
C test of exogeneity of inputs (P value)	0.5616		0.6366		0.8267	
Relevance tests of excluded instruments (P-values)						
Ln(labor/ha.)	0.0000		0.0000		0.0000	
ln(quantity of organic fertilizer/ha.)	0.0000		0.0000		0.0000	
ln(quantity of traditional seeds/ha.)	0.0000		0.0000		0.0000	
ln(quantity of improved seeds/ha.)	0.7372		0.4403		0.0013	
Used pesticide	0.0000		0.0000		0.0002	
Fertilizer macro-dosing used	0.0505		0.5953		0.4869	
Fertilizer micro-dosing used	0.0000		0.0000		0.0771	
Inorg. x organic fertilizer interaction	0.1342		0.0000		0.1101	
ln(value of inorg. fert./ha)x macrodose	0.9978		0.8647		0.8388	
ln(value of inorg. fert./ha) x microdose	0.0000		0.0002		0.0001	

NE – Coefficient not estimable due to limited number of observations.

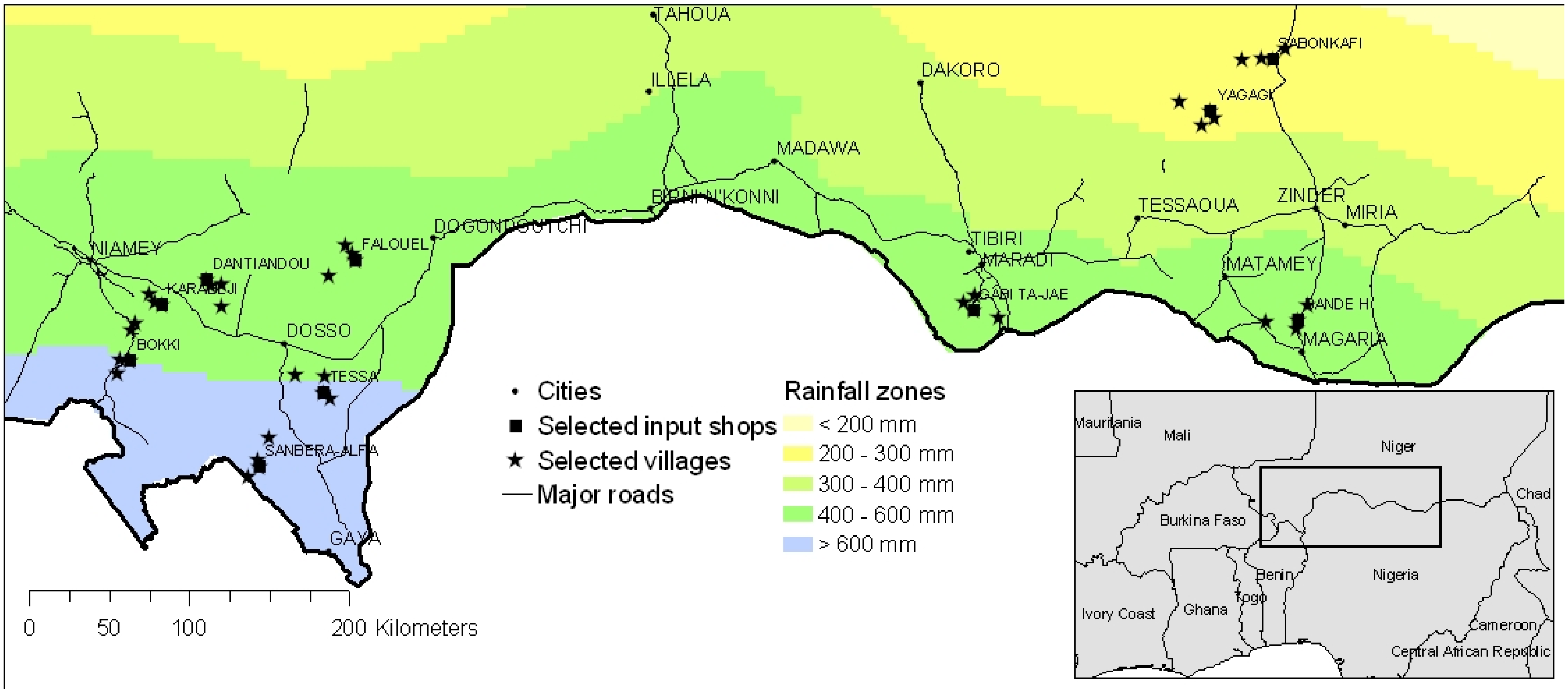
I – Variable statistically insignificant (Wald test) and dropped from restricted model.

*, **, *** mean that the coefficient is statistically significant at the 10%, 5%, 1% level, respectively.

+, ++, +++ mean that the coefficient in the reduced form model is positive and statistically significant at the 10%, 5%, 1% level, respectively.

-, --, --- mean that the coefficient in the reduced form model is negative and statistically significant at the 10%, 5%, 1% level, respectively.

Figure 1. The study regions



Annex. Derivation of equations (2) and (3)

Conditional upon its choice of crop mix[16], the household selects the level of inputs to maximize the expected utility of income:

(A1) $$\max_{l_{hp}, x_{hp}, L_o} Eu[\sum_p A_{hp}(p^c y^c{}_{hp} - w_x x_{hp}) - w_l(\sum_p A_{hp} l_{hp} + L_0 - L_h) + OI(L_0, PC_h, HC_h, SC_h, OC_h)]$$

u( ) is a concave utility function; p^c is a vector of farm level prices of crops c; w_x is a vector of farm level prices of inputs x; w_l is the wage rate for hired labor; L_o is labor used for non-crop activities; OI is income from non-crop activities (on or off-farm); and other variables are as defined in the text.

We assume that input use may be influenced by a liquidity constraint and a labor constraint. The liquidity constraint is given by:

(A2)

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

where B( ) represents the borrowing limit.

The labor constraint is given by:

(A3) $$\sum_p A_{hp} l_{hp} + L_o \leq L_h + L_{\max}(L_h, HC_h, SC_h)$$

L_{max} is the maximum amount of labor that can be hired in by the household due to constraints on the household's capacity to supervise hired labor.

If the household is not risk neutral or the liquidity constraint or labor constraint are binding, the optimal choice of inputs and labor may depend upon all of the predetermined and exogenous variables (C_{hp}, w_x, w_p, p^c, A_{hp}, z_{hp}, T_{hp}, A_h, PC_h, HC_h, I_h, SC_h, OC_h, L_h). We do not have wages, input and output price data at the household level. We assume that these prices will be determined by regional level prices (incorporated into R) as well as the access of the household and plot to the local markets (MA_{hp}). The resulting input demand equations are equations (2) and (3).

[16] We assume initially that crop mix is predetermined with respect to input choice so that we can estimate the impact of crop choice on input use. We relax this assumption in our econometric work, allowing both crop choice and input use to be jointly determined. In this case, input demands are estimated without crop choice as an explanatory variable.